POLLUTION BY PERSISTENT TOXIC SUBSTANCES IN VIETNAM: A REVIEW OF TWO DECADE MONITORING STUDIES

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ABSTRACT

This article provides an overview of the contamination by persistent toxic substances (PTS) in Vietnam on the basis of the results of extensive monitoring studies conducted during the last two decades. Surveys conducted in the framework of Asia-Pacific Mussel Watch Program during early 1990s indicated widespread contamination by polychlorinated biphenyls (PCBs) and organochlorine (OC) 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 have also revealed elevated DDT residues in fish, mussels and birds from Vietnam. Interestingly, DDT 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. 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. Soils collected in dumping sites in Hanoi contained much higher PCDD/F residues as compared to general soils collected far from dumping sites. 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. Daily intakes of DDTs via seafood estimated for Vietnamese general population were among the highest values reported for East Asian countries. In the open dumping sites, intakes of dioxins by residents were significantly greater than those living far from dumping sites. Particularly, 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. Future studies should be focused on the temporal trends of POPs in biota in Vietnam to predict the future trends of contamination and to understand possible toxic impacts on organisms. In addition, human exposure and possible toxic effects, particularly on children should be considered as priority research as they are the most susceptible group and have higher exposure levels to dioxins.

KEYWORDS

DDTs; daily intakes; open dumping sites; persistent toxic substances; Vietnam

INTRODUCTION

Vietnam is located at the center for the Southeast Asian region; it has more than 300 km coastal lines and two major agricultural production areas: the Red River Delta in the north and the Mekong River Delta in the south. These two deltas inhabited by approximately more than 30 million people and are one of the most densely populated areas in the world. The Red River and Mekong Driver delta have recently become one of the most productive agricultural regions of Southeast Asia. Such a strategic geographical position and rapid agricultural development of Vietnam have made this country become an important subject for extensive studies dealing with environmental pollution during the last two decades. This paper provides a concise review of the studies dealing with persistent toxic substances (PTS) in Vietnam. Available data of POP contamination in different environmental compartments in Vietnam were compiled to understand the status and patterns of contamination, their transport behavior and fate in tropical agro-ecosystem.

WIDESPREAD CONTAMINATION

Comprehensive monitoring surveys have been conducted during early 1990s to examine the distribution of PTS such as PCBs, DDTs, HCH and HCB in air, water and sediments from estuary environments from various countries in Asia-Pacific comprising Japan, India, Vietnam, the Philippines, Thailand, Indonesia, Malaysia, the Philippines and Australia (Iwata *et al.*, 1994). These investigations revealed higher residues of DDTs and HCHs in air and water from coastal and estuarine areas in the developing countries of tropical and subtropical regions (India, Thailand and Vietnam), rather than developed nations (Japan and Australia). The distribution in air, water and sediments from northern, central and southern regions of Vietnam showed relatively higher DDT concentrations, supporting the concept of widespread contamination of this insecticide throughout the country. This result suggests extensive use of DDT for agricultural purposes in the past and for malaria control until very recently. Interestingly, in a survey conducted about 10 years later (1998/99) covering an extended area along Red River and Duong River, the two biggest rivers in northern Vietnam, elevated concentrations of DDTs, HCHs and CHLs were reported (Hung and Thiemann, 2002). The levels of DDTs, HCHs and CHLs in Red and Duong River were apparently higher than those reported in the 1990s surveys. In addition, wastewater collected from extensive human activities areas such as canals of Tu Liem district, suburb Hanoi (northern Vietnam) and Thi Nghe River, Hochiminh city (southern Vietnam) contained elevated concentrations of DDTs. It is interesting to note that the levels examined in a recent survey (in suburb Hanoi) (Hung and Thiemann, 2002) were even higher than those reported a decade ago (Iwata *et al.*, 1994). Although backgrounds of analytical methods and sampling locations are different among studies, these observations suggest that the use of DDT for malaria control were relatively extensive and has remained until very recently in both northern and southern Vietnam.

