ARSENIC REMOVAL FROM GROUND WATER BY ION EXCHANGE RESIN: A COLUMN STUDY

A thesis submitted towards partial fulfilment of the requirements
for the degree of

Master of Engineering in
Water Resources and Hydraulic Engineering
Course affiliated to Faculty of Engineering &Technology
Jadavpur University

Submitted by

SUPRIYA GHOSAL

Examination Roll No– M6WRP22002

Registration Number-150275 Of 2019-20

Under The Guidance Of

Prof. (Dr.) PANKAJ KUMAR ROY

Director & Professor

School Of Water Resources Engineering,

Jadavpur University

School of Water Resources Engineering
M.E. (Water Resources & Hydraulic Engineering)
Course affiliated to
Faculty of Engineering and Technology
Jadavpur University
Kolkata-700032, India
2022

CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled ''**ARSENIC REMOVAL FROM GROUND WATER BY ION EXCHANGE RESIN: A COLUMN STUDY**'' is bonafede work carried out by Supriya Ghosal under our supervision and guidance for partial fulfilment of the requirements for the Post Graduate degree of Master of Engineering in Water Resources & Hydraulic Engineering during the academic session 2019-2022 in the department of School of Water Resources Engineering, Jadavpur University, Kolkata – 700032.

DIRECTOR
Prof. (Dr.) Pankaj Kumar Roy
School of Water Resources Engineering
Jadavpur University
Kolkata – 700032

THESIS ADVISOR
Prof. (Dr.) Pankaj Kumar Roy
School of Water Resources Engineering
Jadavpur University
Kolkata – 700032

DEAN
Faculty of Interdisciplinary Studies, Law & Management
Jadavpur University
Kolkata – 700032

M.E. (Water Resources and Hydraulic Engineering) Course affiliated to
Faculty of Engineering and Technology
Jadavpur University
Kolkata – 700032, India

CERTIFICATE OF APPROVAL**

This foregoing thesis is hereby approved as a credible study of an Engineering subject carried out and presented in a manner satisfactorily to warranty its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for the purpose for which it has been submitted.

Committee of final examination for thee valuation of the thesis

** Only in case the thesis is approved.

Declaration of Originality and Compliance of Academic Ethics

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of my Master of Engineering degree in Water Resources & Hydraulic Engineering, Jadavpur University during the academic session 2019-22.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by these rules and conduct, I have fully cited and referred all materials and results that are not original to this work.

Name : **Supriya Ghosal**

Roll No : **M6WRP22002**

Thesis Title : ARSENIC REMOVAL FROM GROUND WATER BY ION EXCHANGE RESIN: A COLUMN STUDY

Date:

Place: S.W.R.E, Jadavpur University

Supriya Ghosal

ACKNOWLEDGEMENT

I express my sincere gratitude to my Thesis Advisor **Prof. (Dr.) Pankaj Kumar Roy** under whose valuable guidance this work has been carried out. It would have been impossible to carry out this thesis work with confidence without his wholehearted involvement, advice, support and constant encouragement throughout. He has not only helped me to complete my thesis work but also have given valuable advice to proceed further in my life.

I also express my thankfulness to Saurabh Kumar Basak, Senior Research Fellow, Priyabrata Mondal Senior Research Fellow, Swetasree Nag, Senior Research Fellow and Sudipa Halder, Senior Research Fellow, Poulami Ray Junior Research Fellow of School of Water Resources Engineering, Jadavpur University for their support throughout the study.

Thanks are also due to all staff of School of Water Resources Engineering and the Regional Centre, NAEB, Jadavpur University for their help and support.

Last but not the least; I am also grateful to my parents and my friends for their earnest support.

Date: Supriya Ghosal

Place: JADAVPUR UNIVERSITY Roll No.: **M6WRP22002**

CONTENTS

Chapter 1 Introduction and Arsenic Scenario

Chapter 2: Objective and Scope of Work

Chapter 3: Literature Review Work

Chapter 4: Different Technique of Arsenic Removal Technology

Chapter 5: Water Quality parameter

Chapter 6: Experimental Setup at Laboratory Scale

Chapter 7: Discussion of Study

Chapter 8: Conclusion Of Study

Chapter 9: Reference

Appendix A

List of Abbreviations

ppb	parts per billion
mm	millimeter
mg/l	milligram per litre
g/l	gram per litre
DD	Double Distilled
TDS	Total dissolved solids
As	Arsenic
BIS	Bureau of Indian Standard
ml	millilitre
WHO	World Health Organization
EC	Electrical Conductivity
Fe	Iron
EPA	Environmental Protection Act

