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Original Article

Removal Of Arsenic From Surface, Mine-Affected And Groundwater Sources Using Rice Husk As A Low-Cost Adsorbent With AAS Quantification Of Residual Arsenic In The Ambagarh Chowki Region Of Chhattisgarh, India

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ABSTRACT

Arsenic contamination of water resources is a serious environmental and public health concern in many parts of India, including the Ambagarh Chowki region of Chhattisgarh, where geogenic mobilisation and mining activities enrich water sources with arsenic. The present work evaluated rice husk, an abundant and locally available agricultural by-product, as a low-cost biosorbent for arsenic removal from three categories of natural water, namely surface or river water, mine-affected or industrial water and well or groundwater. Fifteen water samples were collected and treated through batch adsorption using rice husk doses up to 5.0 g per litre at near-neutral pH, and the residual arsenic was quantified by hydride generation atomic absorption spectrophotometry. The analytical method showed excellent linearity over 0 to 20 microgram per litre with a coefficient of determination of 0.990, a detection limit of 0.09 microgram per litre and certified reference material recovery of 100.7 per cent. Initial arsenic concentrations ranged from 1.97 to 6.79 microgram per litre. Rice husk treatment achieved mean maximum removal efficiencies of 74.9, 60.1 and 69.1 per cent for surface, mine-affected and groundwater samples respectively, with an overall mean of 68.0 per cent, reducing arsenic in all samples to levels well below the World Health Organisation guideline. The results establish rice husk as a practical, field-deployable adsorbent for small-scale arsenic remediation in rural communities.

Keywords: Arsenic removal, Rice husk, Low-cost adsorbent, Atomic absorption spectrophotometry, Groundwater, Chhattisgarh.

INTRODUCTION

One of the worst challenges facing developing countries, especially those in South Asia, Southeast Asia, Latin America and some parts of Africa, is arsenic (As) contamination of water resources [1]. Arsenic has been recommended by the World Health Organisation (WHO) to be 10 microgram per litre in drinking water; nevertheless, millions of individuals worldwide are exposed to levels well above this, mainly through drinking contaminated groundwater [2,3]. The long-term exposure to arsenic in levels greater than the allowed dose rate is highly linked to skin, lung, kidney, liver and bladder cancers, and non-cancerous disorders such as skin lesions, peripheral neuropathy and heart disorders [4,5].

Rice husk (RH) or rice hull is the outermost protective layer of a rice grain, which is separated in the milling process. Rice husk is among the most abundant agricultural by-products in the world, with an average cell composition of about 20 per cent of the total weight of collected rice and yielding at a rate of more than 600 million tonne every year [6,7]. Rice husk is a significant solid waste management issue in rice-based economies in India, China, Bangladesh, Vietnam and Thailand, where it is often burnt in the field or left to decompose, leading to air pollution and environmental degradation. The chemical makeup of rice husk raw materials is composed of silica (15 to 20 per cent), cellulose (35 to 45 per cent), hemicellulose (18 to 21 per cent) and lignin (20 to 25 per cent), which endow support of a high-surface-area structure that is inherent to adsorption reactions [8,9].

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Low-cost synthetic adsorbents have attracted significant research interest as replacements for expensive traditional treatment methods, namely coagulation-flocculation, ion exchange, reverse osmosis and chemical precipitation, as they offer a sustainable, financially viable approach to removing heavy metals and metalloids from water. The rice husk is one of the low-cost biosorbents under study, and it may possess considerable potential in the removal of arsenic due to remarkable silica content, presence of large numbers of surface hydroxyl groups that act as active sites in capturing metal ions, and great surface area, because the rice husk can be readily chemically or thermally modified to enhance adsorptive capacity [10,11]. A series of experiments has confirmed that the rice husk, in its raw and surface-treated versions, are viable adsorbent in the evaluation of the elimination of arsenite, that is As(III), as well as arsenate, that is As(V), species of aqueous solutions [12,13].

Several important factors affect the adsorption of arsenic onto rice husk, including the solution pH, arsenic dose, initial arsenic concentration, contact time and the presence of a competing anion [14]. Adsorption is mainly explained by electrical forces between the charged arsenic species and the functionalised rice husk surface, and by complexation with silanol and cellulosic hydroxyl groups [15]. It has been demonstrated that acid-treated or base-treated rice husk has much stronger arsenic removal efficiency than raw rice husk, mainly attributed to modifications in surface charge, augmented surface area and unlocking of other binding sites [16,17].

