Metals and Food Contamination: Cadmium in Paddy Fields in Thailand and Vietnam

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ABSTRACT

Since the late 1980's considerable focus has rightly been placed on the exposure of large populations in Bangladesh, China, Vietnam, Taiwan and West Bengal, India to naturally excess levels of As in groundwater water. In humans arsenocosis is visually manifested predominantly as palmoplantar keratoderma and hyper-pigmentation of the skin.

In contrast, except in extreme cases of 'Itai Itai' disease Cd-induced human health impacts have no visual manifestation. However, research undertaken over the last 40 years has identified compelling evidence to support the notion that the long-term consumption of cadmium (Cd) contaminated rice contributes to human Cd disease. Numerous reports of health effects of Cd in populations dietarily exposed to Cd have centered on Japan and China where rice-based agricultural systems have become contaminated with Cd from the use of irrigation waters that receive natural runoff and/or un-controlled discharges from non-ferrous mines, smelters and associated industries. Rice is the staple of millions throughout South and Southeast Asia. However, limited research has been conducted outside of Japan and China to quantify the extent and magnitude of rice food chain Cd contamination and determine its negative impacts on public health.

In general background levels of Cd in Thai and Vietnamese soils are well below national and international guideline levels. However, recent collaborative research has identified significantly elevated levels of Cd in soils and crops in isolated intensive rice production systems in a localize area of Northwestern Thailand. The Cd-contaminated rice-based agricultural system investigated is within Phatat Pha Daeng and Mae Tao Mai sub-districts, Mae Sot, Tak Province, Thailand. Irrigation is sourced from Mae Tao Creek the upper stretches of which pass through an actively mined Zn-mineralized zone. Mae Tao Creek is utilized for irrigation by the eight communities with a combined resident population of nearly 6,000 and an annual combined rice production of 7,592 t yr^{-1}. This rice is predominantly for home consumption and sale at local markets. The total area under paddy rice for the 8 villages is estimated as 2,201 ha.

Soil total Cd concentrations for the 1,090 fields sampled during 2001-2005 range from 0.1 – 284 mg Cd kg^{-1} with 84.6% of the fields sampled having a total soil Cd concentration exceeding the upper limit established by the EU for agricultural (sludge amended) soils. Rice grain Cd concentrations for the 1,067 fields sampled during the same period ranged from <0.01 – 7.75 mg Cd kg^{-1} with 67.5% of the fields sampled producing rice grain with Cd concentrations exceeding the recently revised JECFA ML for Cd in rice grain of 0.4 mg kg^{-1}.

The rice grain Cd levels presented in this study are up to >19 times the JECFA ML for rice grain. In comparison, the mean ‘background’ Thai rice grain Cd concentration as reported by Pongsakul and Attajarusit (1999) is 0.043 (±0.019) mg kg^{-1}. It is important to note therefore that the elevated rice grain Cd concentrations presented in this paper are in no way indicative of Thai rice as a whole.

From a public health perspective estimated weekly intake (WI) values of Cd for male and females aged 50yrs as based on field specific and household rice grain samples collected under the IWMI-DOA and IWMI-LDD Projects (2001-2005) range from 24.94 – 93.04 and 24.48 – 91.33 µg Cd per kg BW. This is up to over 13 times the JECFA PTWI value of 7µg Cd per kg BW and poses a significant risk to public health. Initial blood and urine sampling of individuals within the exposed communities have confirmed this risk. However, detailed and scientifically robust dietary and epidemiological studies are still required to both clarify the actual public health impacts and build capacity in local institutions.

Similar situations of isolated irrigated paddy rice-based communities consuming home grown rice cultivated in close proximity to non-ferrous mineralized areas and abandoned non-ferrous mines are thought to occur throughout Northern Vietnam and Southeast Asia. However, to date no detailed bio-physical or epidemiological studies have been undertaken to confirm this risk.

In addition, research presented for Binh Chanh District, Ho Chi Minh City demonstrates the propensity for rice food chain Cd contamination resulting from the use of untreated industrial wastewater. Further, as indicated by preliminary research conducted in Nam Dinh, Northern Vietnam, ‘naturally’ high levels of Cd in soils of the Red River Delta in association with drainage, oxidation and acidification of these soils prior to the critical grain fill stage can result in elevated levels of Cd in rice grain. Coupled with the comparatively high daily rice intake for Vietnam this exposes Fe and Zn deficient individuals particularly women to potential Cd related health risks.

Irrigation, agronomic and soil management-based options are available to mitigate Cd contamination of the rice food chain. In addition, emerging research has indicated that maintaining adequate levels of dietary Fe and Zn may be a viable dietary based means of protecting public health.

However, appropriate management options cannot be implemented unless populations exposed to elevated levels of dietary Cd are systematically identified and public health risk accurately evaluated. IWMI in collaboration with project partners has developed a series of decision support tools that coupled with detailed epidemiological and dietary studies could be utilized to rapidly evaluate areas of concern and facilitate the implement of management options to mitigate potential public health risks.

INTRODUCTION

Elevated levels of cadmium in the rice food chain and impacts on human health

Research undertaken over the last 40 years has identified the relationship between the long-term consumption of cadmium (Cd) contaminated rice and human Cd disease. The long-term consumption of Cd contaminated rice has resulted in chronic and acute human Cd disease as manifested by Itai-Itai disease (Hagino, 1968; Yoshioka, 1970), a form of osteomalacia and proximal tubular renal dysfunction (Shimada et al., 1977; Tohyama et al., 1982; Nogawa et al., 1983; Kido et. al., 1988 Cai et al., 1990; Hochi et al., 1995; Ikeda et al., 2003). Reports of health effects of Cd in populations dietarily exposed to Cd have centered on Japan (Watanabe et al., 1998; Kobayashi et al., 2002; Nogawa et al., 1983; Kido et. al., 1988; Nogawa and Kido, 1993; Kido et al., 1990; Tsuritani et al., 1992) and China (Cui et al., 2004; Jin et al., 2002; Wu et al., 2001; Jin et al., 1999; Cai et al., 1995; Cai et al., 1990; Nordberg, 2003) where rice-based agricultural systems are contaminated with Cd from the use of irrigation waters that receive natural runoff and/or un-controlled discharges from non-ferrous mines and smelters.

Cadmium-induced renal dysfunction in individuals dietarily exposed to Cd is irreversible and progressive despite decreased exposure (Kido et. al., 1988; Nogawa and Kido, 1993). Several studies have also suggested that Cd-induced renal dysfunction interferes with Vitamin D metabolism, with consequential reductions in Ca absorption resulting in osteopenia or osteoporosis particularly in multiparous women (Kido et al., 1990; Tsuritani et al., 1992). Recently, Ikeda et al., (2003) reported a meta-analysis of populations of rice farming families identified in Japan by 1980 who were exposed to high Cd rice for decades. They concluded that these populations showed a threshold of at least 10-11 μg Cd g^{-1} creatinine in urine before they began excretion of significantly increased levels of low molecular weight proteins. Some older persons (>50yrs) in these exposed populations had as high as 80% prevalence of renal tubular proteinuria. With the diagnostic levels clarified, Ezaki et al., (2003) re-evaluated their study of a large population (over 10,000) of urban non-smoking Japanese middle-aged women from across Japan. They had analyzed diet Cd, rice Cd, and blood and urine to determine if the general population in Japan had been excessively exposed to Cd. Urban citizens have been consuming market rice rather than home grown rice, and the average level of Cd in Japanese market rice is higher than many other nations because of the extensive mining history of Japan (Asami, 1984; Watanabe et al., 1996). However, not one of these women in the Ezaki et al., (2003) study was found to suffer renal tubular dysfunction based on the more appropriate diagnostic limits for urine Cd or proteins. This important progress in understanding of risk from increased dietary Cd helps put in perspective the adverse Cd effects claimed in some of the European studies.

Unique health 'risks' posed by elevated levels of Cd in rice grain

Considerable research has also established that levels of dietary Zn as well as Fe and to a lesser extent Ca are known to influence the absorption of Cd and its distribution in organs and tissues (Flanagan et al., 1978; Koo et al., 1978; Fox, et al., 1979; Brzóska and Moniuszko-Jakoniuk*,* 1988*;* Reeves and Vanderpool, 1988; Berglund et al., 1994*;* Reeves and Chaney, 2001).

Cadmium related health risks associated with the long-term consumption of Cd contaminated rice grain are exacerbated by the fact that rice grain Fe, Zn and Ca contents are insufficient for human needs (Hallberg et al., 1977; Pedersen and Eggum 1983). In addition, milling rice grain results in further Fe and Zn losses (Pedersen and Eggum 1983; Zhang et al., 1997) whilst grain Cd concentrations remain un-affected (Yoshikawa *et al.,* 1981). Further, Fe in milled rice has very low bio-availability (Welch and Graham, 1999). Further, rice grain accumulates higher Cd than Zn and Fe levels when compared to rice stem and leaf, thus resulting in high rice grain Cd:Zn and Cd:Fe ratios which significantly increases the risks to human health (Simmons et al., 2003; Chaney et al., 1996).

Simmons et al., (2003) demonstrate that in soils significantly co-contaminated with Zn and Cd the rice plant irrespective of total or bio-available soil Zn concentrations, effectively controls rice grain Zn. However, the rice plant is unable to control the translocation and accumulation of Cd to grain. Despite a 100-fold higher Zn than Cd in rice soils, grain Cd was greatly increased with a mean (n=43) of 1.83 ±1.11 mg kg^{-1} corresponding to total soil Cd ranging from 3.6 to over 280 mg Cd kg^{-1}. In contrast, rice grain Zn remained relatively uniform with a mean (n=43) of 20.2 ±2.28 mg kg^{-1} even though total soil Zn ranged from 254 - 8036 mg kg^{-1} (Simmons et al., 2003). This was evident in the earliest characterization of rice Cd and Zn in the exposed populations of Jintzu Valley (Fukushima et al., 1973).

The emerging paradigm of Cd risk assessment is therefore focused on communities nutritionally deficient in Zn, Fe and Ca consuming Cd contaminated rice. Cadmium contamination of rice has strong gender aspects. As stated previously, Fe deficiency predisposes individuals to a higher Cd absorption and therefore women are a more vulnerable group since they are more prone to Fe deficiency (Berglund et al., 1994). The unique risk associated with a Cd-contaminated rice-based diet is further confirmed by studies undertaken on dietically exposed populations from non-rice growing areas, which did not identify elevated levels of renal dysfunction in the exposed populations (Baker et al., 1977; Ewers et al., 1985; McKenzie-Parnell and Eynon 1987; Strehlow and Barlthrop 1988; Sarasua et al., 1995).

