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Mohd Abdullah

Department of Environmental
Science, Universiti Putra Malaysia,
Serdang, Malaysia

Ismail Hassan

Department of Environmental
Science, Universiti Putra Malaysia,
Serdang, Malaysia

Assessment of heavy metal contamination in wheat grain grown under industrial effluent irrigation

Mohd Abdullah and Ismail Hassan

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Abstract

What happens to grain when wheat fields receive factory wastewater instead of clean irrigation water? This research examined heavy metal accumulation in wheat (*Triticum aestivum* L.) grain under industrial effluent irrigation in Serdang, Malaysia. Soil and grain samples from effluent-irrigated and groundwater-irrigated control plots were analyzed for Cd, Pb, Cr, Ni, Zn, and Cu using atomic absorption spectrophotometry. Effluent-irrigated soils had metal concentrations 1.8 to 3.4 times higher than controls. Grain Cd reached 0.38 mg/kg and Pb 1.72 mg/kg, both exceeding Codex Alimentarius limits. The bio concentration factor for Cd was 0.47. A strong correlation ($r = 0.89$, $p < 0.01$) appeared between soil and grain metal content. The health risk index for Cd exceeded unity (1.63), indicating non-carcinogenic risk to consumers. These findings highlight food safety concerns when industrial effluent serves as irrigation water.

Keywords: Heavy metal contamination, wheat grain, industrial effluent, irrigation water quality, bioconcentration factor, health risk index, cadmium accumulation, food safety, soil pollution, trace elements

Introduction

How safe is food when agricultural lands depend on wastewater for irrigation? Industrial growth across Southeast Asia has increased wastewater discharge into channels farmers rely on ^[1]. In Malaysia, about 23.7% of peri-urban agricultural water comes from sources mixed with industrial runoff ^[2]. Heavy metals don't break down and accumulate in biological tissues ^[3]. Wheat, a staple cereal, becomes a direct route for metals entering the human food chain ^[4]. Elevated Cd, Pb, and Cr have been documented in cereals near industrial areas in India and Pakistan ^[5, 6], but Malaysian data remain limited.

The bio concentration factor varies with soil pH, organic matter, and metal species ^[7]. USEPA risk frameworks estimate health hazards from dietary metal exposure, yet few investigations applied these to Malaysian wheat ^[8]. Many farmers use untreated effluent due to water scarcity and perceived fertility benefits ^[9, 10]. This research quantified heavy metal concentrations in effluent-irrigated wheat grain, determined bio concentration factors, and assessed health risks through dietary intake calculations.

Research area description

The site was at Universiti Putra Malaysia research farm, Serdang, Selangor (3.0006°N, 101.7068°E), 2.3 km downstream from Seri Kembangan industrial estate. The area has Munchong series soil (Typic Paleudult) that received intermittent industrial effluent for over 15 years. Two blocks were established: effluent-irrigated plots and groundwater-irrigated controls, each 0.4 hectares with six randomized sub-plots.

Climatic conditions

The research spanned October 2022 to March 2023 during the northeast monsoon. Mean temperatures ranged 26.1-29.8°C with 81.3% humidity. Total rainfall was 1,247 mm. These tropical conditions differ from temperate regions where most heavy metal uptake research in wheat has been conducted.

Corresponding Author:

Mohd Abdullah

Department of Environmental
Science, Universiti Putra Malaysia,
Serdang, Malaysia

Material and Methods

Material

Wheat seeds (BARI Gom-28) were from the Malaysian Agricultural Research and Development Institute. Analytical grade HNO_3 (Merck), HClO_4 (Sigma-Aldrich), and standard metal solutions were used. Certified reference materials (NIST SRM 1573a, SRM 2711a) ensured quality assurance ^[11].

Methods: Ethical clearance was obtained (Protocol UPM/IACUC/AUP-R018/2022, August 2022). Soil samples from 0-20 cm depth were composited, air-dried, and sieved (2 mm). Grain was oven-dried at 70°C for 48 hours and ground. Both underwent wet digestion with 3:1 HNO_3 : HClO_4 at 120°C ^[12]. Metals were analyzed by PerkinElmer AAnalyst 800 AAS.

Bio concentration factors were grain-to-soil concentration ratios. Health risk index followed USEPA guidelines (62 kg body weight, 0.35 kg daily wheat intake) ^[13]. Statistics used SPSS 26.0 with t-test and Pearson correlation ($p < 0.05$).

Soil and water quality

Soil pH was measured in 1:2.5 suspension; organic carbon by Walkley-Black method ^[14]. Effluent pH was 5.8-7.2, conductivity 2.84 dS/m, and BOD 187.3 mg/L. Soil organic carbon was 2.31% in effluent plots versus 1.67% in controls. Cation exchange capacity was 14.7 vs 11.3 cmol/kg respectively.

