AGRONOMIC PERFORMANCE AND FOOD SAFETY ASSESSMENT OF TOMATO (*Solanum lycopersicum* L.) IRRIGATED WITH POLLUTED WATER FROM RAMGARH LAKE, INDIA

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ABSTRACT---

The use of polluted urban lake water for vegetable irrigation presents a critical trade-off between agronomic benefits and food safety risks. This study evaluated the effects of irrigation with heavy metal-contaminated water from Ramgarh Lake, Gorakhpur, on the growth, yield, and heavy metal accumulation in tomato (Solanum lycopersicum L. cv. Mahyco NO.63 F1 Hybrid). A two-year pot experiment (2024–2025) compared tap water irrigation (control) with raw wastewater from the lake's outflow channel. Polluted water significantly enhanced seed germination (95.2% vs 84.9% in control), vegetative growth (28.5% increase in plant height), and fruit yield (41.1% increase). However, substantial heavy metal accumulation occurred in both soil and edible tissues. Lead concentrations in tomato fruits (1.28 mg/kg) exceeded the FAO/WHO permissible limit of 0.30 mg/kg by over fourfold, while cadmium, arsenic, copper, chromium, and zinc remained within safety thresholds. Bioaccumulation factors for fruits ranged from 0.254 (As) to 0.631 (Cu), indicating moderate metal uptake. Transfer factors from leaves to fruits ranged from 0.873 to 1.014, suggesting restricted metal translocation to reproductive tissues. These findings demonstrate that while Ramgarh Lake water offers agronomic value through nutrient supplementation, its use for tomato irrigation poses significant food safety concerns due to lead contamination, necessitating careful management and continuous monitoring.

Keywords: *Solanum lycopersicum, wastewater irrigation, heavy metals, bioaccumulation, lead contamination, food safety, Ramgarh Lake*---

1. INTRODUCTION

Freshwater scarcity has emerged as a critical constraint on agricultural production in developing countries, driving the widespread use of wastewater for irrigation in peri-urban farming systems (Qadir et al., 2010; FAO, 2021). While wastewater provides essential nutrients—nitrogen, phosphorus, potassium, and organic matter—that can enhance soil fertility and crop productivity, it also introduces toxic contaminants, particularly heavy metals, into agricultural ecosystems (Singh et al., 2023; Hussain et al., 2024). Unlike organic pollutants, heavy metals are non-biodegradable and persist in soils, gradually accumulating in edible plant tissues and entering the human food chain (Alloway, 2013; Rai et al., 2019).

Ramgarh Lake, a natural oxbow lake in Gorakhpur District, Uttar Pradesh, exemplifies the environmental degradation affecting urban water bodies across India. Once spanning 723 hectares with a depth of 4.5 meters, the lake has shrunk to 678 hectares with depths below 3.5 meters, receiving millions of liters of untreated municipal wastewater daily through five major drains (Sharma, 2001; Singh & Sharma, 2022). Previous investigations have documented hypereutrophic conditions, toxic cyanobacterial blooms dominated by *Microcystis* species, and elevated concentrations of lead, cadmium, arsenic, and chromium in lake water and sediments (Singh et al., 2011; Barnwal et al., 2015; Pandey & Chandra, 2016). Despite this contamination, local farmers continue to use lake water for irrigation, creating a potential pathway for heavy metal transfer into food crops.

Tomato (*Solanum lycopersicum* L.) is one of the most widely cultivated and consumed vegetables globally, valued for its nutritional content and economic importance. As a fruit vegetable, its edible portion develops above ground and is physiologically separated from the root system by several transport barriers. While this may reduce direct contamination compared to root vegetables, heavy metals can still accumulate in fruits through vascular transport from contaminated soils (White & Broadley, 2009). Understanding the extent of heavy metal accumulation in tomato fruits under wastewater irrigation is essential for assessing food safety risks.

While previous studies have examined heavy metal contamination in paddy crops irrigated with Ramgarh Lake water (Singh et al., 2011), limited information exists regarding the effects on vegetable crops, particularly tomato, and the associated food safety implications. This study aimed to: (1) evaluate the effects of irrigation with Ramgarh Lake water on tomato growth and yield; (2) quantify heavy metal accumulation in soil and plant tissues; (3) assess bioaccumulation and translocation patterns; and (4) compare metal concentrations in edible fruits with international food safety standards.

