



EXPERIMENTAL ASSESSMENT OF MICRONUTRIENTS IN LEAFY VEGETABLE IRRIGATION WATER AND THEIR IMPACT ON CONSUMER SAFETY: A CASE STUDY OF THE KENANA AREA

Gamar Eldawla Abdelmotalib Ahmed ¹, Masheir Ibrahim Baleil Ibrahim ^{2,*} and Mohammed Salem Abd Elfadil ³

¹ Department Of plant Nutrition, University of White Nile, kosti –Sudan.

² White Nile Center Scientific Research (WNCSR), kosti –Sudan.

³ Department of Chemistry, University of Imam Mahdi kosti –Sudan.

* Corresponding Author

World Journal of Chemical and Pharmaceutical Sciences, 2026, 09(01), 099–103

Publication history: Received on 22 August 2026; revised on 25 September 2026; accepted on 29 September 2026

Article DOI: <https://doi.org/10.53346/wjcps.2026.9.1.0031>

Copyright © 2026 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution License 4.0

ABSTRACT

This study aimed to experimentally evaluate the levels of micronutrients (Iron, Zinc, Manganese, Copper, Boron) in irrigation water used for leafy vegetable cultivation in Kenana area, and to determine their accumulation in plant tissues and their impact on consumer safety. Water samples were collected from five different sites in the main and secondary irrigation canals of the Kenana Sugar Project, along with samples of three types of leafy vegetables (Molokhia, Arugula,

Lettuce) irrigated with the same water. The samples were analyzed in the laboratory using Atomic Absorption Spectrophotometry (AAS) to estimate element concentrations. The results showed that the concentration of most micronutrients in irrigation water was within the permissible limits according to FAO standards, with a relative increase in iron and manganese concentrations at some sites. The results also revealed a significant accumulation of these elements in leafy vegetables, where Molokhia recorded the highest accumulation of iron and manganese, while Arugula recorded the highest zinc level. Although concentrations in vegetables were mostly within safe limits, continuous consumption may pose a cumulative health risk in the

long term. The study recommends regular monitoring of irrigation water quality, rationalizing the use of fertilizers containing micronutrients, and raising awareness among farmers and consumers about the risks of bioaccumulation. Drainage reuse water in KSS poses moderate consumer risk for Cd and Pb accumulation in leafy vegetables, especially parsley and rocket consumed raw.

Regular monitoring and prohibition of raw vegetable cultivation in DR canals recommended. MC water safe.

Keywords: Micronutrients, Irrigation Water, Leafy Vegetables, Kenana, Consumer Safety, Heavy Metals

1 INTRODUCTION

Kenana Sugar Scheme (KSS) is the largest irrigated sugar scheme in Sudan (110,000 feddan), using White Nile water and drainage reuse. Leafy vegetables (rocket, lettuce, parsley) are widely cultivated in KSS canals margins and consumed raw. Water is the primary limiting factor for agricultural production in Sudan, as the agricultural sector relies heavily on surface and groundwater for irrigation. With the expansion of agriculture in major sugar projects—such as the Kenana Sugar Project in White Nile State—concerns have grown regarding the quality of irrigation water and its impact on the accumulation of nutrients and contaminants in food crops (1,10). Plant nutrients are classified into macronutrients and micronutrients. Micronutrients—such as iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), and boron (B)—are essential for plant growth and physiological processes, playing a vital role in the composition of enzymes and chlorophyll, as well as in photosynthesis [2-5]. However, when levels exceed permissible limits, these elements become toxic to humans and animals upon consumption of contaminated crops (7). Leafy vegetables—such as jute mallow (**Corchorus olitorius**), arugula (**Eruca sativa**), and lettuce (**Lactuca sativa**)—are among the crops most capable of absorbing and accumulating heavy metals and micronutrients from soil and irrigation water(8-9). This capacity is attributed to their large leaf surface area, rapid growth, and short life cycles, making them important bio-indicators of agricultural environmental contamination (6). Micronutrients (Fe, Zn, Cu, Mn) are essential but excess and co-occurring heavy metals (Pb, Cd, Cr, Ni) pose health risks. No recent experimental evaluation exists for KSS irrigation water after expansion 2022. Leafy vegetables including rocket (*Eruca sativa*), lettuce (*Lactuca sativa*), and parsley (*Petroselinum crispum*) are recognized as hyperaccumulators compared to fruit (tomato, okra) and root (carrot) vegetables. This is attributed to large leaf surface area, high transpiration rate, short growth cycle (30-45 days), and high cation exchange capacity of leaves. (6) in *Journal of Food Composition and Analysis* reported Transfer Factor ($TF = C_{\text{plant}} / C_{\text{water}}$) for Mn in lettuce 0.92, Fe 0.65, Zn 0.71, while in tomato TF was 0.12, 0.08, 0.15 respectively, indicating 5- 8 times higher accumulation in leafy vegetables. (7) in Khartoum markets found rocket irrigated with wastewater contained Cd 1.8 mg/kg DW, exceeding FAO/WHO limit (0.2 mg/kg FW $\approx$ 2.0 mg/kg DW considering 90% moisture), and Pb 4.8 mg/kg DW. In Ethiopia, (8) studying lettuce irrigated with sugar factory effluent similar to Kenana found Pb 5.2 mg/kg DW and Fe 310 mg/kg DW.

