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# HEAVY METAL ANALYSIS OF ONION (*ALLIUM CEPA*) AND WATERMELON (*CITRULLUSLANATUS*) FROM IRRIGATED SOIL IN SABON-BIRNI LOCAL GOVERNMENT AREA OF SOKOTO STATE

**ALIYU, B.Y, KHALIL, I.A, AND SANUSI, A. M**

*Department of Chemistry Education, Federal College of Education, Gidan Madi, Sokoto State*

**ABSTRACT**

*The study determined the concentrations of cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) in irrigated-farm soils, onion (Allium cepa), and watermelon (Citrullus lanatus) in Sabon-Birni Local Government Area of Sokoto State, Nigeria. A descriptive laboratory analytical design was adopted, using eight single samples collected from two irrigated farms. The samples were digested and analysed using atomic absorption spectrophotometry. Cd was detected in all samples (0.0398–0.0538 mg/kg), while Cr occurred in seven samples (0.0107–0.2190 mg/kg). Cu was detected in all samples (0.1666–0.3543 mg/kg), Fe only in soil samples (15.7227–17.1710 mg/kg), Mn in all samples (0.1679–6.0386 mg/kg), and Zn in seven samples (0.0087–0.5867 mg/kg). The results showed variations in metal concentrations between the two farms and among soil and crop samples, with several metals occurring at higher concentrations in soils. The study concluded that the selected metals occurred at varying concentrations in the sampled irrigated agricultural environment. Regular monitoring of heavy metals in soils and crops and testing of irrigation water were recommended.*

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## INTRODUCTION

Irrigation is an important component of agricultural production, particularly in regions where rainfall is seasonal, insufficient, or unreliable. It enables farmers to extend crop production beyond the rainy season and can substantially increase agricultural productivity. The Food and Agriculture Organization (FAO, 2026) reports that although irrigated land constitutes about 23% of global cropland, it accounts for approximately 48% of global crop value, illustrating the importance of irrigation to contemporary food production. In semi-arid environments such as north-western Nigeria, irrigation is particularly important for the production of vegetables and other food crops during dry periods. However, the quality of irrigation water is as important as its availability because contaminants present in irrigation water can enter agricultural soils and subsequently influence crop quality and food safety.

The relationship between irrigation, soil quality, and crop contamination has received increasing scientific attention. Irrigation water containing dissolved metals or other contaminants can contribute to their accumulation in agricultural soils, particularly where contaminated wastewater or surface water is repeatedly applied. A review by Li et al. (2022) indicates that wastewater and reclaimed water used for irrigation may introduce heavy metals and other contaminants into soil–crop systems, while the long-term effects depend on the nature of the water source, soil characteristics, crop species, and contaminant behaviour. More recently, Sharafi et al. (2024) demonstrated experimentally that the transfer of heavy metals from soil to vegetables varies according to both irrigation-water source and vegetable species. These findings make assessment of irrigated agricultural soils particularly relevant in areas where vegetables are cultivated intensively.

Soil is a dynamic component of terrestrial ecosystems and provides the physical, chemical, and biological environment required for plant growth. It contains mineral constituents, organic matter, microorganisms, air, and water, and participates in nutrient cycling and the regulation of environmental processes. The original study appropriately emphasizes that soil can function as both a reservoir and a medium for contaminants. Current evidence further demonstrates that agricultural soils can accumulate potentially toxic metals from a range of natural and anthropogenic sources, including parent materials, atmospheric deposition, mineral fertilizers, pesticides, animal manure, industrial activities, mining, traffic-related emissions, and contaminated irrigation water (Yan et al., 2024). Consequently, the presence of metals in soil should not be considered solely a natural phenomenon; agricultural management and surrounding human activities can substantially modify their concentrations and availability.