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2. MATERIALS AND METHODS

2.1 Study Site and Water Source

The study was conducted at Mahatma Gandhi P.G. College, Gorakhpur, Uttar Pradesh, India (26°45'N, 83°23'E). Polluted water was collected from the Gura Nala outflow channel of Ramgarh Lake (near Palm Paradise), which serves as the primary discharge point used by local farmers for irrigation. Control irrigation used tap water. The region experiences a subtropical monsoon climate with distinct summer, winter, and monsoon seasons.

Figure 1: Ramgarh Lake of Gorakhpur showing water collection site for irrigation.

2.2 Experimental Design

A pot experiment was conducted over two successive years (September 2024 and September 2025) using a completely randomized design with three replications per treatment. Tomato seeds (*Solanum lycopersicum* L. cv. Mahyco NO.63 F1 Hybrid) were sown in pots (30 cm diameter) containing 5 kg of uniform agricultural soil per pot. Two treatments were established:

- **Control (C):** Plants irrigated with tap water
- **Treated (T):** Plants irrigated with raw wastewater from Ramgarh Lake

Plants were grown until fruit maturity (approximately 90 days after sowing) for growth, yield, and heavy metal analyses.

2.3 Growth and Yield Parameters

Growth parameters were recorded at 30, 60, and 90 days after sowing, including plant height, shoot length, root length, number of leaves, primary branches, lateral roots, fresh and dry biomass of roots and shoots, and net primary productivity. Yield attributes at harvest included days to flowering and fruiting, number of fruits per plant, fruit length, fruit weight, seed yield, biological yield, and harvest index.

2.4 Heavy Metal Analysis

Soil and plant samples were processed according to standard protocols. Plant samples were oven-dried at 70°C for 48 hours and ground to a fine powder. Soil samples were air-dried and passed through a 2 mm mesh. Samples were digested using HNO_3:$HClO_4$ (3:1), and heavy metal concentrations (Pb, Cd, As, Cu, Cr, Zn) were determined by atomic absorption spectrophotometry (AAS, Perkin Elmer A Analyst 400) following APHA (2017) protocols.

Bioaccumulation Factor (BAF) was calculated as the ratio of metal concentration in plant tissue to that in soil (Kabata-Pendias, 2011). Transfer Factor (TF) was calculated as the ratio of metal concentration in fruits to that in leaves (Alloway, 2013).

2.5 Statistical Analysis

Data were expressed as mean ± standard deviation (SD) of three replicates. One-way ANOVA and independent samples t-tests were performed using SPSS version 20.0. Statistical significance was set at $p < 0.05$ and $p < 0.01$.

3. RESULTS

3.1 Seed Germination and Seedling Establishment

Polluted water irrigation significantly enhanced seed germination compared to the control (Table 1). By the 11th day after sowing, average germination reached 95.2% in treated seeds compared to 84.9% in controls. Mean germination time was reduced from 7.13 to 5.92 days, representing a 17.0% reduction. Seedling survival increased by 12.2%, from 82.6% in controls to 92.7% in treated seedlings.

Table 1. Effect of polluted water irrigation on seed germination and seedling establishment of tomato (mean ± SD, n=6; average of two years).

Parameter	Control	Treated	Change (%)
Germination (%) – Day 11	84.96 ± 1.48	95.24 ± 2.32**	+12.10
Mean germination time (days)	7.13 ± 0.16	5.92 ± 0.17**	-17.0
Seedling survival (%)	82.64 ± 1.08	92.68 ± 2.06**	+12.15

** p < 0.01 vs control.

3.2 Vegetative Growth

Plants irrigated with polluted water consistently outperformed controls throughout the growth period (Table 2). At final harvest (90 DAS), plant height increased by 28.5%, root length by 27.8%, and leaf production by 33.0%. Fresh shoot weight and fresh root weight increased by 35.1% and 42.1%, respectively. Dry shoot weight and dry root weight showed increases of 40.1% and 37.8%, respectively. Net primary productivity increased by 33.8%.

Table 2. Vegetative growth parameters of tomato at harvest (90 DAS) (mean ± SD, n=6; average of two years).

