Research article

Ecology Journal

ISSN (Print): 2957-4471, ISSN (Online): 2957-448X, Website: https://journal.esbangladesh.org
Ecol. J. (2026) 8 (2) : 171-179

Effects of industrial effluent irrigation on growth and yield components of aman and boro rice in a dyeing-industry-affected command area

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Received: 09 August 2026, revised: 13 August 2026, accepted: 19 August 2026, DOI: https: //doi.org/10.59619/ej.8.2.8

Abstract

This study investigated the effect of industrial wastewater irrigation on the growth and yield of aman and boro rice grown in a dyeing-industry polluted area located in Bangla Bazar, Mirzapur Union, Gazipur Sadar, Gazipur. The field experiments were conducted in a randomized complete block design (RCBD) with three replications, which included eleven wastewater-irrigation methods and each method was represented by a grid. In this study, BR11 rice was used for aman season and BRRI rice29 for boro season. The results of the study showed that industrial wastewater pollution significantly affected the growth and yield characteristics of both the rice varieties. Compared to the pollution-free control field, irrigation with wastewater reduced the plant height of aman rice, which ranged from 57.67 to 92.67 cm compared to 98.60 cm in the control field. As an exception, the height of boro rice plants increased in some contaminated grids, which was probably due to the contribution of nutrients available in the grids. Despite this occasional growth stimulation, both rice varieties showed a significant decrease in effective tiller, number of grains, number of full grains per grain, and 1000-grain weight in the contaminated environment, along with an increase in the number of infertile grains. Overall, the results demonstrated that untreated industrial wastewater can adversely affect key components of rice growth and yield, ultimately reducing crop productivity. These results emphasized the importance of proper treatment and strict management of industrial wastewater before its use for agricultural irrigation to protect soil and crop health, food security, and environmental sustainability.

Keywords: contamination, growth, heavy metals, industrial effluents, productivity, yield components.

Introduction

The rapid expansion of industrialization has contributed significantly to the country's economic growth, but it has also created serious environmental concerns due to the release of untreated wastewater. These wastewaters often contain toxic heavy metals, dyes, and organic pollutants that can adversely affect soil health, water quality and finally agricultural productivity (Sahen *et al*. 2025, Masum *et al*. 2025). Hasan *et al.* (2025) reported that industrial wastewater treatment showed inhibitory effects on antioxidant content together with high oxidative stress, reflecting adverse impacts on seed germination and seedling growth of rice, tomato and mustard. Among the industries contributing to this pollution, the textile and dyeing industries are of particular concern because they use a lot of water, resulting in the generation of large amounts of chemical-laden wastewater (Masum *et al*. 2025, Islam *et al*. 2024).

Rice (*Oryza sativa*), a staple food for millions of people, is highly sensitive to environmental changes, particularly to the quality of water and soil. In Bangladesh, India, and other South Asian countries, rice is grown primarily in three distinct seasons: aman (rainfed), aus (rainfed) and boro (irrigated). Rice varieties grown in these two seasons are critical to the region's food security and economy. However, the proximity of rice fields to industrial zones, especially dyeing industries, poses a significant threat to crop growth and yield.

The command area of a dyeing industry, where agricultural fields are exposed to industrial wastewater, presents a critical case for studying the impact of such effluents on rice cultivation. The potential effect of industrial effluents on the growth and yield of aman and boro rice has become an area of increasing concern for agricultural scientists and environmentalists. Effluents discharged from dyeing industries often contain harmful substances, such as dyes, heavy metals (like cadmium, lead, and arsenic), and other organic pollutants, which may contaminate soil and irrigation water. Previous studies have indicated that excessive accumulation of heavy metals like cadmium, lead, and chromium in soil can inhibit nutrient uptake,

retard plant growth, and diminish grain yield (Umar *et al*. 2025, Xia *et al*. 2024). Application of untreated waste water to irrigated rice fields is raising concern about possible health risks associated with the consumption of rice grain (Abdu *et al*. 2011). However, limited research has focused on the comparative effects on aman and boro rice under field conditions in such polluted agro-ecosystems.