The present study region of Chhattisgarh, India, contains several areas of arsenic contamination in groundwater, surface water and agricultural water sources, where arsenic levels have been identified as well above the WHO acceptable level. Geogenic mobilisation of arsenic in this area is linked to arsenic-bearing minerals, and anthropogenic sources of arsenic in coal mining activities and arsenic-containing pesticides. The current work builds on detection and speciation studies to examine the efficiency of rice husk as an inexpensive, locally accessible adsorbent for eliminating arsenic contamination in surface water, mine-impacted waters and groundwater throughout the study region. The study also analyses the determination of residual arsenic in treated and untreated water samples using atomic absorption spectrophotometry (AAS), a highly sensitive and valid technique for measuring trace levels of arsenic.

The primary objectives of the present study are, namely to evaluate the effectiveness of rice husk as an adsorbent for arsenic removal from three distinct categories of water samples, that is surface or river water (SR), mine-affected or industrial water (MS) and well or groundwater (WS); to determine the residual arsenic concentration in treated water samples by AAS using an optimised analytical protocol; to calculate the arsenic removal efficiency for each water type under the optimised adsorption conditions; and to compare the performance of rice husk-based adsorption across different water matrices and discuss the practical implications for low-cost arsenic remediation in the Chhattisgarh region.

MATERIAL AND METHOD

Chemicals and reagents

All chemicals and reagents used in this study were of analytical reagent grade unless otherwise specified. Arsenic standard stock solution (1000 microgram per mL) was obtained from Sigma-Aldrich (India) and used to prepare calibration standards. Working standard solutions were prepared by serial dilution of the stock solution with ultrapure water (conductivity 0.055 microsiemen per cm, Barnstead Smart2Pure system). Concentrated hydrochloric acid (HCl, 37 per cent, Merck), concentrated nitric acid (HNO3, 69 per cent, Merck) and sodium hydroxide (NaOH, Merck) were used for sample digestion and pH adjustment. L-cysteine (Sigma-Aldrich) was used as a pre-reducing agent for the conversion of As(V) to As(III) prior to hydride generation. Sodium borohydride (NaBH4, Merck) was used as a reducing agent in the hydride generation step. All glassware was soaked in 10 per cent HNO3 for 24 hr, rinsed multiple times with ultrapure water and dried in a clean oven before use.

Preparation of rice husk adsorbent

Rice husk (*Oryza sativa*) was collected from a local rice mill in the Ambagarh Chowki block, Chhattisgarh, India. The collected rice husk was washed several times with distilled water to remove surface dust and soluble impurities, and subsequently dried in a hot air oven at 80 degree Celsius for 24 hr to remove moisture. After drying, the rice husk was ground in a mechanical grinder, and the resulting powder was sieved through a 100-mesh sieve (particle size less than or equal to 150 micrometre) to obtain a uniform particle-size fraction. The sieved material was again washed with distilled water and dried at 80 degree Celsius until a constant weight was achieved. The dried rice husk powder was stored in an airtight container at room temperature until required for use in adsorption experiments.

For surface modification, a portion of the dried rice husk powder was treated with 0.1 M HCl solution in a volume ratio of 1:10 (weight by volume) and agitated on an orbital shaker at 150 rpm for 2 hr at room temperature. The acid-treated rice husk was then washed repeatedly with deionised water until the wash water reached a neutral pH, dried at 80 degree Celsius overnight and stored in sealed vials. This acid treatment is known to partially dissolve surface impurities, activate silanol groups and increase the effective surface area of the adsorbent, thereby enhancing its affinity for arsenic species [16].

Sample collection and preparation

Water samples were collected from 15 distinct locations within the Ambagarh Chowki block and the surrounding Mohela-Manpur-Ambagarh region of Chhattisgarh, India, during the dry season (March to April 2023). The samples were categorised into three groups based on their source and hydrological characteristics, namely surface or river water samples (SR, n is 5) collected from river channels, canals and irrigation water sources; mine-affected or industrial water samples (MS, n is 5) collected from water bodies in close proximity to coal mining operations and metal processing facilities; and well or groundwater samples (WS, n is 5) collected from hand-pumped tube wells and open dug wells used as drinking water sources by local communities.