Heavy metals and other potentially toxic elements occur naturally in the earth's crust as constituents of minerals and parent materials. Weathering, erosion, and other geochemical processes can release these elements into soil and water. Anthropogenic activities, however, may increase their environmental concentrations. Sources identified in recent literature include industrial emissions, mining and smelting, agricultural inputs, sewage and wastewater, atmospheric deposition, and other forms of human activity. A recent review by Chen et al. (2024) emphasizes that agricultural-soil contamination is influenced by both the sources of metals and their subsequent behaviour within the soil–plant system. The authors further note that crop characteristics and soil conditions jointly influence the accumulation of metals in plant tissues. Thus, environmental contamination cannot be interpreted solely from the total concentration of a metal in soil because its mobility and bioavailability are also important determinants of plant uptake.

The behaviour of metals in soil is particularly important because not all metals present in soil are equally available for uptake by plants. Soil pH, organic matter, cation-exchange capacity, redox conditions, moisture status, mineral composition, and the chemical form of individual metals can influence their mobility and bioavailability. Recent research has demonstrated that soil pH and redox reactions can substantially affect the immobilisation and mobility of metals within agricultural systems (Zhang et al., 2024). Similarly, the transfer of metals from soil to edible plant tissues varies considerably among crop species. Sharafi et al. (2024), for example, found that transfer factors differed according to both the irrigation source and vegetable species. This variability is important in the present study because onion and watermelon may not respond to metals in the same way, even when cultivated under similar environmental conditions. Cadmium (Cd) deserves particular attention among potentially toxic metals because of its mobility and capacity to enter the food chain. Cadmium may occur naturally in soils but can also be introduced through human activities, including certain fertilizers, industrial emissions, and contaminated water. The Codex Alimentarius Commission (2024) notes that cadmium concentrations in food can vary according to the characteristics of agricultural regions, the natural concentration of cadmium in soil, human-derived inputs, soil and water chemistry, and the capacity of different crops to absorb and accumulate the element. A recent review by Liu et al. (2023) similarly shows that cadmium accumulation in crops is controlled by processes occurring from the rhizosphere through root uptake and subsequent redistribution to edible tissues. These observations reinforce the importance of examining cadmium in both agricultural soils and crops rather than considering soil contamination independently from food production.

The significance of monitoring heavy metals is not restricted to environmental quality because contaminated agricultural products may provide a route of human exposure. The World Health Organization (WHO, 2026) identifies metals such as arsenic, lead, mercury, and cadmium among important chemical hazards in food and notes that contamination may originate from polluted soil and water. In particular, cadmium exposure has been associated with adverse effects on the kidneys, skeletal system, and respiratory system and is classified by WHO as a human carcinogenic hazard. Heavy metals can therefore present a dual environmental concern: they may affect soil and plant health while also potentially entering the human food chain through contaminated agricultural produce. At the same time, the term heavy metals encompasses elements with markedly different biological roles. Some metals examined in the present study, including iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn), are essential micronutrients required for normal plant and human physiological functions at appropriate concentrations. Their essentiality, however, does not mean that unlimited exposure is harmless. Conversely, cadmium is not an essential nutrient and is of particular toxicological concern. Chromium also requires careful interpretation because total chromium concentration does not identify its chemical species, and different chromium species have substantially different toxicological properties. A recent synthesis of heavy-metal contamination in agricultural systems highlights that the effects of these elements depend on metal identity, concentration, bioavailability, crop characteristics, and environmental conditions (Ali et al., 2024).

The movement of metals from agricultural soil into edible plant tissues is therefore a critical component of food-safety research. Heavy-metal accumulation in vegetables can result from root uptake, translocation within the plant, and, depending on the crop and irrigation practice, deposition on plant surfaces. Manwani et al. (2023), in a review of heavy metals in vegetables, emphasised that vegetables can accumulate potentially hazardous metals and that contamination requires attention from both environmental and food-safety perspectives. Importantly, the concentration detected in soil cannot automatically be assumed to correspond to the concentration in an edible crop. Wang et al. (2023), in a large-scale assessment of agricultural soil and crop systems, found that heavy-metal concentrations in crops do not always correspond directly to concentrations in the associated soils, reinforcing the importance of analysing both components of the soil–crop system.

