

Article

Enrichment, bioaccumulation and health risks of trace metals in soils and leafy vegetables grown on the banks of the Ugandan lifeline river, River Rwizi

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SUPPLEMENTARY MATERIALS

Table S1: Values of exposure factors used in health risk assessments due to TMTs in soils from banks of River Rwizi, Mbarara City, Uganda

Factor	Description (units)	Factor values	
		Children	Adults
C_{TMT}	Concentration of the TMT in the soils (mg kg ⁻¹)	This study	This study
$IngRS$	Ingestion rate (mg day ⁻¹)	200	100
$IngRV$	Fresh food ingestion rate(kg/person/day)	0.085	0.085
EXF	Exposure frequency (days year ⁻¹)	350	350
EXD	Exposure duration (years)	6	30
FI	Fraction ingested from the contaminated source (unitless)	1.0	1.0
$InhRS$	Inhalation rate of soil as dust (m ³ day ⁻¹)	200	100
CVF	Conversion factor (kg mg ⁻¹)	1×10^{-6}	1×10^{-6}
W_{ab}	Body weight (kg)	15	60
T_{aet}	Average time (days)	Non-carcinogenic: EXD \times 365 days year ⁻¹ ; carcinogenic: 60 years \times 365 days year ⁻¹	
S_{AF}	Surface area of skin exposed to soil as dust (cm ²)	2800	5700
PEF	Particular emission rate (m ³ kg ⁻¹)	1.316×10^9	1.316×10^9
AF	Skin adherence factor (mg cm ⁻²)	0.2	0.7
DAF	Dermal absorption factor (unitless)	0.001	0.001

Based on US EPA [1, 2], Ferreira-Baptista and De Miguel [3], Ajeh et al. [4] and Adedokun et al. [5].

Table S2: Classification values of pollution and risk indices used in study of TMTs in soils from banks of River Rwizi, Mbarara City, Uganda

Pollution and risk indicators	Classification values	Description
Contamination factor (CFs) [6]	CF < 1	Low contamination
	$1 \leq CF < 3$	Moderate contamination
	$3 \leq CF < 6$	Considerable contamination
	CF > 6	Very high contamination
Geo-accumulation index (I_{geo}) [7]	$I_{geo} < 0$ (class 0)	Practically uncontaminated
	$0 < I_{geo} < 1$ (class 1)	Low to median contamination
	$1 < I_{geo} < 2$ (class 2)	Median contamination
	$2 < I_{geo} < 3$ (class 3)	Median to strong contamination
	$3 < I_{geo} < 4$ (class 4)	Serious contamination
	$4 < I_{geo} < 5$ (class 5)	Serious to extreme contamination
Pollution Load index (PLDI)	$I_{geo} > 5$ (class 6)	Extreme contamination
	PLDI < 1	Unpolluted
Ecological risk (E_R^i and PERI) [6]	PLDI > 1	Polluted
	$E_R^i < 40$; PERI < 95	Low contamination
	$40 \leq E_R^i \leq 80$; $95 \leq PERI \leq 190$	Moderate contamination
	$80 \leq E_R^i \leq 160$; $190 \leq PERI \leq 380$	Considerable contamination
	$160 \leq E_R^i \leq 320$; PERI ≥ 380	High contamination
	$320 \leq E_R^i$	Very high contamination

Table S4: Estimated daily intake, hazard quotients, and indices for intake of manganese in leafy vegetables from the banks of River Rwizi, Mbarara City, Uganda.