To understand the magnitude of contamination of POPs in Vietnam, residue concentrations in air, water and sediments were compared with those in other countries in Asia-Pacific (Fig. 1). Higher contamination of DDTs in Vietnamese coastal environments was recorded, again indicating the extensive use of this insecticide in Vietnam. Interestingly, elevated PCB residues were also observed in water and sediments from Mekong River estuary, southern Vietnam; and the levels were comparable to those reported in some locations in India, Japan and Australia (Fig. 1). 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 leakages from army weapons extensively used in Indochina War during 1961-71 (Thao *et al.*, 1993).

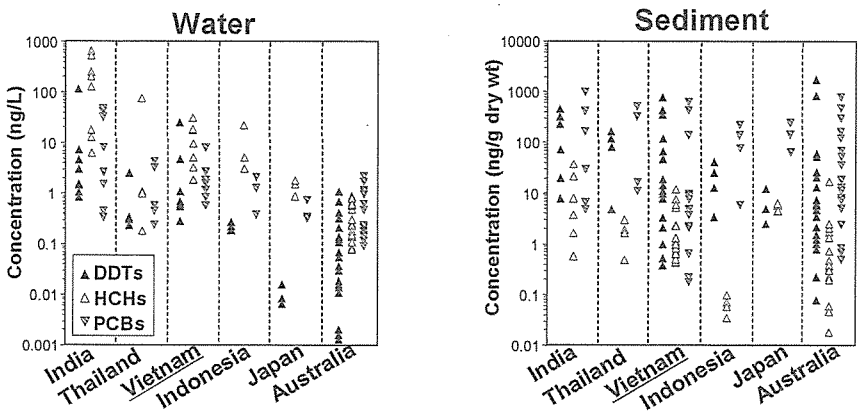

Figure 1. Residue concentrations of persistent organochlorines in water and sediments in coastal and estuary areas from Asia-Pacific countries including Vietnam. Data from Iwata *et al.*, 1994.

As for biological samples, an extensive study on OC contamination in fish and mussels from Asia-Pacific countries including Vietnam were carried out by Kannan *et al.* (1995) and Monirith *et al.* (2003a). Similar to sediment samples, a relatively uniform distribution of OCs was observed in fish in various countries in Asian Pacific region. In Vietnam, residues levels of DDTs were relatively high in both surveys in 1990 and 1997. Mussels collected from coastal areas in north and middle of Vietnam contained elevated DDT concentrations. Subsequent surveys conducted by Nhan *et al.* (1998, 1999) examined OC distribution in clams from different sites along the northern coasts, and results showed a very similar distribution to sediment samples. In particular, residue concentrations of DDTs, HCHs and PCBs were relatively high in the sites near border of China and a decreasing trend was noticed toward southern coast lines. At the two estuary areas: Hai Phong harbor with extensive human and industrial activities, and Thai Binh province, one of the most rice production areas in Vietnam, higher concentrations were again observed. In general, the feature of distribution and magnitude of contamination in sediment and biota (fish and bivalves) was very similar in both local and regional scale, which can be characterized by the enhanced volatilization of semi-volatile organic compounds in high temperature prevailing tropical ecosystems.

International comparison of DDT residues in fish, mussels and birds from Vietnam indicated relatively higher levels of DDTs in Vietnamese samples (Fig. 2). Results of recent surveys in Asia-Pacific Mussel Watch Program showed that DDT levels in Vietnamese mussels were lower than those in mussels from southern China and Hong Kong, but higher than those collected from most of other countries in East Asian region (Monirith *et al.*, 2003a). Kannan *et al.* (1995) reported mean concentration of DDT in fish from Vietnam were the highest among India, Thailand, Indonesia and Australia. Contamination pattern were similar for birds, which showed that DDT residue levels in some resident species in Vietnam were among the highest values reported for the Asian countries surveyed (Minh *et al.*, 2002). It is interesting 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 was 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.

