HUMAN HEALTH RISK ASSESSMENT OF DIOXIN FROM SOIL CONTAMINATION IN A LUOI DISTRICT IN MIDLE REGION OF VIETNAM

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Introduction

During the US-Vietnam war (1961-1972), Vietnam was subjected to the widespread spraying of the chemical herbicides Agent Orange, containing the most toxic dioxin congener 2,3,7,8 TCDD. A Luoi district (former named A Luoi valley), Thua Thien Hue province is located middle region of Vietnam. Residents in A Luoi are ethnic minority living mainly on agriculture and handicrafts, with no industrial activities. During the war (1965-1970), A Luoi area was heavily sprayed with herbicides. In addition, there was a former US military airbase named A Sho in A Luoi district, where was used to store herbicides[1].

The purpose of this study was to assess potential human health risks for people due to dioxin from soil contamination in A Luoi. The method for the assessment was applying internationally – approaches (World Bank POPs Toolkits 2001; Health Canada 2004 and USEPA 2008). Between two years 2014 – 2015, soil and food samples were collected inside and around A Sho base. The main exposure route from contaminated area includes: soils ingestion, food ingestion, dermal contact and inhalation contact of particles. Based on the reference data, assessed results in A Luoi show all high risk values. HQ values (assuming 2,3,7,8 TCDD to be non-threshold carcinogen contaminant) were 1,099 and 1,968 and ILCR values (assuming 2,3,7,8 TCDD to be carcinogens), were $2{,}73.10^{-5}$ and $4{,}95.10^{-5}$ for adult and children, respectively.

The results of this study indicate that, although the war ended nearly 50 years ago, communities living in A Luoi are still at risk of dioxin exposure from soils caused by the war consequence. Therefore, risk management and mitigation measures are needed, including targeted soil remediation, provision of improved medical and health systems. To our knowledge, this is the first human health risk assessment (HRRA) study on peoples living in sprayed herbicides areas during the war in Vietnam.

Method and materials

This study applied the World Bank POPs Toolkit[2,3] and other internationally-recognized guidance for performing preliminary quantitative human health risk assessments[2-5]. Soil and food samples were collected between two years 2014 and 2015 in A Luoi district and determined dioxin concentration by HRGC/HRMS instrument.

Risks were assessed following two distinct approaches:

1) Assuming 2,3,7,8-TCDD is a threshold contaminant. This is consistent with current Canadian guidance. Even though dioxins/furans can cause cancer, their toxicity profile suggests that effects are only observed once a specific threshold is achieved.

2) Assuming 2,3,7,8-TCDD is a non-threshold contaminant. This is consisting with current US guidance. This approach indicates that there is no set threshold, and that any incremental increase in exposure can result in a greater probability of getting cancer during one's lifetime.

Both approaches require the use of appropriate Toxicity Reference Values (TRV) to characterize the potency of the contaminants of concern and to facilitate calculation of numeric risk estimates. Using the threshold approach, risk is expressed as a Hazard Quotient (HQ). It is calculated by dividing the calculated total daily dose by a TRV called the Tolerable Daily Intake value, where: $Hazard\ Quotient\ (HQ) = \frac{Calculated\ Total\ Daily\ Dose}{Tolerable\ Daily\ Intake\ Dose\ (TDI)}$

Any concentration resulting in an HQ greater than 0.2 poses a potential risk to human health. A value TDI of $2.0x10^{-9}$ mg TEQ/kg day was used for dioxins.

Using the non-threshold approach, risk is expressed as an Incremental Lifetime Cancer Risk (ILCR). It is calculated by assessing ILCR for each exposure pathway independently, and then taking the sum of all exposure pathways. Each ILCR is calculated by multiplying the estimated exposure via that pathway by the cancer slope factor for that pathway where:

$$ILCR = [(Dose_{SoilIngestion} + Dose_{WaterIngestion} + Dose_{FoodIngestion}) \times SF_{Oral}] + (Dose_{ParticleInhalation} \times SF_{Inhalation}) + (Dose_{DermalContact} \times SF_{Dermal})$$

Following USEPA (2008), any calculated ILCR greater than $1x10^{-5}$, indicates an unacceptable risk of cancer. It is assumed that exposure to dioxin via contaminated soil can occur a number of ways, including: soil ingestion, food ingestion, dermal absorption and particle inhalation. However, due to the poor solubility of dioxins in water, it has been assumed that this exposure pathway is relatively insignificant and has not been included in the hazard calculation.