Potential food security and economic implications

The MLs established by CCFAC and JECFA are based on only on the 'safe' lifetime consumption of agricultural produce and the *free movement* of products in international trade. MLs set by the JECFA are used internationally as criteria to establish *non-tariff trade barriers*. In addition, ISO 14000 is being sought by many food importers to guarantee that food and fiber are produced using environmentally sustainable practices. The inability of countries within the Greater Mekong Sub-region to comply with CCFAC MLs and ISO 14000 would have a significant impact on export security. With respect to Cd contamination, it must be stressed that detrimental affects on public health result from long-term dietary intake and are primarily at a local/community level.

However, the impacts of Cd contamination take on a national significance due to the need to provide health services, establish effective crop quality monitoring programs and the implementation of effective management and remediation options. In 2004 the Royal Thai Government paid over 1.5 million US$ in compensation to affected communities in Phatat Pha Daeng and Mae Tao Mai sub-districts, Mae Sot District, Tak Province. In addition, in 2005 the Royal Thai Government implemented an action plan that will include prohibiting the cultivation of rice in over 1,700 ha of paddy in Phatat Pha Daeng and Mae Tao Mai sub-districts in 2005/2006 with associated compensation to farm families. Further, an inter-ministerial task force has been formed to develop long-term management plans based on non-food crop production systems.

Factors affecting Cd mobility in paddy soils

The phyto-availability of Cd in soils is a function primarily of the interactions between soil pH and redox condition (Babich and Stotsky 1978; Bingham et al., 1980; Page et al., 1981; Iimura et al., 1981; Chaney et al., 1996). In paddy soils, soil solution pH alters towards near neutral as the system moves from oxidizing to reducing conditions, which reduces Cd phyto-availability (Chaney et al., 1996). However, drainage of fields at the critical grainfill stage in order to optimize yields and facilitate ease of harvesting, decreases soil pH to the antecedent condition and increases Cd phyto-availablity to rice plants (Chaney et al., 1996). In addition, increased acidity upon drainage and the development of oxidizing conditions results in the dissolution of secondary Al precipitates and the release of any sorbed Cd. The increased acidity also leads to desorption of Cd from soil organic matter (Zachara et al., 1992). Conversely, oxidation results in the formation of Fe and Mn oxides and subsequent co-precipitation of Cd (Alloway, 1997). If reducing conditions reoccur, co-precipitated Cd becomes exchangeable and is sorbed onto surfaces of Al and organic matter. In tropical highly weathered soils the adsorption of Cd^{2+} may also be a function of the pH dependant charge associated with the edge of clays, humus polymers and oxides (Zachara et al., 1992). Further, in submerged paddy soils sulphate (SO_4^{2-}) ions may be reduced to sulphide (S^{2-}) resulting in the precipitation of the Cd and Zn sulphide minerals (Iimura et al., 1981; Chaney *et al.,* 1996).

Drainage and oxidation of paddy soils prior to the grain fill stage to maximize rice grain yield and facilitate harvesting results in the rapid transformation of CdS and ZnS to Cd^{2+}, Zn^{2+} and SO_4^{2-}. Cadmium sulphide oxidizes more readily than ZnS (Iimura, 1981; Chaney et al., 1996) and the resultant Cd^{2+} is highly available for uptake. Iimura et al., (1981) observed un-polished rice grain Cd concentrations of 0.75 and 4.85 mg kg^{-1} for rice grown on submerged soil and soil drained after tillering. Simmons et al., (2003) suggest a greater availability of Cd during the grain fill stage which coincides with oxic field conditions. In summary, drainage, oxidation and potentially acidification of paddy soils prior to the critical grain fill stage, significantly increases Cd phyto-availability and risk of Cd accumulation in rice grain.

1. CADMIUM IN PADDY FIELDS IN THAILAND

Cadmium contaminated study area

The Cd-contaminated rice-based agricultural system investigated in this study is within Phatat Pha Daeng and Mae Tao Mai sub-districts, Mae Sot, Tak Province, Thailand and has been previously described by Simmons et al., (2003; 2005). A paddy rice (July-November) and soybean (December-May) rotation is the dominant agricultural practice adopted in the study area with garlic and maize occasionally grown as a rotation crop. Irrigation is sourced from Mae Tao Creek the upper stretches of which pass through an actively mined Zn-mineralized zone. Mae Tao Creek is utilized for irrigation by the eight communities with a combined resident population of 5,796 and an annual combined rice production of 7,592 t yr^{-1} (National Statistical Office, 2002). The total area under paddy rice for the 8 villages is 2,201 ha (National Statistical Office, 2002).

This case study presents a consolidation of the collaborative research conducted by the International Water Management Institute (IWMI) and the Department of Agriculture (DOA) (2001-2003) and IWMI and the Land Development Department (LDD) during (2004-2005). In 2004-2005 LDD-IWMI collected 532 rice grain and 660 soil samples from pre-selected fields within the Phatat Pha Daeng and Mae Tao Mai sub-districts. This data set was combined with the 535 and 430 rice and soil samples collected from individual fields under the collaborative IWMI-DOA Project (2001-2003). Consequently, this report is based on the interpretation of soil and rice grain data from 1,090 and 1,067 individual fields within the Phatat Pha Daeng and Mae Tao Mai sub-districts, respectively (Figures 1 and 2). This represents the most comprehensive and detailed data set for this Cd contaminated area to date.

The soil Cd data was input into an Irrigation Infrastructure-based Cadmium Hazard Mapping model (*Irr-Cad*) to rapidly evaluate the spatial distribution of Cd (Simmons et al., 2004). *Irr-Cad* was developed as a decision support tool for rapid risk assessment in irrigated rice-based agricultural systems receiving contaminated suspended sediment transported in irrigation water. *Irr-Cad* is a General Linear Regression Model (Genstat 5.0) that utilizes the relationship between Field Order in Irrigation Sequence (Field $Order^{IS}$) and spatial Cd distribution to generate weighed coefficients ($Coeff_W$) that express the ratio between the mean total soil Cd in the 'Primary Fields' ($T\text{-}Cd_P$) and mean total soil Cd in all subsequent fields in the irrigation sequence. This reflects the multiplicative relationship between the total Cd concentration in a given field and the fields' proximity to primary outlets from in-field irrigation channels as dictated by inter-field irrigation flows (Simmons et al., 2004). Utilization of the *Irr-Cad* model during the IWMI-LDD collaborative 'Land Zoning' activities (2004-2005) increased the number of fields effectively and accurately covered from 1,090 to 2,537. This corresponds to a study area of 96.7 ha. However, for brevity this paper will focus on an interpretation of soil and rice grain data from the 1,090 and 1,067 individual fields within the Phatat Pha Daeng and Mae Tao Mai sub-districts.

Figure 1. Total soil Cd (mg kg^{-1}) in 1,090 fields of Phatat Pha Daeng and Mae Tao Mai sub-districts, Mae Sot, Tak Province, Thailand: Data derived from IWMI-DOA (2001-2003) and IWMI-LDD (2004-2005) collaborative research projects.

