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Risk Evaluation Associated with *Abelmuscus Esculentus* Consumption Grown on Decommissioned Goldmine Sediment and Water

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Abstract

The presence of toxic elements in mining areas has always been a concern for public health worldwide. Previously conducted studies have mainly focused on separate soil or water contamination as routes to potentially toxic elements, conceivably underestimating residents' risks. This study examined the health risks associated with the consumption of *Abelmuscus esculentus* planted in different sediment compositions; control soil + control water (CSCW), control soil + goldmine water (CSGW), goldmine sediment + control water (GSCW) and goldmine sediment + goldmine water (GSGW). As, Ni, Cr and Cd concentrations in goldmine water were found to be higher than allowable limits. After 21 days, *A. esculentus* seedlings planted on different soil/sediment compositions were harvested for the determination of elements using an inductively coupled plasma-optical electron spectrometer (ICP-OES). Estimated dietary intakes of minerals and toxic metals were lower than recommended limits. The non-carcinogenic risks posed by heavy metals are minimal, but *A. esculentus* in GSGW had 131.67 % greater risks of being hazardous. Carcinogenic risks indicate that *A. esculentus* grown in all soil/sediment compositions had the potential to cause cancer, with GSGW having approximately 63 % higher risks. Farming practices employing goldmine sediment and water present foreseeable hazards to health when not controlled going by findings in this study.

Keywords: *Abelmuscus esculentus*, Carcinogenic risk; Estimated dietary intake; Gold mining; Hazard

Introduction

Consumption of unsafe vegetables can potentially expose humans to metal toxicities (Azeez *et al*., 2020; Alsafran *et al*., 2021). The prevalence of heavy metal contamination from mining activities has become particularly alarming in places where artisanal gold mining is widespread (Gnonsoro *et al*., 2022; Marrugo-Madrid *et al*., 2022). Usually, toxic mines containing heavy and

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radioactive metals (RMs) are flagrantly dumped into rivers near gold mines, resulting in contamination. Environmentally destructive gold mining can contaminate matrixes that are useful for human activities within the ecological landscape (Grant & Wilhelm, 2022; Hao *et al*., 2022). State-licensed and artisanal gold miners benefit economically from mining, but active and decommissioned mining sites pose significant challenges to food security due to their environmental impacts (Gao *et al*., 2020; Orimoloye & Ololade, 2020; Corredor *et al*., 2021).

In terms of food security, the hitherto large portion of arable lands available for agriculture are being mined for gold in some parts of the State, driving away farmers to other occupations or forcing them to use goldmine soil/sediment for farming (Brugger & Zanetti, 2020; Atikpo *et al*., 2021). Using goldmine soil/sediment or goldmine water in agriculture, plants, humans, and animals can be predisposed to toxic metals, which can have detrimental effects (Belle *et al*., 2021; Grant & Wilhelm, 2022). This will create constraints for achieving sustainable development goal 2, that is, achieving food sustenance from inclusive agriculture to drive sustainable development. Clifford *et al*. (2022) reported a negative association between artisanal gold mining and the achievement of SDGs due to environmental hazards arising therefrom and can potentially contaminate the water from the use of Hg. In the wake of the mining boom, international policymakers are dealing with some of the most serious environmental and socioeconomic challenges ever (Haddaway *et al*., 2019; Ofosu & David, 2022).

Presently, in Osun State, the residents, farmers and both national and international adherents of Osun River have escalated their complaints about continuous Osun River pollution, especially at the UNESCO/WORLD Heritage Centre at Osun Groove, cautiously linked to gold mining. Moreover, other adjoining rivers and streams in the proximities of gold mining sites are polluted, and this has created apprehension among the residents of these communities (Anifowose *et al*., 2020). Ironically, gold mining is a budding economic activity in Osun State, which could predispose residents and visitors alike to health challenges if environmental contamination is not curbed.

