



Spatial Distribution and Factors Affecting Soil and Rice Grain Arsenic Concentration in Different Land Types in Ganges River Floodplain Soils of Bangladesh

M.H. Kabir¹, G.K.M.M. Rahman¹, M.M. Rahman¹, Z.U. Ahmed²

10.18805/ag.DF-653

ABSTRACT

Background: When arsenic (As) contaminated groundwater is utilized for irrigation in rice fields, the amount of As in the soil and rice grain changes. Arsenic eventually finds its way into food chains through crop absorption and endangers people's health over time. The purpose of the current study was to describe the spatial pattern of As in soil, rice grain and irrigation water across various land types, as well as how these patterns relate to other environmental factors.

Methods: Two confined basins viz. Faridpur Sadar and Madhukhali and one unconfined basin connected with a river in Boalmari under Faridpur district of Bangladesh with medium high to very low land were selected. The soil and rice sampling points in the command area were grided by 50 m distance. The water samples were collected from shallow tube well (STW) and the Global Positioning System (GPS) was used to georeference each sampling site. The important factors for soil and rice grain As were originated using the multiple linear regression (MLR) study.

Result: Result showed that the As concentration of STW water, soil and rice grain were spatially varied in three sites. The soil and water As showed significantly positive correlation ($r = 0.316$ for Madhukhali and $r = 0.206$ for Faridpur Sadar) in two confined basins, while non-significant relationship was found in open basin (Boalmari). The rice grain As was significantly correlated with all the topographical variables in the Faridpur Sadar specially soil As ($r = 0.307$) while in the other two sites (Madhukhali and Boalmari) did not show strong relationship.

Key words: Arsenic, Contamination, Rice grain, Soil, Spatial variability.

INTRODUCTION

Given that it may have negative effects on ecosystems and human health, arsenic (As) is considered one of the most dangerous substances in the environment (Naidu *et al.*, 2006). A number of chronic illnesses in humans, including cancers of the skin, bladder, lungs, liver and kidneys, are linked to As poisoning (Mehmood *et al.*, 2017). High concentrations of As are toxic to most of the plants because they disrupt metabolic processes, causes several physiological, biochemical abnormalities and cellular disorders and prevent plant growth and reproduction through phytotoxicity (Khan, 2020; Mairaj *et al.*, 2022; Ghritlahre and Singh, 2022). Bangladesh is dealing with a problem of high As concentration in shallow aquifers and growing As in soil usage of this aquifer's water for irrigation every day. Using irrigation when tainted groundwater seeps into rice fields, it becomes more concentrated in the soil, eventually making its way into food chains through crop absorption and posing a long-term health danger to people (Sarker *et al.*, 2022). In actuality, adsorption on precipitating iron oxides during water passage through irrigation channel and across field causes uneven deposition of As in soil by irrigation water. Moreover, soil As buildup within a command area is heterogeneous and can be toxic level to rice in part (Panauallah *et al.*, 2009). Therefore, removal and remobilization of As is higher in confined basin where soil faced deep flood in monsoon season and floodwater flows

¹Department of Soil Science, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh.

²Research and Education in Energy, Environment and Water, University at Buffalo (UB), Buffalo, New York, USA.

Corresponding Author: G.K.M.M. Rahman, Department of Soil Science, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh.

Email: mustafiz@bsmrau.edu.bd

Orcids: 0000-0003-4023-8323, 0000-0002-3051-3566, 0000-0002-2353-6823.

How to cite this article: Kabir, M.H., Rahman, G.K.M.M., Rahman, M.M. and Ahmed, Z.U. (2025). Spatial Distribution and Factors Affecting Soil and Rice Grain Arsenic Concentration in Different Land Types in Ganges River Floodplain Soils of Bangladesh. *Agricultural Science Digest*. 1-8. doi: 10.18805/ag.DF-653.

Submitted: 26-07-2024 **Accepted:** 31-12-2024 **Online:** 23-01-2025

to river. Thus, different land type is an important factor in terms of soil As retention. Thus, given Bangladesh's growing concerns about the quality of ground water used for irrigation and drinking, it is imperative to have a thorough understanding of the geographical variability of As in soils and plants. An extensive range of economic and environmental applications, as well as the evaluation of the connection between geochemistry and health, might be based on a spatial database on soil and ground water

arsenic. Since the remediation of As toxicity in Bangladesh agriculture is now a burning issue in terms of food safety and food security, the identification of currently contaminated and vulnerable areas is an important task for risk assessment and mitigation strategies. Spatial variability analysis has been found to predict environmental variables those have strong influence on As contamination. While Bangladesh has mapped the As risk using a variety of geostatistical interpolations and kriging approaches, the mapping of paddy soil and rice grain uptake, either with or without the inclusion of environmental variables unique to different land types, has not yet been finished. Thus, this study aimed to (1) describe the As's geographical distribution in soil and irrigation water across various land types, (2) ascertain the As uptake pattern in rice with regard to land types and (3) find out a relationship between the environmental variables and irrigation water, soil and rice grain As concentration.