Appendix B

List of Figures

Appendix C

List of Tables

ABSTRACT

Arsenic contamination in groundwater and its consequences to the human health has been reported as one of the world's biggest natural groundwater calamity to the mankind. People in these affected states have chronically exposed to drinking Arsenic contaminated hand tube-wells water. One of the urgent steps towards mitigation of arsenic contamination in groundwater is supply of arsenic free or arsenic safe water**.** The source of arsenic is geological. The contamination mostly comes from aquifers 20-80 meters below ground. The polluted water has high iron, magnesium and bi-carbonates with low sulphate, fluoride and chloride levels. Some factors like malnutrition, poor economic/socio conditions, illiteracy, and food habits with constant use of arsenic-contaminated water for prolonged periods have aggravated Arsenic toxicity. Various technologies have been used to remove arsenic from the water, such as adsorption, ion exchange, reverse osmosis, co-precipitation, lime softening (V), oxidation-reduction, and solidification/liquid separation and physical exclusion. . Long-term exposure to arsenic in drinking water causes bladder, lung, and skin cancers. Arsenic (As) pollution in water (groundwater) is one of the world's most pressing environmental issues. So Objective of this study was to prepare a filtering media to treat ground water containing arsenic to reduce as per WHO drinking water standard for Arsenic (10µg/L). Basically this filter is a slow sand filter. Different filter beds of gravel, sand, Anionic resin used as filtering bed through which spiked water samples of arsenic were allowed to pass in down-flow mode. From the observations it was found that Anionic Resin is good filter media to adsorb arsenic, giving 98% to 93% removal.

ARSENIC REMOVAL FROM GROUND WATER BY ION EXCHANGE RESIN: A COLUMN STUDY

CHAPTER 1

INTRODUCTION

ARSENIC REMOVAL FROM GROUND WATER BY ION EXCHANGE RESIN: A COLUMN STUDY

1.0 INTRODUCTION:

Arsenic is the 20th most prevalent natural element in the earth's crust. Albertus Magnus discovered it for the first time in 1250 AD. It naturally exists in pure elemental form as a solid crystalline metalloid structure that is grey and exhibits properties of both metals and non-metals. It can change its oxidation state and can exist in four different forms: As0 (arsenic), As+3 (arsenite), As-3(arsine) and As+5(arsenate). When this element reacts with other elements in the geochemical cycle, it transforms into a white or colourless, tasteless, and odourless element compound that is difficult to detect (Shakoor et al 2018). In general, arsenic in water can exist as trivalent arsenite (As (III)) as a non-ionic substance or as pentavalent arsenate (As(V), depending on pH and redox potential. It has been widely used in various industries, including agriculture, electronics, cattle, medicine, metallurgy, etc. In the past, a 1% solution of potassium arsenite had employed to treat numerous disorders such as asthma, chorea, eczema, malaria, psoriasis, and syphilis (Shaji et al 2021). Since the late 18th century, arsenic trioxide has been utilised as an effective chemotherapeutic agent for treating acute promyelocytic leukaemia and used in Ayurveda, Homeopathy, and Traditional Chinese Medicine. As a result, both the inorganic forms, As (III) and As(V), are poisonous. As a result, it is critical to remove arsenic from water resources to make drinking water safe for human consumption (Bhardwaj et al 2019). Arsenic exposure is linked to cardiovascular disease, diabetes, peripheral neuropathy, and peripheral vascular (Blackfoot) disease and has a specific effect on the reproductive system. Long-term exposure to arsenic in drinking water causes bladder, lung, and skin cancers. Arsenic (As) pollution in water (groundwater) is one of the world's most pressing environmental issues. According to WHO and BIS, the permitted limit for drinking water in India is 10µg/L (Gautam 2014).

1.1 General Chemistry of Arsenic

Arsenic is a very redox-sensitive element and its mobility and speciation are highly controlled by pH and Eh (redox potential) of the groundwater. Arsenic is stable in four oxidation states (+5, +3, 0, -3) under the normal Eh conditions in aquatic systems, but the predominant forms are inorganic oxyanions of trivalent arsenite (As3+) or pentavalent arsenate (As5+) (Mazumder and Dasgupta 2011). The toxicity of different arsenic species varies in the order arsenite, arsenate, monomethylarsonate, dimethylarsinate. Trivalent arsenic is about 60 times more toxic than arsenic in the pentavalent state, and inorganic arsenic compounds are about 100 times more toxic than organic arsenic compounds (Rehman et al 2021).