Currently, residents are grappling with existential environmental challenges from mining, particularly artisanal. The risks associated with exposure to non-relevant toxic metals are burdensome on public health (Gao *et al*., 2022). Their presence in soil/sediment and water is undesirable as they negatively influence mineral absorption by plants, thereby creating a problematic subsistence within the plant, which can eventually lead to its death (Gnonsoro *et al*., 2022; Peirovi-Minaee *et al*., 2022). They cause organ dysfunction, cancer, cardiovascular disorder, and haematological disruption, among other human diseases (Sahoo *et al*., 2020; Moniakowska *et al*., 2022). Heavy metals such as Cd, Hg and Cr are neurotoxic, causing tremor, pre-natal mortality, cognitive deficiency, while As has been reported to be a potent carcinogen that disrupts kidney, liver, spleen and other organs (Azeez *et al*., 2020; Belle *et al*., 2021; Gnonsoro *et al*., 2022; Grant & Wilhelm, 2022; Marrugo-Madrid *et al*., 2022). However, due to the poverty in the land, residents are oblivious to the risks possibly associated with the consumption of food items planted on goldmine soil/sediment and with goldmine water (Brugger & Zanetti, 2020; Corredor *et al*., 2021).

In light of the fact that mining activities in these areas have been ongoing for years, it is imperative to determine the potential risks for public health in terms of heavy metals such as Cd, As, Pb, Hg, Cr, Mn, Cu, Ni and Zn (Filippini *et al*., 2020; Belle *et al*., 2021). Moreover, a large portion of the mining activities are presently being handled by artisans whose disregard for environmental safety is unmatched. Thus, this prompted the risk assessment of consumption of edible vegetables grown with mining polluted soil/sediment and water (Tomno *et al*., 2020; Azeez *et al*., 2022).

Risk assessment is a critical tool for estimating the health impact of activities affecting public health in different socioeconomic classes to inform the public and government on environmental sustainability policy decisions for better living circumstances (Azeez *et al*., 2022; Hao *et al*., 2022). Studies on contaminant intake from vegetables are reliable ways to estimate contaminant intake levels. As a result, potential contamination of vegetables can be identified (Dai *et al*., 2022; Gnonsoro *et al*., 2022). Even though vegetables are being grown rapidly, little information is available about the level of contamination or the source of the vegetables, so potential consumers may face health risks due to contamination; thus, ensuring food safety is important (Atikpo *et al*., 2021; Peirovi-Minaee *et al*., 2022).

Vegetables are the cheapest sources of nutrients, and people of all ages depend on them. In addition to stunting their growth, toxic metals can limit their nutritional quality and bioactive compound content since they restrict their ability to absorb macro- and micronutrients from the soil (Azeez *et al*., 2020; Alsafran *et al*., 2021). Okro (*Abelmuscus esculentus*) is a vegetable that grows fast, is resistant to drought, is cheap and has a good nutritional profile for human consumption (Durazzo *et al*., 2018). It is a medicinal plant known to be a source of minerals, polyphenols and vitamins required by humans for daily activities (Ibitoye & Kolawole, 2022). Nigerians consume fruits and leaves (known as Ilasa in Yoruba) fresh or dried as a food supplement or as a thickener. The study conducted by Chubike *et al*. (2013) reported that Nigerians consumed an average of 62.5 grams of okra per meal daily.

Toxic elements in mining areas have always been a source of public health concern worldwide (Belle *et al*., 2021; Dai *et al*., 2022). It is crucial to note that previous studies have focused mainly on separate exposure to goldmine-contaminated soil/sediment or water as routes to potentially toxic elements, which might have underestimated the risks faced by residents. Some previous research has highlighted risks associated with the consumption of vegetables planted in/around gold mining activities (Orimoloye & Ololade, 2020; Hao *et al*., 2022; Marrugo-Madrid *et al*., 2022). However, no research has been conducted on the combined risk effects of goldmine soil/sediment and goldmine water on consumers of vegetables since farmers around these locations cultivate their vegetables on decommissioned goldmine sites and water them with gold-polluted water. This study was therefore focused at determining the risk of exposure to toxic metals in *A. esculentus* planted on decommissioned gold mining sites turned farms with additional loads from contaminated water. This would done in order to provide details of possible health hazards associated with the consumption of such vegetables.