MATERIALS AND METHODS

Study area

Given that they are situated in an extremely As-contaminated region of Bangladesh (Sarkar *et al.*, 2022), the two confined

basins at Faridpur Sadar upazila and Madhukhali upazila, as well as the one open or unconfined basin at Boalmari upazila that is connected by a river, were chosen as the study areas (Fig 1a). Two confined basins, Faridpur Sadar and Madhukhali, have land types that range from medium highland to very lowland, whereas Boalmari, an unconfined basin, has a land type that ranges from medium highland to very lowland (SRDI, 2019). The elevation of study areas was determined by the DEM maps (Fig 1b). Site elevation maps or DEM maps were generated by a topographic survey and Thieodolites 3D Model at a 20×20 m resolution and re-processed to a 5×5 m grid using ordinary kriging. The slope of the three respective sites was variable. The land was more slopy at Boalmari with the mean slope 0.50° and was less slope at Faridpur Sadar (0.074°). At the Madhukhali the slope was 0.127° (Fig 2a).

Sample collection and preparation for analysis

The soil samples were collected during the fallow period in between the *aman* and *boro* season (November 2021), whereas, water and rice samples were collected during the *boro* season of 2021-2022 (December 2021 to March 2022). Water samples were obtained from the outlet point of each shallow tube well (STW) using a membrane filter

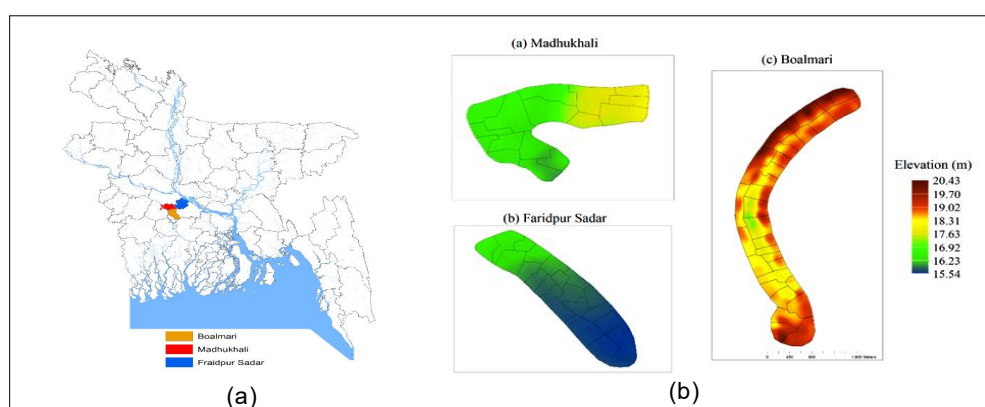


Fig 1: (a) Map of Bangladesh showing the study Upazillas; (b) Digital elevation model (DEM) of study sites: (a) Madhukhali, (b) Faridpur Sadar and (c) Boalmari.

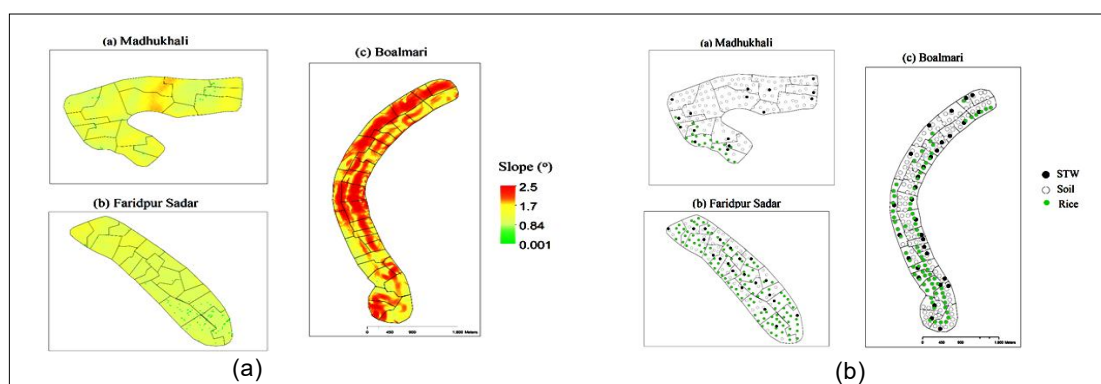


Fig 2: (a) Slope (degree) of the study sites: (a) Madhukhali, (b) Faridpur Sadar and (c) Boalmari Upazilla in Faridpur District; (b) Study area showing the STW positions, soil and rice samples collection locations. (a) Madhukhali, (b) Faridpur Sadar and (c) Boalmari.

(0.45 μm) and then acidified with 2% Nitric acid in a 100 ml plastic pot. Soil sample was collected in 5 m $\times$ 5 m grid at 15 cm depth within the command area of STW (Fig 2b).

Various *boro* rice varieties samples were gathered from the designated locations for additional laboratory analysis of As concentration. A GPS (Global Positioning System) machine (Model: Garmin 60CSx) was used to georeference each of the chosen locations. The collected water, soil and rice samples were prepared and analyzed in the laboratory of the Department of Soil Science, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur 1706, Bangladesh by following the method described previously (Kabir *et al.*, 2015).