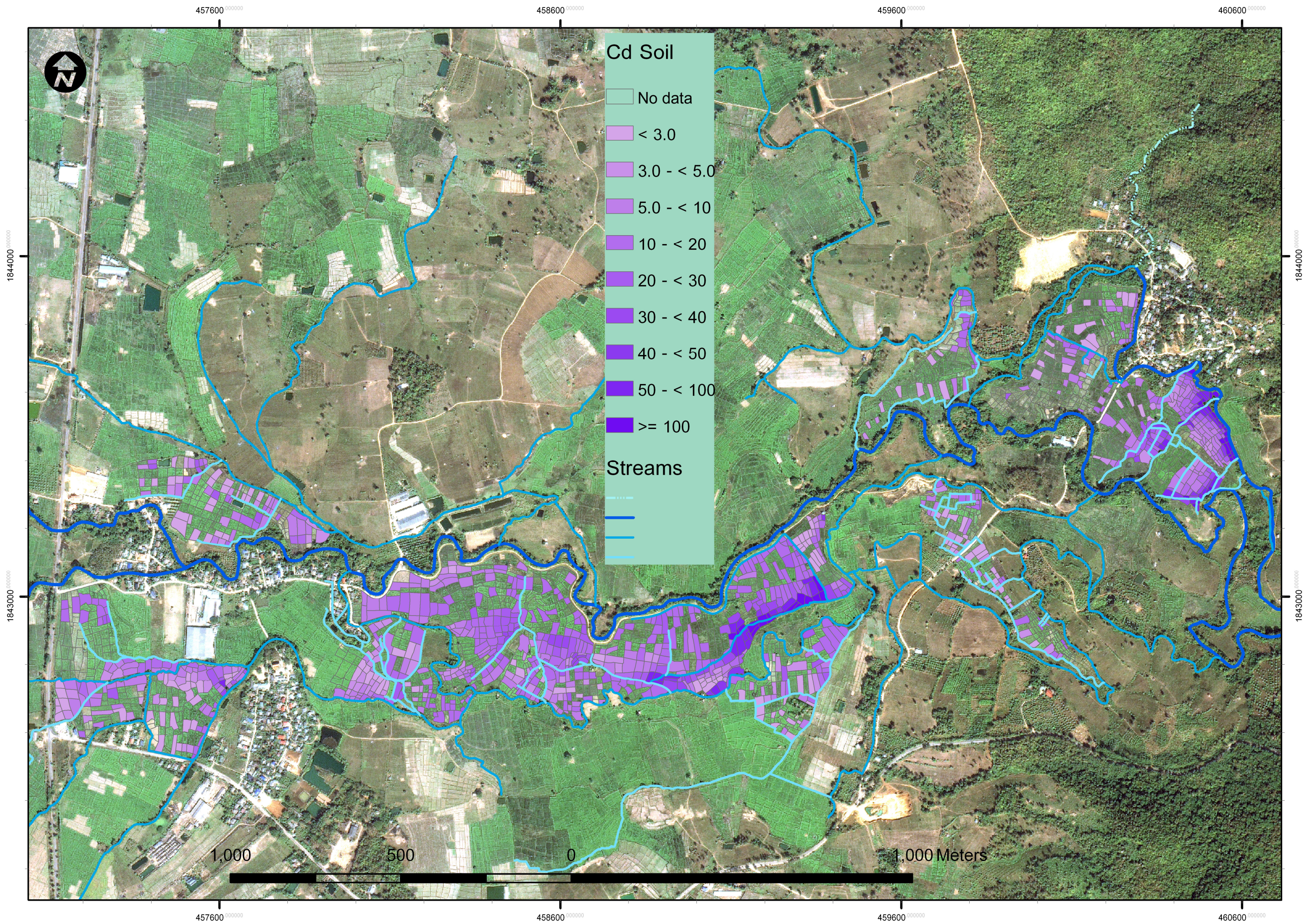
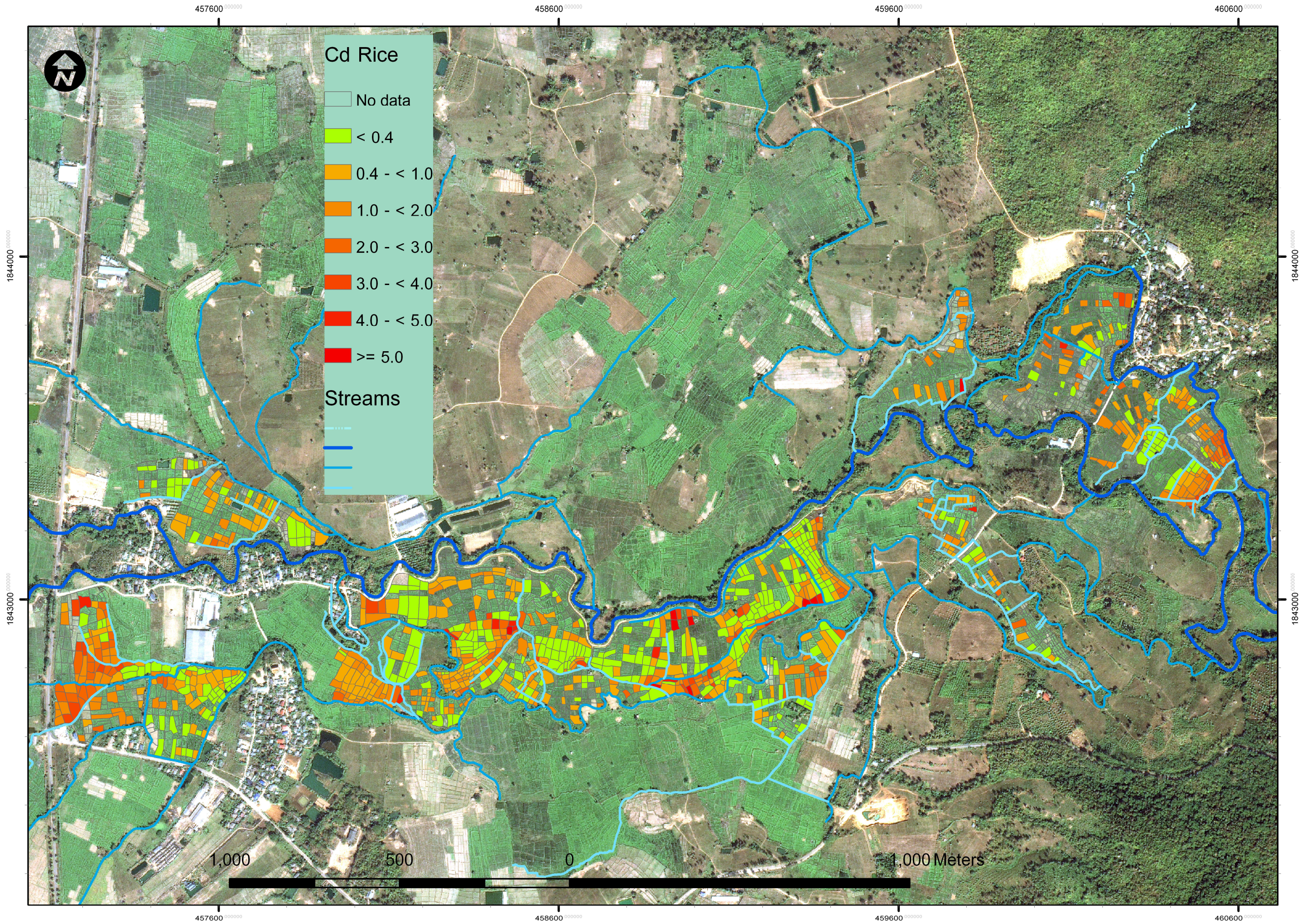


Figure 2. Rice grain Cd (mg kg^{-1}) in 1,067 fields of Phatat Pha Daeng and Mae Tao Mai sub-districts, Mae Sot, Tak Province, Thailand: Data derived from IWMI-DOA (2001-2003) and IWMI-LDD (2004-2005) collaborative research projects.



Soil and rice grain sampling

In November 2004 rice grain samples were collected from 532 pre-selected fields. For each field, rice grain samples were collected at physiological maturity from within a 2 x 2 m sampling plot. For each plot, all rice panicles (cut approximately 5-10 cm from top) were removed and place in appropriately labeled paper bags. Grain samples were subsequently separated and oven dried at 65^{o}C for 48hrs prior to de-hulling and grinding to a fine powder. In addition, in November 2004 - February 2005 concurrent composite soil samples were collected from 10-15 random points (0-20 cm Depth) within the 532 fields previously sampled for rice and an additional 128 fields for input to the *Irr-Cad* model. This data set was combined with the 535 and 430 rice and soil samples collected from individual fields under the collaborative IWMI-DOA Project (2001-2003). Consequently, this case study is based on the interpretation of soil and rice grain data from 1,090 and 1,067 individual fields within the Phatat Pha Daeng and Mae Tao Mai sub-districts, respectively (Figures 1 and 2). This represents the most comprehensive and detailed data set for this Cd contaminated area to date.

Analytical methods

Total soil Cd and Zn was determined in *aqua regia* (3:1 $HCl:HNO_3$) using an open tube digestion method (McGrath and Cunliffe, 1985) and block digester. Plant samples were digested in 2:1, $HNO_3:HClO_4$ using an open tube digestion technique following Zarcinas et al., (1983). Prior to digestion, plant samples were pre-digested overnight at ambient temperature ranging from 26-34^{o}C. This was to avoid excessive reaction on heating. To assess within-batch and between-batch precision, two reagent blanks, two replicates of an In-House Standard Reference Material (IH-SRM), and two duplicates from the previous analytical batch were included in each batch of samples analyzed. Cadmium and Zn concentrations were determined using a Perkin Elmer Analyst 3000 Atomic Adsorption Spectrophotometer. Analytical accuracy was further assessed through the 'real time' comparison of IH-SRM results with, element specific control charts and the use of Continuous Verification Standards (CVS) at regular intervals. Statistical analysis was undertaken using GENSTAT 5 (Genstat Committee, 1993).

RESULTS AND DISCUSSION

Soil Cd Concentrations

Based on the consolidated IWMI-DOA (2001-2003) and LDD-IWMI (2004-2005) data sets soil total Cd concentrations for the 1090 fields sampled range from 0.1 – 284 mg Cd kg^{-1}. This is up to 1,893 times the Thai 'Investigation Value' of 0.15 mg Cd kg^{-1} established by Pongsakul and Attajarusit, (1999) and Zarcinas et al., (2004). Further, 84.59% of the fields sampled have total soil Cd concentrations exceeding the European Union (EU) Maximum Permissible (MP) total soil Cd concentration agricultural (sludge amended) soil of 3.0 mg Cd kg^{-1} (Directive 86/278/EEC) (Table 1). Soil total Zn concentrations ranged from 100 - 8036 mg kg^{-1} and are significantly and positively correlated (R^2 =0.948) with total soil Cd. This is indicative of the geogenic origin the Cd contamination as derived from the Zn-mineralized area, Cd being commonly found as an accessory mineral in Zn-ores.

Table 1 Frequency distribution (n=1090) and summary statistics of total soil Cd in Phatat Pha Daeng and Mae Tao Mai sub-districts, Mae Sot, Tak Province, Thailand.

Total Soil Cd (mg kg^{-1})	Mean (±1 Standard Error)	Number of Fields	Frequency (%)
<3.0*	1.648 (±0.061)	168	15.41
>3.0 - 5.0	3.972 (±0.051)	129	11.83
>5.0 - 10	7.319 (±0.097)	226	20.73
> 10 - 20	14.43 (±0.154)	318	29.17
>20 - 30	24.36 (±0.242)	107	9.82
>30 - 40	35.3 (±0.418)	41	3.76
>40 - 50	45.81 (±0.811)	16	1.47
>50 - 100	71.57 (±2.001)	41	3.76
>100	170.0 (±6.659)	44	4.04
	Total	*1090*	*100*

*European Union (EU) Maximum Permissible (MP) total soil Cd concentration agricultural (sludge amended) soil of 3.0 mg Cd kg^{-1} (Directive 86/278/EEC). Values in parentheses equal ±1 Standard Error.

Rice grain Cd concentrations

Internationally recognized Maximum Levels (ML) for contaminants in foods are established by the Joint FAO/WHO Food Standards Programme, Codex Alimentarius Commission (CAC). Specifically, MLs are established by the Codex Committee on Food Additives and Contaminants (CCFAC) and the Joint FAO/WHO Expert Committee on Food Additives (JECFA). At the 64th JECFA Meeting (JECFA Rome, 8-17 February 2005) polished rice was advanced to step 5 at 0.4 mg Cd kg^{-1}. The 0.4 mg Cd kg^{-1} limit for rice is supported by recent epidemiological studies in Japan (Horiguchi et al., 2004); even higher levels may no longer cause adverse health effects because of improved nutrition of the Japanese population (Nakadaira and Nishi, 2003). Based on the consolidated IWMI-DOA (2001-2003) and LDD-IWMI (2004-2005) data sets (Figure 2) rice grain Cd concentrations for the 1067 fields sampled range from <0.01 – 7.75 mg Cd kg^{-1}. This is up to 19.37 times the JECFA ML for Cd in rice grain of 0.4 mg Cd kg^{-1}. In comparison, the mean 'background' Thai rice grain Cd concentrations as reported by Pongsakul and Attajarusit (1999) was 0.043 (±0.019) mg kg^{-1}. It is important to note therefore that the elevated rice grain Cd concentrations presented in this paper are in no way indicative of Thai rice as a whole. Further, and of grave concern with regards public health 67.48% of the 1067 fields sampled produced rice grain with Cd concentrations exceeding the JECFA (ML) for Cd in rice grain (Table 2).