Materials and Methods

Sampling Location and Planting Experiment

The collection of sediment and water samples from a gold-mined site at the Odo-Rice community and the description of the sampling site as well as samples' characteristics (pH, organic matter, % sand, % clay, % silt) have been described by Azeez *et al*. (2023).

In this study, four planting variations were used: control soil + control water (CSCW), control soil + goldmine water (CSGW), goldmine sediment + control water (GSCW) and goldmine sediment + goldmine water (GSGW). Five *A. esculentus* seeds were sown in each bucket, grown for twenty-one days and harvested for further analysis.

Elemental Analysis of Goldmine Sediment, Water and *A. esculentus*

The elements in goldmine sediment, goldmine water, and control water were determined using an inductively coupled plasma with optical emission spectrometer (ICP-OES, Agilent 720-ES, USA) after digesting 0.5 g of soil/5 mL of water with a 10 mL acid mixture of HNO_3:HCl (7:3). Following the digestion technique described above, 0.5 g of thoroughly mixed post-harvest soil and *A. esculentus* shoots were collected for elemental analysis.

Contamination Intensity and Health Risk Assessment

Contaminated Intensity

The substantial accumulation of toxic metals in the shoots of *A. esculentus* exposed to different soil/sediment and water compositions was expressed using contamination intensity (equation1).

$$Contamination\ intensity\ (CI) = \frac{A.esculentus\ shoot\ content\ of\ heavy/radioactive\ \ metals}{Corresponding\ soil\ composition\ of\ heavy/radioactive\ metals} \qquad 1$$

When CI > 1, *A. esculentus* has substantially accumulated toxic metals. However, when CI < 1, the uptake of these metals was avoided, while when CI = 1, the uptake was minimal.

Estimated dietary intake of *A. esculentus*

The estimated daily intake (EDI) was used to assess the potential risks to human health from the consumption of *A. esculentus* leaves planted on decommissioned goldmine sediment with/without goldmine water. This was done using Equation 2. Chubike *et al.* (2013) reported a daily average consumption of *A. esculentus* of 0.063 kg person^{-1} day^{-1}. The average body weight of Nigerians was assumed to be 60 kg (Azeez *et al.*, 2020).

$$EDI\ (mgkg^{-1}\text{BW}day^{-1}) = \frac{HM\ contents\ (mgkg^{-1})\ x\ daily\ average\ consumption\ of\ A.esculentus\ (kg)}{Average\ Body\ weight\ (kg)} \qquad 2$$

Non-carcinogenic and carcinogenic risks

The target hazard quotient (THQ, equation 3) and hazard index (HI, equation 4) were used to assess the non-carcinogenic risks of *A. esculentus* leaves consumption planted with and without goldmine sediment and water.

$$THQ\ (mgkg^{-1}kg^{-1}BWday^{-1}) = \frac{EDI}{R_fD} \qquad 3$$

where R_fD (oral reference dose) represents the daily allowable dose to which humans can be exposed without harm. For Mn, Al, Cu, Mg, As, Cr, Cd, Zn, Ni and Fe, the R_fD values are 0.14, 7.00, 0.04,5.00, 0.0003, 0.003, 0.001, 0.3, 0.02 and 0.7 $mgkg^{-1}$day^{-1} for respectively [2,4,20].

$$HI = \sum THQ \qquad 4$$

where the hazard index (HI) is the total of the target hazard quotients of the metals under consideration. If HI and THQ < 1, exposure to toxic metals from consuming *A. esculentus* leaves is regarded as safe with minimal effects, but when THQ and HI > 1, there is a high likelihood of experiencing negative effects.