Parameter	Control	Treated	Increase (%)
Plant height (cm)	72.55 ± 2.55	93.10 ± 3.10**	28.32
Shoot length (cm)	54.50 ± 2.85	70.60 ± 1.40**	29.54
Root length (cm)	18.80 ± 0.40	23.05 ± 0.65**	22.61
No. of leaves/plant	143.0 ± 3.5	190.2 ± 3.5**	33.01
No. of primary branches	6.15 ± 0.25	8.70 ± 0.60**	41.46
Lateral roots per plant	40.0 ± 1.0	49.2 ± 0.9**	23.00
Fresh shoot weight (g)	344.9 ± 8.2	466.1 ± 8.5**	35.14
Fresh root weight (g)	49.44 ± 2.08	70.24 ± 1.80**	42.07
Dry shoot weight (g)	53.79 ± 0.85	75.35 ± 2.81**	40.08
Dry root weight (g)	8.00 ± 0.20	11.03 ± 0.34**	37.86
NPP (g/plant/day)	0.69 ± 0.02	0.92 ± 0.03**	33.33

** p < 0.01 vs control.

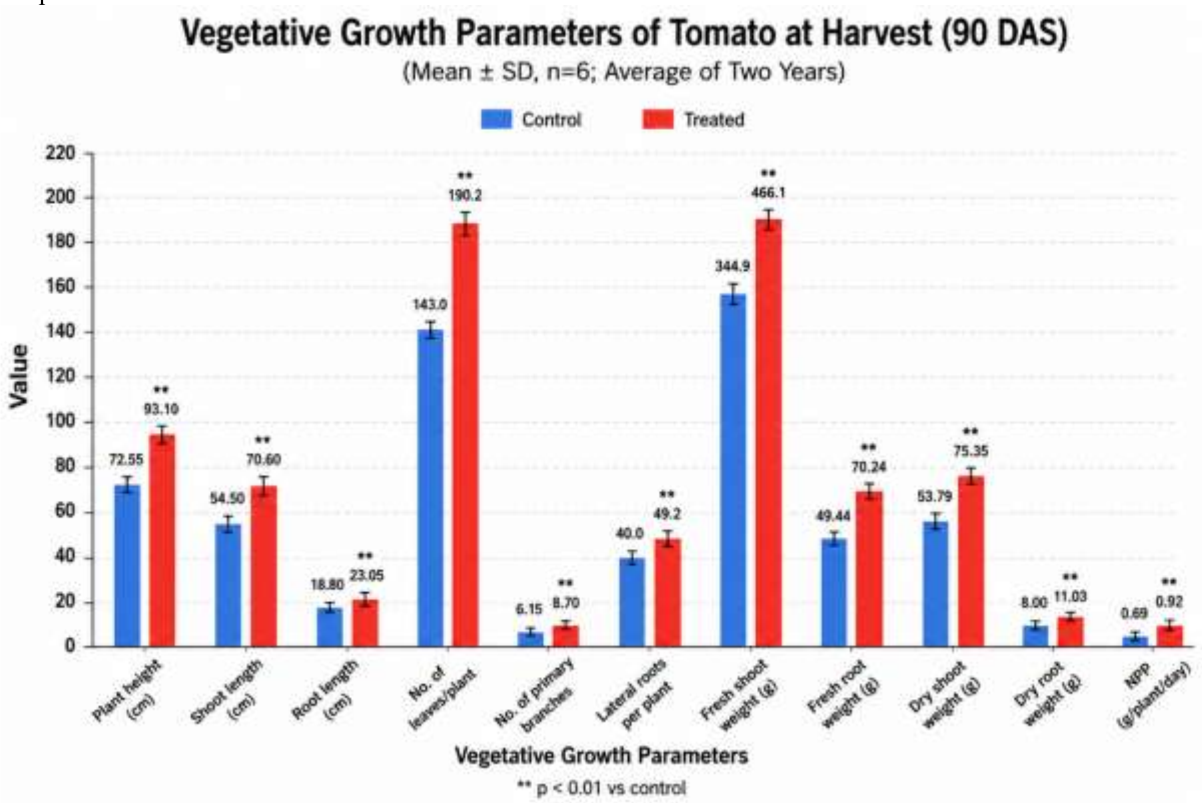

Figure 2. Effect of polluted water irrigation on seed germination and seedling establishment of tomato (mean ± SD, n=6; average of two years).

3.3 Yield and Reproductive Performance

All yield attributes were significantly enhanced under polluted water irrigation (Table 3). Phenological development was accelerated, with days to first flowering reduced by 14.1%, days to first fruiting by 13.2%, and days to fruit maturation by 12.1%. The number of fruits per plant increased by 41.1%, fruit length by 26.5%, and individual fruit weight by 25.1%. Seed yield per plant showed a 62.8% increase, while biological yield improved by 37.0%. The harvest index increased from 9.3% to 11.0%, representing an 18.3% improvement.

