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CURRENT STATUS OF ARSENIC CONTAMINATION IN DRINKING WATER AND TREATMENT PRACTICE IN SOME RURAL AREAS OF WEST BENGAL, INDIA

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The aim of the present investigation was to draw the current scenario of arsenic (As) contamination in drinking water of community tube well and drinking water treated by tube wells installed with different adsorbent media-based treatment plants in districts Nadia, Hooghly and North 24-Parganas districts, West Bengal, India. As removal efficiencies of different treatment plants varied from 23 to 71%, which is largely governed by adsorption capacity of adsorbent and influencing environmental factors. Though investigated treatment plants removed substantial amount of As from tube well water, high As concentration in treated drinking water was retained after passing through the treatment plants. This high level of As concentration in tube well water and retention of high As concentration in treated drinking water were severe for the consumers which therefore, indicating the improvement of removal efficiency of treatment plant by meticulously considering favorable influencing factors or/and application of other high capacity treatment alternatives to adsorb the excess As retained in drinking water and regular monitoring of As concentration in the treated drinking water are indispensable.

Keywords: arsenic, community tube well, drinking water, contamination, treatment plant.

Introduction

Arsenic (As), a naturally occurring element in the earth's crust, is highly toxic metalloid posing serious threat to human health and environment [1, 2] especially in the Gangetic belt of India and Bangladesh during the last few decades. It causes Arsenicosis symptomized by multisystem disorders including predominant manifestations of cutaneous effects [3]. The United States Environmental Protection Agency (USEPA) has identified As as a group A "known" carcinogen. Drinking water rich in As over a long period leads to As poisoning known as arsenicosis manifests with the development of symptoms hyperpigmentation, skin cancer, kidney damage, liver cancer, circulatory disorders, and other ailments [4, 5].

Arsenic enters into soil and contaminates the groundwater by geogenic (weathering of rocks and minerals) reactions/process [6] and anthropogenic (discharge of As content industrial and agricultural wastes) effects [7] followed by subsequent leaching and runoff effects. Various geochemical factors (Red-ox potential (Eh), adsorption/desorption, precipitation/dissolution, As speciation, pH, presence and concentration of competing ions, biological transformation, etc.) in the aquifer control the release and concentration of As in groundwater. Consequently, different domains on earth have infested by As contamination in groundwater which has been envisaged as a global environmental problem.

As a precautionary measure, the USEPA promulgated the new As rule that lowered the maximum contaminant level (MCL) in drinking water to 10 μg/L (10 ppb) for both community and non-transient, non-community water systems (http://www.epa.gov/safewater/arsenic. html). Therefore, it is most important to adopt strategies for achieving the safe concentration of As in drinking water. Among several improved and innovative methods, reverse osmosis, precipitation, coagulation, ion exchange, solvent extraction, adsorption, membrane filtration and ultra-filtration employed [8 – 14], adsorption has been emerged as an promising technique to remove As from contaminated water using the various adsorbent medias like – iron oxide, activated alumina, clay mineral, ceramic, etc.

In India, since the groundwater As contamination was first surfaced from West-Bengal in 1983. It is well conceived that the Bengal Delta Plain (BDP) is currently confronted with elevated level of As in groundwater [15, 16] and prolonged consumption of such contaminated groundwater has led to wide spread As related health problems [17]. The government and several non government organizations implemented various strategies and treatment methods to treat As contaminated groundwater in order to supply As free drinking water for the peoples inhabiting in BDP. Application of artificial recharging (i.e., Groundwater oxygenation and recharge into the same aquifer) and adsorbent media-based small treatment plant with hand operated community tube well are common to treat the contaminated water in rural area of West Bengal, India.

It appears that though various technologies/devices have been introduced to remove the As from drinking water, it is far from inadequate and not satisfactory from the public health point of view. With this information in backdrop, the present investigation was undertaken to draw the current scenario of As level in drinking water of some tube wells of BDP and to assess the practical performance of the small As contaminated water treatment plants installed in some As contaminated community tube wells of Nadia, Hooghly and North 24-Parganas in BDP, West Bengal, India.