Carcinogenic risks of *A. esculentus* consumption planted with and without goldmine sediment and water were calculated using equations 5 and 6

$$LCR = EDI\ x\ CSF\ x\ LT \qquad 5$$

$$Carcinogenic\ risk\ (CR) = \sum LCR \qquad 6$$

where LCR indicates the lifetime cancer risks of toxic metal exposure, CSF denotes the cancer slope factor of toxic metals, indicating their potency to cause cancer, and LT represents the average lifetime of a Nigerian: 54 years (Vanguard Newspaper, 2021). The CSF values of Cr, Cd, As, and Ni are 0.5, 0.38, 1.5, and 1.7 mgkg^{-1}day^{-1}respectively (Alsafran *et al.*, 2021). The carcinogenic risk is estimated to be between 10^{-6} and 10^{-4}. If CR < 10^{-6}, the risk is considered insignificantly low, tolerable between 10^{-6}- 10^{-4}, and potentially carcinogenic if CR > 10^{-4}.

Statistical Analysis

Data are expressed as mean ± standard error of the mean (SEM) of three concordant triplicate values. All data were analysed using analysis of variance (ANOVA) followed by Tukey's Post Hoc test for comparison of means. The significant difference was performed at *p* <0.05 using SPSS 2020 (IBM Corp. Released 2020 IBM SPSS Statistics for Windows, Version 27.0, Armonk, NY).

Results and Discussion

Elemental Contents of Different Soil/Sediment and Water Samples

The gold concentrations in different soil/sediment and water samples varied significantly (p < 0.05), with goldmine water having the highest concentrations, followed by goldmine sediment that was not different from control soil, and control water having the lowest. In comparison to the other two samples, goldmine sediment and goldmine water had significantly ($p < 0.05$) higher K and Mg contents, while Ca was not found in goldmine sediment (Table 1). The Na concentrations were in the following order: goldmine water > control water > control soil > goldmine sediment. The macronutrients in control soil differ substantially ($p < 0.05$) from those in goldmine sediment. These macronutrients are elements that plants require for optimal performance, such as regulating plant nutrient absorption, acting as co-enzymes for plant growth, and improving cation exchangeability for improved root health (Durazzo *et al*., 2018; Azeez *et al*., 2020). Thus, their presence in the soil is beneficial to plant growth. When macronutrient-rich vegetables are consumed, they also benefit humans. They aid in muscle dilation and contraction, bone and tooth strengthening, and homeostasis maintenance (Durazzo *et al*., 2018; Moniakowska *et al*., 2022). Micronutrient concentrations of Fe and Cu were significantly higher in goldmine sediment, Zn in goldmine water, and Mn in control soil. The content of Al was significantly higher in goldmine sediment and lower in control water. The presence of potentially hazardous metals in different samples was observed to follow goldmine sediment > goldmine water > control soil > control water for As and Cd; goldmine water > goldmine sediment > control soil > control water for Ni and Cr. The contents of all heavy metals in the soil/sediment were lower than the permissible limit in all samples, whereas the contents of As, Ni, Cr, and Cd in goldmine water were higher than the WHO limits of 0.01, 0.2, 0.1, and 0.003 mgL^{-1}, respectively (Tomno *et al*., 2020; Dwivedi *et al*., 2021). Heavy metals in control soil might have resulted from the continuous application of agrochemicals on farms, as previously reported by Anifowose *et al*. (2020). In contrast, goldmine contamination could have resulted from the use of chemicals to wash the gold and components in the gold deposits (Hao *et al*., 2022). Heavy metals have been found in toxic goldmines and have been shown to be harmful to human health and plant metabolism (Orimoloye and Ololade 2020). Furthermore, the presence of toxic metals in goldmine sediment and water is undesirable because they impair plant ability to absorb minerals, making it difficult for the plant to survive, which may eventually result in death (Atikpo *et al*., 2021). Heavy metals such as As and Cd are classified as potential carcinogens by the WHO due to their carcinogenic activities and cardiovascular illnesses in human organs, which cause serious irreversible injuries upon exposure (Alsafran *et al*., 2021). Furthermore, As has the potential to deactivate and disrupt over 200 useful enzymes in plants. Although metals such as Cu, Zn, Mn, and Fe are required in trace amounts as enzyme cofactors in plants, exposure to higher concentrations can be disruptive to plant metabolism and harmful to human organs (Tomno *et al*., 2020; Dai *et al*., 2022). Metals such as Cu, Cd, and Al have been linked to dizziness, diarrhoea, headaches, and disruptions in calcium metabolism. Furthermore, chronic Al damage has been reported, and Mn is linked to reproductive deficiency (Azeez *et al*., 2022).