Table 2 Frequency distribution (n=1067) and summary statistics of rice grain Cd in 'high risk' areas of Phatat Pha Daeng and Mae Tao Mai sub-districts, Mae Sot, Tak Province, Thailand.

Rice grain Cd (mg kg^{-1})	Mean (±1 Standard Error)	Number of Fields	Frequency (%)
<0.4*	0.187 (±0.006)	347	32.52
>0.4 - 1.0	0.672 (±0.009)	324	30.37
>1.0 - 2.0	1.409 (±0.017)	241	22.59
>2.0 - 3.0	2.378 (±0.028)	100	9.37
>3.0 - 4.0	3.303 (±0.049)	31	2.97
>4.0 - 5.0	4.37 (±0.052)	15	1.41
>5.0	5.717 (±0.217)	9	0.84
	Total	1067	100

*JECFA Maximum Permissible Level for Cd in rice grain = 0.4 mg Cd kg^{-1} (Report of the 64th Session, JECFA, Rome 8-17 February, 2005). Values in parentheses equal ±1 Standard Error.

Probability-based risk assessment

Table 3 below indicates that for all the soil Cd contamination classes evaluated ranging from <3.0 to >100 mg Cd mg^{-1} (Table 1) there is a 59.8 – 92.9% probability that rice fields within Phatat Pha Daeng and Mae Tao Mai sub-districts **will** produce rice grain that is **unsafe** for human consumption. The risk assessment methodology is based on the probability of a given field producing rice grain with a Cd concentration exceeding the JECFA (JECFA, 2005) ML for Cd in rice grain of 0.4 mg Cd kg^{-1}.

Table 3. Percentage of the 1067 rice fields sampled in 'high risk' areas of Phatat Pha Daeng and Mae Tao Mai sub-districts, Mae Sot, Tak Province, Thailand that produce rice considered to be unsafe for human consumption (Cd >0.4 mg kg^{-1}).

Soil Cd (mg kg^{-1})	% of fields producing rice grain safe for human consumption (Cd <0.4 mg kg^{-1})*	% of fields producing rice grain unsafe for human consumption (Cd >0.4 mg kg^{-1})
<3.0	35.3	**64.7**
>3.0 - 5.0	30.3	**69.7**
>5.0 - 10	25.9	**74.1**
> 10 - 20	40.2	**59.8**
>20 - 30	30.5	**69.5**
>30 - 40	33.3	**66.7**
>40 - 50	25.0	**75.0**
>50 - 100	25.0	**75.0**
>100	7.1	**92.9**

Potential long-term health risks to communities in Phatat Pha Daeng and Mae Tao Mai sub-districts through the consumption of Cd contaminated rice grain

The chronic diet Cd model considers variation from birth to age 50 in both body weight and dietary Cd intake. Kjellström and Nordberg, (1978) assumed that the diet had the same Cd composition over time, but that varied weights of the diet were consumed at different ages in proportion to calorific intake. Thus the PTWI for Cd is described in terms of adult diet composition and intake. For 50 year old adults, that limit was set at 7 µg Cd kg^{-1} Body Weight $week^{-1}$. One should keep in mind that this describes the 50 year protection model. Several authors have recently been stressing the higher dose rate for children (about double that of adults due to higher diet intake per kg Body Weight of growing children), inferring that dietary Cd was too high.

However, the higher Cd dose rate of children is an inherent part of the model. Consideration therefore should be focused on adult diets not exceeding the PTWI, and the existence of a safety factor in this limit as clearly stated by JECFA (2004).

Rice cultivated in Phatat Pha Daeng and Mae Tao Mai sub-districts, Mae Sot, Tak Province, Thailand is primarily for home consumption. This significantly increases the risk of Cd-induced renal dysfunction. In this study potential public health risk is determined through the estimation of Weekly Intake (WI) values based on the mean rice grain Cd concentration for each soil Cd contamination class in comparison with the JECFA Provisional Tolerable Weekly Intake (PTWI) for Cd of 7µg Cd per kg Body Weight (BW).

$$\textbf{WI} = \frac{\text{Weekly Cd intake } \mu g\ kg^{-1}}{\text{Body Weight (BW) kg}}$$

$$\text{Weekly Cd intake } \mu g\ kg^{-1} = (\text{Daily rice intake (kg) x 7}) \text{ x rice grain Cd concentration } (\mu g \text{ Cd } kg^{-1})$$

The results indicate that estimated WI values for Cd based on rice grain intake alone significantly exceed the JECFA PTWI value of 7µg Cd per kg BW (Table 4). Estimated mean WI values for females and males of 50yrs from rice intake alone range from 24.94 – 93.04 and 24.48 – 91.33 7µg Cd per kg BW. This is up to over <u>13 times</u> the JECFA recommended PTWI value and poses a massive risk to public health.

In addition, January 2005 an initial rapid screening of household rice grain samples was undertaken by LDD. Household grain samples were collected from 465 households in four villages within Mae Tao Creek catchment as compared with samples collected from three villages irrigating paddy rice with water sourced from the Mae Ku Creek and Pong Creek. It is important to note that the Mae Ku Creek also originates from the Zn-mineralized area. The results of the household rice grain screening indicate that for villages utilizing irrigation sourced from Mae Ta Creek, between 66-100% of household rice grain samples were associated with estimated WI values > 7µg Cd per kg BW. For women and men of 50yrs in the 4 villages sampled, estimated mean WI of Cd from the consumption of rice alone ranged from 19.92 – 41.73 µg Cd per kg BW and 19.56 – 40.96 µg Cd per kg BW, respectively (Table 5).

In comparison although 29.82% of rice grain samples collected from Khang Phiban were associated with estimated WI values > 7µg Cd per kg BW. Notably, the mean (n=57) estimated WI value of 5.18 and 5.08 µg Cd per kg BW for female and male residents, is within acceptable levels (Table 5). Of concern is the fact that in Mae Ku Noi and Mae Ku Nua, estimated mean Cd WI values are >14.0 and >18.0 µg Cd per kg BW, respectively.

Cadmium levels in urine samples collected from 6000 residents within Phatat Pha Daeng, sub-district indicate potential renal dysfunction in 12% of the resident population as based on the critical urine Cd threshold established by Ikeda et al., (2003) of 10-12 µg Cd g creatinine^{-1} (Personal Communication: Dr. Chantana Padungtod, Bureau of Occupational & Environmental Disease, Department of Disease Control, Ministry of Public Health). It is essential that further detailed dietary and epidemiological studies are conducted to clarify health impacts in the resident population.

Table 4. Estimated Weekly Intake (WI) values of Cd (μg kg BW) based on the range and mean rice grain Cd for each soil Cd contamination class. Data derived from 1,067 rice fields sampled by IWMI-DOA (2001-2003) and LDD-IWMI (2004-2005).

Body Weight (kg)*		58.71	59.81
Daily rice intake (kg)**		0.280	0.280
Soil Cd (mg kg^{-1})	Rice grain Cd (mg kg^{-1})	WI Female (50 yrs)	WI Male (50 yrs)
<3.0	0.01 – 3.09 ***0.747*** (±0.050)	0.3 – 103 ***24.94***	0.3 – 101 ***24.48***
>3.0 - 5.0	0.01 – 3.77 ***0.831*** (±0.067)	0.3 – 126 ***27.74***	0.3 – 124 ***27.23***
>5.0 - 10	0.01 – 5.65 ***1.068*** (±0.074)	0.3 – 189 ***35.65***	0.3 – 185 ***35.00***
> 10 - 20	0.01– 5.95 ***0.906*** (±0.064)	0.3 - 199 ***40.66***	0.3 - 195 ***39.91***
>20 - 30	0.01 – 5.70 ***1.218*** (±0.134)	0.3 - 190 ***42.73***	0.3 - 187 ***41.95***
>30 - 40	0.01 – 2.64 ***1.280*** (±0.168)	0.3 – 88 ***32.68***	0.3 – 87 ***32.08***
>40 - 50	0.286 – 2.07 ***0.979*** (±0.215)	9.3 – 69 ***32.68***	9.2 – 68 ***32.08***
>50 - 100	0.149 – 5.06 ***1.20*** (±0.296)	5.0 - 169 ***40.06***	4.9 - 166 ***39.32***
>100	0.379 – 7.75 ***2.787*** (±0.290)	12.76 - 259 ***93.04***	12.5 - 254 ***91.33***

* National Food and Nutrition Status Survey Report (No.4), 1995, Department of Health, Ministry of Public Health. ** National Nutrition Plan Sub-committee, National Nutrition Committee, 1998. *** Refer to Table n.

Table 5. Estimated Weekly Intake (WI) values of Cd (μg kg BW) based on household rice grain samples (2004 Harvest) from villages within Huai Mae Tao catchment as compared with villages irrigating paddy rice with water sourced from the Huai Mae Ku [(a)] and Huai Pong [(b)] .