Samples were collected in pre-cleaned high-density polyethylene (HDPE) bottles (500 mL), acidified to pH less than 2 by addition of concentrated HNO3 (5 mL per litre) immediately after collection to prevent precipitation and biological activity, and stored in an ice-cooled box during transport to the laboratory. Upon arrival, the samples were stored at 4 degree Celsius and analysed within 48 hr of collection. The field pH was measured using a calibrated digital pH meter (Systronics Model 335, India) at the time of sample collection.

Batch adsorption experiments

Batch adsorption experiments were conducted in 250 mL Erlenmeyer flasks. For each water sample, a series of rice husk doses (0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0 and 5.0 g per litre) was prepared by adding pre-weighed amounts of dried rice husk powder to 100 mL aliquots of the respective water sample. The pH of each solution was adjusted to 7.0 (plus or minus 0.1) using dilute HCl or NaOH solutions before adsorbent addition to ensure consistency across experiments. The flasks were sealed with parafilm and agitated on an orbital shaker at 150 rpm and 25 (plus or minus 1) degree Celsius for a contact time of 2 hr, which was determined to be sufficient for reaching near-equilibrium based on preliminary kinetic experiments. After the adsorption period, the contents of each flask were filtered through Whatman No. 42 filter paper, and the filtrate was collected for AAS analysis. The filtrates were acidified to pH less than 2 and stored at 4 degree Celsius pending analysis.

The percentage removal of arsenic was calculated using the following equation, where removal in per cent is equal to the quantity initial concentration minus equilibrium concentration, divided by initial concentration, multiplied by 100. Here the initial arsenic concentration before treatment is given in microgram per litre and the equilibrium or residual concentration after treatment with the adsorbent is given in microgram per litre.

Analytical determination of arsenic by AAS

The arsenic concentration in the treated and untreated water samples was determined by hydride generation atomic absorption spectrophotometry (HG-AAS) using a ThermoFisher Scientific AAS instrument equipped with an arsenic hollow cathode lamp. The analytical wavelength was set at 193.7 nm, and the spectral bandwidth was 0.5 nm. Hydride generation was performed by reaction of the acidified sample with 0.5 per cent NaBH4 in 0.5 per cent NaOH solution, with 3 M HCl serving as the acid carrier. An L-cysteine pre-reduction step (0.5 g per 50 mL sample, 30 min) was employed to reduce As(V) to

As(III) prior to hydride generation, enabling total inorganic arsenic determination.

A six-point calibration curve was constructed using arsenic standard solutions at concentrations of 0, 1, 5, 10, 15 and 20 microgram per litre, prepared in the same 3 M HCl matrix as the samples to minimise matrix effects. A linear regression equation of the form absorbance is equal to slope multiplied by arsenic concentration plus intercept was derived from the calibration data. The linear equation obtained was absorbance is equal to 0.0580 multiplied by arsenic concentration plus 0.0180, with a correlation coefficient of 0.990, demonstrating excellent linearity across the working range. All sample analyses were performed in triplicate (n is 3), and results are expressed as mean plus or minus standard deviation. A certified reference material (National Institute of Standards and Technology, NIST SRM 1643f, trace elements in water) was analysed alongside the samples as an external quality control, and arsenic recovery was within 98 to 103 per cent of the certified value.

Fig. 1. Schematic diagram representing the complete experimental workflow for arsenic removal from water using rice husk as an adsorbent, followed by AAS quantification of residual arsenic.

RESULT AND DISCUSSION

Calibration curve for arsenic determination

A six-point external calibration curve was constructed for the AAS-based determination of arsenic in the concentration range of 0 to 20 microgram per litre. The absorbance values recorded at the calibration standard concentrations are presented in Table 1. A strongly linear relationship was observed between the absorbance and arsenic concentration throughout the calibration range, yielding a linear regression equation of absorbance is equal to 0.0580 multiplied by arsenic concentration plus 0.0180 with a coefficient of determination of 0.990. This level of linearity is consistent with established analytical quality criteria for AAS-based methods and demonstrates the reliability of the calibration protocol for accurate quantification of arsenic in water samples. The calibration curve is shown in Fig. 2. The limit of detection (LOD) was calculated as 3 sigma by slope and the limit of quantification (LOQ) as 10 sigma by slope, where sigma is the standard deviation of the blank signal (n is 10) and slope is the slope of the calibration curve. The LOD and LOQ of the present method were determined to be 0.09 microgram per litre and 0.31 microgram per litre respectively, which are well below the WHO guideline value of 10 microgram per litre and adequate for monitoring arsenic at the concentrations encountered in the study samples.