Elemental Contents of *A. esculentus* Planted on Different Soil/Sediment Compositions

The Au content of *A. esculentus* shoots grown on CSCW was significantly lower than that of other compositions containing either goldmine water or goldmine sediment (Table 2). Other compositions had a significant decrease in K content when compared to CSCW, while Na had a non-significant decrease. The significantly lower K indicates a possible disruption in photosynthesis pigment formation, stomata gas exchange, and *A. esculentus'* overall health. In comparison to other compositions, the Mg and Ca contents of GSGW were significantly higher (Table 2). This suggests that *A. esculentus* grown in contaminated sediment and water did not interfere with metal absorption as it did with K. The increase in Al contents in *A. esculentus* planted on decommissioned gold sediment and gold-polluted water, while not significant, could indicate a further disruption in the plant's health-promoting ability. The concentration of Fe, As, Cd, Ni, Cr, Cu, Zn, and Mn ranged from

Table 1: Macro-, Micronutrients and Heavy metal concentrations in different soil/sediment and water samples

Groups	Control soil (mgkg^{-1})	Control water (mgL^{-1})	Goldmine soil (mgkg^{-1})	Goldmine water (mgL^{-1})
Au	0.420 ± 0.004^{a}	0.046 ± 0.000^{b}	0.441 ± 0.003^{a}	1.008 ± 0.005^{c}
Na	0.588 ± 0.005^{a}	3.741 ± 0.000^{b}	0.336 ± 0.002^{c}	4.158 ± 0.004^{b}
K	17.682 ± 1.68^{a}	2.278 ± 0.090^{b}	71.358 ± 0.035^{c}	26.523 ± 0.001^{d}
Ca	27.048 ± 2.584^{a}	3.053 ± 0.160^{b}	0.000 ± 0.000^{c}	2.247 ± 0.017^{d}
Mg	1.785 ± 0.171^{a}	1.284 ± 0.060^{b}	42.000 ± 0.004^{c}	1.407 ± 0.009^{ab}
Al	2.667 ± 0.000^{a}	0.137 ± 0.010^{b}	12.726 ± 0.001^{a}	4.158 ± 0.000^{d}
Fe	2.898 ± 0.268^{a}	0.141 ± 0.000^{b}	30.072 ± 0.015^{c}	2.436 ± 0.004^{a}
Cd	0.000 ± 0.000^{a}	0.002 ± 0.000^{a}	0.042 ± 0.000^{b}	0.021 ± 0.000^{c}
Ni	0.021 ± 0.002^{a}	0.002 ± 0.000^{b}	0.651 ± 0.002^{c}	0.756 ± 0.001^{c}
As	0.010 ± 0.003^{a}	0.007 ± 0.000^{b}	0.420 ± 0.014^{c}	0.084 ± 0.000^{d}
Cr	0.042 ± 0.001^{a}	0.009 ± 0.000^{b}	0.084 ± 0.001^{c}	0.105 ± 0.001^{d}
Cu	0.080 ± 0.006^{a}	0.042 ± 0.000^{b}	0.903 ± 0.001^{c}	0.315 ± 0.002^{d}
Zn	0.063 ± 0.011^{a}	0.077 ± 0.000^{a}	0.147 ± 0.001^{b}	0.357 ± 0.000^{c}
Mn	0.189 ± 0.025^{a}	0.003 ± 0.000^{b}	0.105 ± 0.000^{c}	0.021 ± 0.000^{d}

Data expressed as mean ± standard error of mean of three triplicate concordant values. Data with different superscripts for a particular metal across the row are significantly different at $p < 0.05$

Table 2: Macro-, Micronutrients and Heavy metal concentrations in *A. esculentus* planted on different soil/sediment and water compositions