			Female (50 yrs)	Male (50 yrs)		
Body Weight (kg)*			58.71	59.81	Female (50 yrs)	Male (50 yrs)
Daily rice intake (kg)**			0.280	0.280		
Village	No. of Samples	Rice grain Cd (mg kg^{-1})	Estimated WI (μg Cd kg BW)		% of household rice grain samples associated with estimated WI values > 7μg Cd per kg Body Weight (BW)	
Khang Phiban [(b)]	57	*ND – 1.11* **0.155** (±0.028)	*0.33 – 37.0* **5.18** (±0.930)	*0.32 – 36.3* **5.08** (±0.919)	**29.82%**	**29.82%**
Pha Te	38	*0.2 – 2.80* **1.25** (±0.116)	*6.67 – 93.46* **41.73** (±3.874)	*6.55 – 91.75* **40.96** (±3.802)	**97.36%**	**97.36%**
Mae Tao Mai	65	*0.06 – 2.42* **0.596** (±0.058)	*2.00 – 80.79* **19.92** (±1.962)	*1.96 – 79.30* **19.56** (±1.926)	**90.30%**	**89.23%**
Mae Tao San Pae	36	*ND – 3.91* **0.736** (±0.150)	*0.03-130.53* **24.59** (±5.032)	*0.03-128.13* **24.14** (±4.940)	**66.66%**	**66.66%**
Dong Chai	26	*ND – 1.87* **0.667** (±0.111)	*0.03-62.42* **22.29** (±3.707)	*0.03-61.28* **21.88** (±3.639)	**76.92%**	**73.07%**
Mae Ku Noi [(a)]	86	*ND – 2.06* **0.444** (±0.043)	*0.03-68.77* **14.84** (±1.466)	*0.03-67.5* **14.57** (±1.439)	**68.60%**	**65.11%**
Mae Ku Nua [(a)]	157	*ND – 1.97* **0.551** (±0.030)	*0.03-65.76* **18.40** (±1.005)	*0.03-64.55* **18.06** (±0.986)	**82.16%**	**80.89%**

*National Food and Nutrition Status Survey Report (No.4), 1995, Department of Health, Ministry of Public Health. ** National Nutrition Plan Sub-committee, National Nutrition Committee, 1998. Note: Mean values for rice grain Cd (mg kg^{-1}) and estimated WI of Cd (μg Cd kg BW^{-1}) are in bold. The value in parentheses represents ±1 Standard Error. The range in rice grain Cd (mg kg^{-1}) and estimated WI of Cd (μg Cd kg BW^{-1}) is italicized. Shaded cells represent those villages within the Huai Mae Tao catchment.

Additional non-rice dietary exposure pathways

Potential and confirmed human Cd exposure pathways for communities within Phatat Pha Daeng and Mae Tao Mai sub-districts, Mae Sot are illustrated in Figure 3.

Consumption of kidneys derived from livestock fed Cd contaminated feed/fodder
In Cd risk assessment for animal agriculture it is critical to note that when livestock are fed normal diets or diets grown on soils with geogenic Cd enrichment, there is little or no increased Cd in kidney and liver of the livestock. Nearly all Cd and Zn in feeds are excreted in feces, which may be subsequently applied to land as manure. Examples of the low retention of feed Cd have been reported by Kienholz et al., (1979), Decker et al., (1980), Smith et al., (1985), Bray et al., (1985), and Hinesly et al., (1985). In the case of Bray et al., (1985) goats were fed corn silage produced on fields amended with 4 rates of biosolids. The biosolids were high in Cd, higher than presently allowed on land in the US. The silage was appreciably increased in Cd and Zn, but the liver and kidney contained only 0.03% of the Cd in feeds consumed (1.4 mg in liver plus kidney compared to 3900 mg Cd in feeds consumed)

In Phatat Pha Daeng and Mae Tao Mai sub-districts, Mae Sot, rice bran the bi-product of rice polishing is utilized as animal feed (pigs, chickens, ducks) within the affected communities. Rice bran Cd concentrations range from 1.2 – 3.4 mg Cd kg^{-1} (n=20). In addition, rice straw in the study area contains Cd ranging from 0.34 – 22 mg Cd kg^{-1} and, is also utilized as animal fodder. Maize is cultivated (to a limited extent) as a dry season rotation crop to paddy rice in the study area. Cadmium concentrations in maize grain collected from 3 fields ranged from 0.16-0.30 mg kg^{-1}. Maize is utilized from animal feed and the crop residue as fodder. Research needs to be undertaken to confirm that limited Cd is transferred to the in kidney and liver of the livestock and the impact of the long-term application of manure derived from livestock in Mae Sot fed high Cd diets.

Mushroom cultivation
Interviews with farmers and local administrators have confirmed that rice straw from the Cd contaminated area is utilized for Mushroom Culture. Levels of Cd in mushrooms and potential contribution to human dietary Cd intake, needs to be investigated. In addition, the fate of the bi-products from the cultivation of mushrooms needs to be determined.

Soybean and locally grown garlic
Cd concentrations in soybean collected by IWMI-DOA (2001-2003) from 90 individual fields within the study area ranged from 0.34 – 3.37 mg Cd kg^{-1}. All of the soybean samples contained Cd at concentrations exceeding the CCFAC ML for Cd in soybean of 0.2 mg Cd kg^{-1}. The potential human exposure pathway for soybean produced in the affected area is illustrated in Figure 3. However, the contribution to dietary Cd intake in the exposed communities within Phatat Pha Daeng and Mae Tao Mai sub-districts requires clarification. Garlic is produced in a limited number of fields within the affected study area. Cadmium concentrations in garlic bulbs collected from 10 fields sampled in 2001 ranged from 1.27 – 3.39 mg Cd kg^{-1}. All of the garlic bulb samples contained Cd at concentrations exceeding the CCFAC ML for Cd in garlic of 0.05 mg Cd kg^{-1}. Garlic is a common additive in Thai food. The contribution of Cd via garlic to the human dietary intake in the affected communities needs to be investigated.

Additional non-dietary exposure pathways

Smoking

It is widely recognized that tobacco cadmium is efficiently moved to human kidneys (Elinder et al., 1976; Ellis et al., 1979, Bell et al., 1981). For western countries common smoking of cigarettes has a greater effect on Cd body burden than substantially enriched food Cd (Sharma et al., 1983). Tobacco effectively doubles kidney Cd in smokers in developed countries with low Cd diets (Chaney et al., 1996). Smoking transfers about 10% of tobacco Cd into mainstream smoke, and that Cd is effectively absorbed in the lung regardless of Fe-Zn-Ca nutritional status. Any comprehensive epidemiological study should therefore include smoking habits and Cd in cigarettes within the experimental design.

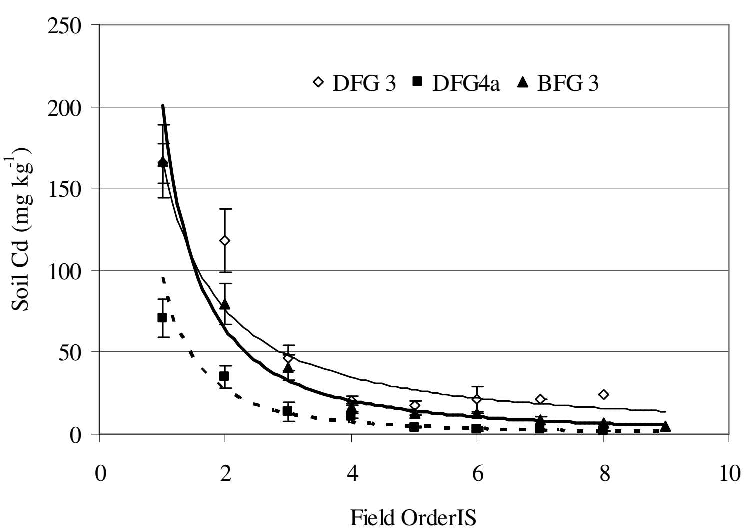
Occupational exposure

A proportion of the adult population of the affected communities in Phatat Pha Daeng and Mae Tao Mai sub-districts work within the mines active within the Zn-mineralized area. Any comprehensive epidemiological study should therefore also incorporate occupational exposure.

Source of elevated levels of Cd

Soil profile and spatial Cd concentrations indicates that irrigation waters withdrawn from Mae Tao Creek are the primary source of the observed elevated levels of Cd. Further, within the irrigation water Cd is primarily associated with the suspended load. This is inferred from the fact that the Cd loading for a given field are dictated by the field's proximity to primary outlets from in-field irrigation channels and inter-field irrigation flows (Figure 4). Further, Simmons et al., (2004; 2005) demonstrate that in agricultural systems receiving Cd contamination via suspended sediment, Field Order in Irrigation Sequence (Field Order^{IS}) is a major factor determining spatial Cd distribution (Figure 5).

Figure 5. Relationship between mean total soil Cd concentration (mg kg^{-1}) for selected Field Groups (FGs) for each Field Order in relation to Field Order^{IS}.



Note: DFG4a: $y = 96.076x^{-1.8442}$ $R^2 = 0.9674$; BFG3: $y = 200.86x^{-1.6489}$ $R^2 = 0.9758$; DFG3: $y = 167.17x^{1.1334}$ $R^2 = 0.8336$.