Age Group	Sampling Site	Estimated daily intake of manganese (mg kg ⁻¹ day ⁻¹)					Hazard Quotient					Hazard Index
		<i>B. oleracea</i>	<i>C. pepo</i>	<i>S. oleracea</i>	<i>S. nigrum</i>	<i>A. hybridus</i>	<i>B. oleracea</i>	<i>C. pepo</i>	<i>S. oleracea</i>	<i>S. nigrum</i>	<i>A. hybridus</i>	
Children	A	1.808093607	0.66713356	1.780245434	0.493523973	0.599075342	12.91495434	4.76524	12.71603881	3.525171	4.27911	38.2005137
	B	1.715039954	1.3815411	0.991666667	1.252488584	2.173515982	12.25028539	9.868151	7.083333333	8.946347	15.52511	53.6732306
	C	0.604237443	0.42003196	0.667269406	0.66794863	0.577883562	4.315981735	3.000228	4.766210046	4.771062	4.12774	20.9812215
	D	0.880273973	0.35401142	1.278978311	0.435246575	1.660702055	6.287671233	2.528653	9.135559361	3.108904	11.86216	32.9229452
	E	0.88163242	0.34015525	0.95227169	0.349528539	1.034457763	6.297374429	2.42968	6.801940639	2.496632	7.388984	25.4146119
Adults	A	0.09040468	0.03335668	0.089012272	0.024676199	0.029953767	0.645747717	0.238262	0.63580194	0.176259	0.213955	1.91002568
	B	0.085751998	0.06907705	0.089012272	0.024676199	0.029953767	0.612514269	0.493408	0.63580194	0.176259	0.213955	2.13193778
	C	0.030211872	0.0210016	0.049583333	0.062624429	0.108675799	0.215799087	0.150011	0.354166667	0.447317	0.776256	1.94355023
	D	0.044013699	0.01770057	0.03336347	0.033397431	0.028894178	0.314383562	0.126433	0.238310502	0.238553	0.206387	1.12406678
	E	0.044081621	0.01700776	0.063948915	0.021762329	0.083035103	0.314868721	0.121484	0.456777968	0.155445	0.593108	1.64168379

Note: Kashanyarazi area (A), Behind Mbarara Regional Hospital (B), Katete area (C), Rugazi Bridge area (D) and Below Bishop Stuart University (E). Values in **bold** exceeded 1, indicating the possibility of non-cancer health effects being experienced by the exposed group.

Table S5: Estimated daily intake, hazard quotients, and indices for intake of zinc in leafy vegetables from the banks of River Rwizi, Mbarara City, Uganda.

Age Group	Sampling Site	Estimated daily intake of zinc (mg kg ⁻¹ day ⁻¹)					Hazard Quotient					Hazard Index
		<i>B. oleracea</i>	<i>C. pepo</i>	<i>S. oleracea</i>	<i>S. nigrum</i>	<i>A. hybridus</i>	<i>B. oleracea</i>	<i>C. pepo</i>	<i>S. oleracea</i>	<i>S. nigrum</i>	<i>A. hybridus</i>	
Children	A	0.95227169	0.81371005	1.713002283	0.724052511	0.63276484	3.174238965	2.71236681	5.71000761	2.413508	2.109216	16.1193379
	B	0.918989726	0.91695205	0.682619863	0.751900685	1.106455479	3.063299087	3.05650684	2.275399543	2.506336	3.688185	14.58972603
	C	0.345453196	0.68126142	0.547861872	0.591332192	0.73288242	1.151510655	2.27087138	1.826206241	1.971107	2.442941	9.662636986
	D	0.407941781	0.67542009	0.823219178	0.531560502	0.816426941	1.359805936	2.25140030	2.744063927	1.771868	2.721423	10.84856164
	E	0.426552511	0.57190639	0.823219178	0.414598174	0.552480594	1.421841705	1.90635464	2.744063927	1.381994	1.841602	9.295856164
Adults	A	0.047613584	0.0406855	0.085650114	0.036202626	0.031638242	0.158711948	0.13561834	0.28550038	0.120675	0.105461	0.805966895
	B	0.045949486	0.0458476	0.034130993	0.037595034	0.055322774	0.153164954	0.15282534	0.113769977	0.125317	0.184409	0.729486301
	C	0.01727266	0.03406307	0.027393094	0.02956661	0.036644121	0.057575533	0.11354356	0.091310312	0.098555	0.122147	0.483131849
	D	0.020397089	0.033771	0.041160959	0.026578025	0.040821347	0.067990297	0.11257001	0.137203196	0.088593	0.136071	0.542428082
	E	0.021327626	0.02859532	0.041160959	0.020729909	0.02762403	0.071092085	0.09531773	0.137203196	0.0691	0.09208	0.464792808

Note: Kashanyarazi Area (A), Behind Mbarara Regional Hospital (B), Katete area (C), Rugazi Bridge area (D) and Below Bishop Stuart University (E). Values in **bold** exceeded 1, indicating the possibility of non-cancer health effects being experienced by the exposed group.

Table S6: Estimated daily intake through ingestion, hazard quotients, and indices for intake of cadmium in leafy vegetables from the banks of River Rwizi, Mbarara City, Uganda.