Table 3. Yield and reproductive attributes of tomato (mean ± SD, n=6; average of two years).

Parameter	Control	Treated	Change (%)
Days to first flowering	32.75 ± 0.35	28.15 ± 0.45**	-14.05
Days to first fruiting	41.80 ± 0.70	36.35 ± 0.35**	-13.04
Days to first fruit maturation	78.90 ± 1.80	69.45 ± 1.45**	-12.16
Fruits per plant	22.7 ± 0.6	32.0 ± 0.6**	+41.00
Fruit length (cm)	4.15 ± 0.05	5.25 ± 0.15**	+26.51
Single fruit weight (g)	63.15 ± 1.25	79.30 ± 0.90**	+25.57
Seeds per fruit	42.65 ± 0.55	56.80 ± 0.70**	+33.18
Seed yield per plant (g)	4.27 ± 0.13	6.95 ± 0.18**	+62.76
100 seed weight (g)	0.245 ± 0.005	0.290 ± 0.005**	+18.37
Biological yield (g/plant)	45.84 ± 0.75	63.07 ± 1.10**	+37.59
Harvest index (%)	9.30 ± 0.30	11.00 ± 0.25**	+18.28

** $p < 0.01$ vs control.

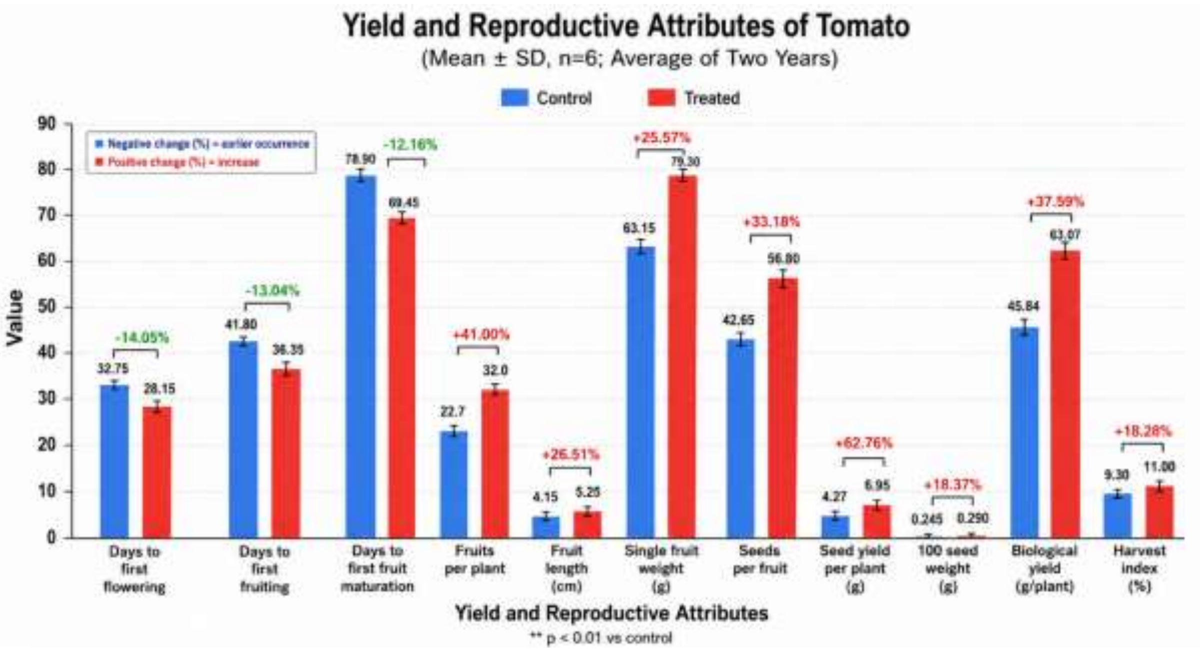

Figure 3. Yield and reproductive attributes of tomato

3.4 Heavy Metal Accumulation in Soil

Soils irrigated with polluted water showed substantial enrichment of all analyzed heavy metals (Table 4). Lead increased by 495.5% compared to controls, while cadmium, copper, chromium, and zinc showed increases of 335.7%, 395.8%, 297.6%, and 371.4%, respectively. Arsenic showed an increase of 189.4%.

Table 4. Heavy metal concentrations in soil (ppm, mean ± SD, n=6; average of two years).