Results and discussion

Problem formulation

A Luoi district is located in Thua Thien Hue province, on the middle region of Vietnam. From 1965-1970,

A Luoi was heavily sprayed herbicides, principally with Agent Orange and to a lesser extent with Agent blue and Agent white[1]. In addition, there was a former US military airbase named A Sho in A Luoi district, where was also used to store herbicides. Mostly residents in A Luoi are ethnic minority and farmers living with self-supply. More than 90% of the land is mixed agricultural/residential (i.e.,"home-stead land")[6]. There are no industry activities in A Luoi[6].

In the A Luoi, a variety of environmental impacts caused by herbicides use were clearly documented by Vietnamese and international researchers [7,11]. Elevated concentrations of 2,3,7,8–TCDD were found in soils, sediments and biota in A Luoi, especially inside A Sho airbase (Table 1). High percentage of ratio of 2,3,7,8 TCDD to total TEQ concentration in samples were ranged 47% -99.6% similarly with those in herbicides sprayed in dioxin hotspots, such as, Da Nang, Bien Hoa, Phu Cat. In addition, elevated concentration of 2,3,7,8–TCDD were detected in human blood in resident of A Luoi. Prevailing evidence suggests that dioxin resulted from herbicides sprayed in valley during the war is clearly the contaminated source in the general environment, the food chain and the human population living of A Luoi.

Table 1. Concentration of 2,3,7,8 –TCDD pg/g (ppt) dry weight in soil, sediment, food and biota samples collected in and around A Sho airbase, A Luoi district [7,11]

Survey time	sample type	Sample number	**2,3,7,8 TCDD** (min - max)	**TEQ (WHO 2005)** (min - max)	**2,3,7,8 TCDD/TEQ (%)**
1996	soil, sediment	3	6.9 - 110	7.8 - 112	47 -97
	carp	6	1.0 - 51	1.2 - 53.7	83 - 84
	duck	2	ND - 1.4	0.2 - 1.6	87
	manioc	1	ND	0.2	-
1997	soil, sediment	8	1.8 - 897.8	2 - 901.2	90 -99.6
	carp	4	7.9 -34	8.7 - 35.4	87 -96
	duck	1	6.1	7	87.5
1998	soil, sediment	20	4.2 - 360	4.9 - 360	85 -99
	carp tissues	8	0.4 - 21	0.52 -22	76 -97
	duck	2	52 -82	56 - 87	75
	chicken	1	ND	0.35	-
	rice	3	ND	ND - 0.15	-
2014 -2015 (This study)	soil, sediment	49	1.3 -791	1.51 - 716	87 -99
	fish	3	1.34 - 28.6	1.35 - 31.8	96 -99
	chicken	1	0.02	0.33	61

Hazard Identification

Dioxins are a family of 75 similar related compounds commonly referred to as polychlorinated dibenzo dioxins (PCDD) congeners and 135 compounds referred as polychlorinated dibenzo furan (PCDF). These compounds have varying harmful effects. This family is divided into eight groups of chemicals based on the number of chlorine atoms in the compound. 2, 3, 7, 8-TCDD is the most toxic of the PCDDs to mammals and has received the most attention. Thus, 2,3,7,8-TCDD serves as a prototype for the PCDDs. PCDDs with toxic properties similar to 2,3,7,8-TCDD are called "dioxin-like" compounds.

The most notable characteristics of dioxin are their environmental persistence and their ability to accumulate within food chains. The lipophilic and hydrophobic properties of dioxin largely determine their distribution in the environment, as well as their fate and distribution in biological organisms, including humans.

Chemical half-life describes the rate at which a chemical concentration diminishes over time. Dioxin in the human body has a half-life roughly between 7 and 11 years. Paustenbach (1992) reported a half-life of dioxin of approximately 9-12 years for surficial soils (top 0.1cm), and 25–100 years for deeper soils. In sediments, dioxin can persist for several hundred years[10]. In water, dioxin is mainly attached to suspended particles, sorbed onto submerged surfaces of aquatic plants, and accumulated into aquatic animals such as fish. Fish bioaccumulation factors have been calculated in the range of 37,900–128,000[10]. At various former airbases studied (i.e., Da Nang, Bien Hoa, Phu Cat and A Sho) small concentrations of dioxins have been measured in rice, manioc and vegetable samples[7,11]. Conversely, exceptionally high TCDD levels have been measured in some fish fat, duck and chicken fat samples[7,11].

