PERSISTENT ORGANIC POLLUTANTS (POPs) IN VIETNAMESE ENVIRONMENT – A REVIEW OF CONTAMINATION, FATE AND TOXIC POTENTIAL

Tu Binh Minh[*,1)], Nguyen Hung Minh[*], Tatsuya Kunisue[*], Mafumi Watanabe[*], Hisato Iwata[*], Pham Hung Viet[**], Nguyen Duc Hue[***], Vo Qui[****], Bui Cach Tuyen[*****] and Shinsuke Tanabe[*]

[*]*Center for Marine Environmental Studies, Ehime University, Bunkyo-cho 2-5, Matsuyama 790-8577, Japan*
[**]*Center for Environmental Technology and Sustainable Development, Hanoi National University, 334 Nguyen Trai Street, Hanoi, Vietnam*
[***]*Faculty of Chemistry, Hanoi National University, 19 Le Thanh Tong Street, Hanoi, Vietnam*
[****]*Center for Natural Resources and Environmental Studies, Hanoi National University, 19 Le Thanh Tong Street, Hanoi, Vietnam*
[*****]*University of Agriculture and Forestry, Hochiminh City, Vietnam*
[1)]*Present affiliation: Faculty of Agriculture, Ehime University, Tarumi 3-5-7, Matsuyama 790-8566, Japan*
Corresponding author: Shinsuke Tanabe. Tel./Fax: +81-89-927-8171,
E-mail: shinsuke@agr.ehime-u.ac.jp

ABSTRACT

The present paper provides a comprehensive overview of the contamination by persistent organic pollutants (POPs) in Vietnam based on the results of extensive monitoring studies conducted in our laboratory during the last decade. Surveys conducted in the framework of Asia-Pacific Mussel Watch Program during early 1990s indicated widespread contamination by polychlorinated biphenyls (PCBs) and organochlorine insecticides, particularly DDTs and HCHs in various environmental compartments such as air, water, soils, sediments and fish collected from different parts of Vietnam. Recent studies conducted under the Core University Program supported by the Japan Society for the Promotion of Science (JSPS) also revealed elevated contamination by DDTs in fish, mussels and birds from Vietnam. Interestingly, DDT residue concentrations in fish and birds from Vietnam are among the highest values reported for the countries in Asia-Pacific region, suggesting the role of Vietnamese environment as a potential emission source of DDTs in this region. In addition, open dumping sites for municipal wastes in some major cities such as Hanoi and Hochiminh city is a matter of concern with regard to environmental pollution, particularly contamination by dioxins (PCDDs) and related compounds such as dibenzofurans (PCDFs) and coplanar PCBs. Our recent investigation has indicated that soils collected in dumping sites in Hanoi contained higher PCDD/F concentrations as compared to general soils collected far from dumping sites. In general, dioxin contamination in soils from dumping sites from Hanoi and Hochiminh City, Vietnam were lower than those in soils from other Asian developing countries. However, PCDD/F concentrations in a few soil samples from Hanoi exceeded the environmental guideline values, suggesting potential health effects on humans and wildlife living near these dumping sites. Future studies should be focused on the temporal trends of POPs in biota in Vietnam to predict the future trend of contamination and to understand possible toxic impacts on organisms.

Keywords: DDTs, POPs, Vietnam

INTRODUCTION

Global contamination and toxic effects of persistent organic pollutants (POPs) has been an emerging environmental issue and has received considerable attention during the past decades. Although the extent of contamination by POPs has been dominant in industrialized nations, an increasing number of recent investigations highlighted the role of Asia-Pacific region as a potential source of emission for these chemicals, particularly to pristine areas such as the Arctic and the Antarctic (e.g. see review by Tanabe *et al.*, 1994; Tanabe, 2002).