Experimental

Study area and sampling. Thirty four water samples from hand operated community tube wells (depth 150 – 200 ft) of the As contaminated predetermined seven village areas of three districts, Nadia (22°41′23″ N and 72°51′24″ E) (22 samples; 1 – 22), Hooghly (22°89′56″ N, 88°40′25″ E) (6 samples; 23 – 28) and North 24-Parganas (22°53′00″ N, 88°33′00″ E) (6 samples; 29 – 34) in West Bengal, India were collected in March, 2013 for examining the current status of As concentration from drinking water sources of tube well. A large number of village people (100 to 150 people/tube well) are depended on these tube wells everyday for drinking water.

With a view to provide As free drinking water to the villagers, a number of organizations installed the various adsorbent media-based small As treatment plants with the hand operated community tube wells to treat the As contaminated water and supply the As free drinking water.

The preliminary survey revealed that four types of adsorbent media-based treatment plants namely, Anir Engenderers (AE, Activated Al_2O_3), Pal Trockner (PT, MnO + Silica gel + gravel + sand), Ion Exchange (IE, resin) and Amal Filter (AF, Activated Al_2O_3) are prevalent in the district of Nadia, West Bengal, India.

The performance of different treatment plants installed with the tube wells were compared among different tube wells by monitoring the As content of treated drinking water from these sources and As removal efficiency was then determined. For this purpose, the water samples were collected from two sources – inlet (I, representing the background drinking water of each tube well) and outlet (O, representing the treated drinking water of each tube well) of four types of treatment plants (samples herein called as AEI and AEO for Anir Engenderers, PTI and PTO for Pal Trockner, IEI and IEO for Ion exchange, AFI and AFO for Amal Filter). The three tube wells of each type of treatment plant installed in three different locations in the study area were considered as three replicates and mean of three values was used for assessment.

Sample analysis. The 50 ml water samples were acidified by hydrochloric acid and analyzed by using flame atomic absorption spectrometry (VARIAN, AA 240) to determine the As content of tube well water. The As concentration of water was calculated and expressed as milligram per litre (mg/L). The physico-chemical properties such as, temperature, pH, oxidation reduction potential, total dissolved solid, salinity and conductivity were measured by PCS Tester 35 multi-parameters and dissolved oxygen was recorded by HQ40d ("Eutech Instruments Pte Ltd", Singapore). The concentration of bicarbonate alkalinity, hardness, organic carbon, ammonium-N, nitrite-N, nitrate-N and orthophosphate and iron (Fe) content in water samples were analyzed using the standard methods described by APHA [18].

Statistical analysis. The correlation studies of obtained data were performed by EXCEL. The means of removal efficiency were compared following the one way analysis of variance (ANOVA) and least significance difference (LSD) using the statistical package (EASE, M-STAT). The accepted level of statistical significance was at $p < 0.05$.

Results and discussion

The As content of water varied from 0.019 to 0.309 mg/L, 0.023 to 0.081mg/L and 0.030 to 0.050 mg/L in investigated villages of Nadia, Hooghly and North 24-Parganas, respectively. The concentration of As was highly variable in all water samples collected from three districts of West Bengal (Fig. 1). Results of the investigation showed that the As concentration (0.019 – 0.309 mg/L) of tube well water samples of Nadia district was higher compared to that of the remaining two (Hooghly and North 24-Parganas) districts (0.023 – 0.081 mg/L) examined. The maximum As concentration (0.309 mg/L) found in Nadia district was 6.18 times higher than the the permissible limit set by Indian Standards for drinking water (0.05 mg/L) and 30 times higher than WHO Standards (0.01 mg/L). Banerjee and Ghosh observed high variability of As concentrations in the groundwater ranging from <0.03 to 0.231 mg/L in the different sites of Nadia during the study period of 2005 – 2006 [16]. On the other hand, the level of As in drinking water determined in 2013 in the present study was higher than in 2005 – 2006. It appears that As level of drinking water in the region is on rising over the period of time. This is perhaps due to alteration in geochemical reactions influenced by changing anthropogenic driven geochemical factors causing As invasion (i.e., As contamination) to the neighboring new areas in the districts. Therefore, the health hazardous problems caused by As contaminated drinking water have quantitatively augmented in the villagers of investigated areas especially in Nadia district. In this respect, it is worth mentioning that ground water As contamination was significantly detected in 1983 in West Bengal, India, when some village people were diagnosed to be suffering from disease "Arsenicosis" due to drinking of As contaminated water. Presently, the ground water contamination with As is now widespread in 79 blocks (areas) in 8 districts especially in Nadia, 24 Parganas, Malda, Murshidabad and Burdwan of West Bengal. It has assumed that about 6 billion people are exposed to As contaminated ground water (> 0.05 mg/L) [19].