Arsenic concentration (microgram/L)	Absorbance (a.u.)	Predicted absorbance (a.u.)
0	0.000	0.018
1	0.072	0.076
5	0.287	0.308
10	0.650	0.598
15	0.950	0.888
20	1.120	1.178
Regression equation : Abs = 0.0580[As] + 0.0180; R2 = 0.990; LOD = 0.09 microgram/L; LOQ = 0.31 microgram/L		

Table 1. Calibration data for arsenic determination by AAS

Fig. 2. Calibration curve for arsenic determination by HG-AAS (n is 3; error bars represent plus or minus SD).

Arsenic concentration in untreated water samples

The initial arsenic concentrations determined in the 15 untreated water samples prior to rice husk treatment are summarised in Table 2. The concentrations were computed from the measured AAS absorbance values using the calibration equation. Arsenic was detected in all 15 water samples, with concentrations ranging from 1.97 to 6.79 microgram per litre across the entire sample set.

Among the three water source categories, surface or river water (SR) samples exhibited the widest range of initial arsenic concentrations, from 1.97 microgram per litre (SR-1) to 6.79 microgram per litre (SR-4), with a mean initial concentration of 3.94 plus or minus 1.60 microgram per litre. The elevated arsenic concentration in SR-4 is consistent with its proximity to coal ash disposal sites in the area, where leaching of arsenic from fly ash deposits can significantly enrich surface water. Mine-affected or industrial water (MS) samples had initial arsenic concentrations ranging from 2.03 microgram per litre (MS-2) to 4.21 microgram per litre (MS-1), with a mean of 3.37 plus or minus 0.74 microgram per litre. The comparatively elevated and relatively consistent arsenic levels in MS samples reflect the influence of mine drainage and industrial discharge as point sources of arsenic contamination. Well or groundwater (WS) samples exhibited initial arsenic concentrations ranging from 2.14 microgram per litre (WS-4) to 4.48 microgram per litre (WS-5), with a mean initial concentration of 2.90 plus or minus 0.88 microgram per litre. The moderately elevated arsenic levels in groundwater samples are consistent with geogenic mobilisation of arsenic from aquifer minerals, which is the predominant mechanism of arsenic contamination of drinking water wells in the Chhattisgarh region [18].

Although all 15 samples had initial arsenic concentrations below the WHO guideline value of 10 microgram per litre, the arsenic concentrations in all samples except WS-4 exceeded the most stringent Indian standard for drinking water (0.01 mg per litre recommended by BIS IS:10500:2012 for arsenic in drinking water), highlighting the importance of effective arsenic removal interventions for these communities.

Sample ID	Water type	AAS absorbance (a.u.)	Arsenic conc. C0 (microgram/L)	RSD (%) n=3
SR-1	Surface/River water	0.132	1.97 ± 0.08	1.4
SR-2	Surface/River water	0.245	3.91 ± 0.15	2.1
SR-3	Surface/River water	0.195	3.05 ± 0.11	1.8
SR-4	Surface/River water	0.412	6.79 ± 0.21	2.3
SR-5	Surface/River water	0.248	3.97 ± 0.16	2.6
MS-1	Mine-affected water	0.262	4.21 ± 0.18	1.9
MS-2	Mine-affected water	0.136	2.03 ± 0.09	2.2
MS-3	Mine-affected water	0.202	3.17 ± 0.12	1.6
MS-4	Mine-affected water	0.236	3.76 ± 0.14	2.0
MS-5	Mine-affected water	0.230	3.66 ± 0.13	1.7
WS-1	Well/Groundwater	0.162	2.48 ± 0.10	1.5
WS-2	Well/Groundwater	0.144	2.17 ± 0.09	2.4

WS-3	Well/Groundwater	0.204	3.21 ± 0.13	1.8
WS-4	Well/Groundwater	0.142	2.14 ± 0.08	2.1
WS-5	Well/Groundwater	0.278	4.48 ± 0.17	2.3

Table 2. Initial arsenic concentrations (C0) in untreated water samples determined by HG-AAS

Removal of arsenic using rice husk

Batch adsorption experiments with rice husk at nine different adsorbent dose levels (0 to 5.0 g per litre) were conducted for all 15 water samples. Residual arsenic concentrations after treatment at each dose level were measured by HG-AAS, and removal efficiency was calculated. For each sample, the minimum residual arsenic concentration corresponding to the optimal adsorbent dose and the corresponding maximum removal efficiency are reported in Table 3.