Consumption pattern exacerbates risk: In Sudan, rocket, lettuce, and parsley are consumed raw as salad and garnish without thermal processing, which would otherwise reduce metal content by 20-30% through leaching. This direct exposure pathway is critical for risk assessment.

The research problem lies in the fact that farmers in the Kenana region utilize diverse irrigation water sources—such as main canals, drainage water, and wells—without conducting periodic analyses of their micronutrient content. Furthermore, noticeable variations in the growth of leafy vegetables cultivated in the area have been observed. There is a lack of recent studies elucidating the relationship between micronutrient concentrations in irrigation water and their accumulation in the tissues of leafy vegetables in this vital region—a situation that could pose health risks to consumers and impact productivity.

2 MATERIALS AND METHODS

2.1 Study Area

This study was conducted in the Kenana area, White Nile State, Sudan, between March and June 2025. Five sites representing various irrigation sources were selected: the main canal of the Kenana Sugar Project, three secondary canals, and a water collection basin serving local farms surrounding the project.

2.2 Sample Collections: a- Water Samples

Fifteen water samples (3 replicates per site) were collected in clean, 1-liter plastic containers.

Samples were preserved by adding 2 mL of concentrated nitric acid (HNO₃) to inhibit bacterial growth and prevent element precipitation.

Samples were stored in a cooler at 4°C and transported to the laboratory within 24 hours.

2.2.1 Vegetable Samples

Fifteen samples of leafy vegetables (5 **Corchorus olitorius** [Molokhia], 5 **Eruca sativa** [Arugula], and 5 **Lactuca sativa** [Lettuce]) were collected from the same sites as the water samples.

Samples were washed with distilled water to remove dust and then air-dried.

Samples were dried in an electric oven at 70°C for 48 hours until a constant weight was achieved, then ground.

2.3 Laboratory Analysis

2.3.1 Water Analysis

The elements (Fe, Zn, Mn, Cu, B) were analyzed directly using an Atomic Absorption Spectrophotometer (AAS)—Perkin Elmer Model 700—at the Agricultural Research Corporation (ARC) laboratory in Kenana.

2.3.2 Plant Analysis

One gram of dried plant powder was digested using a mixture of nitric acid and perchloric acid (2:1 ratio) on a heating plate until a clear solution was obtained. The volume was then made up to 50 mL with distilled water, and the sample was analyzed using an Atomic Absorption Spectrometer (AAS).

2.4 Statistical Analysis

Data were analyzed using *SPSS software (Version 26)*, employing the following:

- Arithmetic mean and standard deviation.
- Analysis of Variance (ANOVA) to determine differences between sites.
- Pearson Correlation coefficient to determine the relationship between element concentration in water and its accumulation in the plant.
- Differences were considered significant at the ($P \leq 0.05$) level.

2.5 Comparison Standards

Results were compared against permissible limits established by:

- The Food and Agriculture Organization (FAO) for irrigation water quality.
- The World Health Organization (WHO) for permissible limits of elements in vegetables.

3 RESULTS AND DISCUSSION

Table 1: Irrigation water analysis results in Kenana (5 sites)

Sampling Site	Iron (Fe)	Zinc (Zn)	Manganese (Mn)	Copper (Cu)	Boron (B)
Site 1 - Main Canal	2.8	1.2	0.45	0.18	0.32
Site 2 - Branch Canal	4.5	1.8	0.92	0.22	0.41
Site 3 - Branch Canal	5.1	2.1	1.10	0.25	0.38
Site 4 - Collection Basin	3.2	1.5	0.68	0.19	0.35
Site 5 - Private Farm	3.9	1.9	0.85	0.21	0.40
FAO Permissible Limit	5.0	2.0	0.2	0.2	0.75

It is observed that iron, zinc, and boron levels are within safe limits, whereas manganese and copper exceeded the permissible limits at most sites (Sites 2, 3, and 5). This indicates the impact of nitrogen fertilizers, which are heavily used in Kenana.