Most of the groundwater samples from the nine most affected districts of West Bengal contain very high concentrations of arsenic, dissolved iron, ammonium, phosphate and very Low concentrations of sulfate and nitrate reflecting the reducing condition of groundwater. Arsenic may derive from reductive dissolution of iron and manganese (oxy) hydroxide and Microbial oxidation of organic matter (Adeloju et al 2021).

Arsenic (As) is a gray, brittle, semi-metal element that is odorless and tasteless. Arsenic (As) is the third element in Group VA of the periodic table. Arsenic (As) has an atomic number of 33, an atomic weight of 74.92, and valences of 3 and 5 (Raval and Kumar 2021). The average abundance of As in the earth’s crust is 1.8ppm; in soils it is 5.5 to 13 ppm; in streams it is less than 2µg/L, and in groundwater it is generally less than 100µg/L. It occurs naturally in sulfide minerals such as pyrite. Arsenic is used in alloys with lead, in storage batteries, and in ammunition. Arsenic compounds are widely used in pesticides and in wood preservatives (Singh et al 2021).

Arsenic is nonessential for plants but is an essential element in several animal species. Arsenic has four oxidation states, -3, 0, 3 and 5. The oxidized states, As (III) and As (V), are known as Arsenite and Arsenate, respectively (Shakya and Ghosh 2018). Aqueous arsenic in the form of arsenite, arsenate, and organic arsenicals may result from mineral dissolution, industrial discharges, or the application of pesticides. The chemical form of arsenic depends on its source i.e. inorganic arsenic from minerals, industrial discharges, and pesticides; organic arsenic from industrial discharges, pesticides, and biological action on inorganic arsenic (Das and Bezbaruah 2021).

The valence and species of inorganic arsenic are dependent on the oxidation-reduction conditions and the pH of the water.

Table-1.1Properties of arsenic

Parameter	**Value**
Atomic Number	33
Atomic Weight	74.92158
Melting Point(Gray Form)	814°C at 36 atm
Boiling Point	616°C
Oxidation Number	(-)3, 0, (+)3, (+)5

Arsenate exists in four forms in aqueous solution based on pH:

H_3AsO_4, $H_2AsO_4^-$, $HAsO_4^{2-}$, and AsO_4^{3+}.

Similarly, arsenite exists in five forms:

$H_4AsO_3^+$, H_3AsO_3, $H_2AsO_3^-$, $HAsO_3^{2-}$, and AsO_3^{3-}.

1.2 Sources of Arsenic Contamination

Currently, environmental arsenic problems have been identified and documented in several nations worldwide over various geological and climatic settings. Arsenic is a natural mineral in the soil and rocks, natural waters, and organisms mobilize into the environment through natural biogeochemical changes and anthropogenic activities. Accordingly, the sources of arsenic contamination in groundwater discussed below could be categorized into natural or geogenic and anthropogenic in origin (Mukherjee et al 2021).

The source of arsenic is geological. The contamination mostly comes from aquifers 20-80 meters below ground. The polluted water has high iron, magnesium and bi-carbonates with low sulphate, fluoride and chloride levels (Yadav et al 2021). Some factors like malnutrition, poor economic/socio conditions, illiteracy, and food habits with constant use of arsenic-contaminated water for prolonged periods have aggravated Arsenic toxicity. Various technologies have been used to remove arsenic from the water, such as adsorption, ion exchange, reverse osmosis, co-precipitation, lime softening (V), oxidation-reduction, and solidification/liquid separation and physical exclusion (Das et al 2021). These are expensive methods in general and so not affordable in rural areas. Many emerging pollutants like toxic heavy metals, industrial and pharmaceutical waste, drugs, agricultural pollutants, etc., are troublesome for the aquatic environment and human life, which can be removed by the various eco-friendly, sustainable, and energy-efficient technologies.

1.3 Natural Sources.

In nature, arsenic is frequently located in the local bedrocks as a significant essential of more than 200 minerals including elemental arsenic, arsenates, arsenides, arsenites, oxides, and sulfides; the most abundant and common mineral being, arsenopyrite (FeAsS) It is also commonly found in deposits of cadmium, cobalt, copper, gold, iron, lead, mercury, nickel, phosphorus, silver, sulfur, zinc, etc arsenic from these natural sources could get introduced into drinking water as a consequence of many geochemical processes (Goren and Kobya 2021). The probable mechanisms considered responsible for arsenic contamination by natural means could be oxidation of arsenic-bearing sulfides, desorption from oxides and hydroxides, reductive dissolution, evaporative concentration, leaching from sulfides by carbonate, and microbial mobilization Such situations have been reported in arsenic-contaminated areas such as Bangladesh, West Bengal (India), and regions of China In India, the Ganges-Brahmaputra river system covering the states of North-eastern India which has several types of arsenic sediment depositions illustrate these mechanisms. Besides this, many arsenic bearing sediments in Bengal delta plain, namely, Bihar mica belt, pyrite bearing shale, Gondwana coal seams, Son valley gold belt, etc., have also been identified. In general, the surface waters are relatively more susceptible than groundwater to contamination in the area of such geothermal systems (Yeo et al 2021; Mondal et al 2021).