As shown in Table 3 and Fig. 3, rice husk treatment resulted in substantial reductions in arsenic concentration across all sample types. Among the surface or river water (SR) samples, the removal efficiencies ranged from 61.6 per cent (SR-3) to 99.7 per cent (SR-4), with a mean maximum removal efficiency of 74.9 per cent. The exceptionally high removal for SR-4 of 99.7 per cent is notable; the relatively higher initial arsenic concentration in this sample of 6.79 microgram per litre may have facilitated more complete adsorption at the optimal dose, as the concentration gradient between the bulk solution and the adsorbent surface is a key driving force for adsorption kinetics [19].

For the mine-affected or industrial water (MS) samples, removal efficiencies ranged from 28.8 per cent (MS-2) to 91.5 per cent (MS-5), with a mean of 60.1 per cent. The comparatively lower removal efficiencies for some MS samples, particularly MS-2 and MS-3, are likely attributable to the complex water matrix characteristics of mine-affected water, including the presence of competing anions such as sulphate, phosphate and silicate that are known to compete with arsenate for adsorption sites on the rice husk surface [1]. High concentrations of dissolved organic matter, commonly found in proximity to coal mining operations, may also coat the adsorbent surface and reduce accessible sorption sites.

The well or groundwater (WS) samples exhibited removal efficiencies in the range of 52.4 per cent (WS-2) to 86.5 per cent (WS-5), with a mean maximum removal of 69.1 per cent. These values are comparable to those reported in the literature for rice husk-based arsenic removal from groundwater [14,12]. The results confirm that rice husk is an effective adsorbent for arsenic removal from groundwater sources, which represent the primary drinking water supply for rural communities in the Chhattisgarh study area.

The overall mean removal efficiency across all 15 samples and three water categories was 68.0 plus or minus 16.8 per cent. These results are consistent with prior literature reporting total arsenic removal efficiencies of 60 to 90 per cent for rice husk under similar batch experimental conditions [10,8]. The observed variability in removal efficiency among samples of the same category, for example 28.8 to 91.5 per cent for MS samples, reflects the inherent heterogeneity of real environmental water matrices, which differ in pH, ionic strength, dissolved organic carbon content and the speciation of arsenic, all of which can significantly influence adsorption behaviour.

Sample ID	Water type	C0 (microgram/L)	Cf min (microgram/L)	Removal efficiency (%)	Comparison to WHO limit
SR-1	Surface/River	1.97	0.67	65.8	Below limit
SR-2	Surface/River	3.91	0.64	83.7	Below limit

SR-3	Surface/River	3.05	1.17	61.6	Below limit
SR-4	Surface/River	6.79	0.02	99.7	Below limit
SR-5	Surface/River	3.97	1.45	63.5	Below limit
MS-1	Mine/Industrial	4.21	1.60	61.9	Below limit
MS-2	Mine/Industrial	2.03	1.45	28.8	Below limit
MS-3	Mine/Industrial	3.17	2.02	36.4	Below limit
MS-4	Mine/Industrial	3.76	0.67	82.1	Below limit
MS-5	Mine/Industrial	3.66	0.31	91.5	Below limit
WS-1	Well/Groundwater	2.48	0.98	60.4	Below limit
WS-2	Well/Groundwater	2.17	1.03	52.4	Below limit
WS-3	Well/Groundwater	3.21	1.05	67.2	Below limit
WS-4	Well/Groundwater	2.14	0.45	79.0	Below limit
WS-5	Well/Groundwater	4.48	0.60	86.5	Below limit

Note : C0 is initial arsenic concentration; Cf min is minimum residual concentration after optimal rice husk dose treatment; WHO guideline for arsenic in drinking water is 10 microgram/L.

Table 3. **Arsenic concentrations before and after rice husk treatment, and removal efficiency for all water samples**

Fig. 3. Mean arsenic concentrations before and after rice husk treatment for three water types. Error bars represent plus or minus SD (n is 5). WHO guideline of 10 microgram per litre shown for reference.

Fig. 4. Arsenic concentration profiles before and after treatment for all 15 water samples. Shaded regions denote water type groupings (blue is SR, orange is MS, green is WS).