Figure 3. Postulated human cadmium exposure pathways: Mae Sot Thailand

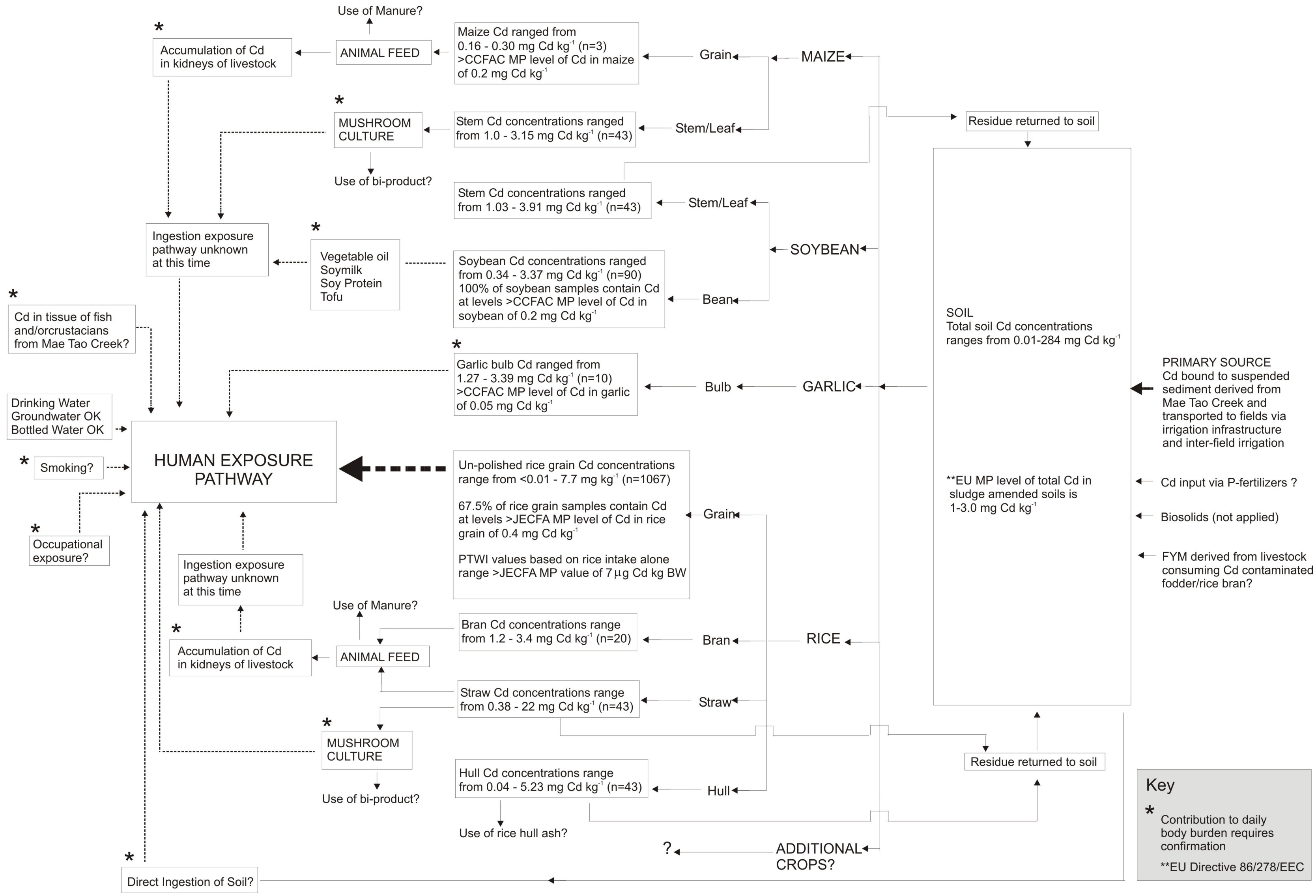
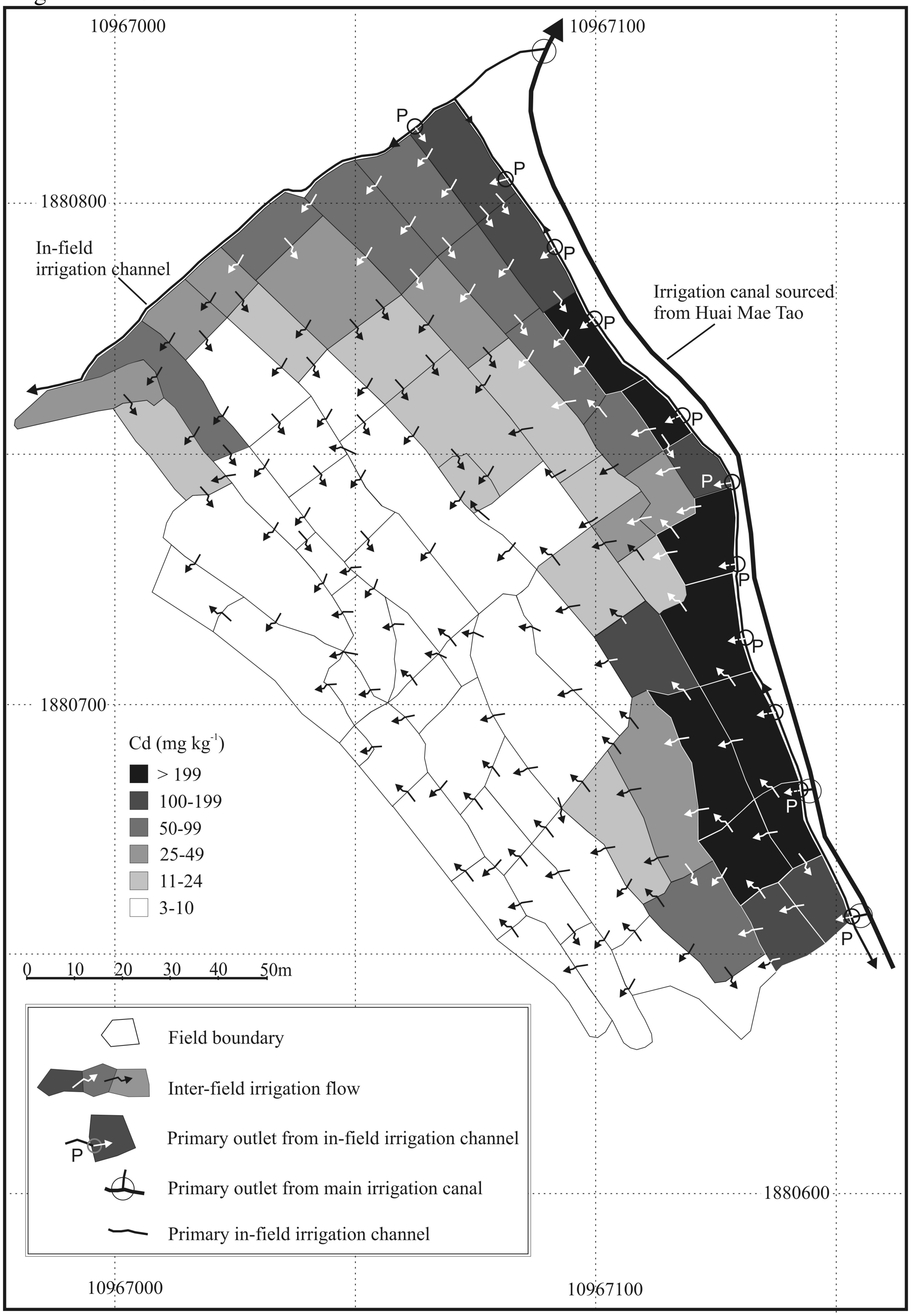
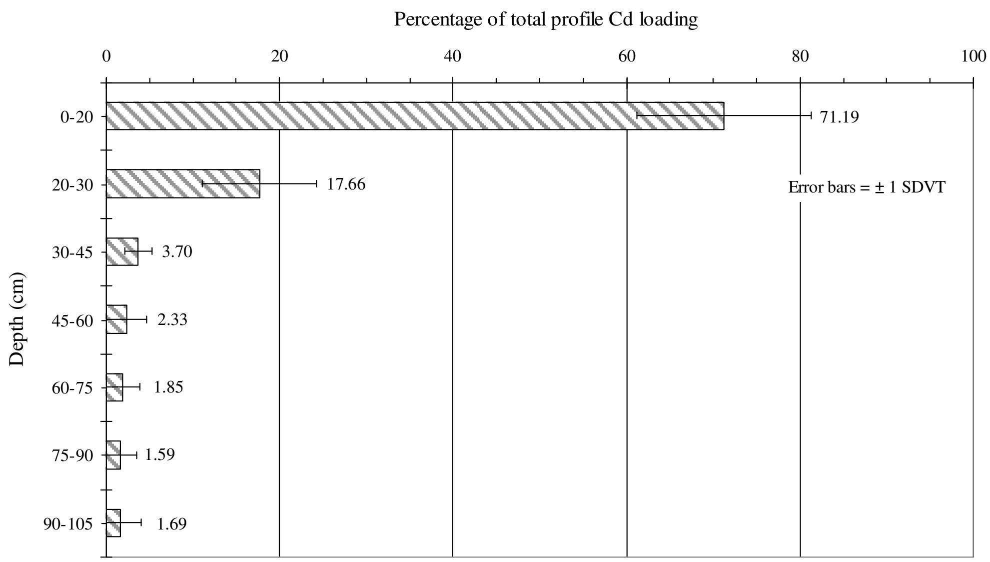


Figure 4. Field Group 1 adjacent to Baan Pha Te, Mae Sot, Tak Province: Spatial distribution of Cd (mg kg^{-1}) in relation to primary outlets from in-field irrigation channels and inter-field irrigation flows.



In addition, the vertical profile distribution of Cd indicates that for the 15 soil profiles investigated, 88.84% (±9.58) of the total profile Cd loading is within the top 0-30 cm of the soil profile (Figures 6). This strongly infers the surface loading of Cd thereby adding support to the proposition that contamination is associated with the deposition of sediments through irrigation waters. Further, elevated levels of Cd in sediment of Mae Tao Creek were confirmed by the Pollution Control Department, Ministry of Natural Resources and Environment in 2004. Cd and Zn concentrations for samples collected upstream of the Zn-mineralized area ranged from 0.3 – 0.83 and 34 - 99 mg kg^{-1} (MONRE, 2004). In contrast, Cd and Zn concentrations in sediment collected downstream of the Zn-mineralized area ranged from 1,717 – 12,594 mg kg^{-1} (MONRE, 2004).

Figure 6. Mean (n=15) soil profile Cd concentration (mg kg^{-1}) with depth as expressed as a percentage of total profile Cd loading.



2. VIETNAM

In general as is the case in Thailand, background levels of Cd in Vietnamese soils are below national and international standards. However, localized Cd contamination of irrigated urban and peri-urban rice-based agro-ecosystems of Vietnam has been identified.

Background levels of heavy metals in agricultural soils of Vietnam

Pham Quang Ha et al., (2003) investigated the distribution of selected heavy metals in fluvisols, acrisols and ferrasols in the North and Northern Central Vietnam and found that mean total soil Cd, concentrations varied according to soil type (Table 6). In addition, 'background' levels of Cd in agricultural soils of Northern Vietnam were investigated by the ACIAR Project LWR119/1998 as compared to selected forest and polluted areas. With the exception of the maximum Cd concentration of polluted areas the ACIAR results indicate the non-contaminated status of agricultural soils of Vietnam (Table 7).

Table 6. Mean background PTE concentrations (mg kg^{-1}) in fluvisols, acrisols and ferrasols in North and Northern Central Vietnam

Soil Type	Cd (mg kg^{-1})
Fluvisols	0.85
Acrisols	0.48
Ferrasols	1.24
EU MP levels (mg kg^{-1})	1-3
*VN Standard (TNVN 7209-2002)	2

EU Maximum Permissible (MP) levels for sludge amended soils (EEC, 1986. Directive 86/278/EEC)
*VN Standard (TNVN 7209-2002) for agricultural soils

Table 7. Soil total Cd concentrations (mg kg^{-1}) of Northern Vietnam as related to selected land-uses (ACIAR Project LWR119/1998).

Land Use	Cd
Polluted areas (n= 25)	0.02 – 7.24 (**0.54**)
National parks (n=25)	0.01 – 0.24 (**0.07**)
Agricultural areas (n=156)	0.00 – 1.7 (**0.10**)
Vegetable production areas (n=38)	0.00 – 0.32 (**0.09**)
EU MP levels (mg kg^{-1})	1-3.0
VN Standard (TNVN 7209-2002)	2.0

*VN Standard (TNVN 7209-2002) for agricultural soils. EU Maximum Permissible (MP) levels for sludge amended soils (Directive 86/278/EEC). Values in parentheses indicates the arithmetic mean.