Metal	Control	Treated	Increase (%)
Pb	0.426 ± 0.010	2.535 ± 0.095**	+495.5
Cd	0.007 ± 0.001	0.031 ± 0.001**	+335.7
As	0.024 ± 0.001	0.068 ± 0.002**	+189.4
Cu	0.169 ± 0.005	0.951 ± 0.020**	+462.7
Cr	0.041 ± 0.001	0.160 ± 0.008**	+297.6
Zn	0.145 ± 0.005	0.684 ± 0.015**	+371.4

** $p < 0.01$ vs control.

3.5 Heavy Metal Accumulation in Plant Tissues

Heavy metal concentrations in tomato tissues were substantially higher in treated plants than in controls (Table 5). Leaves accumulated lead (1.46 ppm), cadmium (0.015 ppm), arsenic (0.020 ppm), copper (0.613 ppm), chromium (0.084 ppm), and zinc (0.391 ppm). Tomato fruits contained lower concentrations: lead (1.28 ppm), cadmium (0.014 ppm), arsenic (0.018 ppm), copper (0.600 ppm), chromium (0.078 ppm), and zinc (0.368 ppm).

Table 5. Heavy metal concentrations in tomato tissues (ppm, mean ± SD, n=6; average of two years).

Tissue	Pb	Cd	As	Cu	Cr	Zn
Control leaves	0.117 ± 0.009	0.004 ± 0.001	0.011 ± 0.001	0.124 ± 0.006	0.019 ± 0.001	0.027 ± 0.005
Control fruit	0.112 ± 0.009	0.003 ± 0.001	0.009 ± 0.001	0.122 ± 0.006	0.017 ± 0.001	0.023 ± 0.001
Treated leaves	1.464 ± 0.038**	0.015 ± 0.001**	0.020 ± 0.001**	0.613 ± 0.018**	0.084 ± 0.006**	0.391 ± 0.011**
Treated fruit	1.284 ± 0.038**	0.014 ± 0.001**	0.018 ± 0.001**	0.600 ± 0.015**	0.078 ± 0.004**	0.368 ± 0.011**