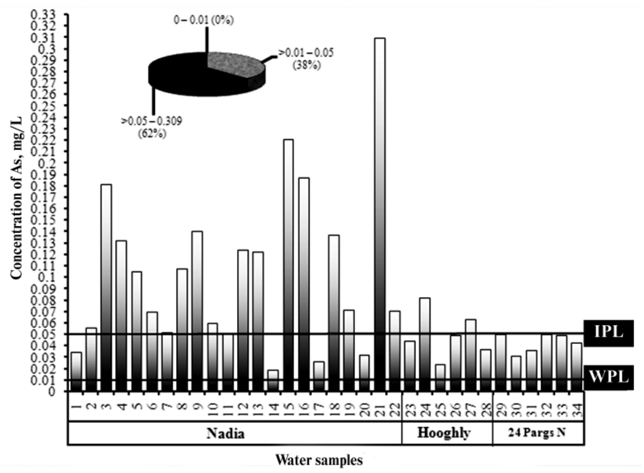

Fig. 1. Arsenic concentration in drinking water of community tube wells investigated (Inset representing the frequency distribution of As concentration) (24 Pgs N, North 24-Parganas; IPL, Indian permissible limit for As; WPL, WHO permissible limit for As).

Of 22 samples of Nadia districts, the As concentration in about 77% of the samples tested (17 tube wells) were about 40 to 518% higher than the Indian recommended permissible limit of As for drinking water (0.05 mg/L). Following the same criterion, the As content in drinking water procured from 2 tube wells in the district of Hooghly was higher, whereas all the tube wells examined in the district of North 24-Parganas appeared to have no As contamination.

Frequency distribution of As content in drinking water samples revealed that about 62% of all the samples examined had higher concentration classes (> 0.05 – 0.309 mg/L; i.e., > Indian recommended permissible limit of As for drinking water) that occurred exclusively in the district of Nadia, whereas lower (0 – 0.01 mg/L; i.e., ≤ WHO recommended permissible limit of As for drinking water) and moderate (>0.01 – 0.05 mg/L; i.e., between > WHO and ≤ Indian recommended permissible limit of As for drinking water) occurred by 0% and 38%, respectively in Nadia, Hooghly and North 24-Parganas see (see Fig. 2). It is obvious that majority of tube wells used for supply of drinking water in the district of Nadia are heavily contaminated with highly risk level of As which has also been claimed by some researchers earlier [3, 15, 17]. Furthermore, from the above results, it may be proposed that people are getting slowly poisoned by intaking high rate of As through drinking water.

It is illustrated in Fig. 2 that the people in the highest As contaminated area drink 5 l 0.309 mg/L As containing drinking water/d, the amount of As ingested by a people/d would be about 1.54 mg. Intake of such high amount of As for prolonged period would cause various health hazards in people. As a consequence, the people suffer from skin lesion, chronic lung disease, chronic cough and bronchitis in the investigated areas [17, 20 – 22]. Arsenic toxicity may also cause paresthesia and abdominal pain, chronic diarrhoea, hepatomegaly, ascites and non-pitting edema of the limbs in a large number of people in West Bengal and Bangladesh [17, 23, 24]. The epidemiological study in Nadia district also revealed a gender difference with males being more sufferers than females [17]. As accumulates in hair, skin and nails, resulting in strong pigmentation of hands and feet (i.e., keratosis), high blood pressure, and cardiovascular, respiratory, endocrine, neurological and metabolic dysfunctions/disorders [25, 26].