During the recent decade, in the context of the Asia-Pacific Mussels Watch Program and the JSPS Core University Program, our laboratory has conducted extensive studies on the contamination, fate and human health implications of POPs on the global and regional scales. By analyzing the residue

concentrations of various kinds of POPs such as organochlorine insecticides like DDTs, HCHs, CHLs and HCB; and industrial chemicals like polychlorinated biphenyls (PCBs), dioxins and dibenzofurans (PCDD/Fs), we identified the emission sources of these contaminants in Asian developing countries including Vietnam. This paper gives an overview of the results of the monitoring surveys in Vietnam, an agriculture-based country located at the center of the South East Asian region. The extent of contamination, fate and human health implications of POPs in Vietnam are discussed.

PRODUCTION AND USAGE OF POPs IN VIETNAM

In general, information on the production and usage of POPs, particularly organochlorine (OC) insecticides and PCBs in Vietnam as well as some other developing countries in East Asian region are still limited or obscure. Systematic inventory of toxic man-made chemicals is lacking in these countries due to their limited capacity to conduct comprehensive monitoring surveys. Recently, the United Nations Environment Programs (UNEP) has initiated various monitoring programs for POPs at regional and global levels and the results have been summarized at different workshops. According to the reports, active ingredients for insecticides were not produced in Vietnam. In fact, before 1985, pesticides such as DDT, HCB were imported from former Soviet Union and some socialistic countries with to a quantity of 6,500 – 9,000 tons/year. The statistical data showed that the total quality of DDT imported to Vietnam for malaria control from 1957 to 1990 is 24,042 tons. During 1986-1990, approximately 800 tons have been used. These amounts are still lower than those in some other countries in region such as Malaysia, Indonesia and India (Sinh *et al.*, 1999). DDT usage for malaria control ceased in Vietnam in 1995 and some other chemicals such as pyrethroid compounds have been used to in the place of DDT (Sinh *et al.*, 1999).

The information about usage of PCBs in Vietnam is still obscure. Statistical data showed that about 27,000 – 30,000 tons of oils contaminated by PCBs were imported from former USSR, China and Rumania (Sinh *et al.*, 1999). In addition, electrical equipments containing PCBs like transformer were also imported from Australia until the mid-1980s (Kannan *et al.*, 1995). Other possible source of PCBs in Vietnam could be the weapons extensively used during the Indochina War (Thao *et al.*, 1993). Regarding dioxins, the main source in Vietnam in the past was the Orange Agent and other herbicides sprayed in South Vietnam during the American War. Recently, Stellman and co-worker (Stellman *et al.*, 2003) provided revised estimates about the amounts of herbicides used in Vietnam. During 1961-1971, at least about 45 million litres of Agent Organe were sprayed (Stellman *et al.*, 2003). 2,4,5-T, a constituent of Agent Orange is known to be contaminated with 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD). However, the combustion derived sources of dioxins in Vietnam have been unknown. Various kinds of combustion processes may facilitate the widespread contamination of dioxins and related compounds in Vietnam. However, no investigation has been conducted so far on the extent of contamination by dioxins derived from combustion and its potential for human health implications.

MAGNITUDE OF CONTAMINATION

On the basis of Asia-Pacific Mussel Watch Program conducted in 1990s, our laboratory disclosed widespread and relatively high contamination of DDTs in various environmental compartments such as air, water, sediment and soils and also fish from both north and south Vietnam (Thao *et al.*, 1993, Iwata *et al.*, 1994, Kannan *et al.*, 1995). This result suggests the widespread usage of DDTs in Vietnam in the past for both agricultural purposes and malaria control. In addition, relatively higher concentrations of PCBs were observed in municipal wastewater from Hochiminh City, Vietnam (Iwata *et al.*, 1994). Interestingly, survey during 1989-1993 showed that Vietnamese fish also contained higher PCB residues as compared to fish from other Asian countries. The high PCB contamination in Vietnam observed during our survey in early 1990s could be derived from both the electrical equipments imported from industrialized nations like former Soviet Union and Australia and the army weapons extensively used in Indochina War during 1961-71.