Statistical and geostatistical analysis

Numerous statistical analyses, including analysis of variance (ANOVA), coefficient of variation (CV), correlation and stepwise multiple linear regression (MLR) were conducted using the statistical software R (Version 4.3.2; 2023-10-31) (Team, 2021). Using the variables elevation, land slope, irrigation year and distance from STW, stepwise multiple

regression analysis was performed to predict the STW irrigation water As, soil As and rice grain As concentration data. Standard deviations (SD) and geometric means (GM) were employed to determine the baseline range of As concentration. All geostatistical analysis and map output visualization was done using QGIS, ArcGIS and the gstat package (Pebesma, 2023) in the R statistical computer environment.

RESULTS AND DISCUSSION

Spatial distribution of STW water As

The concentration of arsenic in STW water was spatially varied at all three sites (Fig 3a) ranging between 0.062–0.271 mg L^{-1} in Madhukhali, 0.031–0.196 mg L^{-1} in Boalmari and 0.052–0.520 mg L^{-1} in Faridpur Sadar upazila with the mean value of 0.122 mg L^{-1} , 0.094 mg L^{-1} and 0.139 mg L^{-1} respectively (Table 1). The presence of As containing minerals such as arsenopyrite (Ivy *et al.*, 2023) and their subsequent breakdown (Akinbile and Haque, 2012) and oxy-hydroxide reduction (Smedley and Kinniburgh, 2002)

Table 1: Descriptive statistics of selected site characteristic and arsenic concentration in groundwater, soil and rice grain.

	N	Mean $\pm$ SD	Max.	Min.	CV (%)
Madhukhali					
Elevation (m)	151	16.86 $\pm$ 0.55	18.00	16.03	3.26
Slope (o)	151	0.127 $\pm$ 0.086	0.402	0.005	67.72
Water As (mg L^{-1})	16	0.122 $\pm$ 0.057	0.271	0.062	46.72
Age of STW	16	9.39 $\pm$ 2.56	14.00	4.00	27.26
Distance from STW (m)	151	101.21 $\pm$ 61.32	261.81	12.05	60.59
Soil As (mg kg^{-1})	151	15.93 $\pm$ 6.2	42.00	3.80	38.92
Rice grain As (mg kg^{-1})	20	0.44 $\pm$ 0.13	0.69	0.22	29.55
Rice grain P (mg kg^{-1})	20	1924.8 $\pm$ 489.4	2955.1	915.1	25.43
Soil pH	20	7.47 $\pm$ 0.253	7.77	7.04	3.39
Faridpur Sadar					
Elevation (m)	157	15.90 $\pm$ 0.31	16.89	15.45	1.95
Slope (o)	157	0.074 $\pm$ 0.045	0.248	0.005	60.81
Water As (mg L^{-1})	21	0.139 $\pm$ 0.052	0.520	0.052	37.41
Age of STW	21	8.13 $\pm$ 4.18	18.00	3.00	51.41
Distance from STW (m)	157	78.79 $\pm$ 40.18	211.63	17.16	50.99
Soil As (mg kg^{-1})	157	13.02 $\pm$ 4.38	31.00	5.40	33.64
Rice grain As (mg kg^{-1})	104	0.368 $\pm$ 0.155	0.751	0.095	42.12
Rice grain P (mg kg^{-1})	104	1773 $\pm$ 305.18	26.29	1203	17.21
Soil pH	104	7.37 $\pm$ 0.57	8.15	5.29	7.67
Boalmari					
Elevation (m)	192	18.73 $\pm$ 0.61	20.29	17.362	3.26
Slope (o)	192	0.50 $\pm$ 0.31	1.57	0.004	62.00
Water As (mg L^{-1})	31	0.094 $\pm$ 0.043	0.196	0.031	45.74
Age of STW	31	6.90 $\pm$ 4.07	22.00	2.000	58.99
Distance from STW (m)	192	81.86 $\pm$ 48.22	265.39	11.074	58.91
Soil As (mg kg^{-1})	192	12.08 $\pm$ 3.83	28.50	4.800	31.71
Rice grain As (mg kg^{-1})	77	0.31 $\pm$ 0.18	0.92	0.030	58.06
Rice grain P (mg kg^{-1})	77	2257 $\pm$ 319.39	2945	1370	14.15
Soil pH	77	7.7 $\pm$ 0.214	8.17	7.03	2.77

N= No. of observation, SD= Standard deviation, STW= Shallow tube well.

the redox potentiality may vary and the As concentration may vary in three experimental sites.

Spatial distribution of soil As

Arsenic concentration in soil samples in all three study sites showed high variability (Fig 3b) ranging from 3.8 - 42.00 mg kg⁻¹, 4.8 - 28.5 mg kg⁻¹ and 5.4 - 31.00 mg kg⁻¹ with the mean value 15.93, 12.08 and 13.02 mg kg⁻¹ in Madhukhali, Boalmari and Faridpur Sadar upazila respectively (Table 1). The soil As concentration in Boalmari was lower than the other two sites might be the As concentration of the STW water in Boalmari was lower than the other sites and some portion of the buildup soil As can be washed out by frequent flooding in the open Basin at Boalmari. In case of Madhukhali and Faridpur Sadar, the soil As concentration was comparatively high (Fig 3b) due to exposure of soil to irrigation water contained elevated level of As and also less possibility to loss soil As by lateral water movement due to unconfined basin.