Age Group	Sampling Site	Estimated daily intake of cadmium (mg kg ⁻¹ day ⁻¹)					Hazard Quotient					Hazard Index
		<i>B. oleracea</i>	<i>C. pepo</i>	<i>S. oleracea</i>	<i>S. nigrum</i>	<i>A. hybridus</i>	<i>B. oleracea</i>	<i>C. pepo</i>	<i>S. oleracea</i>	<i>S. nigrum</i>	<i>A. hybridus</i>	
Children	A	0.027712329	0.02377283	0.02716895	0.024452055	0.021055936	27.71232877	23.77283105	27.16894977	24.45205	21.05594	124.1621005
	B	0.026489726	0.01222603	0.013584475	0.020512557	0.040753425	26.48972603	12.2260274	13.58447489	20.51256	40.75342	113.56621
	C	0.019018265	0.01630137	0.015622146	0.012905251	0.015622146	19.01826484	16.30136986	15.62214612	12.90525	15.62215	79.46917808
	D	0.019697489	0.01358447	0.017659817	0.011682648	0.012905251	19.69748858	13.58447489	17.65981735	11.68265	12.90525	75.52968037
	E	0.019833333	0.01100342	0.01915411	0.01086758	0.012226027	19.83333333	11.00342466	19.15410959	10.86758	12.22603	73.08447489
Adults	A	0.001385616	0.00118864	0.001358447	0.001222603	0.001052797	1.385616438	1.188641552	1.358447488	1.222603	1.052797	6.20810502
	B	0.001324486	0.0006113	0.000679224	0.001025628	0.002037671	1.324486301	0.61130137	0.679223744	1.025628	2.037671	5.6783105
	C	0.000950913	0.00081507	0.000781107	0.000645263	0.000781107	0.950913242	0.815068493	0.781107306	0.645263	0.781107	3.973458902
	D	0.000984874	0.00067922	0.000882991	0.000584132	0.000645263	0.984874429	0.679223744	0.882990867	0.584132	0.645263	3.776484017
	E	0.000991667	0.00055017	0.000957705	0.000543379	0.000611301	0.991666666	0.550171233	0.957705479	0.543379	0.611301	3.654223743

Note: Kashanyarazi Area (A), Behind Mbarara Regional Hospital (B), Katete area (C), Rugazi Bridge area (D) and Below Bishop Stuart University (E). Values in **bold** exceeded 1, indicating the possibility of non-cancer health effects being experienced by the exposed group.

Table S7: Estimated daily intake, hazard quotients, and indices for intake of lead in leafy vegetables from the banks of River Rwizi, Mbarara City, Uganda.

Age Group	Sampling Site	Estimated daily intake of lead (mg kg ⁻¹ day ⁻¹)					Hazard Quotient					Hazard Index
		<i>B. oleracea</i>	<i>C. pepo</i>	<i>S. oleracea</i>	<i>S. nigrum</i>	<i>A. hybridus</i>	<i>B. oleracea</i>	<i>C. pepo</i>	<i>S. oleracea</i>	<i>S. nigrum</i>	<i>A. hybridus</i>	
Children	A	0.006276027	0.006248858	0.006724315	0.009210274	0.007118265	1.793150685	1.785388128	1.921232877	2.631507	2.03379	10.16506849
	B	0.006045091	0.00737637	0.006113014	0.00658847	0.007878995	1.72716895	2.107534247	1.746575342	1.88242	2.251142	9.714840183
	C	0.009726484	0.00904726	0.006724315	0.006928082	0.009386872	2.778995434	2.584931507	1.921232877	1.979452	2.681963	11.94657534
	D	0.01022911	0.009101598	0.007539384	0.004292694	0.010025342	2.92260274	2.600456621	2.154109589	1.226484	2.864384	11.76803653
	E	0.010364954	0.007063927	0.00777032	0.001290525	0.002798402	2.961415525	2.01826484	2.220091324	0.368721	0.799543	8.36803653
Adults	A	0.000313801	0.000312443	0.000336216	0.000460514	0.000355913	0.089657534	0.089269406	0.096061644	0.131575	0.101689	0.508253424
	B	0.000302255	0.000368818	0.000305651	0.000329424	0.00039395	0.086358447	0.105376712	0.087328767	0.094121	0.112557	0.485742009
	C	0.000486324	0.000452363	0.000336216	0.000346404	0.000469344	0.138949772	0.129246575	0.096061644	0.098973	0.134098	0.597328767
	D	0.000511455	0.00045508	0.000376969	0.000214635	0.000501267	0.146130137	0.130022831	0.107705479	0.061324	0.143219	0.588401826
	E	0.000518248	0.000353196	0.000388516	0.00006453	0.00013992	0.148070776	0.100913242	0.111004566	0.018436	0.039977	0.418401826

Note: Kashanyarazi Area (A), Behind Mbarara Regional Hospital (B), Katete area (C), Rugazi Bridge area (D) and Below Bishop Stuart University (E). Values in **bold** exceeded 1, indicating the possibility of non-cancer health effects being experienced by the exposed group.