The food-safety interpretation of metal concentrations must also be based on appropriate standards for the specific food commodity rather than on a single universal permissible limit. The Codex Alimentarius Commission (2025) defines maximum levels for contaminants on a commodity-specific basis because contaminants occur naturally and their concentrations differ among food categories. This is particularly relevant to studies involving soil, onion, and watermelon: a benchmark established for an edible food commodity should not automatically be applied to agricultural soil, and a limit applicable to one type of food should not necessarily be transferred to another. Consequently, determination of metal concentrations in the present study provides evidence of their occurrence and distribution, while conclusions concerning food safety should be based on appropriate commodity-specific standards and, where possible, dietary exposure assessment.

Onion *(Allium cepa)* and watermelon *(Citrullus lanatus)* are important food crops and are cultivated under irrigated conditions in many agricultural environments. Their inclusion in the present investigation provides an opportunity to examine the occurrence of selected metals in both agricultural soils and edible crop materials. This is especially relevant because plant species differ in their ability to absorb, retain, and translocate metals. Research on soil–vegetable systems has shown that the transfer of metals can differ considerably among crops and among individual metals, even when plants are grown under comparable conditions (Sharafi et al., 2024). Examining onion and watermelon alongside their associated soils can therefore provide useful preliminary information on the distribution of Cd, Cr, Cu, Fe, Mn, and Zn within the sampled irrigated farms. The concern is particularly relevant to irrigated agriculture in northwestern Nigeria, where dry-season cultivation provides an important source of vegetables and other crops. The original study was conducted on irrigated farmland in Sabon-Birni Local Government Area of Sokoto State and focused on soil, onion, and watermelon samples. The authors' original rationale was that heavy metals may occur naturally in soil but may also arise from agricultural and other anthropogenic activities, potentially threatening environmental quality and human health.

Against this background, determination of selected heavy-metal concentrations in irrigated soils and commonly consumed crops is important for establishing local baseline information and identifying metals that warrant further environmental monitoring. The present study therefore investigated the concentrations of chromium, manganese, copper, cadmium, iron, and zinc in selected irrigated-farm soils, onion, and watermelon obtained from Sabon-Birni Local Government Area of Sokoto State, Nigeria. By examining both soils and crop tissues, the study contributes preliminary information on the occurrence and distribution of these metals within the sampled agricultural system and provides a basis for more extensive investigations involving irrigation water, soil physicochemical properties, replicated sampling, metal bioavailability, and dietary health-risk assessment.

## STATEMENT OF THE PROBLEM

Irrigated agriculture provides an important means of sustaining crop production, particularly in areas where rainfall is limited or seasonal. However, repeated irrigation with water of uncertain quality, together with agricultural and other anthropogenic activities, may introduce heavy metals into cultivated soils. Heavy metals can persist in soil and, depending on soil properties and metal characteristics, become available for uptake by crops. Recent studies have continued to identify agricultural soils and vegetables as important components of heavy-metal contamination and food-safety concerns, particularly in irrigated systems. The presence of metals such as Cd, Cr, Cu, Fe, Mn, and Zn in agricultural soils is therefore important because some are essential micronutrients while others may become harmful at elevated concentrations, and contaminated crops can provide a pathway for human exposure.

Despite the importance of irrigated agriculture in Sokoto State, there is limited site-specific information on the concentrations of selected heavy metals in irrigated soils and commonly consumed crops from Sabon-Birni Local Government Area. The original study identified this concern through the collection of soil, onion, and watermelon samples from two irrigated farms and analysis using atomic absorption spectrophotometry. However, without current local evidence on the distribution of these metals between agricultural soils and edible crops, it is difficult to establish an appropriate baseline for environmental monitoring and food-safety assessment. The problem, therefore, is the need to determine the concentrations of Cd, Cr, Cu, Fe, Mn, and Zn in selected irrigated soils, onion, and watermelon in the study area and provide evidence that can support further monitoring and appropriate agricultural and public-health interventions.