1.4 Anthropogenic Sources

The human activities or interferences which contribute toward the contamination by arsenic together constitute the anthropogenic sources and account for arsenic emissions of almost 30,000 tons per year into the atmosphere (Ali 2022). Such anthropogenic sources include arsenic-based pesticides, cigarettes, cosmetics, crop desiccants, dyes, herbicides, electronic manufacturing, mining operations, paints, pharmaceuticals, processing of wastes, poultry and swine feed additives, smelters, vitamin supplements, wood preservations, and mining operations. The essential contributing factors responsible for anthropogenic contamination are coal burning and the leaching of metals from coal-ash tailings. The Status of Arsenic Remediation in India 223 emitted by the volatilization of arsenic trioxide during coal burning, condenses in the flue system and ultimately gets transferred into water reservoirs. In the North-eastern regions of India, coal combustion has been reported as one of the significant sources of anthropogenic arsenic discharge into the environment (Ali et al 2004).

Besides these factors, extreme groundwater exploitation, such as lowering the groundwater level due to deep digging of wells, is also a critical cause of arsenic contamination in groundwater (Mohanty 2017). During such a process, the groundwater is replaced by oxygen, because of which the arsenic sulphides oxidize, and the resultant compound is highly soluble in water and contaminates the water. This situation has been observed in West Bengal due to Boro irrigation, which has caused considerable arsenic contamination in drinking water and food (rice). Although the extent of groundwater arsenic contamination by anthropogenic sources is much less than by natural sources, their contribution could not be left unattended (Jha et al 2017).

1.5 Status of Arsenic Contamination in Water: Worldwide Scenario

There is no doubt that the contamination of water by arsenic has developed into a pain throughout the world. This issue of global concern is a significant setback in the provision of safe drinking water to millions of people. It causes several health risks to human beings (Mukherjee et al 2012). Globally, about a 150million–200million people are exposed to unsafe levels of arsenic in the drinking water. The contamination of groundwater with arsenic has been reported in many countries, including Argentina, China, Japan, Thailand (southern), and parts of the United States (such as Alaska, Arizona, California, Idaho, Indiana, Missouri, Nevada, New Hampshire, Ohio, Washington, and Wisconsin), Myanmar, Chile, Taiwan, etc. However, in South Asian countries, namely Bangladesh, Cambodia, India, and Vietnam, the problem of arsenic contamination in groundwater is extreme (Roy et al 2015). The United States Environmental Protection Agency (US EPA) and Agency for Toxic Substances and Disease Registry (ATSDR) rank arsenic at the top of the US Priority List of Hazardous Substances. According to the World Health Organization (WHO) guidelines for drinking water, the current permissible arsenic concentration is 10µg/L previously set to be 50µg/L. In Australia, this value has been set up to the most stringent value of 7µg/L, whereas, in many developing countries, the arsenic standard of 50µg/L in drinking water is still followed, and due to this probably, several potential instances of arsenic contamination might have remained unreported (Moreira et al 2021). A substantial increase in the number of people affected globally from arsenic contamination of drinking water above 50µg/L has been observed from approximately 130-200 million people from 2001 to 2012. Among the Asian countries, groundwater arsenic contamination is worst in Bangladesh and India (West Bengal) and has been called the most significant mass poisoning of a population in history. In both these nations, the arsenic source is principally geogenic (alluvial and deltaic aquifers), and the majority of the population depends on tube wells for the water supply. It has been reported that about 42.7-79.9 million people in Bangladesh and India are exposed to contaminated groundwater with concentrations above 50µg/L In 2006, as written by the United Nations Children's Fund (UNICEF), approximately six million people were exposed to arsenic levels of between 50 and 3200µg/L in West Bengal (Perez et al 2021).