Interestingly, continued monitoring studies in recent years (1997-2003) have also indicated elevated contamination of DDTs in different environmental media. Our most recent data in the Mussel Watch Program showed that DDT residue concentrations in mussels from Vietnam are among the highest reported for the countries surveyed in South East Asian region (Monirith *et al.*, 2000; 2003)

(Figure 1). Resident birds collected from Red river delta estuary, North Vietnam, contained elevated concentrations of DDTs (Minh *et al.*, 2002). DDT residue levels in resident birds from North Vietnam were also higher than those in other countries in the region (Figure 1). It is worthy to note that though the recent amounts of DDTs used in Vietnam were lower than those of other countries in the region, the extent of DDT contamination in environmental samples in Vietnam is higher. This observation suggests that the application of DDTs in Vietnam has continued until very recently, resulting in elevated contamination of these compounds in different species occupying low to high trophic levels in food chain.

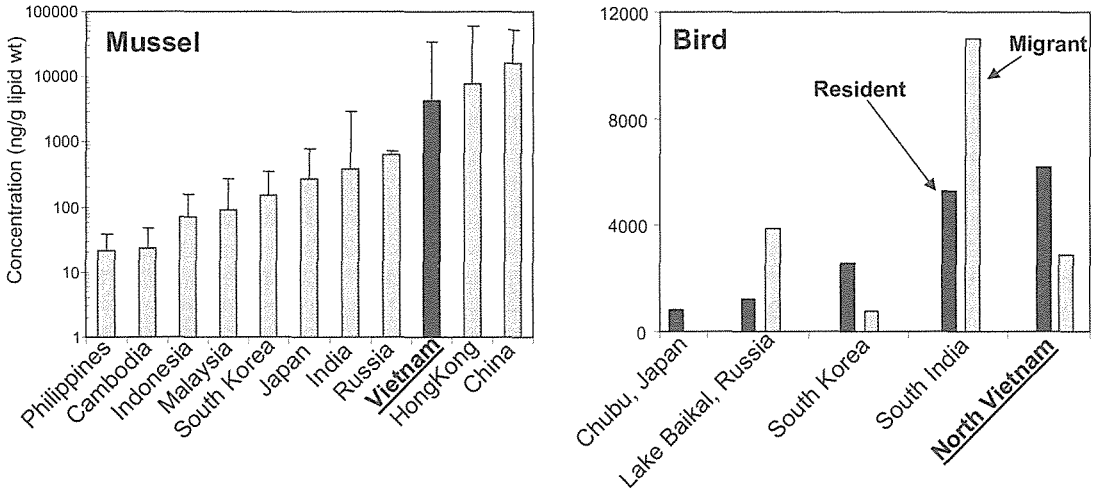

Figure 1. Comparison of DDT residue levels in mussels and birds from Vietnam and other countries in Asia-Pacific region. Data cited from Monirith *et al.*, 2003 and Minh *et al.*, 2002.

In the urban/sub-urban areas of developing countries, including Vietnam, large scale dumping of municipal waste is quite common. The major problems in those dumping sites are the natural low temperate combustions and burning by waste pickers scavenging in the dumping sites. These are favorable factors for the formation of dioxins (PCDDs) and related compounds such as dibenzofurans (PCDFs) and coplanar PCBs. To find an answer for the question that whether open dumping sites is a potential source of dioxins and dibenzofurans, we extended our research to make clear the status of PCDD/F contamination in dumping sites from Vietnam as well as in some other Asian developing countries (Minh *et al.*, 2003). As shown in Figure 2, TEQ (toxic equivalents) concentrations in soils from dumping sites from Hanoi and Hochiminh City were lower than those in soils from other Asian developing countries such as Philippines, India and Cambodia. Only one sample from the dumping site in Hanoi contained elevated PCDD/F concentrations. This result suggests less contamination by PCDD/Fs in dumping sites in Vietnam and the role of dumping sites in Vietnam as potential source of dioxins seems less pronounced as compared to other countries in the region. In addition, elevated concentrations of PCDD/Fs were observed in soils from Cambodia and Philippines, and these levels were comparable or higher than those reported in soils from some dioxin-contaminated areas in developed nations (Minh *et al.*, 2003). On the basis of the result of this study, we have addressed a new environmental issue that open dumping site is a potential source of PCDD/Fs, and dioxin contamination in dumping sites may become a key environmental problem in Asian developing countries in the 21st century.