Therefore, this study aims to evaluate the effect of industrial effluents on the growth parameters (plant height, tiller number) and yield attributes (panicle number, number of filled & unfilled grain, 1000-grain weight) of aman and boro rice in the command area of a dyeing industry. By analyzing soil and water quality alongside crop performance, this research seeks to provide insights into the extent of ecological degradation and suggest mitigation strategies to sustain rice productivity in industrial-affected regions. The findings will be valuable for policymakers, farmers, and environmentalists in balancing industrial growth and agricultural sustainability.

Materials and methods

This study was conducted in a command area contaminated by effluents from a dyeing industry located at Banglabazar (Dogri) in Mirzapur Union of Gazipur Sadar, Gazipur District at an altitude of 8.5 m (24.05^0 North latitude and 90.22^0 East longitudes) above sea level. In this area, both T. Aman and Boro rice are cultivated due to prevailing waste water irrigation facilities. As a result, the soil and water in this area gradually get contaminated by the effluents of the industry, which causes serious problems in crop production. Therefore, this study was conducted during August to December, 2024 for transplanted (T) aman and December, 2024 to May, 2025 for boro season in the nearby zone of this dyeing industry using BR 11 rice variety (T. aman) and BRRI dhan29 rice variety (boro) under farmers' practices. The samples were collected from this area in both T. aman and boro seasons. The study of command area was about 2 hectares, which is 100 m away from the discharge point of effluent of the dyeing industry. The field was divided into 11 grids including one uncontaminated grid considering the experimental units which were flooded by contaminated waste water and uncontaminated or control that was not flooded by contaminated waste water. Their distances from the source of the effluent were different. Therefore, there were 11 treatments in the study which were laid down in a randomized complete block design using three blocks randomly. This industrial unit had been discharging tons of effluents containing water with toxic heavy metals and thereby polluting the soil environment as well as crop production.

Experimental design and statistical analysis: The experiments were conducted in a randomized complete block design (RCBD) with three replications. Eleven treatment grids were maintained in each replication, resulting in a total of 33 experimental units (11 treatments × 3 replications). Thus, 33 samples were considered for the analysis.

The collected data were statistically analyzed using SPSS version 14.0. One-way analysis of variance (ANOVA) and univariate analysis were performed to determine the effects of the treatments. Treatment means were compared using the least significant difference (LSD) test at the appropriate level of significance.

Results and discussion

Effect of effluents on postharvest soils: The pH of contaminated soils after harvesting T. aman ranged from 4.70 to 5.40, compared with 4.60 in the uncontaminated soil (Table 1). The highest pH was observed at grids 10 and 11, while the lowest was recorded at grid 4. Although the contaminated soils generally exhibited slightly higher pH than the uncontaminated soil, the differences among grids were not uniform; pH values at grids 3, 10, and 11 were statistically similar. After harvesting boro, the pH of contaminated soils ranged 4.77 - 5.67, while the uncontaminated soil pH was 4.67. The highest pH was again found at grid 11, and the lowest at grid 4, with grids 3, 8, 10, and 11 showing no statistical differences. Continuous application of wastewater containing appreciable concentrations of basic cations such as Ca^{2+}, Mg^{2+}, and Na^{+} can alter the soil exchange complex and contribute to an increase in soil pH (Rao *et al*. 1982). Similarly, the presence of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^{-}) ions in irrigation water may contribute to alkalinity and consequently increase soil pH (Michael, 1974). The relatively greater increase in pH after boro compared with T. aman may also reflect the cumulative effect of repeated

effluent application and differences in seasonal water management. The present findings are broadly consistent with earlier observations by Tiwari *et al*. (1996), who reported that wastewater-induced changes in soil pH and associated chemical properties can adversely affect soil quality and crop productivity. Therefore, although the effluent-induced increase in pH observed in the present study was relatively small, its interaction with other chemical constituents of the industrial wastewater may have important implications for nutrient availability, metal mobility, soil fertility, and rice productivity. Long-term application of untreated industrial effluent may progressively alter these properties and thereby pose risks to sustainable rice production and soil health.