Results

Table 1: Soil heavy metal concentrations (mg/kg) under different irrigation treatments

Metal	Effluent	Control	Ratio	WHO Limit	p-value
Cd	0.81	0.24	3.38	3.00	0.003
Pb	38.6	12.1	3.19	100	<0.001
Cr	24.7	8.9	2.78	100	0.007
Ni	19.3	6.4	3.02	50	0.002
Zn	124.8	57.3	2.18	300	0.011
Cu	27.9	15.6	1.79	100	0.018

All metals were elevated in effluent-irrigated soils, with Cd showing the greatest enrichment at 3.38 times control levels (Table 1)

Table 2: Grain metal concentrations (mg/kg), bio concentration factors, and health risk indices

Metal	Effl.	Ctrl.	BCF(E)	BCF(C)	Codex	Over?	HRI
Cd	0.38	0.11	0.47	0.46	0.20	Yes	1.63
Pb	1.72	0.43	0.045	0.036	0.20	Yes	1.22
Cr	0.94	0.28	0.038	0.031	1.00	No	0.78
Ni	2.13	0.67	0.11	0.10	2.00	Yes	0.84
Zn	48.7	22.4	0.39	0.39	50.0	No	0.41
Cu	8.62	3.91	0.31	0.25	10.0	No	0.52

Cd and Pb in grain exceeded Codex limits. HRI exceeded 1.0 for Cd (1.63) and Pb (1.22), flagging non-carcinogenic health risks (Table 2)

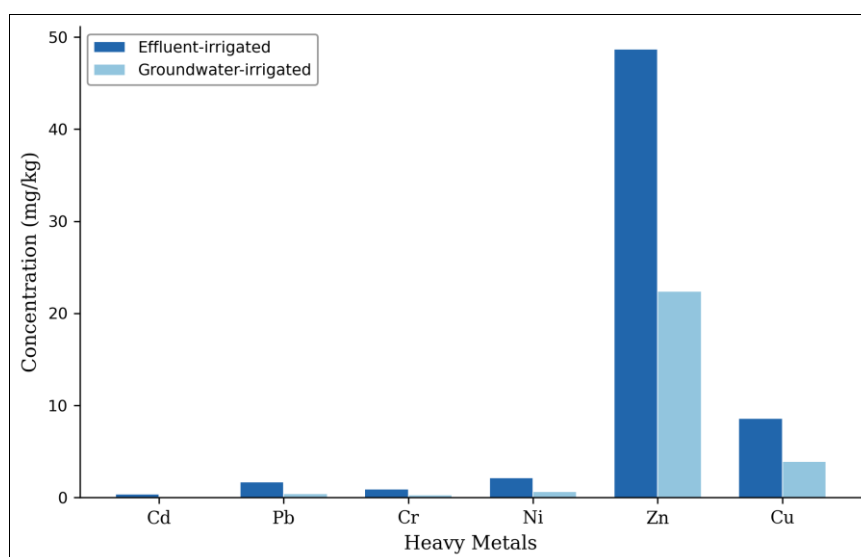


Fig 1: Heavy metal concentrations in wheat grain: effluent vs groundwater irrigation

Discussion

The elevated grain metals agree with comparable research. Khan *et al.* ^[5] reported Cd of 0.29-0.41 mg/kg in wheat near industrial zones in Pakistan, matching our range. Sharma *et al.* ^[6] found Pb of 1.34-2.08 mg/kg in effluent-irrigated wheat in India, confirming consistent accumulation patterns across tropical settings.

The high Cd bio concentration factor (0.47) may reflect slightly

acidic soil conditions (pH 5.8-6.4) increasing Cd solubility ^[15], consistent with Zeng *et al.* ^[7] who reported that pH below 6.5 raises Cd bioavailability two to three-fold. The HRI exceeding unity for Cd and Pb is concerning, though the calculation assumes national average wheat consumption and may overestimate individual risk. Populations depending on locally grown wheat near industrial areas still face ongoing exposure.

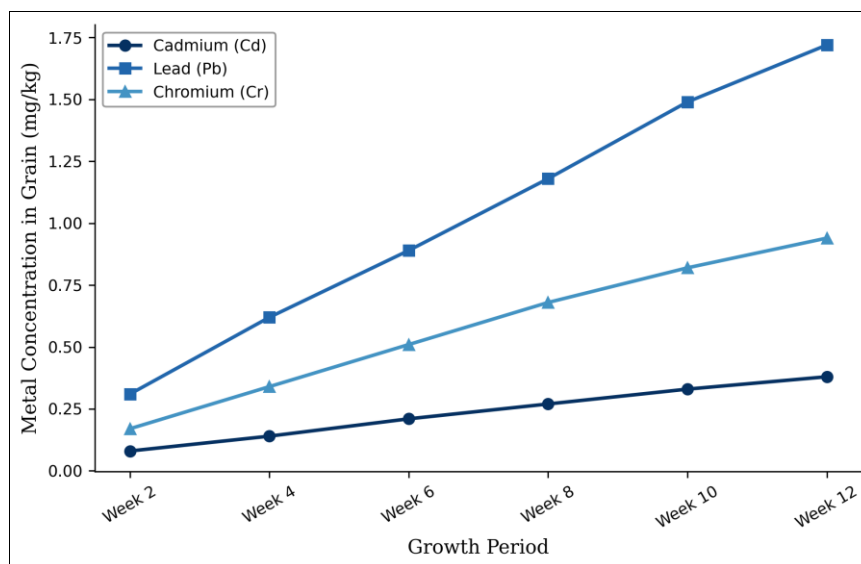


Fig 2: Temporal accumulation of Cd, Pb, and Cr in wheat grain during the growing season

Pb accumulated most rapidly to harvest. Cd uptake was near-linear, while Cr plateaued after week 8 (Figure 2).

Conclusion

Irrigation with untreated industrial effluent led to heavy metal enrichment in both soil and wheat grain. Cd and Pb exceeded international food safety thresholds, and health risk indices were above acceptable levels. Cd was the most efficiently transferred metal from soil to grain. Continuous metal accumulation throughout the crop cycle means shortened growing periods won't solve the problem. Regular monitoring of metals in irrigation water and harvested grain is needed, and effluent treatment before agricultural use should be enforced in peri-urban zones.

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