Cadmium in Paddy Soils and Rice Grain in Nam Dinh, Vietnam: a Potential Public Health Risk?

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Introduction

Since the late 1980's considerable focus has quite 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. 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. 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.

The long-term consumption of Cd contaminated rice has resulted in chronic and acute human Cd disease as manifested by Itai-Itai disease (Yoshioka, 1970), a form of osteomalacia and proximal tubular renal dysfunction (Kido et. al., 1988 Cai et al., 1990; Hochi et al., 1995; Ikeda et al., 2003). 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). Reports of health effects of Cd in populations dietarily exposed to Cd have centered on Japan (Watanabe et al., 1998; Kobayashi et al., 2002; Kido et. al., 1988; Nogawa and Kido, 1993; Tsuritani et al., 1992) and China (Cui et al., 2004; Jin et al., 2002; 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. 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 (Brzóska and Moniuszko-Jakoniuk, 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, 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

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to control the translocation and accumulation of Cd to grain. 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).

This research was undertaken as a component of the DANIDA Project *'Waste Water reuse in Agriculture in Vietnam'*. The aim of this project activity was to assess the assimilation of Cd and other heavy metals (treatment potential) of rice based irrigation systems with (untreated) wastewater application, and potential impacts on crops, soil and human health.

Materials and Methods

The project 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. In 2003, composite (20 point) soil samples (0-20cm depth) were collected using a screw auger from 41 and 12 pre-selected farmer plots in the wastewater and Red River irrigated study areas respectively. These samples were subsequently air dried and ground to pass a <1.0mm sieve. Total soil Zn, Pb, Ni, Cr, Cu and Cd were determined in *aqua regia* (3:1 $HCl:HNO_3$) following McGrath and Cunliffe, (1985). Soil pH_w and EC were determined on a 1:5 soil:water suspension (Rayment and Higginson, 1992) and Organic Carbon (OC) determined following the Walkley-Black Method (Walkley, 1947; Nelson and Sommers, 1996). At physiological maturity rice whole plants were harvested from three $1m^2$ sub-plots from each farmer plot previously sample for soil. For each plot, fifty panicles (including stem, leaf and grain) were randomly selected from the bulk rice plant sample. These were subsequently separated into stem/leaf and grain oven dried at 65°C for 48 hrs and ground. Total rice grain and stem/leaf Zn, Pb, Ni, Cr, Cu and Cd were determined in 2:1, $HNO_3:HClO_4$ following Johnson, and Ulrich, (1959). All soil and rice grain and stem/leaf samples were analyzed in duplicate and SRMs and reagent blanks incorporated in each analytical batch.

Results and Discussion

The results indicate that at both wastewater irrigated sub-area in Hong Long Cooperative and and Red River irrigated sub-area in Tan Tien Cooperative total soil Zn, Pb, Ni, Cr, Cu and Cd are within the EU (Directive 86/278/EEC) and Vietnamese (TCVN 7209-2002) guideline values (Table 1). Further, with the exception of Pb, Cu and Cr there is no significant difference in soil heavy metal concentrations between the wastewater and Red River irrigated plots.

Table 1. Total soil Cd, Zn, Pb, Ni, Cr and Cu (mg kg^{-1}) in the wastewater irrigated and Red River irrigated study sites in Nam Dinh, Vietnam.

	Element Concentrations (mg kg^{-1})					
Study Area	**Cd**	**Zn**	**Pb**	**Ni**	**Cr**	**Cu**
Red River Irrigated: Tan Tien Cooperative	0.858a (± 0.049)	41.04a (±1.024)	41.60a (±0.700)	34.55a (±0.796)	30.43a (±1.106)	34.48a (±0.540)
Wastewater Irrigated: Hong Long Cooperative	0.910a (±0.036)	40.31a (±0.451)	46.63b (±0.538)	33.47a (±0.446)	27.87b (±0.435)	38.13b (±0.487)
[1]EU	1-3	150-300	50-300	30-75	-	50-140
[2]Vietnam	2	200	70	-	-	50

[1]Directive 86/278/EEC [2]TCVN 7209-2002. Between study sites, mean values not followed by a common letter are significantly different at $p<0.05$ (two-tailed) as determined by t-Test (Two Sample Assuming Equal Variances).
Values in parentheses equal ±1 Standard Error.

The results indicate that soil pH is significantly lower in the wastewater irrigated plots as compared to the Red River irrigated plots with values of 5.22 (± 0.15) and 5.51 (± 0.14), respectively. In addition, a significant difference in Total Org-C (%) and EC were observed between the wastewater irrigated sub-area in Hong Long Cooperative and Red River irrigated sub-area in Tan Tien Cooperative with values of 2.29% (±0.68) and 1.71% (±0.24) and 51.57 (± 13.84) and 162.7 (± 41.5) respectively.

However, for brevity only total soil and rice Cd and Zn will be discussed in detail. 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 2).

Table 2. 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).

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}. 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). No significant difference in rice grain Cd concentrations were observed between the wastewater and Red River irrigated sites with mean values of (n=41) 0.123 (± 0.02) and (n=12) 0.129 (± 0.01) mg Cd kg^{-1}.

Table 3. Total rice grain Cd and Zn (mg kg^{-1}) in the wastewater irrigated and Red River irrigated study sites in Nam Dinh, Vietnam.

Study Area	Cd	Zn	Cd:Zn Ratio	% Samples with Cd:Zn ≥0.015
Red River Irrigated: Tan Tien Cooperative	0.123a (± 0.02)	10.90a (±0.578)	0.012a (± 0.003)	41.67
Wastewater Irrigated: Hong Long Cooperative	0.129a (±0.01)	11.88a (±0.325)	0.011a (±0.001)	46.34 .

Between study sites, mean values not followed by a common letter are significantly different at $p<0.05$ (two-tailed) as determined by t-Test (Two Sample Assuming Equal Variances). Values in parentheses equal ±1 Standard Error.

To what extent do the observed rice grain Cd concentrations pose a risk to public health? 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 Provisional Tolerable Weekly Intake (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}.

$$WI = \frac{WCdi}{BW}$$

Where, W Cd_i (μg kg^{-1}) is the weekly intake of Cd = daily rice intake (kg) x 7 x rice grain Cd concentration (μg Cd kg^{-1}); and BW = body weight (kg)

The 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 of rice grain Cd observed at the Nam Dinh study sites, and daily rice intake for Vietnam of 0.466 kg d^{-1} weekly intake (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.

Conclusions and Perspectives

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. 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). Chaney et al., (1996) indicated that a Cd:Zn ratio of <0.015 effectively provides protection from Cd-induced health impacts. For the samples collected at the Tan Tien and Hong Long cooperatives, over 41.6% and 46.3% had a Cd:Zn greater than the critical value recommended by Chaney et al., (1996) (Table 3).

The 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. As previously mentioned, the mean total soil Cd concentration at the Nam Dinh study site is indicative of Cd concentrations in alluvial soils of the Red River and Mekong River Deltas. Further, as indicated by Pham Quang Ha et al., (2003) the pH of soils in the Nam Dinh study sites are indicative of the pH of soils in the Red River and Mekong Deltas To what extent therefore, are communities within these deltaic areas exposed to high 'background levels' of dietary Cd via the rice food chain?

It must be noted that the WI values calculated for communities consuming rice cultivated at the Nam Dinh are 'estimated' WI values only. It is strongly recommended that further detailed studies combining soil/crop/irrigation investigations with epidemiological and dietary studies be undertaken to accurately determine public health risks and devise effective community and policy level interventions.

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