However, Pham Quang Ha et al., (2003) indicated that total soil Cd concentrations in Fluvisols sampled within the National Base Line Program as well as alluvial soils (mainly Fluvisols) of the Red River and Mekong River deltas utilized for rice production are relatively high as compared to the EU MP levels (Table 8). For agricultural (sludge amended) soils the EU MP level ranges from 1-3 mg Cd kg^{-1} as a function of soil pH.

Table 8. Soil Cd concentration (mg kg^{-1}) in Fluvisols (National Base Line Program) as compared to alluvial soils of the Red River and Mekong River Deltas

	Fluvisols	Alluvial soils of the Red River delta	Alluvial soils of Mekong River delta
No. sampling locations	190	42	49
Range* (mg kg^{-1})	0.745-0.833	0.891-1.064	0.606-0.715
Mean (mg kg^{-1})	0.789 (± 0.307)	0.978 (± 0.278)	0.888 (± 0.280)
EU MP level for soil Cd (mg kg^{-1})	1-3.0		

*95% confidence interval
EU Maximum Permissible (MP) levels for sludge amended soils (Directive 86/278/EEC).

Sources of Cd contamination to rice-based agricultural systems in Vietnam

Potential sources of Cd contamination to agricultural systems in Vietnam include; natural runoff from non-ferrous ore mineralized areas, uncontrolled runoff and leaching from the extraction and processing of non-ferrous ores; agricultural use of municipal sewage sludge; bio-solids from agro-industries; widespread use of untreated and/or partially treated industrial and/or domestic wastewater; pesticides; and phosphatic fertilizers. As indicated in Table 9. biosolids and inorganic phosphate fertilizers in Vietnam often contain Cd as a contaminant. However, when compared to the EU maximum permissible level of Cd in sewage sludge of 20-40 mg Cd kg^{-1} (Directive 86/278/EEC) the levels of Cd in biosolids in northern Vietnam are negligible. Further, limit values for Cd in fertilizers in EU member states ranges from 21.5 – 90 mg Cd kg P_2O_5 (Oosterhuis, et al., 2000).

In addition, Cupit et al., (2002) proposed a phased reduction of Cd in phosphate fertilizers from 60 mg Cd kg P_2O_5 in 2006 to 20 mg Cd kg P_2O_5 in 2015. The levels of Cd in inorganic phosphate fertilizers represented in Table 9 are well below the limit values proposed by Cupit et al., (2002).

Table 9. Cadmium concentration (mg kg^{-1}) in biosolids and inorganic phosphate fertilizers sampled in Northern Vietnam

Material	Cd	Location
Cow manure	0.48	Vinh Phuc province
Chicken manure	1.50	Ha Tay provine, Hanoi
	1.48	ACIAR Project LWR/119/1998
Pig manure	0.54	Ha Tay province
Human manure	0.39	Ha Tay provine, Hanoi
Mineral organic fertilizer	0.70	Hanoi
Super phosphate	2.77	Lamthao town (BTPB)
Super phosphate	2.70	Lamthao town (BN)
FMP phosphate	2.53	Vandien town (BTPB)
FMP phosphate	2.63	Vandien town (BN)
Apatite mineral	4.25	Lao Cai (BTPB)
Apatite mineral	2.88	Thanh Hoa (BTPB)

(Source: ACIAR Project LWR119/1998 and NISF)

Potential Cd contamination associated with non-ferrous ore extraction, processing and smelting.

As stated previously, reports of health effects of Cd in populations not occupationally exposed to Cd have centered on Japan (Watanabe et al., 1998; Kobayashi et al., 2002; Nogawa et al., 1983; Kido et. al., 1988; Nogawa and Kido, 1993; Kido *et al.,* 1990*;* Tsuritani *et al.,* 1992), China (Cui et al., 2004; Jin et al., 2002; Wu et al., 2001; Jin et al., 1999; Cai et al., 1995; Cai et al., 1990; Nordberg, 2003) and recently, Thailand (Simmons et al., 2005). Vietnam has proven resources for Zn and other base metals. In the colonial era Vietnam was a major Zn ore and non-ferrous metal producing center. From 1920 to 1930, approximately 500,000 metric tons of Zn ore were exported from Vietnam. This ore was of an exceptionally high grade of up to 40% Zn with a relatively high concentration of Cd. The main areas of activity were the Cho Dien-Cho Don and Bac Thai deposits located in Băc Can, Tuyên Quang and Thai Nguyen provinces. In addition, historically active non-ferrous ore extraction was undertaken in a further 15 provinces predominately in Northern and Central Vietnam (Table 10). Historically active locations of ore extraction are of considerable concern due to a lack of continued maintenance and control over discharge/runoff from ore waste containment facilities.

Evaluation of potential soil and crop Cd contamination via the agricultural use of domestic/industrial wastewater

To date research into Cd and other heavy metal contamination of soils in Vietnam has been primarily focused on urban and peri-urban areas of Hanoi and Ho Chi Minh City. In the peri-urban Hoc Mon District, Ho Chi Minh City, Quang, (2000) reported total Cd concentrations in alluvial soils ranging from 0.48-1.05, respectively (Table 11). These values are below the Vietnamese (TCVN 7209:2002) and EU (Directive 86/278/EEC) permissible levels for agricultural soils.

Table 10: Location and status of non-ferrous base metal ore deposits in Vietnam

Province	Mineral Deposit	Status	Province	Mineral Deposit	Status
Lai Châu	Cu (x2) Pb,	Closed Closed	Yên Bái	Pb/Zn/Ag Cu	Closed Closed
Laò Cai	Cu Cu (x2) Pb/Zn	Closed Potential Area Closed	Băc Thai	Pb/Zn (x2) Zn/Pb Pb/Zn/Ag	Potential Area Active Potential Area
Hà Giang	Pb/Zn	Potential Area	Dà Năng	Cu	Potential Area
Cao Băng	Pb/Zn (x1) Zn/Pb/Sn Cu/Ni P	Closed Potential Area Potential Area Closed	Tuyên Quang	Pb/Zn/Au Pb/Sr/Ba Pb Pb/Zn/Ba	Potential Area Potential Area Potential Area Closed
Són La	Pb/Zn (x2) Pb/Zn (x2) Zn/Cu/Au Ni/Cu Ni/Co/Cu/Se Cu (x2) Cu (x2) Cu	Closed Potential Area Closed Potential Area Potential Area Potential Area Closed Active	Hòa Bình	Zn/Pb/Cd Pb/Zn Cu	Potential Area Potential Area Potential Area
Lang Son	Pb/Zn/Cu Pb/Zn/Cd P	Active Closed Potential Area	Hòa Bình	Zn/Pb/Cd Pb/Zn Cu	Potential Area Potential Area Potential Area
Thanh Hóa	Pb/Zn Zn/Au/Cu Pb/Zn P	Closed Active Potential Area Potential Area	Nghe An	Pb/Zn Pb/Zn/Sn Pb/Zn/Au P	Closed Potential Area Active Closed
Vinh Phu	Zn/Pb	Closed	Băc Thai	Zn/Pb/Ag/Cd	Closed
Ha Bác	Pb/Zn/Ba	Closed	Quang Ninh	P	Potential Area
Quang Binh	Pb/Zn P P	Closed Active Potential Area	Thua Thien Hue	Pb/Zn	Potential Area

Source: Atlas of Mineral Resources of the UNESCAP Region: Volume 6, Viet Nam (UNESCAP, 1990)

Table 11. Soil Cd contamination (mg kg^{-1}) in irrigated rice-based production systems in Vietnam

Contamination Source	Location	Cd (mg kg^{-1})
Domestic and/or Industrial wastewater	Nha Be & Binh Chanh Districts HCM City	Min 1.37 Max 1.58
Discharge from Ni/Cd battery and P-fertilizer factories	Hanoi	Min 0.68 Max 1.55
*Domestic and Industrial wastewater	Thu Duc District HCM City	Min ***6.30*** Max ***8.90***
EU MP levels (mg kg^{-1})		1.0 -3.0

EU Maximum Permissible (MP) levels for sludge amended soils (Directive 86/278/EEC).
Data provided by Dr. Nguyen Cong Vinh NISF. *Quang, (2000).

In Hanoi, Cd levels were investigated in the heavily industrialized and densely populated southwestern Districts of Thanh Tri and Tu Liem. The main cropping systems are rice-rice and rice–rice–vegetables. Thanh Tri and Tu Liem districts provide a high proportion of the vegetables and food products for Hanoi City. The intensive peri-urban rice and vegetable production systems in Thanh Tri and Tu Liem Districts are irrigated primarily by the Tolich and Kimnguu Rivers. Nguyen, (1997) estimated that the Tolich and Kimnguu Rivers receive 24,900 m^3 and 130,000 m^3 of untreated combined industrial-urban wastewater on a daily basis. The industrial sector of Thanh Tri and Tu Liem Districts includes tanneries, Cd/Ni battery, phosphate and chemical manufacturing businesses and electro-plating and engineering activities. In 1996, soil samples (0-15cm depth) were collected from vegetable and rice fields within Thanh Tri and Tu Liem Districts (Ho *et al*., 1998). With the exception of one vegetable field within an area irrigated by wastewater discharging from the Vandien Phosphate Factory total soil Cd concentrations ranged from of 0.08-0.4 mg kg^{-1} and were within the Vietnamese (TCVN 7209:2002) and EU (Directive 86/278/EEC) permissible levels for agricultural soils. An elevated Cd level of 1.33 mg kg^{-1} was only recorded for the area receiving wastewater discharging from the Vandien Phosphate Factory, respectively.

In a follow up survey conducted in 1997 additional soil samples were collected from previously un-sampled but spatially comparable sites within Thanh Tri and Tu Liem Districts (Ho and Egashira*,* 1999). The results indicate that Cd concentrations in soil ranged from 0.16 – 0.36 mg kg^{-1}. Cadmium levels are comparable to the values presented by Ho et al., (1998). However, it should be noted that for the Cd contaminated soils in Mae Sot, Thailand, rice grain with Cd concentrations ranging from 0.56 – 1.28 mg kg^{-1} were derived from acid soils (pH >5.5 to <6.0) with total Cd concentrations ranging from only 0.15 – 0.27 mg kg^{-1}.