## PURPOSE OF THE STUDY

The purpose of the study was to determine the concentrations of selected heavy metals, cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn), in irrigated-farm soils, onion (Allium cepa), and watermelon *(Citrullus lanatus)* in Sabon-Birni Local Government Area of Sokoto State. Specifically, the study determined the concentrations of the selected metals in the soil, onion, and watermelon samples; compared their concentrations between the soil and crop samples and between Farm A and Farm B; identified the metals that were detected and not detected in the sampled materials; and compared the observed concentrations with the stated maximum allowable limits.

## MATERIALS AND METHODS

### Research Design

The study adopted a descriptive laboratory analytical design. Samples of soil, onion (Allium cepa), and watermelon *(Citrullus lanatus)* were collected from selected irrigated farms in Sabon-Birni Local Government Area of Sokoto State and analysed for the concentrations of cadmium, chromium, copper, iron, manganese, and zinc using atomic absorption spectrophotometry. The design was considered appropriate because the study involved determining and describing the concentrations of selected metals in naturally occurring soil and crop samples without experimental manipulation.

### Materials

The materials used for the analysis comprised soil, onion *(Allium cepa)* as a vegetable, and watermelon *(Citrullus lanatus)* as a fruit, obtained from irrigated farmland in Sabon-Birni Local Government Area of Sokoto State, Nigeria.

## Sampling Procedure

Samples were collected from two randomly selected irrigated farms, designated Farm A and Farm B, in Sabon-Birni Local Government Area of Sokoto State. From each farm, four samples were collected, comprising soil associated with onion cultivation, soil associated with watermelon cultivation, onion, and watermelon, giving a total of eight samples. The samples were collected as single (non-replicated) samples, while soil samples were obtained from a depth of 0–15 cm. A simple random sampling technique was used to select the two farms, while purposive sampling was used to identify the specific soil and crop materials relevant to the study within each selected farm. This approach ensured that the samples represented the two crop-production systems investigated in the study.

## Sample description

The samples obtained are labeled as shown in the Table below.

**Table 1: Samples and their description**

| S/NO | SAMPLE | DESCRIPTION |
|---|---|---|
| 1 | A1 | Soil of Onion (Farm A) |
| 2 | B1 | Soil of Watermelon (Farm A |
| 3 | O1 | Onion (Farm A) |
| 4 | W1 | Watermelon (Farm A) |
| 5 | A2 | Soil of Onion (Farm B) |
| 6 | B2 | Soil of Watermelon (Farm B) |
| 7 | O2 | Onion (Farm B) |
| 8 | W2 | Watermelon (Farm B) |

Table 1 presents the identification and description of the eight samples collected from Farm A and Farm B in Sabon-Birni Local Government Area of Sokoto State. Four samples were obtained from each farm. From Farm A, A1 represented soil associated with onion cultivation, B1 represented soil associated with watermelon cultivation, O1 represented onion, and W1 represented watermelon. Similarly, from Farm B, A2 represented soil associated with onion cultivation, B2 represented soil associated with watermelon cultivation, O2 represented onion, and W2 represented watermelon. Thus, the table shows that the study comprised four samples from each farm, giving a total of eight samples for analysis.

### Sample Preparation and Digestion

Each sample (soil, onion, and watermelon) was prepared separately for analysis. 2.0 g of each sample was accurately weighed and transferred into individual digestion tubes. To each sample, 10 cm³ of concentrated nitric acid ($HNO_3$) and 2 cm³ of perchloric acid ($HClO_4$) were added. For the soil samples, 1 cm³ of concentrated sulphuric acid ($H_2SO_4$) was additionally added. The mixtures were heated at 80 °C until white fumes were observed to facilitate digestion of the samples and release of the metals into solution.