Elements	CSCW (mgkg^{-1})	CSGW (mgkg^{-1})	GSCW (mgkg^{-1})	GSGW (mgkg^{-1})
Au	0.008 ± 0.001^{a}	0.057 ± 0.005^{b}	0.059 ± 0.002^{b}	0.057 ± 0.002^{b}
Na	4.285 ± 0.040^{a}	4.838 ± 0.029^{a}	4.368 ± 0.040^{a}	4.266 ± 0.054^{a}
K	65.810 ± 0.062^{a}	58.055 ± 0.604^{b}	48.474 ± 0.474^{c}	54.009 ± 0.329^{b}
Ca	3.002 ± 0.000^{a}	2.090 ± 0.000^{b}	1.800 ± 0.000^{c}	6.090 ± 0.408^{d}
Mg	16.403 ± 0.096^{a}	16.407 ± 0.103^{a}	16.526 ± 0.095^{a}	22.435 ± 0.134^{b}
Al	0.114 ± 0.002^{a}	0.114 ± 0.001^{a}	0.120 ± 0.002^{a}	0.117 ± 0.002^{a}
Fe	0.146 ± 0.001^{a}	0.157 ± 0.001^{a}	0.114 ± 0.001^{b}	0.102 ± 0.001^{c}
Cd	0.003 ± 0.000^{a}	0.005 ± 0.000^{a}	0.004 ± 0.000^{a}	0.002 ± 0.000^{a}
Ni	0.001 ± 0.000^{a}	0.004 ± 0.002^{a}	0.002 ± 0.000^{a}	0.003 ± 0.000^{a}
As	0.005 ± 0.000^{a}	0.001 ± 0.000^{b}	0.020 ± 0.001^{a}	0.015 ± 0.001^{b}
Cr	0.001 ± 0.000^{a}	0.001 ± 0.000^{a}	0.001 ± 0.000^{a}	0.002 ± 0.000^{a}
Cu	0.055 ± 0.000^{a}	0.069 ± 0.001^{b}	0.005 ± 0.000^{c}	0.041 ± 0.001^{d}
Zn	0.082 ± 0.000^{a}	0.092 ± 0.001^{b}	0.061 ± 0.001^{c}	0.050 ± 0.001^{d}
Mn	0.085 ± 0.000^{a}	0.091 ± 0.001^{a}	0.056 ± 0.001^{b}	0.056 ± 0.001^{b}

Data expressed as mean ± standard error of mean of three triplicate concordant values. CSCW – control soil + control water, CSGW – control soil + goldmine water, GSCW – goldmine soil + control water, GSGW – goldmine soil + goldmine water. Data with different superscripts for a particular metal across the row are significantly different at $p < 0.05$

0.102 - 0.157, 0.001 - 0.020, 0.002 - 0.005, 0.001 - 0.003, 0.001 - 0.002, 0.005 - 0.055, 0.050 - 0.092, and 0.056 - 0.091 mg/kg, respectively. These metals are not recommended above the WHO/FAO limits of 5.0, 0.15, 0.2, 10.0, 2.0, and 1.5 mg/kg in vegetables for Fe, As, Cd, Ni, Cu, and Zn (Sahoo *et al*., 2020; Peirovi-Minaee *et al*., 2022).

Micronutrient concentrations were generally higher in *A. esculentus* planted on CSCW when compared to GSGW and opposite was obtained for potentially toxic metals for GSGW. Although all heavy metal levels were below the allowable limits, their accumulation in *A. esculentus* tissue, combined with the additive and synergistic effects of these metals, may cause more harm than expected (Alsafran *et al*., 2021; Atikpo *et al*., 2021). Additionally, the effects of their synergy will be stronger in some organs than others.

Health risk assessment

Dietary exposure studies of vegetable consumption are reliable ways to determine contaminant intake levels in a population. This provides critical information about potential vegetable contamination. Despite the rapid cultivation of vegetables, little information is provided about the level of contamination or source information about the growing area of the vegetables, so would-be consumers are exposed to potential health hazards caused by contamination, thus making food safety crucial (Atikpo *et al*., 2021; Filippini *et al*., 2020; Gnonsoro *et al*., 2022; Hao *et al*., 2022; Peirovi-Minaee *et al*., 2022).