The variations in physico-chemical properties of water samples collected from investigated community tube well were shown in Table. Temperature and pH ranged from 24.8 to 28°C and 6.4 to 7.6 in all samples investigated. The concentration of dissolved oxygen is nearly zero (0 – 2.01 mg/L) with few exceptions and oxidation reduction potential (72.6 – 146 mv) also showed the lower value. Both the parameters revealed the anoxic environment and reducing condition of groundwater. The values of total dissolved solid, salinity and conductivity ranged from 344 to 560 mg/L, 240 to 378 mg/L, and 481 to 785 μs/cm, respectively. The bicarbonate alkalinity (290 – 504 mg/L), hardness (140 – 356 mg/L), organic carbon (3.6 – 16.2 mg/L), orthophosphate (0.05 – 1.40 mg/L) and ammonium-N (0.01 – 1.0 mg/L) also varied markedly in different samples, whereas no marked variation in the concentrations of nitrite-N (0 – 0.05 mg/L) and nitrate-N (0 – 0.003 mg/L) were pronounced among the samples investigated. The concentration of iron (Fe) ranged from 0.01 to 4.28 mg/L in all samples examined. No strong correlation was found

Physico-chemical parameters of water samples of community tube wells investigated in Nadia, Hooghly and North 24-Parganas

Samples		Parameters														
		T, °C	pH	DO	ORP	TDS	Sal	Cond	BA	Hard	OC	OP	NH_4N	NO_2N	NO_3N	Fe
Nadia	1	27.9	6.6	0	133.3	467	321	658	440	356	16.2	0.08	0.74	0.002	0	1.42
	2	27.5	7	0	140.1	487	334	690	458	312	15	1.4	0.9	0.002	0	0.91
	3	25.4	7.2	0	144.7	417	281	589	372	196	11.4	0.23	0.84	0.003	0	1.34
	4	24.8	7.5	1.32	124.7	422	290	596	398	216	12.6	0.29	1.03	0.002	0	4.28
	5	24.9	7.2	0	72.6	377	260	535	290	168	16.2	0.28	0.23	0.002	0	0.08
	6	27.9	7.2	0	82.3	344	240	481	314	224	6.6	0.11	0.22	0.003	0	0.22
	7	26	7.3	1.66	146	467	313	658	426	148	10.8	0.17	0.01	0.002	0.003	0.02
	8	26.3	7.5	0	138.8	350	244	503	302	140	11.4	0.92	0.69	0.002	0	1.04
	9	26.5	7.2	0	139.2	412	300	555	356	204	12.6	0.28	0.02	0.002	0	0.19
	10	24.8	7.4	0	143.1	470	322	651	410	224	7.2	0.32	0.74	0.003	0	0.1
	11	25.6	7.6	0	139	560	378	785	504	348	4.8	0.46	1	0.002	0	0.15
	12	26	7.4	0	140	356	242	501	312	180	10.8	0.5	0.99	0.003	0	0.06
	13	25.7	7.6	0	146	470	288	491	388	188	3.6	0.55	0.6	0.003	0	0.85
	14	28	6.6	2.01	149	344	221	485	310	260	11	0.28	0.66	0.007	0	2.21
	15	28	6.8	1.72	138	356	248	531	432	228	8.6	0.09	0.28	0.009	0	1.04
	16	28	6.7	1.5	134.2	421	288	590	501	304	4.5	0.05	0.07	0.003	0.002	0.03
	17	26.8	6.9	1.09	143.5	461	315	652	467	140	3.6	0.05	0.58	0.005	0	0.24
	18	26	7	1	122	450	314	647	480	264	3.8	0.008	0.21	0.05	0.001	0.02
	19	27	6.7	1.5	134.2	616	288	590	294	240	3.8	0.13	0.63	0.01	0	0.53
	20	28	7	2	145	421	445	490	364	276	6	0.05	0.22	0.02	0.002	0.01
	21	27	7.1	1.7	146	360	242	507	478	188	7.8	0.11	0.15	0.009	0	0.93
	22	27.9	7	0	132.9	452	310	632	417	236	11	0.08	0.49	0.024	0.002	0.06

Table. Cont.