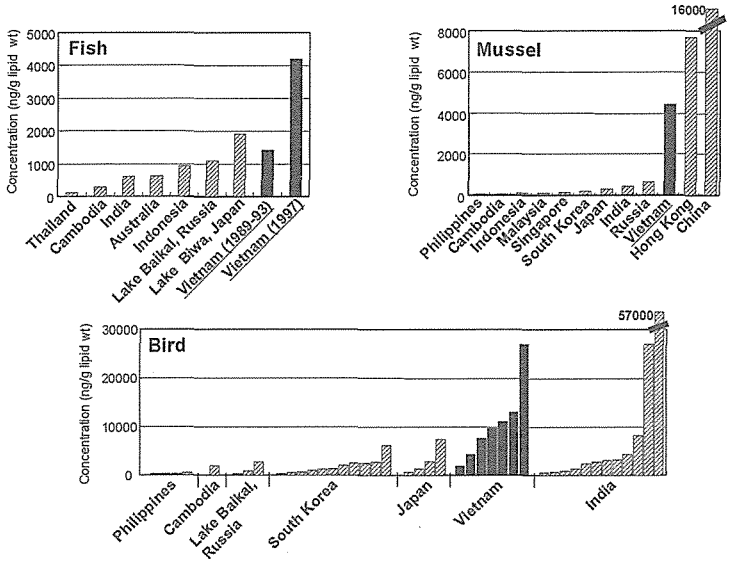

Figure 2. Comparison of DDT residue levels in fish, mussels and birds from Asia-Pacific countries including Vietnam. Data for fish were cited from Kannan *et al.*, 1995; Nakata *et al.*, 1995; Gugure *et al.*, 1997; Kunisue *et al.*, 2002 and Minh *et al.*, 2002; mussels from Monirith *et al.*, 2003a; and birds from Tanabe *et al.*, 1998; Hoshi *et al.*, 1998; Choi *et al.*, 2001; Minh *et al.*, 2002; Kunisue *et al.*, 2003 and Monirith *et al.*, 2003b.

DIOXIN CONTAMINATION

Southern Vietnam has long been considered as a well known region where Agent Orange was extensively sprayed during 1961-71 in the American War, resulting in severe dioxin contamination in various environmental media and food chain including humans. During the last three decades, Schecter and co-workers have been conducting a number of investigations on the dioxin contamination in southern Vietnam, including sediment, foodstuffs and particularly, human samples living near the "hot spot" of dioxin contamination (e.g. Schecter et al., 1990, 1995).

In general, the dioxin contamination as a result of Agent Orange can be characterized by the predominant of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD), the major contaminants of the herbicide 2,4,5-T, a constituent of Agent Orange. 2,3,7,8-TCDD is one of the most toxic congener and has received the most attention. Recently, Dwernychuk *et al.* (2002) surveyed soils, sediments, and foods from Aluoi Valley, a "hot spot" of Agent Orange spraying and the former US Army Base sites. The highest concentration of PCDD/Fs in soil were 2200 pg/g dry wt, which were much higher than those in background levels in many industrialized countries in the world. Of a greater concern, however, are high levels of PCDD/Fs in breast milk, a major dietary intake for breast-fed children. Survey throughout the valley indicates that breast-fed infants of primiparas groups had intake values that 27-fold exceeding the Tolerable Daily Intake (TDI) proposed by WHO. This fact highlighted a new environmental issue that first child exposed to high level of contaminants and therefore be at higher risk.

Except for the dioxin problems caused by Agent Orange in southern Vietnam, there have been no studies investigating the contamination status, bioaccumulation characteristics, fate and toxic implications of dioxins in a tropical environment in Vietnam until our laboratory reported this concern regarding dioxin contamination in dumping sites for municipal wastes in 2003 (Minh *et al.*,

2003). These open dumping sites are usually located near human habitats; therefore, exposure to various toxic chemicals that originated from dumping sites is of serious concern because of the effects on human health, wildlife and environmental quality. Our recent survey indicates that the concentrations of PCDD/Fs in soils from dumping sites in Hanoi were significantly higher than those in Hochiminh city. Mean and range concentrations in dumping sites from Hanoi were 6100 pg/g dry wt (95 pg/g TEQs), and 125 - 50,500 pg/g dry wt (0.4 - 850 pg/g TEQ), respectively. In general, dioxin residues in soils from Vietnam were less than those in other Asian countries examined in this study, indicating less dioxin contamination in Vietnam. However, one soil sample contained very high concentration of PCDD/Fs (50 ng/g dry wt basis; 850 pg/g TEQs) (Minh *et al.*, 2003). This level is greater than most of the background levels soils in industrialized countries and even higher than those reported for dioxin-contaminated locations in the world. In addition, it is interesting to note that PCDD/F levels in soils collected from dumping sites were significantly higher than those in agricultural and resident soils collected far from dumping sites. These results suggest that open dumping sites could be a potential source of dioxins in Vietnam and deserve further studies.