Hazardous metal contamination intensity in *A. esculentus* follows the trend GSGW (1.98) > GSCW (0.988) > CSGW (0.933) > CSCW (0.676). As a result, *A. esculentus* in GSGW accumulated toxic metals with CI > 1, implying that its physiological indices and ability to support health would be severely compromised. The high concentrations of potentially hazardous toxic metals in such plants will have a significant impact on public health if consumed. The other compositions have a CI of approximately1, indicating that heavy metal uptake was minimal (Adewumi *et al*., 2020; Azeez *et al*., 2022).

Assessing the health risks associated with the consumption of *A. esculentus* planted on different soil/ sediment compositions was done by estimating dietary intake and comparing it with the recommended limits (Table 3). The EDI trends ranged from 1.05E-06 for Cr and U to 6.91E-02 for Na in CSCW, 1.05E-06 for As, Cr and U to 6.10E-02 for Na in CSGW, 1.05E-06 for Cr to 5.09E-02 for Na in GSCW and 2.10E-06 for Cr to 5.67E-02 for Na in GSGW. All EDI values are lower than WHO/FAO limits (Filippini *et al*., 2020; Alsafran *et al*., 2021; Marrugo-Madrid *et al*., 2022). Generally, the EDI of macro- and micronutrients was higher than heavy metals. In addition, *A. esculentus* planted on GSGW had higher EDI for toxic metals than other compositions. Consequently, *A. esculentus* on CSCW is preferable for consumption to other compositions.

Regarding a concurrent additive effect of the association between *A. esculentus* consumption planted on different soil/sediment compositions and non-cancer related illnesses estimated with THQ and HI (Table 4), both THQ and HI <1 imply that the likelihood of suffering severe health consequences from consuming *A. esculentus* planted on different soil/sediment compositions is minimal when heavy metal effects are considered. The HI sequence is GSGW > GSCW > CSCW >CSGW. *A. esculentus* in GSGW had a 131.67 % higher risk of being hazardous than in the CSCW, suggesting that consumption of this type predisposes residents to more non-cancer risks (Alsafran *et al*., 2021).

Some metals found in *A. esculentus* shoots are known carcinogens or cocarcinogens, raising the question of cancer risk when their levels are above the threshold (Azeez *et al*., 2020). The carcinogenic risks of Cr in *A. esculentus* ranged from 2.84E-05 for CSCW, CSGW, and GSCW to 5.76E-05 for GSGW, Cd ranged from 4.31E-05 for GSGW to 1.08E-04 for CSGW, As ranged from 8.51E-05 for CSGW to 1.70E-03 for GSCW, and Ni ranged from 9.64E-05 for CSCW to 3.84E-04 for CSGW. For each composition, the total LCR is as follows: GSCW > GSGW > CSCW > CSGW. As, Cd, and Ni have tolerable risks in many of the

Table 3: Estimated dietary intake of elements from consumption of *A. esculentus* planted on different soil/sediment and water compositions

Metals	CSCW	CSGW	GSCW	GSGW	DI intake limit*
Au	8.40E-06	5.99E-05	6.20E-05	5.99E-05	
K	4.50E-03	5.08E-03	4.59E-03	4.48E-03	
Na	6.91E-02	6.10E-02	5.09E-02	5.67E-02	
Ca	3.15E-03	2.19E-03	1.89E-03	6.39E-03	
Mg	1.72E-02	1.72E-02	1.74E-02	2.36E-02	5.00
Al	1.20E-04	1.20E-04	1.26E-04	1.23E-04	1.00
Fe	1.53E-04	1.65E-04	1.19E-04	1.07E-04	0.7
Cd	3.15E-06	5.25E-05	4.20E-05	2.10E-05	0.001
Ni	1.05E-06	4.20E-06	2.10E-06	3.15E-06	0.02
As	5.25E-06	1.05E-06	2.10E-05	1.58E-05	0.0003
Cr	1.05E-06	1.05E-06	1.05E-06	2.10E-06	0.003
Cu	5.78E-05	7.25E-05	5.25E-06	4.31E-05	0.04
Zn	8.61E-05	9.66E-05	6.41E-05	5.25E-05	0.3
Mn	8.93E-05	9.56E-05	5.88E-05	5.88E-05	0.14