Hooghly	23	26	7.1	0	147.1	438	297	619	485	172	13	0.11	0.04	0.01	0	0.1
	24	27	7.4	1.5	145.6	485	338	695	357	256	4	0.19	0.45	0.007	0	1.03
	25	24.8	7.2	1.3	146	395	378	562	321	196	1.9	0.67	0.98	0.007	0	0.31
	26	27	7.2	0	145	468	318	662	480	192	10.8	0.09	0.26	0.07	0	0.17
	27	27.7	7.1	0	144.1	435	301	624	391	144	6	0.11	0.22	0.007	0	1.5
	28	26.8	7.1	0	146	445	304	487	471	200	12.7	0.12	0.04	0.02	0.001	2
North 24-Parganas	29	25.7	6.8	1	143	444	369	675	400	349	13.2	0.07	0.65	0.045	0	4.1
	30	27	7.2	0	146	542	309	764	370	321	7.8	0.06	0.041	0.04	0	3.04
	31	27.5	7.4	2	140.3	467	278	569	367	220	8.2	0.086	0.03	0.02	0.003	3.1
	32	24.9	6.6	0	144	356	358	580	435	324	7.7	1.1	0.7	0.01	0	4
	33	26	7	0	139	487	267	710	479	310	9.8	0.9	0.28	0.04	0	1.98
	34	23	7.4	0	140	390	311	481	420	216	6.5	0.07	0.3	0.1	0	2.3

Note. DO, dissolved oxygen (mg/L); ORP, oxidation reduction potential (mv); TDS, total dissolved solid (mg/L); Sal, salinity (mg/L); Cond, conductivity (μs/cm); BA, bicarbonate alkalinity (mg/L); Hard, hardness (mg/L); OC, organic carbon (%); OP, orthophosphate (mg/L); NH_4N, ammonium-N (mg/L); NO_2 N, nitrite-N (mg/L); NO_3 N, nitrate-N (mg/L); Fe, Iron (mg/L).

between the As concentration of water and other parameters (pH, $r = 0.066$; oxidation reduction potential, $r = -0.1$; conductivity, $r = -0.028$; salinity, $r = -0.444$; Fe, $r = -0.154$; orthophosphate, $r = -0.107$; ammonium-N, $r = -0.091$; nitrite-N, $r = -0.222$; nitrate-N, $r = -0.086$) investigated.

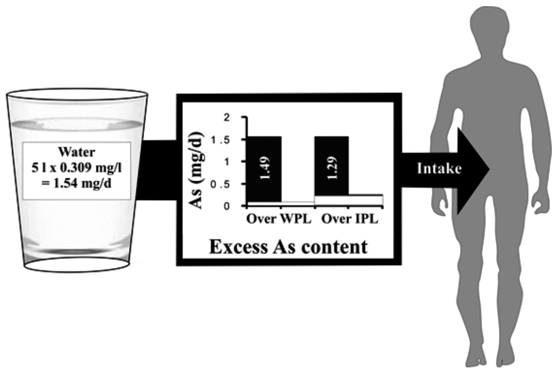

Fig. 2. Excess As intake (compared to IPL and WHO of As for drinking water) of a people drinking with 5 L/d 0.309 mg/L As containing drinking water.

The results also revealed the remarkable variation in As removal and removal efficiencies in different adsorbent media-based treatment plants investigated (Fig. 3). The removal efficiencies of AE (42%), PT (71%), IE (23%) and AF (42.5%) differ significantly from each other (ANOVA, $p < 0.05$). The results also suggested that though investigated treatment plants function effectively with sufficient removal efficiency, the As concentration of the treated water of different treatment plants is still higher than the recommended permissible limit of As for drinking water, which is high risk for human health and environment (see Fig. 3). However, the As removal efficiency of PT (Pal Trockner) treatment plant was higher (71%) compared to that of the remaining three treatment plants. It signifies that Pal Trockner treatment plant having the MnO, Silica gel, gravel and sand as adsorbents media is relatively better in treating As contaminated water. Various adsorbent medias have been used by a number of scientist to remove As from aqueous phase efficiently [27 – 31]. Though, arsenite [As(III)] and arsenate [As(V)] species are not analyzed, it may be assumed that oxidation of As(III) to As(V) is responsible for showing the greater As removal efficiency in some treatment plants. Besides, it should be mentioned here that the removal efficiency of a treatment plant largely depends on the As concentration of influent water, adsorption capacity of media, retention/contact period of water with adsorbent, amount of adsorbent, length of filter, and other various interacting environmental factors. Absorption process is greatly influenced by the various factors of adsorbent and adsorbate [32, 33].