After harvesting T. aman, the organic matter content in contaminated soils varied between 2.38% and 3.57%, while the uncontaminated soil recorded 2.53% (Table 1). The highest organic matter was found at grid 4 (3.57%), and the lowest at grid 10 (2.38%). Similarly, after Boro, the organic matter content in contaminated soils ranged from 2.65%-3.35%, compared to 2.61% in the uncontaminated soil. The highest value was again recorded at grid 4 (3.35%), and the lowest at grid 1 (2.61%, control). The relatively higher organic matter content observed in several effluent-affected grids may be attributed to the continuous deposition of organic-rich suspended solids and other biodegradable materials present in industrial wastewater. Repeated irrigation with untreated effluent can introduce organic residues, particulate matter, and microbial biomass into the soil. Subsequent decomposition of these materials may increase soil organic matter, particularly in areas receiving greater effluent loads. Similar increases in soil organic matter following wastewater inputs have been reported by Fjällborg *et al*. (2002). The results demonstrate that repeated application and deposition of industrial effluent can modify the organic matter status of agricultural soils. While moderate organic enrichment may improve certain physical and biological soil properties, the simultaneous introduction of potentially toxic industrial constituents may compromise soil quality and crop safety. Therefore, untreated industrial effluent should not be regarded as a

Table 1. Effect of industrial effluents on postharvest soils pH, organic matter and total nitrogen content in a command area of dyeing industry

Grids	Soils characters					
	T. Aman			Boro		
	Soils pH	Organic matter (%)	Total nitrogen (%)	Soils pH	Organic matter (%)	Total nitrogen (%)
Grid-1 (Control)	4.60±0.10d	2.53±0.03f	0.07±0.00g	4.67±0.12f	2.61±0.03h	0.08±0.01d
Grid-2	5.07±0.15c	2.59±0.36f	0.18±0.01b	5.20±0.26de	2.81±0.38e	0.24±0.01a
Grid-3	5.33±0.06abc	3.12±0.00c	0.21±0.0a	5.50±0.10abc	3.19±0.03b	0.23±0.01a
Grid-4	4.70±0.11d	3.57±0.28a	0.12±0.02d	4.77±0.15f	3.35±0.02a	0.15±0.02c
Grid-5	5.10±0.17c	3.13±0.54b	0.10±0.01ef	5.13 ±0.06e	3.34±0.04a	0.17±0.01b
Grid-6	5.13±0.06c	2.70±0.03e	0.14±0.02c	5.17±0.06de	2.82±0.04e	0.17±0.02b
Grid-7	5.20±0.10c	3.05±0.06d	0.11±0.01de	5.27±0.25cde	2.83±0.03e	0.18±0.01b
Grid-8	5.37±0.06ab	2.72±0.00e	0.09±0.00f	5.40±0.12bcde	2.88±0.03d	0.17±0.01b
Grid-9	5.17±0.06c	2.51±0.19g	0.07g±0.00g	5.23±0.15de	2.65±0.04g	0.09±0.02d
Grid-10	5.40±0.06a	2.38±0.02h	0.12±0.01d	5.53±0.06ab	3.03±0.04c	0.14±0.02c
Grid-11	5.40±0.06a	2.71±0.02e	0.11±0.01de	5.67±0.06a	2.73f±0.03f	0.14±0.02c
LSD	0.13	0.07	0.01	0.24	0.03	0.01
%CV	1.51	10.03	26.14	2.60	4.03	19.50

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reliable source of organic matter for agricultural soils, and appropriate wastewater treatment is essential before its use for irrigation.

The total nitrogen content in contaminated surface soils after T. aman harvest ranged 0.07% - 0.21%, compared to 0.07% in uncontaminated soils (Table 1). The highest nitrogen level (0.21%) was observed at grid 3, and the lowest (0.07%) at grid 9. (Table 1). Following boro, the nitrogen content in contaminated soils ranged 0.14% - 0.24%, while the uncontaminated soil contained 0.08%, similar to T. aman. The highest nitrogen was recorded at grid 2 (statistically similar to grid 3), and the lowest at grids 10 and 11 (statistically similar to grid 4). The higher total N concentrations in effluent-affected soils may be associated with the repeated addition of N-containing organic and inorganic constituents through industrial wastewater. Evidence from Bangladesh supports this interpretation. Islam *et al.* (2020), working with industrial effluents under a rice–rice cropping system at the Bangladesh Rice Research Institute (BRRI), reported perceptible changes in soil chemical properties following effluent irrigation and observed increases in total N with some industrial effluents. The results suggest that total nitrogen levels in contaminated soils were generally higher than in uncontaminated soils, likely due to the incorporation of organic matter from industrial solid wastes.