Table S8: Estimated daily intake, hazard quotients, and indices for intake of chromium in leafy vegetables from the banks of River Rwizi, Mbarara City, Uganda.

Age Group	Sampling Site	Estimated daily intake of chromium (mg kg ⁻¹ day ⁻¹)					Hazard Quotient					Hazard Index
		<i>B. oleracea</i>	<i>C. pepo</i>	<i>S. oleracea</i>	<i>S. nigrum</i>	<i>A. hybridus</i>	<i>B. oleracea</i>	<i>C. pepo</i>	<i>S. oleracea</i>	<i>S. nigrum</i>	<i>A. hybridus</i>	
Children	A	0.001005251	0.000882991	0.00081507	0.00081507	0.00088299	0.335084	0.294330289	0.271689498	0.271689498	0.294330289	1.467123
	B	0.000882991	0.001018836	0.00108676	0.00095091	0.00081507	0.294330	0.339611872	0.362252664	0.316971081	0.271689498	1.584855
	C	0.001086758	0.001086758	0.00108676	0.00115468	0.00108676	0.362253	0.362252664	0.362252664	0.384893455	0.362252664	1.833904
	D	0.001018836	0.000978082	0.00095091	0.00101884	0.00108676	0.339612	0.326027397	0.316971081	0.339611872	0.362252664	1.684475
	E	0.001018836	0.000706393	0.00096450	0.00081507	0.00115468	0.339612	0.235464231	0.321499239	0.271689498	0.384893455	1.553158
Adults	A	0.0000503	0.0000503	0.00004075	0.00004075	0.00004415	0.016754	0.016754186	0.013584475	0.013584475	0.014716514	0.075394
	B	0.0000441	0.0000441	0.00005434	0.00004755	0.00004075	0.014717	0.014716514	0.018112633	0.015848554	0.013584475	0.076979
	C	0.0000543	0.0000543	0.00005434	0.00005773	0.00005434	0.018113	0.018112633	0.018112633	0.019244673	0.018112633	0.091695
	D	0.0000509	0.0000509	0.00004755	0.00005094	0.00005434	0.016981	0.016980594	0.015848554	0.016980594	0.018112633	0.084903
	E	0.0000509	0.0000509	0.00004822	0.00004075	0.00005773	0.016981	0.016980594	0.016074962	0.013584475	0.019244673	0.082865

Note: Kashanyarazi Area (A), Behind Mbarara Regional Hospital (B), Katete area (C), Rugazi Bridge area (D) and Below Bishop Stuart University (E). Values in **bold** exceeded 1, indicating the possibility of non-cancer health effects being experienced by the exposed group.

Table S9: Estimated daily intake, hazard quotients, and indices for intake of copper in leafy vegetables from the banks of River Rwizi, Mbarara City, Uganda.

Age Group	Sampling Site	Estimated daily intake of copper (mg kg ⁻¹ day ⁻¹)					Hazard Quotient					Hazard Index
		<i>B. oleracea</i>	<i>C. pepo</i>	<i>S. oleracea</i>	<i>S. nigrum</i>	<i>A. hybridus</i>	<i>B. oleracea</i>	<i>C. pepo</i>	<i>S. oleracea</i>	<i>S. nigrum</i>	<i>A. hybridus</i>	
Children	A	0.111800228	0.170077626	0.109762557	0.511455479	0.071454338	0.074533486	0.113385084	0.073175038	0.34097032	0.047636225	0.649700152
	B	0.102019406	0.082186073	0.078110731	0.161519406	0.114652968	0.068012938	0.054790715	0.05207382	0.107679604	0.076435312	0.35899239
	C	0.029885845	0.146984018	0.12701484	0.111256849	0.089929224	0.019923896	0.097989346	0.08467656	0.074171233	0.059952816	0.336713851
	D	0.04319863	0.125113014	0.094276256	0.062488584	0.098759132	0.028799087	0.083408676	0.062850837	0.041659056	0.065839422	0.282557078
	E	0.054881279	0.11098516	0.093732877	0.041704338	0.085853881	0.036587519	0.073990107	0.062488584	0.027802892	0.057235921	0.258105023
Adults	A	0.005590011	0.008503881	0.005488128	0.025572774	0.003572717	0.003726674	0.005669254	0.003658752	0.017048516	0.002381811	0.032485008
	B	0.00510097	0.004109304	0.003905537	0.00807597	0.005732648	0.003400647	0.002739536	0.002603691	0.00538398	0.003821766	0.017949619
	C	0.001494292	0.007349201	0.006350742	0.005562842	0.004496461	0.000996195	0.004899467	0.004233828	0.003708562	0.002997641	0.016835693
	D	0.002159932	0.006255651	0.004713813	0.003124429	0.004937957	0.001439954	0.004170434	0.003142542	0.002082953	0.003291971	0.014127854
	E	0.002744064	0.005549258	0.004686644	0.002085217	0.004292694	0.001829376	0.003699505	0.003124429	0.001390145	0.002861796	0.012905251