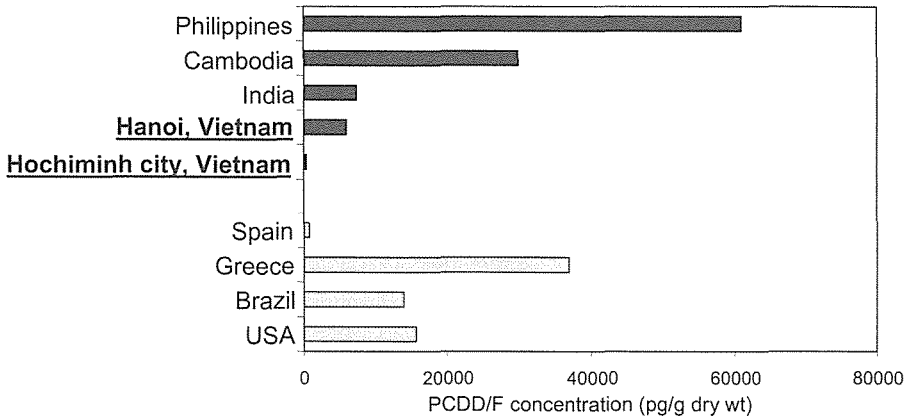

Figure 2. Comparison of PCDD/F residue levels in soils from dumping sites in Vietnam and other Asian developing countries. Data cited from Minh *et al.*, 2003

TRANSPORT AND FATE IN TROPICAL ECOSYSTEM

Multimedia monitoring research conducted in our laboratory not only helped to increase knowledge of the status of contamination, but also provided in-depth insights into the transport behavior and fate of POPs in tropical ecosystem in Asian developing countries. On a global scale, we had made clear that fate of persistent OCs in open ocean is different from that in coastal environment (Iwata *et al.*, 1993, 1994; Tanabe *et al.*, 1994). Open ocean plays the role as a final sink for POPs, and cold waters from high latitudes like Arctic Ocean, which are located far from pollution sources, serve as significant reservoirs (Iwata *et al.*, 1993). On the other hand, pronounced contamination by OC insecticides was observed in coastal waters of Asian countries as results of extensive usage for agriculture and public health purposes (Iwata *et al.*, 1994). In a smaller scale, latitudinal distribution of persistent OCs such as PCBs, DDTs, HCHs in sediments from the southern Vietnamese estuary was also examined (Iwata *et al.*, 1994). Results showed higher residues of PCBs, DDTs, HCHs and CHLs in sediments from Hochiminh City and an apparent downward trend from the upper to lower stream of the estuary. HCH concentrations showed relatively uniform distribution along with the latitudes, indicating higher degree of atmospheric transport. Other persistent compounds with higher octanol-water partition coefficient and lower Henry's Law constants such as DDTs, PCBs and CHLs, showed larger spatial variation with latitudes. In general, the degree of usage, the climate and the physico-chemical properties of persistent organic compounds are the major factors controlling the magnitude of contamination in the environment. When comparing the distribution of OCs in different environmental media in Asia-Pacific region, we found that distribution patterns in fish and sediment were relatively similar and showed less spatial variation. The pattern in air and water showed greater geographical variability. A recent extensive survey of OC insecticides from Red and Duong river, the two largest rivers flow through the northern delta region of Vietnam, and various lakes in Hanoi indicated that DDT and HCH residue levels in rivers is apparently greater than those in lakes (Hung and Thiemann, 2002). This observation suggests the different behavior of semivolatile compounds in tropical lakes and in rivers, showing shorter retention time in lakes than in rivers. Elevated temperatures may enhance volatilization of such compounds, leading to shorter residence time in tropical water phase, lower residue levels and relatively uniform distribution in sediments and aquatic biota. In this context, the role of the tropics in Asia-Pacific region as potential emission sources for higher latitude areas deserves further attention.