Spatial distribution of rice grain As

Like STW water and soil As, the variability of rice grain As was also observed in three experimental sites (Fig 3c). Rice grain As were ranging from 0.22 - 0.69, 0.030 - 0.92 and 0.095 - 0.751 mg kg⁻¹ with the mean value 0.44, 0.31 and 0.368 mg kg⁻¹ at Madhukhali, Boalmari and Faridpur Sadar respectively (Table 1). In comparison to rice grains at Boalmari, those at Madhukhali and Faridpur Sadar were relatively higher. The reason behind the higher As concentration in rice grain at confined basin might be due to the

higher irrigation water As concentration and soil As as discussed in the previous section. Significantly positive correlation between water As vs grain As and soil As vs grain As was observed previously (Kabir *et al.*, 2015). The coefficients of variation (CV) of As in irrigation water, soil and rice grain were very high that indicate the variability of As concentrations also high in the all three study sites except elevation.

Factors affecting soil as concentration

The content of As in the soil has a non-significantly negative correlation with elevation ($r = -0.098$ ns, $n=151$) at Madhukhali and also negatively correlated ($r = -0.244$, $p<0.001$, $n=192$) at Boalmari. In case of Faridpur Sadar, the relationship was positive but non-significant ($r=0.078$ ns, $n=157$) (Table 2). However, there was a strong positive association between slope and soil As (Table 2) in the both confined basins ($r=0.314$, $p<0.001$ and $n=151$ for Madhukhali and $r=0.156$, $p<0.05$ and $n=157$ for Faridpur Sadar) while at Boalmari the relationship was negative and non-significant ($r=-0.029$ ns, $n=192$). Seasonal flood occurs frequently in unconfined basin at Boalmari, as a result occurring the dissolution and remobilization of soil As and washed out from the higher elevation area and accumulate in the lower elevated area. Thus, soil As gradually decreased with the increase in elevation was clearly observed in Boalmari. In case of Madhukhali and Faridpur Sadar, there is no significant relationship between elevation and soil As concentration, might be due to confined basin and less water movement.

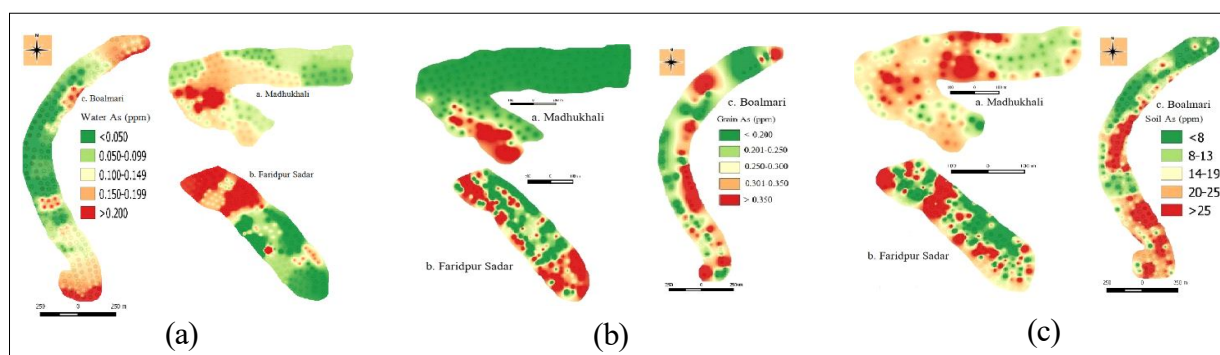


Fig 3: Spatial distribution of (a) irrigation water, (b) soil and (c) grain arsenic concentration at Madhukhali, Faridpur Sadar and Boalmari.

Table 2: Pearson correlation coefficient (r) between soil As of selected sites, topographical variables and irrigation water As concentration.

Variables	r -value		
	Madhukhali	Faridpur Sadar	Boalmari
Water as	0.316***	0.206**	0.039 ^{ns}
Elevation	-0.098 ^{ns}	0.078 ^{ns}	-0.244***
Slope	0.314***	0.156*	-0.029 ^{ns}
Age of STW	0.389***	0.247***	0.182**
Distance from well	-0.109 ^{ns}	-0.204**	-0.121 ^{ns}

*, ** and *** indicate significance at $p < 0.05$, < 0.01 and < 0.001 , respectively.