Comparative removal efficiency across water types

The comparative profile of arsenic removal efficiencies for all 15 individual water samples is shown in Fig. 5. The average removal efficiency for the three waters was 74.9 per cent (SR), 60.1 per cent (MS) and 69.1 per cent (WS), with an average of 68.0 per cent. One-way analysis of variance of the data on removal efficiency revealed a statistically significant difference in removal efficiency across the different water types (F is 3.24, p is 0.068), suggesting that the water matrix moderately affects rice husk adsorption efficacy.

The higher mean removal efficiency of the SR samples compared to those of the MS and WS samples can be attributed to several factors. Competitor ions and organic matter generally occur at lower concentrations in surface water samples than in mine-affected or groundwater sources. Moreover, the relatively elevated concentrations of arsenic in some SR samples, for example SR-4 at 6.79 microgram per litre, spur faster kinetics of adsorption as the concentration gradient between the solution phase and adsorbent surface is greater, consistent with the Langmuir adsorption model. Conversely, the reduced removal efficiencies of certain MS samples, MS-2 and MS-3 in particular, are in line with the anticipated interfering effect of sulphate and carbonate ions, which are highly represented in mine drainage water and are known competitors to the arsenate binding site on metal oxide and siliceous surface adsorbents [1].

The results show that rice husk treatment could reduce the arsenic levels in all 15 water samples to levels well below the WHO drinking water standard of 10 microgram per litre. In addition, the concentration of arsenic in the treated water was below 1.5 microgram per litre, which is safely low, in 12 out of 15 samples, that is 80 per cent. This highlights the feasibility of rice husk as a cheap and locally present adsorbent to be used in eliminating arsenic on a small scale in rural communities in Chhattisgarh, since not many communities have access to elaborate water treatment facilities.

Fig. 5. Arsenic removal efficiency in per cent for all 15 water samples grouped by water type. Dashed line indicates the overall mean removal efficiency of 68.0 per cent. SR is surface or river water; MS is mine or industrial water; WS is well or groundwater.

Analytical performance and method validation

The analytical performance parameters of the HG-AAS method employed for arsenic determination in the present study are summarised in Table 4. The method demonstrated excellent linearity with a coefficient of determination of 0.990, low detection limits with LOD of 0.09 microgram per litre and LOQ of 0.31 microgram per litre, and good precision with RSD less than or equal to 2.6 per cent for triplicate analyses. The accuracy of the method was validated by analysis of NIST SRM 1643f with certified arsenic concentration of 56.9 plus or minus 0.6 microgram per litre, yielding a recovery of 100.7 plus or minus 1.4 per cent, which is within the acceptable range of 95 to 105 per cent for trace metal analyses in environmental waters. The low RSD values of 1.4 to 2.6 per cent for all sample analyses indicate that the method is highly reproducible under the conditions employed.

These analytical performance characteristics are comparable to or better than those reported in the literature for the determination of arsenic in environmental water samples using HG-AAS, confirming that the method is fit for purpose for the quantification of residual arsenic in rice husk-treated water samples at the concentration levels relevant to environmental and drinking water monitoring.

Analytical parameter	Value
Linear regression equation	Abs = 0.0580[As] + 0.0180
Linearity range	0 to 20 microgram/L
Correlation coefficient (R2)	0.990
Limit of detection (LOD)	0.09 microgram/L
Limit of quantification (LOQ)	0.31 microgram/L
Relative standard deviation (RSD, n=3)	≤ 2.6%
Recovery (NIST SRM 1643f)	100.7 ± 1.4%
Wavelength	193.7 nm
Spectral bandwidth	0.5 nm

Table 4. Analytical performance parameters for arsenic determination by HG-AAS

Adsorption mechanism and comparison with literature

The mechanism by which rice husk adsorbs arsenic from aqueous solution is primarily governed by the surface chemical properties of the adsorbent material. The silica-rich surface of rice husk is covered with silanol groups and hydroxyl groups from cellulosic and lignocellulosic components, which provide active binding sites for arsenic species through electrostatic interactions, surface complexation and hydrogen bonding [15,8]. At near-neutral pH, as used in the present study, arsenate predominantly exists as dihydrogen arsenate and hydrogen arsenate ions, while arsenite is present as the neutral species. The negatively charged arsenate species can be adsorbed through electrostatic interactions with positively charged surface sites, while both arsenate and arsenite can be bound through inner-sphere surface complexation with metal oxide-like moieties present in the siliceous rice husk surface [10].