CSCW – control soil + control water, CSGW – control soil + goldmine water, GSCW – goldmine soil + control water and GSGW – goldmine soil + goldmine water *DI – dietary intake $mgkg^{-1}$day^{-1} Filippini et al., 2020; Alsafran et al., 2021; Marrugo-Madrid et al., 2022

Table 4: Carcinogenic and non-carcinogenic calculations from consumption of *A. esculentus* planted on different soil and water compositions

	THQ					LCR			
Metals	CSCW	CSGW	GSCW	GSGW		CSCW	CSGW	GSCW	GSGW
Mg	3.45E03	3.45E-03	3.47E-03	4.71E-03					
Al	1.20E-04	1.20E-04	1.26E-04	1.23E-04					
Fe	2.19E-04	2.36E-04	1.71E-04	1.53E-04					
Cd	3.15E-03	5.25E-03	4.2E-03	2.10E-03		6.46E-05	1.08E-04	8.62E-05	4.31E-05
Ni	5.25E-05	2.10E-04	1.05E-04	1.58E-04		9.64E-05	3.86E-04	1.93E-04	2.89E-04
As	1.75E-02	3.50E-03	7.00E-02	5.25E-02		4.25E-04	8.51E-05	1.70E-03	1.28E-03
Cr	3.50E-04	3.50E-04	3.50E-04	7.00E-04		2.84E-05	2.84E-05	2.84E-05	5.67E-05
Cu	1.44E-03	1.81E-03	1.31E-04	1.08E-03					
Zn	2.87E-04	3.22E-04	2.14E-04	1.75E-04					
Mn	6.38E-04	6.83E-04	4.20E-04	4.20E-04					
HI	2.72E-02	1.60E-02	7.91E-02	6.21E-02	∑LCR	6.15E-04	6.07E-04	2.01E-03	1.66E-03

THQ – target hazard quotient, HI – hazard index, LCR – Life-time cancer risk, CSCW – control soil + control water, CSGW – control soil + goldmine water, GSCW – goldmine soil + control water and GSGW – goldmine soil + goldmine water compositions, with the exception of Cd in CSGW, As in GSCW and GSGW, and Ni in CSGW, GSCW, and GSGW, where long-term exposure could cause cancer.

This study evaluated the probability of cancer and non-carcinogenic illnesses that may result from exposure to the combined effects of goldmine sediment and goldmine water and found that continuous farming on soil/sediment contaminated with toxic elements from gold mining would result in life-long health risks. This is consistent with the reports of Gnonsoro *et al*. (2022), Hao *et al*. (2022) and Peirovi-Minaee et al. (2022) on fruits and vegetables sourced from Au, Pb, and Cu mining. To protect public health from eating vegetables around mining sites, authorities must take appropriate measures, such as providing alternative farms where vegetables can be grown (El-Gamal *et al*., 2019; Adewumi *et al*., 2020; Azeez *et al*., 2022).

Conclusion

The present study evaluated the concentration of toxic elements in goldmine areas, which are frequently underestimated by considering just one source of pollution while ignoring the other. This was achieved by estimating the combined effects of goldmine sediment and goldmine water on compacting different soil/sediment compositions in which seeds of *A. esculentus* were grown for 21 days. As Ni, Cr, and Cd concentrations in goldmine water exceeded WHO/FAO limits, whereas their contents were lower in other matrices. Heavy metals' ability to cause non-cancer-related illnesses was minimal for THQ and HI< 1. *A. esculentus* grown on goldmine sediment, on the other hand, had a higher risk of promoting disease. Carcinogenic risks indicate that *A. esculentus* grown on all soil compositions had the potential to cause cancer due to the presence of carcinogenic metals. However, goldmine soil had significantly higher carcinogenic risks.

Competing interest

The authors declare that they have no competing interests.

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