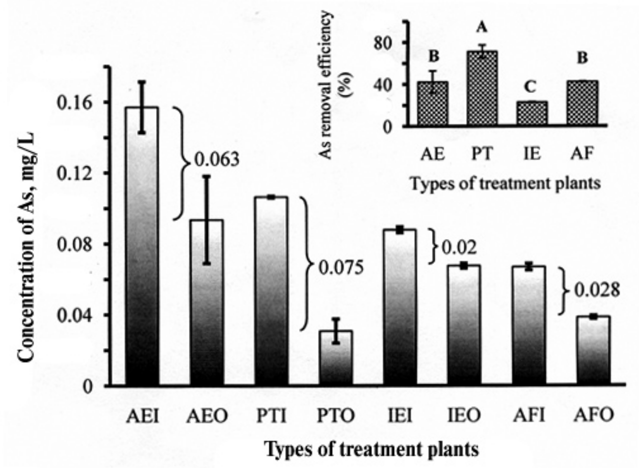

Fig. 3. Arsenic removal (third bracket with values) of different adsorbent media-based As treatment plants installed with community tube wells investigated. Inset showing the As removal efficiencies of different treatment plants (Scripts (A, B and C) over bars of inset indicate the difference of removal efficiency).

Conclusions

It is concluded that majority of the community tube wells are contaminated with remarkably high concentration of As especially in the district of Nadia. Though investigated treatment plants removed substantial amount of As from tube well water, higher concentration of As still retained in treated drinking water compared to the Indian (0.05 mg/L) and WHO (0.01 mg/L) permissible limits of As for drinking water. It, therefore, clearly indicating the incapability of treatment plants in treating such highly As contaminated drinking water. Consequently, this high level of As concentration in tube well water and retention of high As concentration in treated drinking water posing severe threat to public health that should be consider in order to avoid the severe human health hazardous impacts. Therefore, (i) improvement of removal/adsorption capacity of investigated treatment plants and/or (ii) installation of high capacity treatment plants and/or (iii) consideration of other such high capacity treatment alternatives are indispensable to mitigate this problem in order to provide safe As free drinking water to the people. Summarily, the maintenance of high rate As removing influencing factors to improve the efficiency of treatment plant and/or consideration of other high capacity treatment alternatives to achieve the permissible limit of As concentration by removing the higher amount of As from drinking water and regular monitoring of As concentration in the treated drinking water are urgently indispensable in order to mitigate such tremendous problem and to save the rural people from the dreaded human health hazardous impacts of As.

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References

[1] *Hemond H.M., Solo-Gabriele H.F.* // Risk Anal., 2004, **24**, N1, P. 51 – 64.

[2] *Murphy B.L., Toole A.P., Bergstrom P.D.* // Env. Geochem. Health, 1989, **11**, N3/4, P. 163 – 169.

[3] *Sengupta S.R., Das N.K., Datta P.K.* // Indian J. Dermatol. Venereol. Leprol., 2008, **74**, N6, P. 559 – 570.

[4] *National* academy of Sciences, Arsenic-Medical and Biological Effects of Environmental Pollutants, Washington: US Government Printing Office, 1977.

[5] *National* Research Council, Arsenic in Drinking Water, Washington: National Acad. Press, 1999.

[6] *Robertson F.N.* // Environ. Geochem. Health., 1989, **11**, N3/4, P. 171 – 185.

[7] *Gupta S.K., Chen K.Y.* // J. Water Pollut. Cont. Fed., 1978, **50**, N3, P. 493 – 506.

[8] *Barer R.M.* Zeolites and clay minerals as sorbent and molecular sieves, New York: Acad. Press, 1987.