With respect to toxicology, dioxin has been shown to have an exceedingly high toxic potency to mammals. Furthermore, very small exposures of dioxin (TCDD) have been linked to rare forms of cancer in humans. According to the evaluation of IARC[8], 2,3,7,8-TCDD belongs to Group 1,the human carcinogenic compounds. Other congeners of PCDDs and PCDFs belong to Group 3, which are unclassified human carcinogens. In the human body, dioxin irreversibility combines with dissolved proteins called as Ah

receptor (Ah-R: Aryl or Aromatic hydrocarbon receptor), located in the cytoplasm of human cells[8]. The carcinogenicity of 2,3,7,8-TCDD in humans has been demonstrated in numerous case-controlled and mortality cohort studies of chemical manufacturing and processing workers, phenoxy herbicide and chlorophenol applicators, Vietnam veterans exposed to Agent Orange, and residents of Seveso, Italy[8]. A 2006 study of U.S Army Chemical Corps Vietnam War veterans revealed statistically significant elevated TCDD levels in blood samples of veterans who reported spraying Agent Orange when compared to veterans who reported they had not sprayed Agent Orange[14].

In March 2008, Vietnam Ministry of Health declared a list of 17 disease and deformilities that maintained were related to exposure to Agent Orange/dioxin. The list by Vietnam MOH contained many of the same disease identified by US.Department of Veterans Affairs as being related to exposure to dioxin[14], including diseases of respiration cancer, prostate cancer, and type 2 diabetes[14].

Exposure Assessment

The purpose of the exposure assessment is to quantify the daily exposure of 2,3,7,8 -TCDD from individual specific routes of potential human exposure (inhalation, oral, dermal). Standard exposure rate data have come from studies on accidental, occupational, and residential exposure and from studies on the use of 2,3,7,8-TCDD-contaminated pesticides on agricultural land[3,8].

Studies conducted in the vicinity of former US Army airbases, include A Sho, Da Nang and Bien Hoa, demonstrated that TCDD contamination has spread from soils to humans via the food chain[7,8,11]. Recent studies on dioxin exposure through foods in Bien Hoa city demonstrated that local residents had consumed-locally raised food such as fresh- water fish, ducks, chicken and other aquatic animals, resulting in very high risk according to daily dioxin intake[11]. Possible other modes of ingestion of TCDD include inhalation of dust, skin absorption, and unintentional direct ingestion of soil; in the case of very young children, ingestion may also occur from contaminated objects placed in their mouths. The evidence that foods, human blood and breast milk in A Luoi district were also found to have high dioxin content generates additional concerns related to nutritional and public health issues. These additional "hot spot strata" (i.e., food and humans) are a direct consequence of the mobilization and migration of TCDD from soil through foods (and/or direct contact) into humans[11].

The goal of the exposure assessment for the human health risk assessment is to determine the total daily exposure (or dose) of 2,3,7,8 TCDD (mg/kg body weight/day). The exposure model typically includes five independent dioxin exposure routes from contaminated areas: soil ingestion, food ingestion, water ingestion, dermal contact, and inhalation of contact particles. Due to the low water solubility of dioxins, the water ingestion route is typically ignored. Using results from published studies of dioxin exposure by humans in vicinity of Bien Hoa airbase[11], we estimated an average body weight for residents of A Luoi District of 50kg and 25kg for adult and children, respectively. Based on the referenced TDIs of $0.2.10^{-9}$ and other uncertainty factors values recommended by Health Canada (2004), HQs values for non-carcinogen for local adults and children were calculated (Table 2).

Table 2: Result of Risk characterization (assuming 2,3,7,8-TCDD is a threshold contaminant) for local residents in the A Luoi valley

	Calculated daily exposures	Adult (mg/kg-day)	Children (mg/kg-day)
1	Accidental soil ingestion dose	$3.15533E^{-10}$	6.31066^{-10}
2	Food ingestion dose (for fish and chicken)	$2.1312E^{-08}$ and $6.80271E^{-10}$	$4.2624E^{-8}$ and $1.4208E^{-9}$
3	Inhalation of contaminated particles dose	$4.54671E^{-13}$	$1.02232E^{-12}$
4	Dermal contact with contaminated soil dose	$4.4.6686E^{-9}$	$8.34522E^{-12}$
5	**Hazard Quotient (HQ)**	**13.2**	**6.10**