It was observed from the Table 2 and Fig 4 that, in all three locations, there was a positive correlation between the concentration of soil As and STW water As ($r=0.316$, $p<0.001$, $n=16$, Madhukhali, $r=0.039$ ns, $n=31$, Boalmari and $r=0.206$, $p<0.01$, $n=21$, Faridpur Sadar). That indicate the higher soil As buildup due to higher As containing irrigation water. Similarly, the amount of As in the soil and STW age had a positive correlation (Table 2) at all the sites ($r=0.389$, $p<0.001$, $n=16$, Madhukhali, $r=0.182$, $p<0.001$, $n=31$, Boalmari and $r=0.247$, $p<0.001$, $n=21$, Faridpur Sadar). Over time, using water tainted with As may raise the amount of As in soil (Panaullah *et al.*, 2009). Thus, the amount of As in the soil at each of the three locations was highly associated with the age of STW.

In all the three sites, the soil As concentration was negatively correlated with the distance from well (Table 3) ($r= -0.109$ ns, $n=151$, Madhukhali, $r= -0.121$ ns, $n=192$, Boalmari and $r= -0.204$, $p<0.01$, $n=157$, Faridpur Sadar). In the study areas, As concentrations in the water and As input to soil decrease with distance from the inlet. Similar finding was observed previously (Panaullah *et al.*, 2009). From stepwise multiple linear regression analysis, irrigation water As (estimate 18.87, $p<0.05$), slope (estimate 20.17, $p<0.001$) and year of STW operation (estimate 0.67, $p<0.001$) at Madhukhali; age of STW (estimate 0.30, $p<0.001$) and distance from STW (estimate -0.03, $p<0.01$) at Faridpur Sadar and elevation (estimate -1.68, $p<0.001$) and distance from STW (estimate -0.013, $p<0.05$) at Boalmari, were significant variable in the MLR model (Table 3) that explain 25%, 12% and 8 % of the variability in soil As concentration, respectively. Thus, the MLR model for the soil As concentration will be Soil As (Madhukhali) = $4.78 + 20.17$ (slope) + 18.87 (water As) + 0.67 (age of STW). Soil As (Boalmari) = $44.62 - 1.68$ (elevation) – 0.013 (distance from well). Soil As (Faridpur Sadar) = $13.00 + 0.30$ (age of STW) – 0.03 (distance from well).

Factors affecting rice grain as concentrations

At Madhukhali, where the soil type ranged from medium highland to medium lowland, a definite negative asso-

ciation ($r=-0.426$, $p<0.05$) between the content of As in rice grains and elevation was discovered. On the other hand, no significant relationships were observed at Faridpur Sadar and Boalmari (Table 4 and Fig 5). In general, less As was found at the high elevation areas and high in low elevation areas (discussed previous section). As a result, rice plant subjected to less As uptake at higher elevation zone than the lower elevation zone, thus rice grain As is negatively correlated with changing the elevation at Madhukhali. Opposite findings in Boalmari due to seasonal seasonal flooding and Faridpur Sadar due to narrow elevation range (15.45 - 16.89m).

The rice grain As was positively correlated with slope (Table 4) in all the sites like Faridpur Sadar ($r=0.296$, $p<0.01$), Madhukhali ($r=0.573$, $p<0.01$) and Boalmari ($r=0.107$ ns). In confined basin (Madhukhali and Faridpur Sadar), rice grain As is positively correlated with the slope due to uneven irrigation in upper and lower slope. In unconfined basin (Boalmari), the relationship was positive but non-significance because of flooding effects. Rice grain As was positively correlated with STW water As (Table 4) at

Table 3: Coefficients of significant predictors of multiple linear regression of soil arsenic concentration.

	Estimates	Adjusted R ²
Madhukhali		
Intercept	4.78**	0.25
Slope	20.17***	
Water as	18.87*	
Age of STW	0.67***	
Faridpur Sadar		
Intercept	13.00***	0.12
Age of STW	0.30***	
Distance	-0.03**	
Boalmari		
Intercept	44.62***	0.09
Elevation	-1.68***	
Distance	-0.013*	

*, ** and *** indicate significance at $p<0.05$, <0.01 and <0.001 , respectively.

Table 4: Pearson correlation coefficient (r) between rice grain as and selected site, topographical variables and soil and irrigation water As concentration.

Variables	r -value		
	Madhukhali	Faridpur Sadar	Boalmari
Elevation (m)	-0.426*	0.160 ^{ns}	-0.060 ^{ns}
Slope (o)	0.573**	0.296**	0.107 ^{ns}
Water as (mg L ⁻¹)	-0.035 ^{ns}	0.217*	0.124 ^{ns}
Age of STW	-0.354 ^{ns}	0.203*	0.093 ^{ns}
Distance from STW (m)	0.275 ^{ns}	0.072 ^{ns}	-0.024 ^{ns}
Soil as (mg kg ⁻¹)	0.234 ^{ns}	0.307**	0.123 ^{ns}
Grain Phosphorus (ppm)	-0.024 ^{ns}	-0.243*	0.024 ^{ns}
Soil pH	-0.006 ^{ns}	0.172 ^{ns}	-0.074 ^{ns}

*, ** and *** indicate significance at $p<0.05$, <0.01 and <0.001 , respectively.