As mentioned earlier, very little information is available regarding the contamination of PCDD/Fs in Asian developing countries. Therefore, fate and behavior of these compounds in developing countries is still obscure. On the basis of the residues concentrations in soils from dumping sites, flux of PCDD/Fs to soils can be estimated (Figure 3). The estimated fluxes to soils in dumping sites in Asian developing countries including Vietnam were surprisingly higher. Fluxes to soils in Asian

dumping sites were higher than those of some other locations in the world, including contaminated areas in the United States and Hong Kong (Figure 3). The loads of PCDD/Fs to the dumping sites were also estimated. Results indicated that dumping sites in Philippines and India with a huge area of approximately 23 and 140 ha, could receive the highest annual amount of 3900 and 1400 mg/yr PCDD/Fs (35 and 8.8 mg TEQs/yr), respectively (Table 1). Dumping site in Hochiminh city, Vietnam, had the lowest loading rate due to the less contamination of PCDD/Fs in soils. As for comparison, total annual fluxes to the Kanto region, Japan, one of the most polluted areas in the world, were estimated and found to range from 50 to 900g TEQ with a total area of 32,000 km^2 (approximately 3 millions ha) (Ogura *et al.*, 2001). The area of dumping sites in India is 140 ha, which is 21,000 times smaller than that of Kanto region; and this area was estimated to receive an amount of 8.8 mg TEQs every year (Table 1). This data suggest that dumping sites in India and Philippines may be significant reservoirs of PCDD/Fs. Possible impacts on human health and wildlife living near dumping sites are of great concern and warrant further comprehensive studies. On the basis of the results of this study, it is important to note that despite the decrease in global pollution by POPs in the future; developing countries may continue to be a potential source of certain compounds, particularly PCDD/Fs.

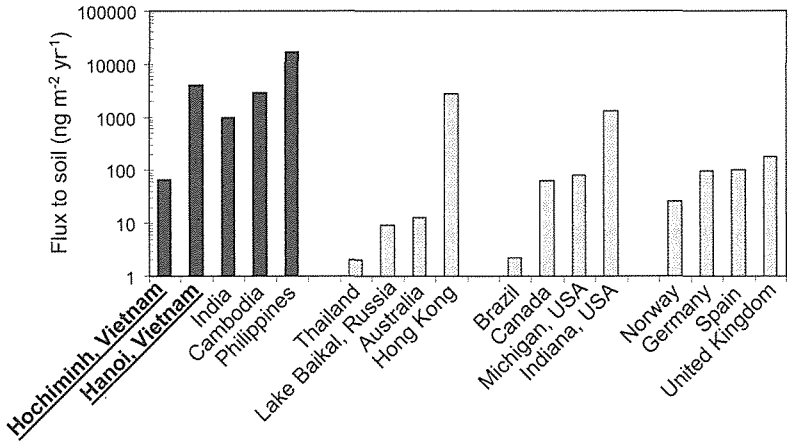

Figure 3. Flux of PCDD/Fs to soils in dumping sites in Vietnam and other Asian developing countries. Estimation of flux was described in Minh *et al.*, 2003.

Table 1. Estimated load of PCDD/Fs to dumping sites areas in Asian developing countries

Country	Area of dumping site	Load	
	(m^2)	(mg/year)	(mg TEQ/year)
Philippines	230,000	3900	35
Cambodia	30,000	87	1.1
India	1,400,000	1400	8.8
Hanoi, Vietnam	50,000	210	3.2
Hochiminh city, Vietnam	300,000	20	0.12

Description for estimation of load of PCDD/Fs to dumping sites refers Minh *et al* ., 2003