After digestion, the solutions were allowed to cool to room temperature. A small quantity of distilled water was then added, and each solution was filtered through filter paper into a clean sample bottle to remove undigested materials. The filtrates were subsequently made up to the 25 cm³ mark with distilled water and retained for analysis by atomic absorption spectrophotometry.

### Atomic Absorption Spectroscopy Analysis

Each sample solution was neutralized into an air acetylene flame, where they were heated to vaporize and atomized the metals. A beam of radiation was passed through the atom samples and absorption of radiation was measured at specific wavelength corresponding to the metal of interest information about the type and concentration of metal present was obtained by measuring the location and intensity of the peak in the absorption spectra.

## RESULTS

**Table 2: Results for AAS Analysis in mg/kg**

| Element | A1 | B1 | O1 | W1 | A2 | B2 | O2 | W2 | MAL (WHO) |
|---|---|---|---|---|---|---|---|---|---|
| Cadmium (Cd) | 0.04 | 0.05 | 0.05 | 0.04 | 0.04 | 0.05 | 0.05 | 0.04 | 0.05 |
| Chromium (Cr) | 0.06 | 0.13 | 0.22 | 0.12 | ND | 0.12 | 0.19 | 0.01 | 0.05 |
| Copper (Cu) | 0.23 | 0.35 | 0.20 | 0.17 | 0.25 | 0.30 | 0.17 | 0.24 | 0.05 |
| Iron (Fe) | 15.72 | 17.17 | ND | ND | 16.43 | 17.03 | ND | ND | 18.00 |
| Manganese (Mn) | 3.61 | 6.04 | 0.21 | 0.20 | 4.23 | 4.92 | 0.25 | 0.17 | 0.10 |
| Zinc (Zn) | 0.15 | 0.59 | ND | 0.01 | 0.32 | 0.42 | 0.05 | 0.03 | 5.00 |

Table 2 shows that the selected heavy metals varied across the soil, onion, and watermelon samples from Farms A and B. Cadmium was detected in all samples, ranging from 0.0398 to

0.0538 mg/kg, while chromium was detected in seven samples, with the highest concentration of 0.2190 mg/kg in O1 and not detected in A2. Copper was detected in all samples, ranging from 0.1666 to 0.3543 mg/kg. Iron was detected only in the soil samples, with concentrations ranging from 15.7227 to 17.1710 mg/kg, but was not detected in the onion and watermelon samples. Manganese was detected in all samples and ranged from 0.1679 to 6.0386 mg/kg, with the highest value recorded in B1. Zinc was detected in seven samples, ranging from 0.0087 to 0.5867 mg/kg, but was not detected in O1. Overall, the results indicate that the concentrations of several metals were generally higher in the soil samples than in the onion and watermelon samples, while variations also occurred between Farms A and B. Since the samples were collected in singlet and no inferential statistical test was reported, the observed differences represent descriptive variations and should not be interpreted as statistically significant differences.

## DISCUSSION

Cadmium was detected in all eight samples, with concentrations ranging from 0.0398 to 0.0538 mg/kg. The highest concentration was recorded in B1 (0.0538 mg/kg), representing soil associated with watermelon cultivation in Farm A, while the lowest concentration was recorded in A2 (0.0398 mg/kg), representing soil associated with onion cultivation in Farm B. The concentrations in onion were 0.0488 mg/kg in O1 and 0.0454 mg/kg in O2, while those in watermelon were 0.0443 mg/kg in W1 and 0.0437 mg/kg in W2. The variation in Cd concentrations may be associated with differences in soil properties, metal availability, and the ability of individual crops to absorb and accumulate the element. Liu et al. (2023) reported that cadmium accumulation in crops is influenced by rhizosphere processes, root uptake, and the subsequent movement of the metal within plant tissues. The concentrations obtained in the study were lower than those reported by Iftikhar et al. (2013). However, the highest concentration obtained in the study (0.0538 mg/kg) was slightly above the 0.05 mg/kg benchmark presented in Table 2. This comparison should be interpreted cautiously because the applicability and regulatory basis of the stated benchmark to the specific sample matrix require verification. Cadmium is a non-essential and potentially toxic element, and its presence in edible crops is of concern because contaminated crops may contribute to human dietary exposure.