** p < 0.01 vs control.

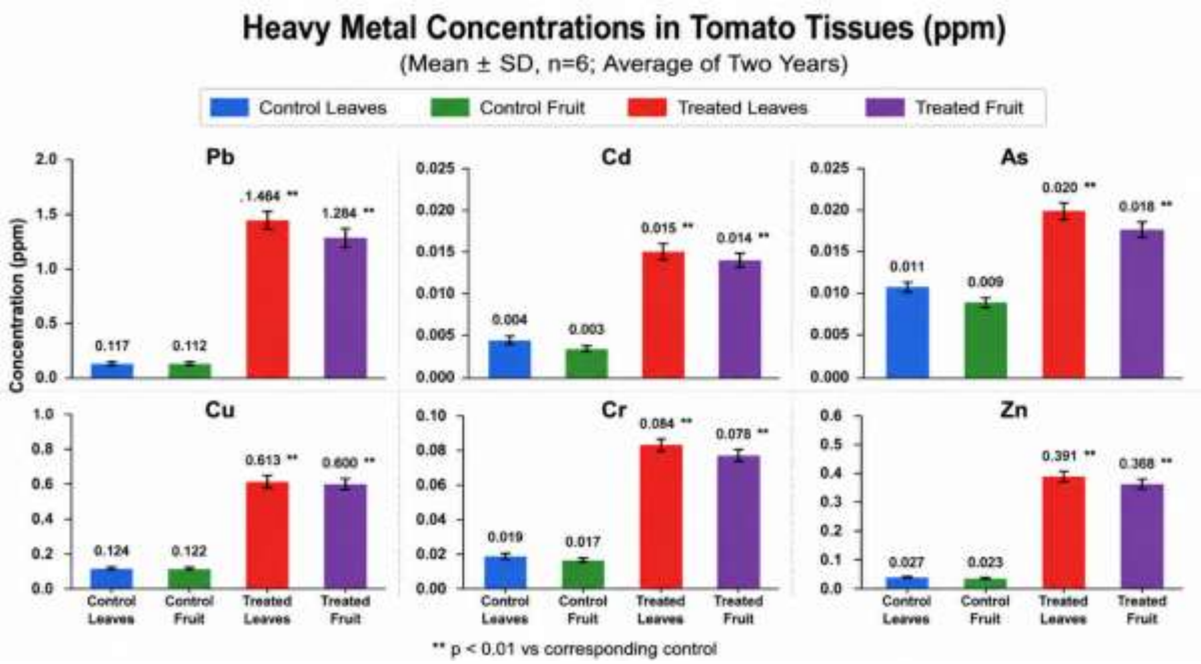

Figure 5. Heavy metal concentrations in tomato tissues

3.6 Bioaccumulation and Transfer Factors

Bioaccumulation factors (BAF) varied among metals (Table 6). Copper showed the highest BAF values in leaves (0.645) and fruits (0.631). Arsenic exhibited the lowest BAF for both leaves (0.294) and fruits (0.265). Transfer factors from leaves to fruits ranged from 0.873 (Pb) to 1.014 (Cu), indicating restricted translocation of most metals to reproductive tissues.

Table 6. Bioaccumulation and transfer factors in tomato (mean ± SD, n=6; average of two years).

Metal	BAF (Leaf/Soil)	BAF (Fruit/Soil)	TF (Fruit/Leaf)
Pb	0.578 ± 0.020	0.507 ± 0.018	0.877 ± 0.028
Cd	0.484 ± 0.022	0.452 ± 0.025	0.934 ± 0.050
As	0.294 ± 0.012	0.265 ± 0.015	0.900 ± 0.040
Cu	0.645 ± 0.023	0.631 ± 0.018	0.978 ± 0.039
Cr	0.525 ± 0.015	0.488 ± 0.018	0.929 ± 0.030
Zn	0.572 ± 0.015	0.538 ± 0.015	0.941 ± 0.025

3.7 Comparison with FAO/WHO Permissible Limits

Comparison of heavy metal concentrations in tomato fruits with FAO/WHO permissible limits revealed a critical food safety concern (Table 7). Lead concentrations (1.28 mg/kg) exceeded the recommended limit of 0.30 mg/kg by over fourfold. Cadmium, arsenic, copper, chromium, and zinc remained within permissible limits.

Table 7. Comparison of heavy metal concentrations in tomato fruits with FAO/WHO permissible limits (mg/kg).

Heavy Metal	FAO/WHO Limit	Tomato Fruit	Status
Pb	0.30	1.284 ± 0.038	**Exceeded**
Cd	0.20	0.014 ± 0.001	Within limit
As	0.10	0.018 ± 0.001	Within limit
Cu	40.00	0.600 ± 0.015	Within limit
Cr	2.30	0.078 ± 0.004	Within limit
Zn	60.00	0.368 ± 0.011	Within limit

4. DISCUSSION

4.1 Agronomic Benefits of Wastewater Irrigation

The significant improvements in seed germination, vegetative growth, and yield observed in this study demonstrate the agronomic value of Ramgarh Lake water. Enhanced germination from 84.9% to 95.2% can be attributed to the readily available nitrogen, phosphorus, and potassium in wastewater, which accelerate metabolic activation and reserve mobilization during germination (Marschner, 2012; Bewley et al., 2013). The reduction in mean germination time (17.0%) indicates faster metabolic activation and earlier radicle emergence under nutrient-rich conditions.

The substantial increases in vegetative growth parameters—plant height (28.5%), root length (22.6%), leaf production (33.0%), and branching (41.5%)—reflect improved nutrient availability stimulating cell division, elongation, and overall biomass production. Nitrogen promotes chlorophyll synthesis and protein formation, phosphorus supports energy metabolism and root development, while potassium regulates osmotic balance and enzyme activation (Taiz et al., 2018; Marschner, 2012). The 42.1% increase in fresh root weight suggests enhanced root system development, improving water and nutrient acquisition capacity.

The 41.1% increase in fruit number and 25.6% increase in individual fruit weight represent substantial economic benefits for farmers. Early flowering and fruiting (approximately 5 days earlier) suggest that improved nutritional status accelerated reproductive development (Taiz et al., 2018). The 62.8% increase in seed yield and 37.6% increase in biological yield reflect enhanced assimilate partitioning to reproductive structures. The improved harvest index (from 9.3% to 11.0%) indicates more efficient allocation of biomass to economically valuable fruits (Qadir et al., 2020; Hussain et al., 2024).

The enhanced growth responses observed across both experimental years confirm that the nutrient content of Ramgarh Lake water consistently supported tomato cultivation. The availability of nitrogen, phosphorus, and potassium in wastewater promoted vigorous vegetative development, increased flower production, and enhanced fruit set, ultimately translating to higher marketable yield (Singh et al., 2023).