ENVIRONMENTAL AND HUMAN HEALTH IMPLICATIONS

Widespread contamination by OC insecticides, particularly DDTs in different environmental samples of Vietnam has been apparent as indicated in our survey in early 1990s. In a survey of estuarine sediments collected from various locations from the northern to southern part of the country, high concentrations of DDTs were observed (Iwata *et al.*, 1994). The Environment Canada has recently updated the sediment quality guidelines for protection of the aquatic life. The Interim Fresh water Sediment Quality Guidelines (ISQGs) and the Probable Effect Levels (PELs) for *p,p'*-DDE are 1.42 and 6.75 ng/g dry wt, respectively, while these values for *p,p'*-DDT are 1.19 and 4.77 ng/g dry wt

(Canadian Environmental Quality Guideline, 2002). Among the 18 locations examined throughout Vietnam, about half of the sediment samples contained *p,p'*-DDE and *p,p'*-DDT greater than the ISQG values. Some samples collected from the municipal sewage canal contained elevated levels of DDTs, far exceeding the probable effect levels (PELs). PCB concentrations in Vietnamese sediments in these locations were also beyond the PEL level for PCBs. Likewise, residue concentrations of DDTs in soils collected from some locations from north, middle and south Vietnam (Thao *et al.*, 1993) approached or exceeded the guideline level of 700 ng/g dry wt proposed by Environment Canada and the level of 1000 ng/g dry wt recommended by Japanese Government. Taking into account all these facts, it is important to note that the magnitude of contamination by DDTs in Vietnam is of concern and warrant further studies. From the environmental health and global contamination point of view, the role of Vietnam as potential source of DDTs for other countries in the region as well as in higher latitudes should be considered as the priority research focus in future.

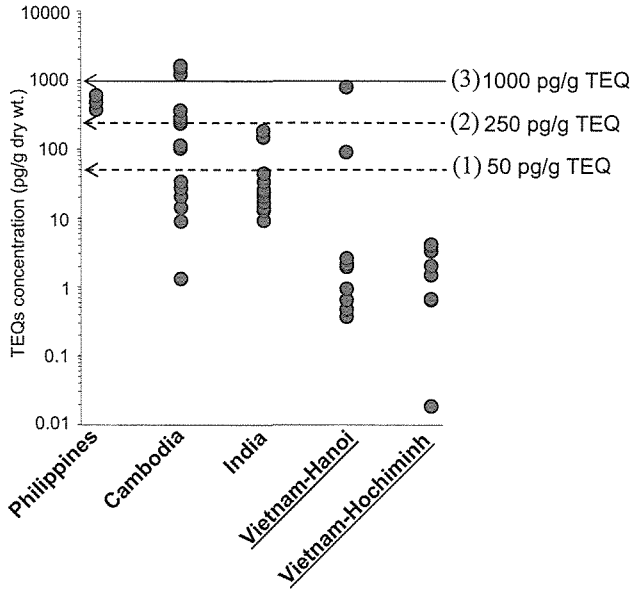

Figure 4. Concentrations of PCDD/Fs (pg/g dry wt) in soils from dumping sites in Asian developing countries in comparison with various environmental guidelines. (1) 50 pg/g TEQs dry wt, recommended by ATSDR for bioavailability, ingestion rates, pathways, etc; (2) 250 pg/g TEQs dry wt, recommended by Japanese Government for the continuous monitory necessity; (3) 1000 pg/g TEQs dry wt, Japanese Standard and level proposed by ATSDR for stronger actions and research exposure and health studies. See text for further details of guideline values.