In contrast to Hanoi, Quynh and Ba, (2003) identified significant Cd contamination in soils of rice-based agricultural systems in 6 selected Districts of Ho Chi Minh City (Table 12). In 2000, Ho Chi Minh City was associated with 1,000 registered industrial factories, 28,500 handicraft foundations and 12 industrial zones (Quynh and Ba, 2003). In Nha Be and Binh Chanh Districts, irrigated rice-based agricultural systems receive irrigation from the Tan Hao, Lo Gom Te Doi, Tau Hu and Ben Nghe canals. A high proportion of the wastewater discharged from these industries is untreated and used directly for agriculture. A detailed breakdown of heavy metal contamination in soils of Nha Be District is presented in Table 13.

Table 12. Mean total soil Cd concentrations (mg kg^{-1}) in soils of rice-based agricultural systems receiving untreated wastewater from Ho Chi Minh City.

District	No. Samples	Cd (mg kg^{-1})
Nha Be	88	9.9
Binh Chanh	10	10.3
Thu Duc	8	6.8
No. 2	10	5.5
No. 7	4	4.7
No. 9	6	4.9
	EU MP levels (mg kg^{-1})	1-3.0
	*VN Standard (TNVN 7209-2002)	2.0

Adapted from Quynh and Ba, (2003). EU Maximum Permissible (MP) levels for sludge amended soils (Directive 86/278/EEC) *VN Standard (TNVN 7209-2002) for agricultural soils

Table 13. Mean Cd concentrations (mg kg^{-1}) in soils of rice-based agricultural systems receiving untreated wastewater in Nha Be District, Ho Chi Minh City.

Soil Type	Cd (mg kg^{-1})
Red-Yellow alluvial soil (Pfm)	16.7
Alluvial soil/potential acid sulphate soil (Ppm)	14.0
Acid sulphate soil (Sj2m)	14.5
Acid sulphate soil (Sj2Rm)	7.6
Acid sulphate soil at depth (Sp2m)	12.4
Acid sulphate soil organic horizonn (Sp2hm)	7.8
EU MP levels (mg kg^{-1})	1-3.0
*VN Standard (TNVN 7209-2002)	2.0

Adapted from Quynh and Ba, (2003) and Kuo et al., (1983).
EU Maximum Permissible (MP) levels for sludge amended soils (Directive 86/278/EEC)
*VN Standard (TNVN 7209-2002) for agricultural soils

Elevated levels of Cd in rice grain in case study locations in Vietnam: Does it pose a potential public health risk?

Preliminary results from the IWMI-DANIDA Project *'Waste Water reuse in Agriculture in Vietnam'* indicate a mean (n=53) soil Cd concentration of 0.91 (± 0.229) mg kg^{-1}. The IWMI-DANIDA study area is located in My Tan commune, south of Nam Dinh city and is split between a 30ha wastewater irrigated (Nam Dinh City municipal wastewater) sub-area in Hong Long Cooperative and a 16 ha Red River irrigated sub-area in Tan Tien Cooperative. No significant difference was observed in the soil Cd concentration between the wastewater and Red River irrigated sites with mean values of (n=41) 0.910 (± 0.036) and (n=12) 0.858 (± 0.049) mg Cd kg^{-1}.

Further, the mean (n=53) soil Cd concentration of 0.91 (± 0.229) mg kg^{-1} is indicative of the 'background' Cd levels found in soils of the Red River Delta by Pham Quang Ha et al., (2003) (Table 8). Cd concentrations in the concurrent rice grain samples (n=52) collected in 2003 ranged from 0.15 – 0.38 mg Cd kg^{-1} and are within the recently established JECFA MP level for Cd in rice grain of 0.4 mg Cd kg^{-1} (JECFA 2005).

Average daily rice intake in Vietnam is 0.466 kg d^{-1} (National Institute of Nutrition, 2004) and average body weight of a male and female aged 50 years is 61 kg and 55 kg, respectively. Consequently, based on the range in rice Cd concentration at the Nam Dinh study site, and the relatively high average daily rice intake for Vietnam (as compared to Thailand) WI values for men and women of 50yrs would range from 8.90 – 22.54 and 8.02 – 20.32 µg Cd per kg BW. In the My Tan commune, rice is grown on family plots primarily for home consumption. Excess is sold to local markets. The high estimated WI values (>7µg Cd per kg BW) would therefore suggest that residents of the aforementioned communes are exceeding their weekly intake of Cd. The elevated levels of Cd in rice grain may to a large extent be explained by the fact that the soils in the Nam Dinh study area have a mean (n=53) pH_{water} of 5.2 (± 0.15). This confirms the findings of Iumura et al., (1981) who observed that the relative uptake of Cd by rice plants was greatest within the pH range 4.5-5.5.

Further, as previously mentioned, the mean (n=53) soil Cd concentration at the Nam Dinh study site are indicative of Cd concentrations in alluvial soils of the Red River and Mekong River Deltas. At similar soil pH (pH 5.0), to what extent are communities within these deltaic areas exposed to high 'background levels' of dietary Cd via the rice food chain?

Similarly, Quynh and Ba, (2003) identified rice grain Cd concentrations grown on Cd contaminated paddy soils of Binh Chanh District, Ho Chi Minh City ranging from 0.38 – 0.56 mg Cd kg^{-1} (Table 14).

Therefore, based on the range in rice Cd concentration recorded for the Binh Chanh District by Quynh and Ba, (2003) and the daily rice intake for Vietnam of 0.466 kg d^{-1} (National Institute of Nutrition, 2004) WI values for men and women of 50yrs would range from 22.54 – 33.21 and 20.32 – 29.95 µg Cd per kg BW. As is the case for Nam Dinh, these values significantly exceed the JECFA PTWI value of 7µg Cd per kg BW.

Table 14. Cadmium concentration in soil and rice plant tissues (mg kg^{-1}) from selected areas of Binh Chanh District, Ho Chi Minh City.

	Cd concentration (mg kg^{-1})		
Sampling Location	Soil	Un-polished rice grain	Straw/Leaf
BC 3	7.6	0.38	1.26
BC 5	9.8	0.52	2.03
BC 9	14.5	0.55	2.37
BC 12	10.3	0.56	2.09
BC 13	9.6	0.55	1.96
BC 14	9.9	0.41	1.28
BC 32	10.3	0.48	2.33
Mean	10.28	**0.49**	1.90
STDEV	2.074	0.072	0.457
CV	20.17	14.71	24.04

Adapted from Quynh and Ba, (2003).

It must be noted that although based on robust laboratory analysis the WI values calculated for communities consuming rice cultivated at the Nam Dinh and Binh Chanh study sites are 'estimated' WI values only. Further detailed epidemiological and dietary studies must be undertaken to accurately determine actual public health risks. In this regard, as previously noted, adequate levels of dietary Fe and Zn have been shown to effectively protect against Cd-induced renal dysfunction. In 1995, 40% of Vietnamese women between 15 and 40 yrs were considered anaemic (Fe deficient). In 2004, the national average had through a national Fe supplementation program declined to 28% (National Institute of Nutrition in Vietnam (National Institute of Nutrition, 2004). However for pregnant women, the percentage with anemia is still high at 34% (National Institute of Nutrition, 2004).

Conclusions

Simmons et al., (2003) demonstrate that in soils significantly co-contaminated with Zn and Cd, rice plants irrespective of total or bio-available soil Zn concentrations, effectively controls rice grain Zn. However, the rice plant is unable to control the translocation and accumulation of Cd to grain. This was evident in the earliest characterization of rice Cd and Zn in exposed populations of Jintzu Valley (Fukushima et al., 1973). Considerable research has also established that levels of dietary Zn as well as Fe and to a lesser extent Ca are known to influence the absorption of Cd and its distribution in organs and tissues. Further, Cd related health risks associated with the long-term consumption of Cd contaminated rice grain are exacerbated by the fact that rice grain Fe, Zn and Ca contents are insufficient for human needs. In addition, milling rice grain results in further Fe and Zn losses whilst grain Cd concentrations remain un-affected.

Rice is the staple of millions throughout South and Southeast Asia. The emerging paradigm of Cd risk assessment is focused on communities nutritionally deficient in Zn, Fe and Ca consuming home grown Cd contaminated rice. This has been confirmed by research undertaken in Japan, China and more recently in Thailand and Vietnam

The Mae Sot case study clearly indicates that subsistence rice-based communities can be exposed to significantly elevated levels of dietary Cd as a result of the cultivation of rice on soils receiving Cd contaminated sediment derived from areas of Zn-mineralization and associated high geogenic Cd. Similar situations of rice-based communities consuming home grown rice cultivated in close proximity to non-ferrous high geogenic Cd areas and abandoned non-ferrous mines are known to occur throughout Northern Vietnam, South and Southeast Asia.

In many emerging industrial countries of South and Southeast Asia urban populations are rapidly expanding. However, urban sewerage, drainage and treatment systems have not kept pace with this increased demand and hence are incapable of preventing or reducing the negative health and environmental impacts associated with the uncontrolled release of partially and/or untreated industrial/domestic wastewaters. This has resulted in the un-controlled disposal of municipal and industrial wastewater to agricultural land. The Binh Chanh case study in Vietnam demonstrates the propensity for rice food chain Cd contamination resulting from the use of untreated industrial wastewater.

As indicated by the Nam Dinh case study, the 'naturally' high levels of Cd in soils of the Red River and Mekong Deltas in association with drainage, oxidation and acidification of these soils prior to the critical grain fill stage can result in the accumulation of Cd in rice grain. Similar, examples have also been identified in association with red soils of Southern China. Coupled with high daily rice intake this potentially exposes Fe and Zn deficient individuals particularly women to Cd related health risks.

Irrigation, agronomic and soil management-based options are available to mitigate Cd contamination of the rice food chain. In addition, emerging research has indicated that maintaining adequate levels of dietary Fe and Zn may be a viable dietary based means of protecting public health.

However, appropriate management options cannot be implemented unless populations exposed to elevated levels of dietary Cd are systematically identified and public health risk accurately evaluated. IWMI in collaboration with project partners has developed a series of decision support tools that coupled with detailed epidemiological and dietary studies could be utilized to rapidly evaluate areas of concern and facilitate the implement of management options to mitigate potential public health risks.

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