4.2 Heavy Metal Accumulation and Food Safety Concerns

Despite the agronomic benefits, the progressive accumulation of heavy metals—particularly lead—raises serious food safety concerns. Lead concentrations in tomato fruits (1.28 mg/kg) exceeded the FAO/WHO permissible limit of 0.30 mg/kg by over fourfold, indicating that regular consumption of these tomatoes could contribute to chronic lead exposure. Lead has no known biological function in humans and is associated with neurological impairment, renal dysfunction, and cardiovascular disease even at low exposure levels (WHO, 2021; Tchounwou et al., 2012; EFSA, 2010).

The presence of lead in tomato fruits is particularly concerning because lead typically exhibits poor phloem mobility and limited translocation to reproductive tissues (Alloway, 2013; White & Broadley, 2009). However, prolonged wastewater irrigation apparently increased soluble lead in the rhizosphere, allowing a fraction to bypass root sequestration mechanisms and enter the vascular system, ultimately reaching developing fruits (Shahid et al., 2021). The transfer factor for lead (0.877) indicates that approximately 12.3% of leaf lead concentrations were transported to fruits, demonstrating that physiological barriers provide partial but incomplete protection.

The bioaccumulation factor for fruits (0.507) indicates moderate uptake efficiency from soil, consistent with findings from previous wastewater irrigation studies (Rai et al., 2019; Zhou et al., 2020). While lower than typical values for root vegetables, the accumulation of lead in tomato fruits at concentrations exceeding safety limits represents a significant health risk, particularly for populations consuming these vegetables regularly (WHO, 2021).

Cadmium, arsenic, copper, chromium, and zinc remained within permissible limits, though their progressive accumulation warrants monitoring. Cadmium is particularly concerning due to its high mobility and long biological half-life in humans (Clemens & Ma, 2016; JECFA, 2011), while arsenic's presence reflects contamination from both geogenic and anthropogenic sources (Smedley & Kinniburgh, 2002).

4.3 Soil Contamination and Long-term Implications

The substantial enrichment of all analyzed heavy metals in soils irrigated with polluted water represents a significant environmental concern. Lead concentrations in treated soils (2.54 ppm) were 495.5% higher than controls, while cadmium, copper, and zinc showed similar levels of enrichment. These elevated concentrations reflect continuous metal loading from wastewater irrigation and the persistent nature of heavy metals in agricultural soils (Alloway, 2013; Bolan et al., 2023).

Unlike organic pollutants, heavy metals cannot be degraded biologically and therefore accumulate progressively with repeated irrigation (Kabata-Pendias, 2011). Their retention in soil depends on factors such as pH, organic matter content, clay mineral composition, and cation exchange capacity (Bolan et al., 2023). In the present study, the observed accumulation indicates that adsorption sites in the soil may be approaching saturation, increasing the bioavailable fraction available for plant uptake.

The long-term implications of soil contamination are particularly concerning. Heavy metals in soils can persist for decades and may continue to accumulate even if wastewater irrigation is discontinued (Alloway, 2013). This persistence poses ongoing risks to crop quality, groundwater quality, and ecosystem health (Hussain et al., 2024). Regular monitoring of soil metal concentrations is therefore essential for assessing the sustainability of wastewater irrigation practices.

4.4 Comparative Metal Accumulation and Translocation

The distribution of heavy metals within tomato plants revealed important patterns. Fruits consistently contained lower concentrations of all metals than leaves, reflecting physiological barriers that restrict metal translocation to reproductive tissues. This pattern is consistent with the role of vegetative tissues as primary storage sites for metals and the selective transport mechanisms that protect developing fruits (White & Broadley, 2009; Clemens & Ma, 2016).

Copper showed the highest bioaccumulation and transfer efficiency (BAF fruit 0.631, TF 0.978), reflecting its role as an essential micronutrient with active transport systems (Marschner, 2012). Zinc showed similar patterns, while lead displayed lower translocation efficiency (TF 0.877), consistent with its poor phloem mobility and sequestration in root tissues (Alloway, 2013). Arsenic exhibited the lowest bioaccumulation (BAF fruit 0.265), suggesting efficient detoxification mechanisms in vegetative tissues (Zhao et al., 2010).

The observation that all TF values were below unity (except copper at 0.978) indicates that heavy metals accumulated predominantly in leaves, while only a proportion was translocated to fruits. This selective partitioning represents an adaptive strategy that protects reproductive tissues and enhances seed viability by limiting the accumulation of potentially toxic elements (White & Broadley, 2009).