As for PCDD/Fs, the formation of these contaminants in open dumping sites in Asian developing countries raised a considerable human health concern for not only communities living near the dumping sites, but also for people who live far away because PCDD/Fs may undergo atmospheric transport and deposit in distant areas. For risk assessment of soils contaminated by dioxins and related compounds, The Agency for Toxic Substances and Disease Registry (ATSDR) proposed guidelines recommending that areas having soil concentrations within the range from 50 to 1000 pg TEQ/g should be evaluated for bioavailability, ingestion rates, community concerns, etc., and soils with the concentrations over 1000 pg TEQs/g should be considered for stronger actions like health studies, exposure investigations, etc. (ATSDR guideline, 1999). Japanese Government recently issued new standards for dioxins in soil, establishing 1000 pg TEQ/g as the maximum acceptable level and those within 250 – 1000 pg TEQ/g be kept under surveillance. Results of this study revealed that many soil samples in dumping sites contained TEQ concentrations exceeding 250 pg/g TEQs (Figure 4), suggesting the necessity of continuous monitoring. Particularly, some soils from Cambodia and Hanoi dumping sites contained TEQ concentrations beyond the level of 1000 pg/g, suggesting their potential for causing adverse health risk for humans and wildlife.

In the perspective of human health implication, surveys conducted in early 1990s on OCs in foodstuffs provided useful information regarding the dietary intake of these compounds by Vietnamese population (Kannan *et al.*, 1992). Interestingly, the estimated average daily intakes based on the exposure through foodstuff to PCBs in Vietnam were higher than India, Thailand and comparable to those reported for developed nations like USA and Germany. Particularly, average daily intake of DDTs by Vietnamese was estimated to be 19 μg/person/day; and this value was the highest as compared to the countries in the region and in developed nations (Kannan *et al.*, 1992). Although the data used for estimation has been reported a decade before, this fact clearly suggests elevated exposure to DDTs and PCBs by Vietnamese population and that the usage of DDTs has been extensive during the past 10 year.

Table 2. Estimated daily intakes of PCBs and DDTs from seafoods in countries in Asia-Pacific region

Country	**Seafood consumption** (g/person/day)	**Intake of PCBs** (ng/person/day)	**Intake of DDTs** (ng/person/day)
Cambodia	54.2	40	18
China	68.5	170	16440
Hong Kong	68.5	250	8200
India	12.3	47	52
Indonesia	53.4	69	53
Japan	173	5200	610
South Korea	140	520	490
Malaysia	158	160	220
Philippines	81.1	460	32
Thailand	78.6	240	440
Vietnam	**51.8**	**72**	**2100**
Russia	53.2	3400	640

Intakes of PCBs and DDTs were estimated based on the mean concentrations in mussels reported by Monirith *et al.*, 2002 and 2003.
Seafood consumption data cited from WHO (2000)
(http://apps.fao.org/lim500/wrap.pl?FoodBalanceSheet&Domain=FoodBalanceSheet)

Surveys in the framework of recent Asia-Pacific Mussel Watch Program indicated that dietary intake of DDTs and PCBs from fish in Vietnam were higher than those in Cambodia and Thailand, but still lower than those in industrialized nations such as Australia, Japan and Hong Kong (Monirith *et al.*, 2000). On the basis of the recent data of average seafood consumption reported by Food and Agriculture Organization of the United Nations, the average daily intake of PCBs and DDTs from seafood for different countries in Asia-Pacific region were estimated (Monirith *et al.*, 2003) (Table 2). Interestingly, results again showed that intakes of DDTs by Vietnamese population were apparently higher than those reported in other countries examined (Table 2).

In addition to the elevated exposure of DDT via seafood to Vietnamese general population, certain cohorts living near the municipal dumping sites may be at a higher risk by toxic substances: dioxins and dibenzofurans. A methodical approach has been developed to evaluate the risk of exposure to PCDD/Fs via soil ingestion and dermal absorption (Minh *et al.*, 2003). Human exposure to PCDD/Fs in soil is considered to be different for children and adult due to the differences in the ingestion rate as well as body weight of children and adult. Intakes of dioxins were estimated to be the highest in people of Philippines, followed by Cambodia, India, Hanoi (North Vietnam), and Hochiminh City (South Vietnam). Intakes of PCDD/Fs by the people living near dumping sites were about 2 to 200-fold greater than those for the people in control sites, and thus emphasizing the greater health risk, threatening these people. In addition, it is important to note that the estimated intakes of dioxins via soil ingestion and dermal exposure for children were higher than those for adults, suggesting greater risk of dioxin exposure for children in dumping sites (Minh *et al.*, 2003). Further