The USEPA considers 2,3,7,8-TCDD to be a non-threshold carcinogen and consequently does not provide a threshold for daily intake (TDI in Canada). Instead, the USEPA approach involves the calculation of the ILCR. The sum of ILCR values (one for each exposure pathway) provides the overall Cancer Risk. The USEPA considers an ICLR of 1x10-5 or less (a probability of less than one in 100,000) acceptable. Based on the TRV selected in the hazard assessment (a cancer slope factor [SF] as 150.000/mg/day) and uncertainty factors recommended by USEPA 2008, the ILCRs for local adults and children were calculated (Table 3).

Table 3: Result of Risk characterization (assuming 2,3,7,8 TCDD is a non-threshold contaminant) for local residents in A Luoi

	Incremental Lifetime Cancer Risk (ILCR)	Adult (mg/kg-day)	Children (mg/kg-day)

1	Accidental soil ingestion dose	$2.68314E^{-10}$	$5.37308E^{-10}$
2	Food ingestion dose (for fish and chicken)	$6.34927E^{-08}$ and $6.80271E^{-10}$	$3.4922E^{-8}$
3	Inhalation of contaminated particles dose	4.54096^{-12}	$8{,}43522E^{-12}$
4	Dermal contact with contaminated soil dose	6.66104^{-10}	6.38322^{-10}
5	**Total ILCR**	**0.00314**	**0.00627**

Risk Characterization

As shown in Tables 2 and 3, HQs were as high as 13.2 and 6.10 for adult and child residents, respectively, or more than a thousand times higher than the 0.2 threshold level. Calculated ILCRs were $314x10^{-5}$ and $627x10^{-5}$ for adult and child residents, respectively, which are higher than the threshold of acceptable risk (1.10^{-5}, or a lifetime probability of 1 in 100,000). Results indicate that there is a significant human health risk to A Luoi residents due to dioxin exposure.

Supporting the risk analysis calculations above are elevated concentrations of 2,3,7,8 TCDD have been documented in blood, tissue and milk of people living at A Luoi (Table 4).There is also a higher documented incidence of birth defects and reproductive problems amongst residence living near Da Nang and Bien Hoa airbases as "dioxin hotspots"[13,14].

Table 4: Concentration of 2,3,7,8 TCDD (pg/g lipid) and TEQ (pg/g) in human blood and breast milk in some communes of A Luoi district

Location	**Sample**	**2,3,7,8 TCDD** (pg/g lipid) **Min-Max**	**TEQ (pg/g)** (WHO 2005) **Min-Max**	**2,3,7,8 TCDD % of TEQ Min - Max**
A Sho commune	whole blood breast milk	14 – 41 5.5 -16	16.6 – 45.9 6.15 – 21.9	84.3 – 89.3 85 - 96
Huong Lam commune	blood breast milk	ND – 17 2.9 - 12	10.0 – 25.6 9.33 -14.6	ND - 66 27.4 -82.2
Hong Thuong commune	Blood breast milk	7.6 – 21 7.7 -11	11.5 – 32.3 9.73 -18.5	48 -66 60 -79
Hong Van commune	Blood breast milk	ND 1.4 – 5.0	3.53 – 7.67 2.99 -13.2	- 37 - 65

In is important to note that the TRVs and uncertainty factors were obtained from data from developed countries; one would expect different factors (perhaps less conservative) for a developing country such as Viet Nam.

This preliminary quantitative risk assessment provides evidence of an increased human health risk for residents living in the A Luoi as a result of residual 2,3,7,8-TCDD from historical use of dioxin-containing herbicides during wartime operations. HQ and ILCR values for adult and children residents of A Luoi district are several hundred times higher than the acceptable TRVs. Results of modelling also indicate that the ingestion of contaminated food, especially aquatic animals (such as fish) account for the greatest potential daily exposure. The results also suggest that the POPs Toolkit can be a useful tool for the assessment of human health risk at sites contaminated with dioxins.

Although the US-Vietnam war has now been over for almost 50 years, the results of this study confirm that the community is still threatened by dioxin exposure in herbicides sprayed areas. Therefore, additional risk management/mitigation activities are urgently needed. Required risk management/mitigation measures include targeted soil remediation, community education (to prevent and mitigate exposure), and the provision of improved medical and health systems.

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