[9] *Bailey S.E., Olin T.J., Brica R.M., Adrin D.D.* // Water Res., 1999, **33**, N11, P. 2469 – 279.

[10] *Kentish S.E., Stevens G.W.* // Chem. Eng. J., 2001, **84**, N2, P. 149 – 159.

[11] *Barron-Zambrano J., Laborie S., Vier M. et al.* // Desalination, 2002, **144**, N1, P. 201 – 206.

[12] *Hunsom M., Pruksathorn K., Damronglerd S. et al.* // Water Res., 2005, **39**, N4, P. 610 – 616.

[13] *Pacheco S., Tapia J., Medina M., Rodriguez R.J.* // Non-Crystalline Solids, 2006, **352**, N52/54, P. 5475 – 5481.

[14] *Roy P., Mondal N.K., Bhattacharya S. et al.* // Appl. Water Sci., 2013, **3**, N1, P. 293 – 309.

[15] *Rahman M.M., Mandal B.K., Chowdhury T.R. et al.* // J. Environ. Sci. Health, A, 2003, **38**, N1, P. 25 – 59.
[16] *Banerjee R., Ghosh A.R.* // Ecology, Environ. and Conserv., 2010, **16**, N2, P. 221 – 227.
[17] *Guha Mazumder D.N., Ghosh A., Majumdar K.K. et al.* // Indian J. Community Med., 2010, **35**, N2, P. 331 – 338.
[18] *APHA.* American Water Works Association and Water Pollution Control Federation, Standard Methods for the Examination of Water and Wastewater. – New York: Amer. Public Health Assoc., 1995.
[19] *IARC* (World Health Organization) // IARC Monograph on the Evaluation of Carcinogenic Risks to Humans, 2004, **84**, P. 271 – 441.
[20] *Guha Mazumder D.N., Haque R., Ghosh N. et al.* // Int. J. Epidemiol, 2000, **29**, P. 1047 – 1052.
[21] *Guha Mazumder D.N., Ghosh N., De B.K. et al.* // Epidemiol. Study on Various Non Carcinomatous Manifestations of Chronic Arsenic Toxicity in a District of West Bengal // Eds. C.O. Abernathy, R.L. Calderon, W.R. Chappell. Oxford, UK: Elsevier Sci., 2001, P. 153 – 164.
[22] *Mukherjee S.C., Rahman M.M., Chowdhury U.K. et al.* // J. Environ. Sci. Health, A, 2003, **38**, P. 165 – 183.
[23] *Rahman M.M., Sengupta M.K., Ahamed S. et al.* // Clin. Toxicol. (Phila), 2005, **43**, P. 823 – 834.
[24] *Mukherjee S.C., Saha K.C., Pati S. et al.* // Ibid, 2005, **43**, P. 835 – 848.
[25] *Yunus M., Sohel N., Hore S.K. et al.* // J. Medical Sci., 2011, **27**, P. 371 – 376.
[26] *Jiang J.-Q, Ashekuzzaman S.M., Jiang A. et al.* // Int. J. Environ. Res. Public Health, 2013, **10**, N1, P. 18 – 46.
[27] *Gulledge J.H., O'Connor J.T.* // J. Amer. Water Works Assoc., 1973, **65**, P. 548 – 552.
[28] *Altundogan H.S., Altundogan S., Tumen F., Bildik M.* // Waste Management, 2002, **22**, N3, P. 357 – 363.
[29] *Jeong Y., Maohong F., Singh S. et al.* // Chem. Eng. Proc., 2007, **46**, N10, P. 1030 – 1039.
[30] *Hussam A., Ahamed S., Munir A.K.M.* // Technol. Clean Water, 2008, **38**, N3, P. 14 – 23.
[31] *Bhakta J.N., Munekage Y.* // Int. J. Environ Sci. Technol., 2013, **10**, N2, P. 315 – 324.
[32] *Bhakta J.N., Munekage Y.* // Int. J. Environ. Res., 2011, **5**, N3, P. 585 – 594.
[33] *Liu R., Lu Y., Shen X. et al.* // J. Nanosci. Nanotechnol., 2013, **13**, N4, P. 2835 – 2841.

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