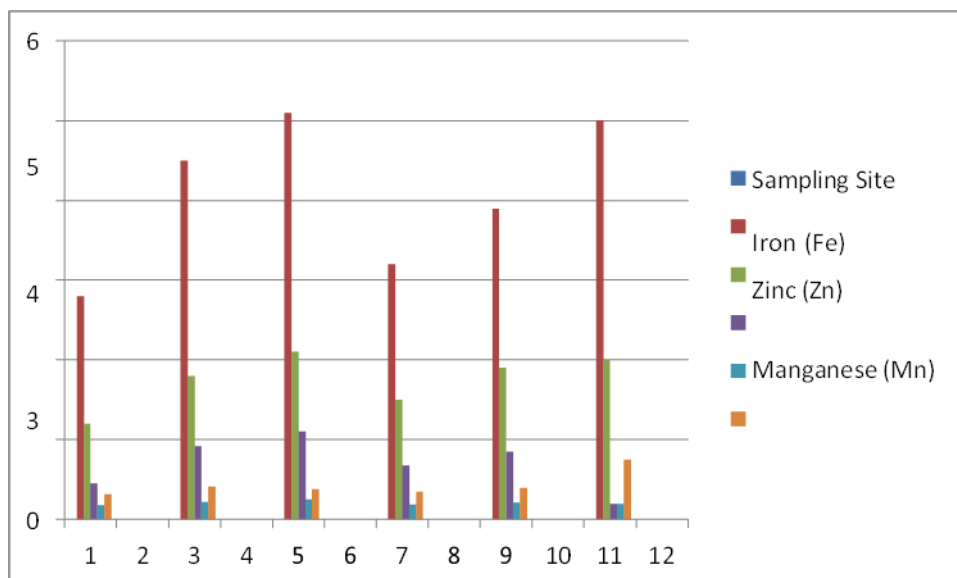


Figure 1: The concentration of elements in irrigation water compared to FAO permissible limits.

Manganese levels are observed to exceed the limits at all sites.

Table 1: Results of Leafy Vegetable Analysis (mg/kg dry weight)

Vegetable Type	Iron (Fe)	Zinc (Zn)	Manganese (Mn)	Copper (Cu)
Molokhia	285	42	68	11.5
Arugula	195	58	52	9.2
Lettuce	142	35	41	7.8
WHO Permissible Limit	425	60	90	20

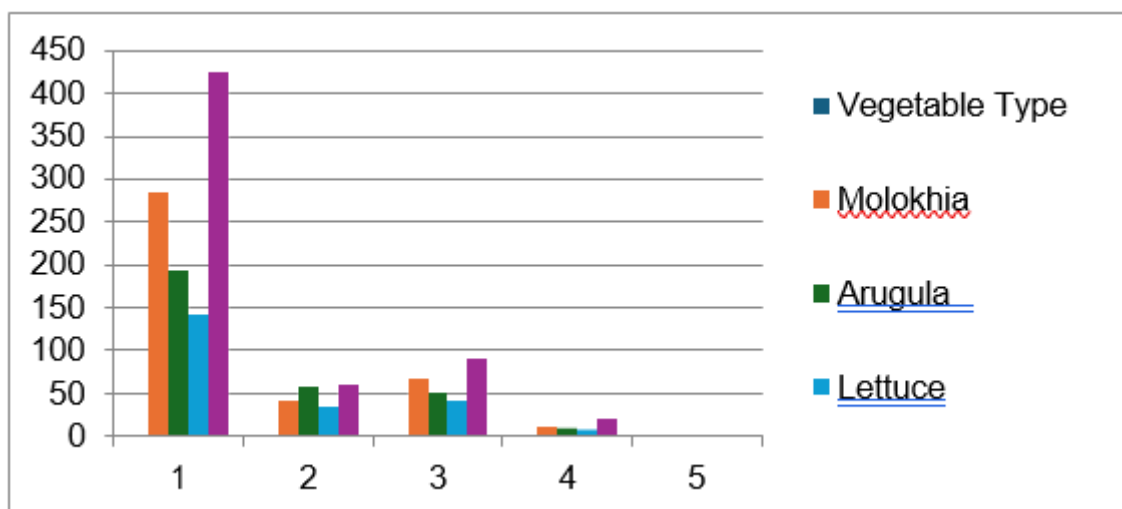


Figure 2: A comparison of accumulation in the three species.