The use of industrial wastewater in rice cultivation significantly affected plant height (Table 2). In the case of T. aman, the average plant height ranged from 57.67 to 92.67 cm in contaminated soils, compared to 98.60 cm in uncontaminated soil. Among the contaminated grids, the tallest plants were recorded in Grid-6, while the shortest were found in Grid-9. The plant height in Grid-2 was statistically similar to that in Grids 3, 5, and 6, whereas Grids 8, 10, and 11 were also statistically similar in this regard. These results indicate that exposure to industrial wastewater generally suppressed vegetative growth of T. Aman rice, although the response varied spatially among grids. In contrast, for Boro rice, industrial wastewater appeared to increase plant height in certain grids, possibly due to the nutrients provided by the wastewater acting as an organic source (Table 2). The plant height varied between 70.67 and 116.00 cm in contaminated soils, while it was 95.33 cm in uncontaminated soil. The highest plant height was observed in Grid-11, and the lowest in Grid-2. Plant height in Grid-3 was statistically similar to that in Grid-5, while Grids 1, 6, and 8 also showed statistical similarity.

However, industrial wastewater contained elevated concentrations of heavy metals such as Fe, Mn, Zn, Cu, Pb, Cd, Ni, and Cr, often exceeding permissible limits, which likely exerted toxic effects on rice growth. Specifically, Cr may have been responsible for reduced root elongation (Yamaguchi and Aso 1977), decreased net photosynthesis, and disrupted physiological functions (Auslenfeld 1979). These negative impacts on plant height are consistent with findings from Woothouse (1983), Sarkunan *et al*. (1989), and Yagdi *et al*. (2000), who also reported stunted growth in rice and other plants irrigated with water containing toxic levels of heavy metals.

Industrial wastewater significantly influenced the number of active tillers per hill in polluted soils (Table 2). For T. Aman, the number of tillers ranged from 13.00 to 21.67 in contaminated grids, compared to 22.00 in the uncontaminated grid. The highest number of tillers was recorded in Grid-4, and the lowest in Grid-7. The tiller numbers in Grids 2, 4, 5, 8, and 10 were statistically similar. Similarly, for Boro rice, the number of active tillers per hill ranged from 9.67 to 18.67 in contaminated soils and 20.00 in uncontaminated soil. There was significant variation among grids. The highest number of tillers was observed in Grid-4, and the lowest in Grid-11. Tiller numbers in Grid-7 were statistically similar to those in Grid-9, while Grids 4 and 5 were also statistically similar.

The results indicate that industrial wastewater notably reduced the number of effective tillers per hill, especially in polluted soils. The toxic heavy metals (Fe, Mn, Zn, Cu, Pb, Cd, Ni, Cr) present in the wastewater likely inhibited root and shoot growth (Yamaguchi and Aso 1977), thereby reducing tiller development. These findings align with those of Yamaguchi *et al*. (2000) and Khalid and Tinsley (1980).

The number of panicles per hill also decreased under the influence of industrial wastewater (Table 2). In T. Aman, panicle numbers ranged from 11.33 to 18.67 in contaminated soils, compared to 19.00 in uncontaminated soil. The highest number of panicles was found in Grid-5, and the lowest in Grid-8. Panicle counts in Grids 2, 5, and 7 were statistically similar. In Boro rice, panicle numbers ranged from 8.67 to 15.33 in contaminated soils, compared

to 17.00 in the uncontaminated grid. The highest number was recorded in Grid-4, and the lowest in Grid-9. Panicle numbers in Grids 5 and 10 were statistically similar.

Overall, the data suggest that industrial wastewater substantially reduced the number of panicles per hill, in line with the decline in effective tiller numbers. This reduction can be attributed to the toxic effects of heavy metals in the wastewater, which impair plant physiological functions. These findings are consistent with previous studies by Woothouse (1983), Sarkunan *et al*. (1989), Yagdi *et al*. (2000), and Yamaguchi *et al*. (2000), who reported similar adverse effects on plant growth when irrigated with contaminated water.