Faridpur Sadar ($r=0.217$, $p<0.05$) and Boalmari ($r=0.1274ns$), while negatively correlated at Madhukhali ($r= - 0.035ns$). In Faridpur Sadar (confined basin) the rice grain As concentration was positively correlated with STW water As might be irrigation with high As containing water. On the other hand, due to flooding effect no significant relationship was found in unconfined basin (Boalmari). Rice grain As concentration was positively correlated ($r=0.203$, $p<0.05$) with the age of STW (Table 4) at Faridpur Sadar but there were no significant relationship between rice grain As and age of STW in other two site (Madhukhali and Boalmari). It

might be due to Faridpur Sadar STW water As concentration was higher than the other two sites and time span of irrigation was also higher. Therefore, longer period of time exposure to higher As concentration the rice plant uptake more As and show a positive correlation at Faridpur Sadar. A positive correlation was found (Table 4) between rice grain As and distance from STW in both the confined basin ($r = 0.072ns$, Faridpur Sadar and $r = 0.275ns$, Madhukhali), while negative correlation ($r= - 0.024ns$) was observed at unconfined basin (Boalmari). Distance field from the STW faced combatively lower As containing water and results

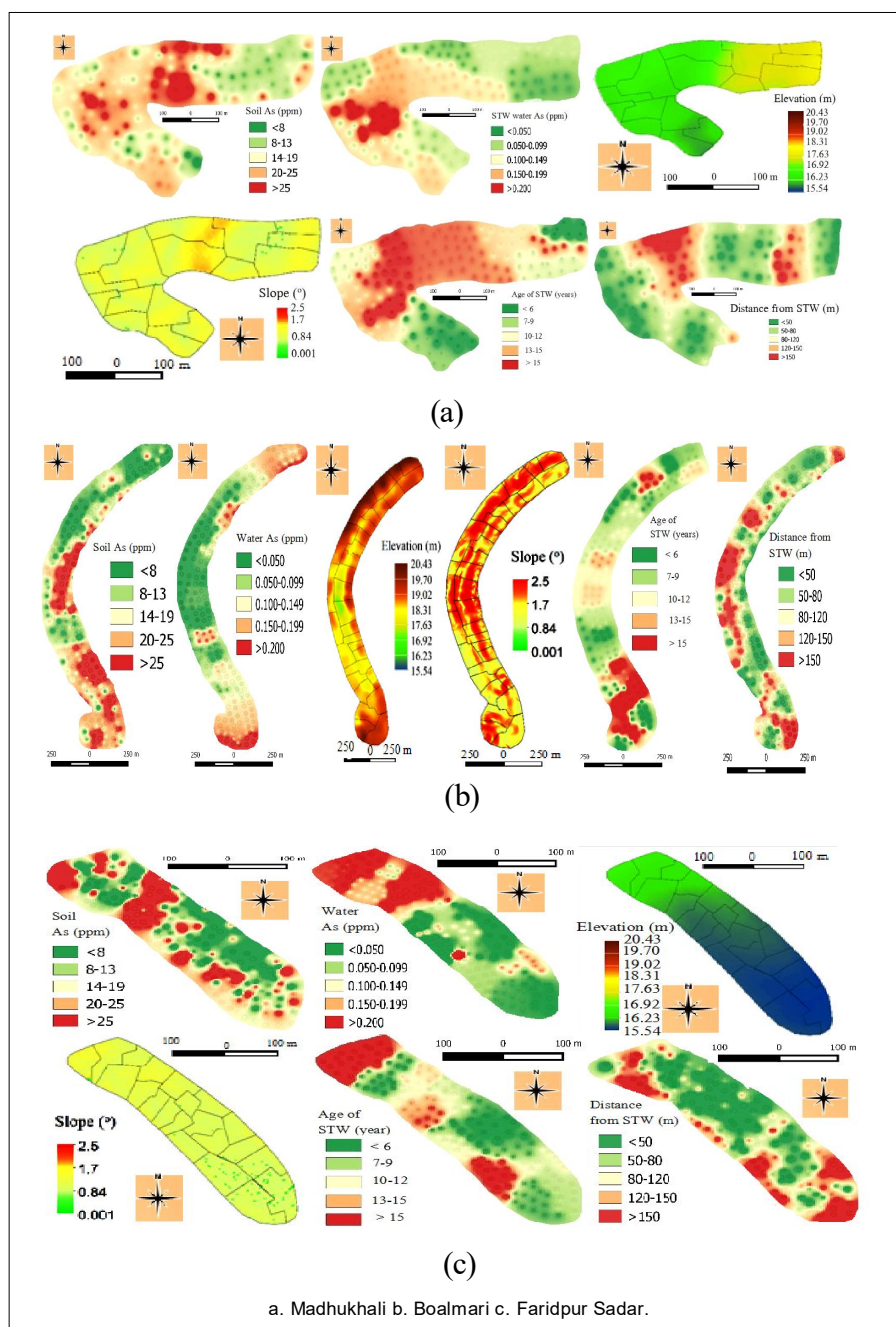


Fig 4: Factors affecting soil arsenic concentration.

the lower uptake by the rice plant and finally rice grain in Boalmari. But there has no significant relationship between rice grain As and distance from STW at Madhukhali and Faridpur Sadar. This deviation occurs might be due to some other dependent factors like rice variety, soil texture, soil P content *etc.* The rice grain As concentration were positively correlated (Table 4) with the soil As concentration in all the three sites *viz.* Madhukhali ($r = 0.234ns$), Faridpur Sadar ($r = 0.307$, $p < 0.01$) and Boalmari ($r = 0.123ns$). Due to the elevated As present in the irrigated water as well as in soil, the rice growing at all the three sites uptake more As from

the soil-water solution and that's why grain As is positively correlated at all the sites.