TRENDS OF CONTAMINATION

There have been a few reports suggesting the role of the southern Asian region as possible emission source for the pristine areas such as the Arctic and the Antarctic (Iwata *et al.*, 1993; Kunisue *et al.*, 2002). Despite OCs were banned in most of the developed nations, high consumption of OC insecticides for enhancing food production and eradicating vector-born diseases has been a virtual fact in developing countries. While OC residues levels in developed nations showed a rapid decrease, the status of contamination in developing world seemed different with slower rate of decline. Though well-designed studies on the temporal trends of contamination in POP from Vietnam have been limited, trends of OC residues in river water and sediments from Red River estuary and human breast milk from women living in suburb areas of Hanoi and Hochiminh city were investigated along those lines.

Viet (2004) examined residue concentrations of DDTs and γ-HCH (lindane) the two most common insecticides used extensively in Vietnam, in water and sediments from Red River delta. River water and sediments were collected at the same locations annually in both dry and wet season and were examined for the trends of contamination during 1995 - 2001. DDT residues in water have declined relatively rapidly during 1995 - 1998 and remained constant until recent years at the levels below 10 ng/L. DDT residues in sediment dropped by a factor of 2 during 1997 - 2000. DDT was officially banned in Vietnam in 1995 (Sinh *et al.*, 1999). The reduction of DDT concentrations in both water and sediment from Red River, northern Vietnam indicate the effect of legislative action to reduce the degree of environmental pollution. An interesting result were observed for trends of lindane in sediment, showing peak concentrations in 1997 and lower levels during 1995 - 96 and 1999 - 01. Recent studies examined HCH residues in sediment from different sites in Red River Delta and estuary and elucidated that HCH concentrations in 1997 survey were also higher than those analyzed in sampling survey in 1995 (Nhan *et al.*, 1999). Such a fluctuation trend of HCH contamination suggests the sporadic input of this insecticide into the watershed of Red River. In general, result in water and sediment in recent years indicated a rapid decline of DDTs and HCHs in surface water, but slow reduction trend in sediment. There are indeed severe gap in the monitoring of trends of contamination in biota samples from Vietnam. Temporal monitoring of residue concentrations in biota will provide more realistic hints to understand trends of contamination in the environment.

In addition to the studies on the trends of POP levels in the environmental samples, time trends of human exposure is also an important issue for understanding the long term toxic impacts on general population. Minh *et al.* (2004) assessed the decline rate of human exposure to DDTs and PCBs over the 10 years period (1989 and 2001) (Fig. 3). A first order kinetic approach has been used to estimate the declining rate of DDTs and PCBs in human breast milk collected from Vietnam. The decrease of persistent organic pollutants such as DDTs, PCBs and HCHs in human breast milk was suggested to follow first-order kinetic (Noren and Meironyte, 2000). Another important factor for the assessment is half-life ($t_{decl/2}$) defined as the duration in which initial concentrations decrease to a half. On the basis of the residue concentrations of OCs in 1989 reported by Schecter *et al.* (1989) and the levels in 2001 obtained by Minh *et al.* (2004), the rate constant and $t_{decl/2}$ were estimated.

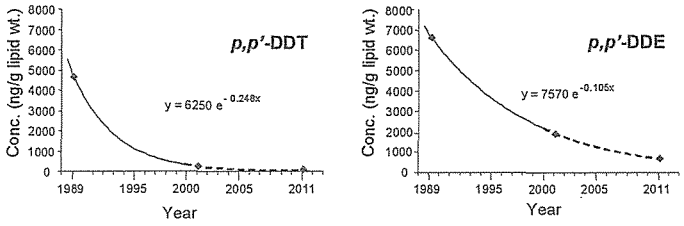

Figure 3. Estimation of time trend curve of p,p-DDT and p,p-DDE residues in human breast milk in Vietnam. Data from Minh *et al.*, 2004.