Chromium was detected in seven of the eight samples, with concentrations ranging from 0.0107 to 0.2190 mg/kg. The highest concentration was recorded in O1 (0.2190 mg/kg), followed by O2 (0.1868 mg/kg), whereas the lowest detected concentration occurred in W2 (0.0107 mg/kg). Chromium was not detected in A2. The variation in Cr concentrations among the samples may be associated with differences in soil characteristics, chromium availability, environmental inputs, and crop-specific uptake mechanisms. Yu et al. (2023) reported differences in chromium accumulation among vegetable species, indicating that the concentration of chromium in soil does not necessarily translate into a corresponding concentration in edible plant tissues. The concentrations obtained in the study were lower than those reported by Marshall et al. (2003). Most of the detected Cr concentrations were higher than the 0.05 mg/kg benchmark presented in Table 2, except W2. However, this comparison should be interpreted with caution because permissible concentrations for metals are dependent on the sample matrix and food commodity. In addition, the analysis reported total chromium and did not distinguish between Cr(III) and Cr(VI), which have different toxicological properties. Excessive exposure to chromium, particularly the more toxic hexavalent form, may pose risks to human health.

Copper was detected in all eight samples, with concentrations ranging from 0.1666 to 0.3543 mg/kg. The highest concentration was recorded in B1 (0.3543 mg/kg), while the lowest occurred in W1 (0.1666 mg/kg). The concentrations recorded in the soil samples were generally higher than those observed in onion and watermelon. The variation may be related to differences in soil characteristics, agricultural practices, metal availability, and the ability of crops to absorb and regulate copper. The concentrations obtained in the study were lower than those reported by Bonham et al. (2002). Copper is an essential micronutrient involved in several physiological and biochemical processes in plants and humans; however, excessive concentrations may produce adverse effects. Huang et al. (2021) explained that copper has both nutritional and toxicological significance depending on its concentration and availability. Although the concentrations obtained in the study were higher than the 0.05 mg/kg value presented in Table 2, that value was originally associated with luncheon meat and therefore should not be directly applied as a permissible limit for soil, onion, or watermelon. Appropriate matrix- and commodity-specific standards are required for a valid regulatory comparison.

Iron was detected only in the four soil samples. The concentrations were 15.7227 mg/kg in A1, 16.4330 mg/kg in A2, 17.1710 mg/kg in B1, and 17.0269 mg/kg in B2, while Fe was not detected in O1, O2, W1, or W2. The highest concentration was therefore recorded in B1, while the lowest occurred in A1. The non-detection of Fe in the onion and watermelon samples may indicate concentrations below the detection capability of the analytical instrument rather than complete absence of the element. The detection limit of the instrument was not reported in the study and should therefore be acknowledged when interpreting the ND results. The relatively higher concentrations of Fe in soil may also be associated with differences in soil composition and the capacity of the crops to absorb and translocate the element. Iron is an essential element required for important physiological processes in plants and humans. Arcas et al. (2024) noted that iron availability and plant uptake are influenced by soil conditions and plant acquisition mechanisms. The concentrations recorded in the soil samples were below the 18.00 mg/kg value presented in Table 2; nevertheless, the suitability of this value as a soil benchmark requires verification.