From stepwise multiple linear regression analysis, slope (estimate 1.188, $p < 0.01$) and water As (estimate 0.147, $p < 0.05$), at Madhukhali; elevation (estimate -1.118, $p < 0.05$), slope (estimate 0.179, $p < 0.05$) and water As (estimate 1.34, $p < 0.05$) at Boalmari and slope (estimate 0.954, $p < 0.001$) and soil As (estimate 0.106, $p < 0.001$) at Faridpur Sadar, were significant variable in the MLR model (Table 5) that explain 24, 9 and 15 % of the variability in soil As concentration, respectively.

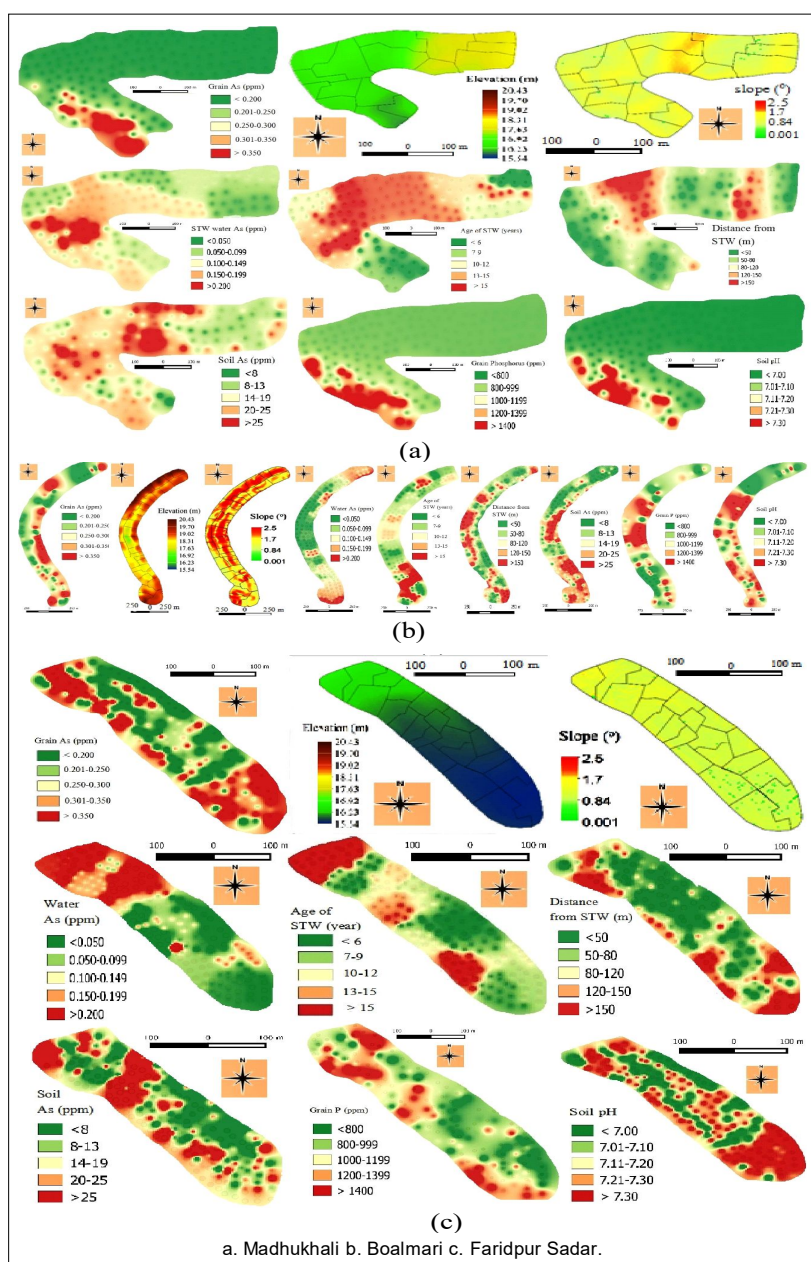


Fig 5: Factors affecting grain arsenic concentration.

Table 5: Coefficients of significant predictors of multiple linear regression of rice grain arsenic concentration.

	Estimates	Adjusted R ²
Madhukhali		
Intercept	0.316***	0.24
Slope	1.188**	
Water as	0.147*	
Faridpur Sadar		
Intercept	0.165***	0.15
Slope	0.954***	
Soil as	0.106***	
Boalmari		
Intercept	2.31**	0.09
Elevation	-1.118*	
Slope	0.179*	
Water as	1.34*	

*, ** and *** indicate significance at $p < 0.05$, < 0.01 and < 0.001 , respectively.