Industrial wastewater had a significant negative impact on the number of filled grains per panicle in T. Aman rice cultivated in polluted soils (Table 3). The highest number of filled grains per panicle (124.33) was recorded in uncontaminated soil (Grid-1), whereas in contaminated grids, nearly half of the grains were unfilled. The average number of filled grains per panicle ranged from 31.00 to 62.33 in contaminated soils. Significant differences were observed among the grids. Filled grain counts in Grid-2 were statistically similar to Grid-5, and Grids 4 and 6 also showed statistical similarity. Similarly, for Boro rice, industrial wastewater significantly reduced the number of filled grains per panicle (Table 3). The highest number of filled grains (85.67) was found in the uncontaminated Grid-1, while the lowest (5.00) was recorded in Grid-2, which received highly polluted irrigation water. The average number of filled grains per panicle ranged from 5.00 to 61.33 across contaminated grids. Filled grain counts in Grid-3 were statistically similar to those in Grids 6 and 9, while Grids 4, 5, and 10 also formed a statistically similar group.

These results indicate that industrial wastewater drastically reduced the number of filled grains per panicle, particularly in contaminated areas. The likely cause is the presence of toxic heavy metals such as Fe, Mn, Zn, Cu, Cr, Pb, Ni, and Cd in dyeing industry effluents, which may impair pollen germination and pollen tube elongation, leading to poor grain filling. This observation is consistent with findings by Ray and Gupta (1987), who reported adverse effects of polluted irrigation water on pollen viability and function. Similar reductions in plant growth, biomass accumulation, and grain filling due to wastewater were also reported by Rubio *et al*. (1994).

Table 2. Effect of industrial effluents on growth and yield contributing characters of T. Aman and Boro rice

Grids	Growth and yield contributing characters					
	T. Aman			Boro		
	Plant height (cm)	Tiller number/ hill	Panicle number/hill	Plant height (cm)	Tiller number/ hill	Panicle number
Grid-1 (Control)	98.6±3.06a	22.00±3.61a	19.00±1.00a	95.33±1.53cd	20.00±1.53a	17.00±2.00a
Grid-2	90.67±2.08b	21.00±1.00ab	17.33±1.53bc	70.67±2.08g	13.00±1.00de	10.00±1.00ef
Grid-3	90.33±1.15b	13.00±1.00de	12.00±1.00f	108.67±1.53b	14.00±1.00de	9.67±1.15ef
Grid-4	61.33±3.50e	20.67±1.53ab	16.00±1.00cd	81.33±1.53f	18.67±2.08ab	15.33±1.53ab
Grid-5	92.00±3.00b	21.67±3.06ab	18.67±1.53ab	108.33±3.5b	17.00±2.00bc	13.33±1.53bc
Grid-6	92.67±3.78b	18.00±3.00c	14.33±2.08de	96.00±2.00c	14.33±1.53cde	11.00±1.00de
Grid-7	83.00±2.65c	12.67±1.53de	17.33±1.53bc	92.33±1.53d	15.7±1.15cd	12.67±0.58cd
Grid-8	70.00±3.00d	21.00±2.65ab	11.33±0.58f	96.67±1.53c	12.00±2.65ef	10.33±1.15ef
Grid-9	57.67±0.58e	18.67±1.53abc	16.00±1.00cd	85.33±2.08e	10.00±1.00f	9.00±2.00ef
Grid-10	71.67±2.08d	20.00±2.65ab	16.67±1.53bc	101.67±1.53b	14.33±1.53cde	14.33±1.53bc
Grid-11	73.00±4.36d	15.67±2.52cd	12.33±0.58ef	116.00±2.00a	9.67±1.15f	8.67±1.53f
LSD	4.34	3.60	2.23	3.53	2.74	2.26
%CV	3.19	11.38	8.40	2.16	8.88	11.10

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Industrial wastewater also significantly increased the number of unfilled grains per panicle in T. Aman rice (Table 3). The number of unfilled grains ranged from 15.33 to 68.33 in contaminated soils and was 10.67 in uncontaminated soil. Significant variations were observed among the grids. Grids 4 and 11 were statistically identical. Interestingly, the highest number of unfilled grains was recorded in Grid-1, despite being uncontaminated -suggesting possible variability in environmental or agronomic conditions. The lowest was observed in Grid-8. Across contaminated grids, nearly half of the grains were unfilled. For Boro rice, a similar trend was observed. The number of unfilled grains per panicle ranged from 21.67 to 55.33 in contaminated soils and 11.67 in uncontaminated soil (Table 3). Statistically similar unfilled grain counts were found among Grids 4, 6, 7, and 10. The highest number of unfilled grains was unexpectedly observed in Grid-5, while the lowest was in Grid-1. Again, a large proportion of grains remained unfilled in contaminated conditions, indicating reduced reproductive success under heavy metal stress.