4.5 Comparison with Previous Studies

The findings of this study are consistent with previous investigations on wastewater irrigation in tomato and other vegetable crops. Gupta et al. (2024) reported significant enrichment of Pb, Cd, and As in wastewater-irrigated vegetables, with lead frequently exceeding food safety limits. Hussain et al. (2024) emphasized that crop species, irrigation duration, and soil properties are the principal determinants of heavy metal accumulation.

Alghobar and Suresha (2017) reported elevated heavy metal concentrations in tomatoes irrigated with sewage water from Mysore, Karnataka, with levels exceeding national and WHO standards. Alam et al. (2024) demonstrated that wastewater irrigation increased heavy metal bioaccumulation in tomato, though vermicompost amendments reduced metal uptake. The present study extends these findings by providing site-specific evidence from the Indo-Gangetic plains and quantifying lead contamination exceeding safety limits.

Zhou et al. (2020), in a global meta-analysis, concluded that fruit vegetables generally accumulate lower heavy metal concentrations than root vegetables under wastewater irrigation. However, the present study demonstrates that lead accumulation in tomato fruits can still exceed safety thresholds when irrigation water is sufficiently contaminated. This highlights the need for context-specific risk assessment.

4.6 Implications for Sustainable Agriculture

The findings highlight a critical trade-off between agricultural productivity and food safety when using polluted water for irrigation. While Ramgarh Lake water offers substantial agronomic benefits—enhanced germination, growth, yield, and reduced fertilizer requirements—the lead contamination in edible fruits poses unacceptable health risks. Although tomato shows lower accumulation than root vegetables, the presence of lead in fruits at concentrations exceeding safety limits cannot be ignored.

Several strategies could mitigate these risks:

Wastewater Treatment: Installing functional municipal wastewater treatment plants would be the most effective solution, though it requires significant investment. Even primary treatment to remove suspended solids and reduce heavy metal concentrations would substantially improve water quality (FAO, 2021; WHO, 2021).

Water Management: Blending wastewater with freshwater could reduce contaminant concentrations. Seasonal irrigation scheduling that minimizes heavy metal exposure during critical growth periods may also reduce accumulation in edible tissues (Hussain et al., 2024).

Crop Selection: Cultivating low-accumulating crop varieties or selecting tomato cultivars with reduced metal uptake potential should be explored (Singh et al., 2023).

Soil Amendments: Application of organic amendments (compost, manure), biochar, lime, and phosphate fertilizers can immobilize heavy metals through adsorption, precipitation, and complexation, reducing bioavailability and plant uptake (Bolan et al., 2023; Rinklebe et al., 2019).

Monitoring: Regular monitoring of irrigation water, soil, and crop metal concentrations is essential for risk assessment and management. Establishing threshold levels and early warning systems would enable timely interventions (FAO, 2021; WHO, 2021).

5. CONCLUSION

This study demonstrates that irrigation with polluted water from Ramgarh Lake produces a dual response in tomato cultivation. The nutrient-rich wastewater significantly enhances germination (12.1% increase), vegetative growth (28.5% increase in plant height), and yield (41.1% increase in fruit number), offering substantial agronomic benefits. However, continuous irrigation leads to progressive accumulation of heavy metals—particularly lead—in both soil and edible fruits. Lead concentrations exceeding FAO/WHO permissible limits by over fourfold indicate serious food safety concerns.

The moderate bioaccumulation factor for lead in fruits (0.507) and the transfer factor (0.877) indicate that physiological barriers provide partial protection but do not eliminate contamination. The presence of lead in tomato fruits at concentrations exceeding safety limits represents a significant health risk, particularly for populations consuming these vegetables regularly.

Sustainable utilization of this resource requires integrated management approaches that balance agricultural productivity with environmental protection and public health. Regular monitoring of irrigation water, soil, and crop metal concentrations is essential. Where lead concentrations exceed safety limits, appropriate mitigation measures—including wastewater treatment, blending with freshwater, soil amendments, and cultivation of low-accumulating varieties—should be implemented.

The findings contribute to a better understanding of the ecological and agricultural consequences of urban wastewater reuse and provide scientific evidence for developing safer irrigation practices in peri-urban farming systems. Future research should focus on long-term field experiments, human health risk assessment, and development of cost-effective remediation strategies to ensure sustainable wastewater utilization in agriculture.

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