Thus, the MLR model for the rice grain As concentration will be

Rice grain As (Madhukhali) = $0.316 + 1.188 (\text{slope}) + 0.147 (\text{water As})$.

Rice grain As (Boalmari) = $2.31 - 1.118 (\text{elevation}) + 0.179 (\text{slope}) + 1.34 (\text{water As})$.

Rice grain As (Faridpur Sadar) = $0.165 + 0.954 (\text{slope}) + 0.106 (\text{soil As})$.

CONCLUSION

Spatial structure of arsenic distribution in soil and crops were distinctly developed at Madhukhali, moderately at Faridpur Sadar but very weakly developed at Boalmari. It was found that average less As was put a figure on the unconfined basin (Boalmari) compared to other two (Faridpur Sadar and Madhukhali) confined basins sites. As uptake by rice was more in low elevation area where rice plant was exposed to high As contaminated stagnant water. On the other hand, due to washing out of As from higher elevation with the flood water results the comparatively lower As uptake by the rice. Soil As increased substantially in rice fields irrigated by contaminated ground-water, while less amount of As in non-rice crop soil was attributed from less irrigation. Irrigation with elevated As containing water in boro rice definitely increases the As content in soil as well as uptake by the crops.

ACKNOWLEDGEMENT

The authors would like to extend their gratitude to the farmers of the study area for their support and help for collecting the samples.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

REFERENCES

- Akinbile, C.O. and Haque, A. (2012). Arsenic contamination in irrigation water for rice production in Bangladesh: A review. *Trends in Applied Sciences Research*. 7:331.
- Ghritlahre, S.K. and Singh, A. (2022). Arsenic contamination and their effects on leguminous crops and consumers: A review. *Bhartiya Krishi Anusandhan Patrika*. 37: 133-136. doi: 10.18805/BKAP496.
- Ivy, N., Mukherjee, T., Bhattacharya, S., Ghosh, A. and Sharma, P. (2023). Arsenic contamination in groundwater and food chain with mitigation options in Bengal delta with special reference to Bangladesh. *Environmental Geochemistry and Health*. 45: 1261-1287.
- Kabir, M., Rahman, G., Ahmed, Z. and Rahman, M. (2015). Spatial variability of rice grain arsenic in confined and unconfined Basins of Ganges River Floodplain Soils of Bangladesh. *Journal of Environmental Science and Natural Resources*. 8: 51-55.
- Khan, F. (2020). Effect of arsenic on growth, lipid peroxidation and antioxidant defence system in cowpea. *Legume Research- An International Journal*. 43: 200-205. doi: 10.18805/LR-457.
- Mairaj, S., Nagar, R.D., Bhardwaj, L.K., Rehman, F., Punnakal, A., Chauhan, A. and Jindal, T. (2022). Antioxidant responses of arsenite-induced oxidative stress in rice (*Oryza sativa* L.) and its modulation by eugenol (extracted from *Ocimum sanctum*). *Indian Journal of Agricultural Research*. 56: 396-400. doi: 10.18805/IJARE.A-5734.
- Mehmood, T., Bibi, I., Shahid, M., Niazi, N.K., Murtaza, B., Wang, H., OK., Y.S., Sarkar, B., Javed, M.T. and Murtaza, G. (2017). Effect of compost addition on arsenic uptake, morphological and physiological attributes of maize plants grown in contrasting soils. *J. Geochem. Explore*. 178: 83-91.
- Naidu, R., Smith, E., Owens, G. and Bhattacharya, P. (2006). *Managing Arsenic in the Environment: From Soil to Human Health*. CSIRO Publishing.
- Panaullah, G.M., Alam, T., Hossain, M.B., Loeppert, R.H., Lauren, J.G., Meisner, C.A., Ahmed, Z.U. and Duxbury, J.M. (2009). Arsenic toxicity to rice (*Oryza sativa* L.) in Bangladesh. *Plant and Soil*. 317: 31-39.
- Pebesma, E. (2023). The meuse data set: A brief tutorial for the gstat R package. In: Citeseer.
- Sarkar, A., Paul, B. and Darbha, G.K. (2022). The groundwater arsenic contamination in the Bengal Basin-A review in brief. *Chemosphere*. 299: 134369.
- Sarker, A., Kim, J.E., Islam, A.R.M.T., Bilal, M., Rakib, M.R.J., Nandi, R., Rahman, M.M. and Islam, T. (2022). Heavy metals contamination and associated health risks in food webs-a review focuses on food safety and environmental sustainability in Bangladesh. *Environmental Science and Pollution Research*. 29: 3230-3245.
- Smedley, P.L. and Kinniburgh, D.G. (2002). A review of the source, behaviour and distribution of arsenic in natural waters. *Applied Geochemistry*. 17: 517-568.
- SRDI. (2019). Annual Report: Soil Resource Development Institute. Ministry of Agriculture. Pupils Republic of Bangladesh.
- Team, R.C. (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.