Note: Kashanyarazi Area (A), Behind Mbarara Regional Hospital (B), Katete area (C), Rugazi Bridge area (D) and Below Bishop Stuart University (E).

Table S10: Carcinogenic risk values for ingestion of cadmium and lead in soils sampled along the stretch of Rwizi River, Mbarara City, Uganda.

Ingested matrix	Age Group	Sampling Site	Cancer risk ($\times 10^{-6}$)		Total cancer risk ($\times 10^{-6}$)
			Cd	Pb	
Soils	Children	A	1.9038	1.1302	3.0340
		B	1.8036	1.3204	3.1240
		C	1.8036	1.8257	3.6293
		D	1.6533	0.6434	2.2967
		E	1.8036	0.3760	2.1796
	Adults	A	0.2505	0.0015	0.2519
		B	0.2004	0.0016	0.2020
		C	0.2004	0.0023	0.2027
		D	0.2004	0.0008	0.2012
		E	0.2004	0.0005	0.2009

Note: Kashanyarazi Area (A), Behind Mbarara Regional Hospital (B), Katete area (C), Rugazi Bridge area (D) and Below Bishop Stuart University (E).

Table S11: Carcinogenic risk values of cadmium and lead from consumption of leafy vegetables grown along the stretch of Rwizi River, Mbarara City, Uganda

Trace metal	Age Group	Sampling Site	Cancer risk values				
			<i>B. oleracea</i>	<i>C. pepo</i>	<i>S. oleracea</i>	<i>S. nigrum</i>	<i>A. hybridus</i>
Cadmium	Children	A	1.39E-02	1.19E-02	1.36E-02	1.23E-02	1.05E-02
		B	1.33E-02	6.13E-03	6.81E-03	1.03E-02	2.04E-02
		C	9.53E-03	8.17E-03	7.83E-03	6.47E-03	7.83E-03
		D	9.87E-03	6.81E-03	8.85E-03	5.85E-03	6.47E-03
		E	9.94E-03	5.51E-03	9.60E-03	5.44E-03	6.13E-03
	Adults	A	6.94E-04	5.96E-04	6.81E-04	6.13E-04	5.27E-04
		B	6.64E-04	3.06E-04	3.40E-04	5.14E-04	1.02E-03
		C	4.76E-04	4.08E-04	3.91E-04	3.23E-04	3.91E-04
		D	4.93E-04	3.40E-04	4.42E-04	2.93E-04	3.23E-04
		E	4.97E-04	2.76E-04	4.80E-04	2.72E-04	3.06E-04
Lead	Children	A	5.33462E-06	5.31153E-06	5.71567E-06	7.82873E-06	6.05053E-06
		B	5.13833E-06	6.26991E-06	5.19606E-06	5.6002E-06	6.69715E-06
		C	8.26751E-06	7.69017E-06	5.71567E-06	5.88887E-06	7.97884E-06
		D	8.69474E-06	7.73636E-06	6.40848E-06	3.64879E-06	8.52154E-06
		E	8.81021E-06	6.00434E-06	6.60477E-06	1.09695E-06	2.37864E-06
	Adults	A	2.66731E-07	2.65577E-07	2.85784E-07	3.91437E-07	3.02526E-07
		B	2.56917E-07	3.13495E-07	2.59803E-07	2.8001E-07	3.34858E-07
		C	4.13375E-07	3.84509E-07	2.85784E-07	2.94443E-07	3.98942E-07
		D	4.34737E-07	3.86818E-07	3.20424E-07	1.8244E-07	4.26077E-07
		E	4.40511E-07	3.00217E-07	3.30239E-07	0.548505E-07	1.18932E-07

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