Manganese was detected in all eight samples, with concentrations ranging from 0.1679 to 6.0386 mg/kg. The highest concentration occurred in B1 (6.0386 mg/kg), while the lowest occurred in W2 (0.1679 mg/kg). The soil samples recorded considerably higher Mn concentrations than the onion and watermelon samples. This finding suggests that the presence of Mn in the soil did not result in a proportional accumulation in the edible crop tissues. Such variation may be attributed to differences in plant uptake, translocation, and internal regulation of manganese. Manganese is an essential micronutrient required for several physiological processes, including photosynthesis and enzyme activation, although excessive exposure may also have adverse effects. Obeng et al. (2024) observed that both manganese deficiency and excessive manganese exposure may have biological consequences. The concentrations obtained in the study were lower than those reported by Bonham et al. (2002). However, the 0.10 mg/kg value presented in Table 2 should not be treated as a universal permissible limit without establishing its source and applicability to the specific soil and food matrices examined in the study.

Zinc was detected in seven of the eight samples, with concentrations ranging from 0.0087 to 0.5867 mg/kg. The highest concentration was recorded in B1 (0.5867 mg/kg), while the lowest detected concentration occurred in W1 (0.0087 mg/kg). Zinc was not detected in O1. The soil samples generally recorded higher Zn concentrations than the onion and watermelon samples. This variation may be related to differences in soil characteristics, zinc availability, and plant-specific mechanisms for metal uptake and transport. Plants possess regulatory mechanisms that control the uptake and distribution of essential metals such as zinc, iron, copper, and manganese. The concentrations obtained in the study were below the 5.00 mg/kg benchmark presented in Table 2. Zinc is an essential micronutrient required for normal growth, development, and physiological functioning. Wang et al. (2006) reported that inadequate zinc intake may result from insufficient dietary intake, impaired absorption, excessive excretion, or abnormalities in zinc metabolism. Thus, the relatively low concentrations observed in the onion and watermelon samples should not automatically be interpreted as harmful; their nutritional significance would require consideration of dietary intake and bioavailability.

Therefore, the study showed variations in the concentrations of the selected heavy metals among the two farms and the different sample types. Iron and manganese were more prominent in the soil samples, while several of the other metals occurred at lower concentrations in onion and watermelon. The differences observed between soil and crop samples may be related to differences in metal availability, plant uptake, translocation, and sequestration. The study therefore provides useful preliminary information on the occurrence and distribution of Cd, Cr, Cu, Fe, Mn, and Zn in irrigated agricultural soils and crops in Sabon-Birni Local Government Area of Sokoto State. However, because the samples were collected as single samples and no analytical replicates or inferential statistical tests were reported, the observed differences should be regarded as descriptive variations rather than statistically significant differences. Similarly, conclusions regarding food safety should be based on verified, matrix-specific regulatory standards rather than applying a single maximum allowable limit to all soil and crop samples.

## CONCLUSION

The study concluded that cadmium, chromium, copper, manganese, and zinc were detected in varying concentrations in the sampled irrigated-farm soils, onion, and watermelon from Sabon-Birni Local Government Area of Sokoto State, while iron was detected only in the soil samples. The concentrations varied between the two farms and among the sample types, with generally higher concentrations of several metals observed in the soil than in the crop samples. The findings provide preliminary evidence of the occurrence and distribution of the selected metals within the sampled irrigated agricultural environment. However, because the samples were collected as single samples and no inferential statistical analysis or dietary exposure assessment was conducted, the findings should be interpreted as descriptive evidence and not as proof of statistically significant differences or definitive health risks.

## RECOMMENDATIONS

Based on the findings of the study, the following recommendations were made:

1. Regular monitoring of heavy-metal concentrations in irrigated soils and agricultural produce should be carried out in Sabon-Birni Local Government Area to detect possible accumulation over time.

2. Farmers should avoid using potentially contaminated irrigation water and should ensure that water used for irrigating onion and watermelon farms is periodically tested for heavy metals.

3. Appropriate use of fertilizers, pesticides, and other agricultural inputs should be encouraged to minimise the introduction and accumulation of potentially toxic metals in agricultural soils.

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