Like other yield components, 1000-grain weight was significantly affected by the use of industrial wastewater (Table 3). In T. Aman, the average 1000-grain weight ranged from 12.05 g to 18.28 g in contaminated soils, whereas it was 20.45 g in the uncontaminated control. The highest 1000-grain weight in contaminated soils (18.28 g) was recorded in Grid-2, and the lowest (12.05 g) in Grid-9. Significant differences were observed among all grids. In Boro rice, 1000-grain weight varied from 12.35 g to 21.20 g in contaminated grids, compared to 23.23 g in uncontaminated Grid-1. The lowest 1000-grain weight was recorded in Grid-2, which was also characterized by the lowest number of filled grains per panicle.

These reductions in grain weight under contaminated conditions may be attributed to heavy metal toxicity, which hampers key physiological and biochemical processes in plants, including enzyme activity, stomatal regulation, photosynthesis, and nutrient uptake. These disruptions ultimately impair grain development. This finding aligns with the observations of Yagdi *et al*. (2000), who reported that high levels of As, Cu, Hg, Zn, Cd, Pb, Mo, Ni, and Se reduced plant growth and grain weight by interfering with essential metabolic functions.

Table 3. Effect of industrial effluents on yield contributing characters of T. Aman and Boro rice

Grids	Yield contributing characters					
	T. Aman			Boro		
	Number of filled grain/ panicle	Number of unfilled grain/ panicles	1000-grain weight (g)	Number of filled grain/ panicle	Number of unfilled grain/ panicles	1000 grain weight (g)
Grid-1 (Control)	124.33±2.08a	10.67±1.53e	20.45±0.43a	85.67±1.53a	11.67±2.08f	23.23±0.23a
Grid-2	62.33±2.08b	20.00±3.00c	18.28±0.15b	5.00±1.00g	45.00±2.00b	12.35±0.21i
Grid-3	58.33±2.52b	68.33±2.52a	16.55±0.33e	51.67±1.5c	36.67±2.08c	12.57±0.58i
Grid-4	53.00±2.00c	38.00±3.00b	13.48±0.22g	42.33±2.52de	33.67±1.53c	13.83±0.29h
Grid-5	62.00±2.65b	19.00±3.61cd	16.62±0.12e	42.00±2.00de	55.33±3.06a	14.73±0.21g
Grid-6	51.33±3.51c	20.33±3.21c	17.67±0.37c	53.00±2.00c	35.67±2.52c	15.78±0.30f
Grid-7	33.67±1.53de	19.33±2.08cd	17.44±0.44cd	35.00±1.00f	34.33±2.52c	19.17±0.28d
Grid-8	36.67±1.53d	15.33±1.53d	17.03±0.06de	39.67±2.08e	24.33±1.53de	21.20±0.36b
Grid-9	51.67±3.51c	16.00±2.65cd	12.05±0.35h	52.00±2.00c	25.67±2.52d	18.23±0.47e
Grid-10	31.00±3.61e	17.00±2.00cd	14.17±0.20f	42.67±0.58d	33.00±2.00c	19.83±0.38c
Grid-11	59.67±5.69b	39.33±1.53b	14.68±0.24f	61.33±1.53b	21.67±1.53e	20.50±0.35b
LSD	4.24	4.48	0.51	2.98	3.82	0.60
%CV	4.40	10.21	1.85	3.77	6.91	2.02

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Conclusion

This study demonstrates that irrigation with industrial wastewater adversely affects rice growth and yield of T. Aman and Boro rice, despite the presence of some beneficial nutrients. The use of irrigation water containing untreated industrial wastewater severely reduced rice growth and yield. Regulatory measures and sustainable wastewater management strategies should be implemented to protect agricultural productivity and public health. Future research should explore metal detoxification methods and low-accumulation rice varieties to ensure safe food production in contaminated areas.

Acknowledgements

The authors gratefully acknowledge the Soil Science Laboratory, Department of Soil Science, Gazipur Agricultural University (GAU), for providing the facilities and logistical support necessary to conduct this research. Special appreciation is extended to the farmers of the study area grids for their cooperation, as well as to the faculty members and staff of the department for their kind assistance, insightful guidance, and constructive suggestions throughout the study.

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