Residue levels of *p,p'*-DDT have decreased from 4700 to 2700 ng/g lipid wt. in over 10 years with $t_{decl/2}$ of around 3 years. On the other hand, *p,p'*-DDE decreased rather slowly with a $t_{decl/2}$ of 6 years. This result is somewhat in agreement with those in Sweden showing half-life of 4 and 6 years for *p,p'*-DDT and *p,p'*-DDE, respectively (Noren and Meironyte, 2000). The slightly shorter of half-life observed here could be due to the tropical climate that exist in Vietnam may have facilitated volatilization of *p,p'*-DDT in the environment leading to its faster decrease in food chains (and thus in humans). The estimated half-life is fairly beneficial for assessing the trend of DDT contamination in Vietnamese human breast milk. Assuming that the decrease trend of DDTs remains more or less constant, we can estimate the DDTs levels reaching approximately 700 ng/g lipid wt in the year 2011 (Fig. 3). However, lower residue levels in future can be expected if the use of DDTs is completely phased out from now.

IMPLICATIONS FOR ENVIRONMENTAL QUALITY AND HUMAN HEALTH

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. Among the 18 locations examined throughout Vietnam during the survey in early 1990s (Iwata *et al.*, 1994), 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 canals 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. Taking into

accounts these facts, it is important to note that the magnitude of contamination by DDTs in Vietnam is of concern and warrant further studies.

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. 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. Many soil samples in dumping sites contained TEQ concentrations exceeding 250 pg/g TEQs, 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 (Minh *et al.*, 2003).

Table 1. Estimated daily intakes of persistent organochlorines via mussels by different populations in Asia-Pacific region

Country	Survey year	Seafood consumption[a] (g/person/day	Intake of PCBs[b] (ng/person/day)	Intake of DDTs (ng/person/day)	Intake of HCHs (ng/person/day)
Cambodia	1998	20	15	6.6	< 0.2
China	1999-2001	71	180	17000	57
Hong Kong	1998-99	69	260	8300	14
India	1998	13	49	55	26
Indonesia	1998	52	68	52	2.1
Japan	1994	196	5900	690	63
South Korea	1998	114	420	400	30
Malaysia	1998	156	160	220	< 1.6
Philippines	1998	77	440	31	2.3
Russia	1999	54	3400	650	54
Vietnam	1997	47	66	1900	2.8

[a]Seafood consumption data were cited from FAO Food Balance Sheets, FAO Statistics Division, FAO 2006

[b]Intakes were estimated on the basis of residue concentrations in mussels (Asia-Pacific Mussel Watch Program) reported by Monirith *et al.* (2003a)

In the perspective of human health implication, on the basis of the recent data of average seafood consumption reported by Food and Agriculture Organization of the United Nations, the average daily intakes of PCBs and DDTs from seafood for different countries in Asia-Pacific region were estimated (Table 1). Interestingly, results again showed that intakes of DDTs by Vietnamese population were apparently higher than those reported in other countries examined.

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). Intakes of dioxins were estimated to be the highest in people of Philippines, followed by Cambodia, India, Hanoi (North Vietnam), and Ho Chi Minh 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. Interestingly, 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. The breast fed children intakes of PCDD/Fs estimated on the basis of residues in breast milk of women living in open dumping sites in Asian countries were given in Fig. 4. The intakes estimated for Vietnamese were comparable to those in Cambodia but lower than in the Philippines and India (Kunisue *et al.*, 2004). In addition, it is important to note that intakes estimated for children living near the hot spot of dioxin contamination due to Agent Orange in southern Vietnam were still very high even after the Agent spraying ended almost 3 decades (Dwernychuk *et al.*, 2002). Thus, Vietnam could serve as suitable location for future research on possible toxic effects of dioxins on wildlife and humans due to the unique situation where both current and historical dioxin contamination exists for potentially large exposed population.