investigations should be focused on children and infants as they are the most susceptible group and have higher exposure levels to dioxins.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Multi-media monitoring studies conducted during the last decade on POPs in Asia-Pacific region including Vietnam indicated that contamination by OC insecticides, particularly DDTs, has been apparent. As a consequence, high degree of exposure of general populations to DDTs via foodstuff, particularly fish and other seafood has been of concern over the last many years. In addition, a certain group of people living near the dumping sites of municipal wastes are exposed to elevated concentrations of PCDD/Fs and other toxic chemicals in dumping sites, and may be at higher risk. It is important to note that despite the decrease in global contamination by POPs in the future; developing countries in Asia-Pacific region may continue to be a potential source for certain contaminants such as DDTs and PCDD/Fs. Systematic temporal trend studies are therefore needed for developing countries. Possible toxic effects on human health and wildlife should be investigated. Capacity building on advanced technologies and providing laboratory facilities to developing countries through international cooperative research programs is indispensable.

ACKNOWLEDGEMENTS

This study was supported by grants from the Environmental Science and Technology in the Core University Program between Japan Society for the Promotion of Science (JSPS) and National Center for Natural Science and Technology, Vietnam (NCST), Research Revolution 2002 (RR2002) of Project for Sustainable Coexistence of Human, Nature and the Earth (FY2002) and "21st COE Program" from the Ministry of Education, Culture, Sports, Science and Technology, Japan.

REFERENCES

Canadian Council of the Ministers of the Environment (2002). *Canadian Environmental Quality Guidelines 1999, updated 2001, 2002. Canadian sediment quality guideline for the protection of aquatic life. Summary table updated 2002.*

Hung D. Q. and Thiemann W. (2002). Contamination by selected chlorinated pesticides in surface waters in Hanoi, Vietnam. *Chemosphere* **47**, 357-367.

Iwata H., Tanabe S., Sakai N. And Tatsukawa R. (1993). Distribution of persistent organochlorines in the oceanic air and surface seawater and the role of the ocean on their global transport and fate. *Environ. Sci. Technol.*, **27**, 1080-1098.

Iwata H., Tanabe S., Sakai N., Nishimura A. and Tatsukawa R. (1994). Geographical distribution of persistent organochlorines in air, water and sediments from Asia and Oceania, and their implications for global redistribution from lower latitudes. *Environ. Pollut.*, **85**, 15-33.

Kanan K., Tanabe S., Quynh H. T., Hue N. D. and Tatsukawa, R. (1992). Residue pattern and dietary intake of persistent organochlorine compounds in foodstuffs from Vietnam. *Arch. Environ. Contam. Toxicol.* **22**, 367-374.

Kannan K., Tanabe S. and Tatsukawa R. (1995). Geographical distribution and accumulation features of organochlorine residues in fish from tropical Asia and Oceania. *Environ. Sci. Technol.*, **29**, 2673-2683.

Minh T. B., Kunisue T., Yen N. T. H., Watanabe M., Tanabe S., Hue N. D. and Qui V. (2002). Persistent organochlorine residues and their bioaccumulation profiles in resident and migratory birds from North Vietnam. *Environ. Toxicol. Chem.*, **21**, 2108-2118.

Minh N. H., Minh T. B., Watanabe M., Kunisue T., Monirith I., Tanabe S., Sakai S., Subramanian A., Sasikumar K., Viet P. H., Tuyen B. C., Tana, T. S. and Prudente M. (2003). Open dumping sites in Asian developing countries: a potential source of polychlorinated dibezo-*p*-dioxins and polychlorinated dibenzofurans. *Environ. Sci. Technol.*, **37**, 1493-1502.

Monirith I., Nakata H., Watanabe S., Takahashi S., Tanabe S. and Tana T. S. (2000). Organochlorine contamination in fish and mussels from Cambodia and other Asian countries. *Water Sci. Technol.*, **42**, 241-252.