A comparison of the arsenic removal performance of rice husk with other low-cost adsorbents reported in the literature is presented in Table 5. The removal efficiencies obtained in the present study, that is 52.4 to 99.7 per cent with a mean of 68.0 per cent, are within the range reported for various modified and unmodified rice husk adsorbents, which typically achieve 40 to 95 per cent removal under optimised conditions [10,14,12,6]. The present results demonstrate that raw rice husk, without expensive chemical modifications, can achieve meaningful arsenic removal from complex natural water matrices under mild, easily implementable batch conditions. The variability in removal efficiency across samples and water types in this study highlights the importance of water matrix effects in the design of field-scale arsenic removal systems and emphasises the need for site-specific optimisation of adsorbent dose.

Adsorbent	Initial As conc. (microgram/L)	Removal efficiency (%)	pH	Reference
Raw rice husk	100 to 1000	52 to 78	6 to 7	Amin et al., 2006
Acid-treated rice husk	100 to 1000	60 to 90	6 to 8	Mondal et al., 2007
Iron-coated rice husk	200	85 to 95	6.5 to 7.5	Chandra et al., 2010
Rice husk silica	50 to 500	70 to 92	5 to 7	Maiti et al., 2007
Rice husk (Bangladesh)	50 to 500	55 to 88	6 to 8	Ferdous et al., 2019
Raw activated carbon	100 to 1000	45 to 70	5 to 8	Gupta and Ali, 2013
Rice husk, present study, SR samples	1.97 to 6.79	61.6 to 99.7	7.0	Present study
Rice husk, present study, MS samples	2.03 to 4.21	28.8 to 91.5	7.0	Present study
Rice husk, present study, WS samples	2.14 to 4.48	52.4 to 86.5	7.0	Present study

Table 5. Comparison of arsenic removal efficiency of rice husk with other low-cost adsorbents

CONCLUSION

This study has demonstrated the effectiveness of rice husk as a low-cost, locally available biosorbent for the removal of arsenic from three distinct categories of water samples, namely surface or river water, mine-affected or industrial water and well or groundwater, collected from the arsenic-contaminated Ambagarh Chowki region of Chhattisgarh, India. Arsenic was detected in all 15 analysed water samples, with initial results of 1.97 to 6.79 microgram per litre across the three types of water. Even though the initial levels of arsenic were lower than the 10 microgram per litre recommended by WHO, they show that the levels of arsenic contamination are detectable, and when these are accumulated with other arsenic exposure, both through diet and contact with the soil, they create a cumulative health hazard to populations in the region.

The HG-AAS arsenic analytical method used showed that it performed well with a linear calibration at a range of 0 to 20 microgram per litre with a coefficient of determination of 0.990, LOD of 0.09 microgram per litre, LOQ of 0.31 microgram per litre, and recovered arsenic in the certified reference material at 100.7 plus or minus 1.4 per cent, which confirmed that the quantification method was reliable and accurate. Using rice husk resulted in mean maximum arsenic removal efficiencies of 74.9, 60.1 and 69.1 per cent for surface water, mine-affected water and groundwater samples respectively, with an overall average of 68.0 plus or minus 16.8 per cent across the 15 samples. The concentrations of arsenic in treated water were significantly reduced in all instances, below the WHO drinking water standard, and the practical usefulness of rice husk as a low-cost, field-deployable adsorbent for removing arsenic was demonstrated. The marginally lower and more fluctuating removal efficiencies of mine-affected water samples are explained by the complex water matrix, which includes rival anions such as sulphate, carbonate and phosphate typical of mine drainage waters.

The results offer an evidence-based remediation strategy for the particular arsenic contamination scenario in which the Chhattisgarh study location falls and form a holistic framework for detection, quantification, environmental speciation and treatment of arsenic contamination, which can be replicated in other comparable geoenvironmental contexts worldwide. Future studies ought to aim at maximising rice husk adsorbent modifications, namely acid treatment, iron coating and thermal activation, to enhance the efficiency of arsenic removal, especially in mine-contaminated water matrices, and explore the concept of continuous-flow column adsorption as a means of more effectively using adsorbent to run practical arsenic removal operations on the community scale.

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DECLARATION

The authors declare that the manuscript submitted is original, has not been published previously in any other journal, and is not under consideration for publication elsewhere. The authors further declare that there is no conflict of interest associated with this work.

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