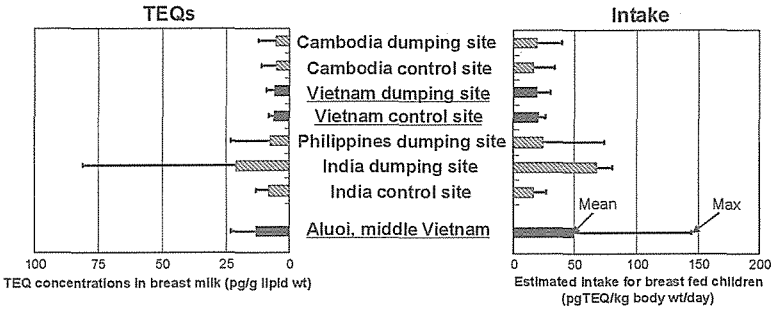

Figure 4. TEQ concentrations and estimated intakes of PCDD/Fs for children from open dumping sites in Asian countries and A Luoi Valley, a former Agent Orange spaying during American War.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Multi-media monitoring studies conducted during the last decade on PTS 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 PTS 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.

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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. Winnipeg, MB, Canada.

Choi J.W., Matsuda M., Kawano M., Min B.Y., Wakimoto T. (2001). Accumulation profiles of persistent organochlorines in waterbirds from an estuary in Korea. *Arch. Environ. Contam. Toxicol.* **41**, 353-363.

Dwernychuk L.W., Cau H.D., Hatfield C.T., Boivin T.G., Hung T.M., Dung P.T., Thai N.D. (2002). Dioxin reservoirs in southern Viet Nam - A legacy of Agent Orange. *Chemosphere* **47**, 117-137.

Guruge K.S., Tanabe S., Fukuda M., Yamagishi S., Tatsukawa R. (1997). Accumulation pattern of persistent organochlorine residues in common cormorants (*Phalacrocorax carbo*) from Japan. *Mar. Pollut. Bull.* **34**, 186-193.

Hoshi H., Minamoto N., Iwata H., Shiraki K., Tatsukawa R., Tanabe S., Fujita S., Hirai K., Kinjo T. (1998). Organochlorine pesticides and polychlorinated biphenyls congeners in wild terrestrial mammals and birds from Chubu region, Japan: Interspecies comparison of the residue levels and composition. *Chemosphere* **36**, 3211-3221.

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

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

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

Kunisue T., Minh T.B., Fukuda K., Wantanabe M., Tanabe S., Titenko A. (2002). Seasonal variation of persistent organochlorines accumulation in birds from lake Baikal, Russia and the role of the South Asian Region as a source of pollution for wintering migrants. *Environ. Sci. Technol.* **36**, 1396-1404.

Kunisue T., Watanabe M., Subramanian A., Sethuraman A., Titenko A.M., Qui V., Prudente M., Tanabe S. (2003). Accumulation features of persistent organochlorines in resident and migratory birds from Asia. *Environ. Pollut.* **125**, 157-172.

Kunisue T., Watanabe M., Iwata H., Subramanian A., Monirith I., Minh T.B., Baburajendran R., Tana T.S., Viet P.H., Prudente M., Tanabe S. (2004). Dioxins and related compounds in human breast milk collected around open dumping sites in Asian developing countries: bovine milk as a potential source. *Arch. Environ. Contam. Toxicol.* **47**, 414-426.

Minh T.B., Kunisue T., Yen N.T.H., Watanabe M., Tanabe S., Hue N.D., 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., 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.

Minh N.H., Someya M., Minh T.B., Kunisue T., Watanabe M., Tanabe S., Viet P.H., Tuyen B.C. (2004). Persistent organochlorine residues in human breast milk from Hanoi and Hochiminh City, Vietnam: Contamination, accumulation kinetics and risk assessment for infants. *Environ. Pollut.* **129**, 431-441.