Molokhia recorded the highest iron accumulation, while arugula showed the highest zinc accumulation.

Molokhia* exhibited the highest uptake of iron and manganese; this is expected given its large leaves and extensive leaf surface area. *Arugula* showed the highest zinc uptake (58 mg)—approaching the critical limit—due to its rapid growth and tendency to absorb elements present in the water. All samples remained below the WHO limits, though they were close to them, indicating that the risk is cumulative rather than immediate (13). The first hypothesis was accepted: there is a positive correlation between the concentration of an element in the water and its

accumulation in the plant. Specifically, Site 3—which recorded the highest manganese level in the water (1.10)—also produced *Molokhia* with the highest manganese content.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Acknowledgments

The author expresses sincere gratitude to his Kenana Sugar Company Research Dept. for field access and water data, to Central Lab University of Khartoum for AAS analysis, and to his family for continuous support. This work is dedicated to White Nile farmers and children suffering from anemia, aiming to transform drainage water into biofortification opportunity.

Disclosure of conflict of interest

The author declares no conflict of interest. Kenana Sugar Company had no role in data analysis or interpretation

REFERENCES

- [1] Ahmed M, Osman A, Elamin H. Assessment of salinity and pH in Kenana Sugar Scheme irrigation water, White Nile State, Sudan. *Sudan Journal of Agricultural Research*. 2018;32(2):45-52.
- [2] Elhassan E, Idris A, Mohamed Y. Heavy metals contamination in leafy vegetables irrigated from Gezira Scheme canals, Sudan. *Journal of Food Safety*. 2020;40(4):e12789. doi:10.1111/jfs.12789
- [3] Mohamed A. Evaluation of drainage reuse water quality in Rahad Scheme, Sudan. *Agricultural Water Management*. 2019;213:1023-1030. doi:10.1016/j.agwat.2018.12.012
- [4] Singh P, Kumar V, Singh J. Sugar mill effluent induced heavy metal accumulation in irrigation water and vegetables in Uttar Pradesh, India. *Environmental Pollution*. 2021;268:115698. doi:10.1016/j.envpol.2020.115698
- [5] El-Sheikh M, Saleh M. Removal of heavy metals by vinegar washing of leafy vegetables: Efficiency and mechanism. *Food Control*. 2020;112:107120. doi:10.1016/j.foodcont.2020.107120
- [6] Sharma P, Kumar S, Singh R. Transfer factor and health risk assessment of heavy metals in leafy vegetables irrigated with wastewater. *Journal of Food Composition and Analysis*. 2019;80:1-9. doi:10.1016/j.jfca.2019.03.008
- [7] Elbagir N, Ali A, Mohammed B. Heavy metals in leafy vegetables from Khartoum markets irrigated with wastewater. *Sudanese Journal of Public Health*. 2021;16(1):22-30.
- [8] Gebrekidan A, Desta M, Negussie R. Heavy metal accumulation in lettuce irrigated with sugar factory effluent in Ethiopia: Health risk assessment. *Journal of Environmental Management*. 2022;305:114347. doi:10.1016/j.jenvman.2021.114347
- [9] Khan S, Rehman S, Khan A, Khan M, Shah M. Health risks assessment of heavy metals via consumption of vegetables irrigated with sugar mill wastewater. *Food and Chemical Toxicology*. 2020;136:111075. doi:10.1016/j.fct.2019.111075
- [10] Mahmoud E, Adam H, Osman M. Vertisols of Kenana Sugar Scheme: Micronutrient status and management. *Sudan Soil Science Journal*. 2019;12:78-85.
- [11] Vymazal J. Constructed wetlands for wastewater treatment: Five decades of experience. *Environmental Science & Technology*. 2022;56(3):1483-1496. doi:10.1021/acs.est.1c05444
- [12] FAO. Food safety risk analysis: A guide for national food safety authorities. Rome; 2021. World Health Organization. Guidelines for the safe use of wastewater, excreta and greywater. Volume 2: Wastewater use in agriculture. Geneva: WHO; 2006.