Monirith I., Ueno D., Takahashi S., Nakata H., Sudaryanto A., Subramanian A., Karuppiah S., Ismail A., Muchtar A., Zheng J., Richardson B.J., Prudente M., Hue N.D., Tana T.S., Tkalin A.V., Tanabe S. (2003a). Asia-Pacific mussel watch: monitoring contamination of persistent organochlorine compounds in coastal waters of Asian countries. *Mar. Pollut. Bull.* **46**, 281-300.

Monirith I., Kunisue T., Iwata H., Tanabe S., Tana T.S. (2003b). Accumulation of persistent organochlorines in resident white-breasted waterhens (*Amaurornis Phoenicurus*) from Cambodia. *Mar. Pollut. Bull.* **46**, 1341-1358.

Nakata H., Tanabe S., Tatsukawa R., Amano M., Miyazaki N., Petrov E. (1995). Persistent organochlorines and their bioaccumulation kinetics in Baikal seal (*Phoca sibirica*) from Lake Baikal, Russia. *Environ. Sci. Technol.* **29**, 2877-2885.

Nhan D.D., Am N.M., Hoi N.C., Dieu L.V., Carvalho F.P., Villeneuve J.P. Cattini C. (1998). Organochlolrine pesticides and PCBs in the Red river delta, North Vietnam. *Mar. Pollut. Bull.* **36**, 742-749.

Nhan D.D., Am N.M., Carvalho F.P., Villeneuve J.P., Cattini C. (1999). Organochlorine pesticides and PCBs along the coast of North Vietnam. *Sci. Total Environ.* **237/8**, 363-371.

Noren K., Meironyte D. (2000). Certain organochlorine and organobromine contaminants in Swedish human milk in perspective of 20-30 years. *Chemosphere* **40**, 1111-1123.

Schecter A., Fuerst P., Fuerst C., Meemken H.A., Groebel W., Constable J.D. (1989). Levels of polychlorinated dibenzofurans, dibenzodioxins, PCBs, DDT, DDE, hexachlorobenzene, dieldrin, hexachlorocyclohexanes, and oxychlordane in human breast milk from the United States, Thailand, Vietnam and Germany. *Chemosphere* **18**, 445-454.

Schecter A., Tong H.Y., Monson S.J., Gross M.L., Raisanen S., Karhunen T., Osterlund E.K., Constable J.D., Cau H.D., Dai L.C., Quynh H.T., Lang T.D., Phuong N.T.N., Phiet P.H., Vu D. (1990). Human adipose tissue dioxin and dibenzofuran levels and "dioxin toxic equivalents" in patients from the North and South of Vietnam. *Chemosphere* **20**, 943-950.

Schecter A., Dai L.C., Thuy L.T.B., Quynh H.T., Minh D.Q., Cau H.D., Phiet P.H., Phuong N.T.N., Constable J.D., Baughman R., Papke O., Ryan J.J., Furst P., Ralsanen S. (1995). Agent Orange and the Vietnamese: The persistence of elevated dioxin levels in human tissues. *Am. J. Pub. Health* **85**, 516-522.

Sinh N.N., Thuy L.T.B., Kinh N.K., Thang L.B. (1999). The persistent organic pollutants and their management in Vietnam. *Proceedings of the Regional Workshop on the Management of Persistent Organic Pollutants (POPs), United Nations Environment Program*, Hanoi Vietnam, pp. 385-406.

Tanabe S., Senthilkumar K., Kannan K., Subramanian A. (1998). Accumulation features of polychlorinated biphenyls and organochlorine pesticides in residents and migratory birds from South India. *Arch. Environ. Contam. Toxicol.* **34**, 387-397.

Thao V.D., Kawano M., Tatsukawa R. (1993). Persistent organochlorine residues in soils from tropical and subtropical Asian countries. *Environ. Pollut.*, **81**, 61-71.

The Agency for Toxic Substances and Disease Registry (ATSDR) (1997). Interim Policy Guideline: Dioxins and Dioxin-like compounds in soil. US Department of Health and Human Services, Public Health Services, Atlanta, GA, USA.

Viet P.H. (2004). Persistent organic pollution and arsenic contamination in water: emerging environmental problems in Vietnam. *Proceedings of the International Symposium on The Development of Water Resource Management System in Mekong Watershed.* Hanoi, Vietnam, pp. 5-14.