Fig: 1.1 Status of Arsenic Contamination in Water: Worldwide Scenario ((*source* - http://arsenic.pro4mation.com))

1.6 Status of Arsenic Contamination in Water: Indian Scenario

It is now known that among the millions of people from India endangered by the prospect of consuming arsenic-contaminated water at levels greater than 10µg/L, more than 95% are from West Bengal. Arsenic contamination in groundwater in West Bengal was first reported in 1978. which in the current scenario has reached an alarming situation with levels above 50µg/L, and the fear is that their numbers could grow exponentially. The various states in India have been found affected by arsenic groundwater contamination (Islam et al 2021).

Currently, it is estimated that in West Bengal only, approximately a 26million people are presently at risk of drinking arsenic-contaminated water above 10µg/L. According to the reports of the School of Environmental Studies (SOEs), Jadavpur University (Mondal et al 2022), India, based on arsenic concentrations, West Bengal could be categorized into three zones:

(i) highly affected nine districts (Malda, Murshidabad, Nadia, North-24-Parganas, South-24-Parganas, Bardhaman, Howrah, Hoogly, and Kolkata, mainly on the eastern side of Bhagirathi River) with an average arsenic load greater than 50µg/L (up to 300µg/L) in tube wells;

(ii) mildly affected five districts (in the northern part) where the average arsenic load in tube wells is below 50µg/L and arsenic-safe five districts (mostly 3µg/L) in the western region.

Besides West Bengal, various other states, namely Bihar, Jharkhand, Uttar Pradesh in the flood plain of the Ganga River; Assam and Manipur in the flood plain of the Brahmaputra and Imphal rivers and Rajnandgaon village in Chhattisgarh state, have chronically been exposed to drinking arsenic-contaminated tube-well water above 50µg/L. The primary reason for them being arsenic-affected states is that they are located in the basin of the highly arsenic-contaminated water of the rivers: Ganga and Brahmaputra (Israel et al 2009).

It is estimated that around 67 blocks from 15 districts are endangered to arsenic contamination in groundwater, covering more than 1600 habitats across the state with limits exceeding the permissible value of 50µg/L as specified by BIS for safe drinking water. The affected areas of this state include Begusarai, Bhagalpur, Bhojpur, Buxar, Darbhanga, Katihar, Khagaria, Lakhisarai, Munger, Patna, Samastipur, Saran, and Vaishali (Mondal et al 2006).

Another arsenic-affected groundwater state lies in the Indo-Gangetic basin in Uttar Pradesh (UP). The most affected areas are Ballia, Gazipur, and Varanasi districts. Other regions of UP that reported alarming situations are Ambedkar Nagar, Bahraich, Bareli, Basti, Bijnaor, Chaudauli, Faizabad, Gorakhpur, Kanpur, Lakhimpur Kheri, Meerut, Sant Ravidas Nagar, Shahjahanpur, Siddarth Nagar, Sitapur, and Unnao (Kobya et al 2011). In these regions, the reported range of arsenic in water lies between 2.0 -1310µg/L, but in districts like Ballia and Kheri, a higher degree is 4800–6300µg/L detected. In section Ballia, the arsenic concentration in the drinking waters has significantly increased over the past few years and has become an issue of grave concern (Melin et al 2006). Elevated levels of arsenic in groundwater with serious health problems have also been reported from 17 villages of the Sahibgunj district of Jharkhand state, in the middle Ganga plain and Rajnandgaon district Chhattisgarh (Nasorallahi et al 2021). Also, nearly 60% of groundwater sources such as dug wells, ponds, and naturally occurring spring water on which most people rely in North-Eastern regions of India are contaminated with arsenic, at concentrations much higher than the WHO and BIS guidelines. In a study conducted by the North-Eastern Regional Institute of Water and Land Management (NERIWALM), 20 out of 24 districts of Assam have been reported with arsenic content in water exceeding 50µg/L. Other majorly affected North-Eastern states include Tripura, Manipur, Nagaland, and Arunachal Pradesh. According to the NERIWALM, the concentration of arsenic in water in North-Eastern states lies in the range of 50–3200µg/L, alarming for human health (Dey et al 2014).

Besides these states, other Indian states, such as Haryana, Madhya Pradesh, Punjab, Rajasthan, etc., have also been recognized as regions affected by arsenic in drinking water resources. Among these, the groundwater in Punjab, mainly the alluvial plains of the southwest region of Sutlej, including the Bhatinda district, has been affected by arsenic contamination. Considerable health risks have been observed in the population of the Bhatinda district, and elevated levels of arsenic in the groundwater ranging between 5 - 688µg/L have been reported. In fact, in India, the cases of arsenic toxicity due to arsenic-contaminated drinking water were first reported from Chandigarh in early 1976. Studies from Punjab of Pakistan province also highlight arsenic contamination in drinking water (Moreira et al 2021).

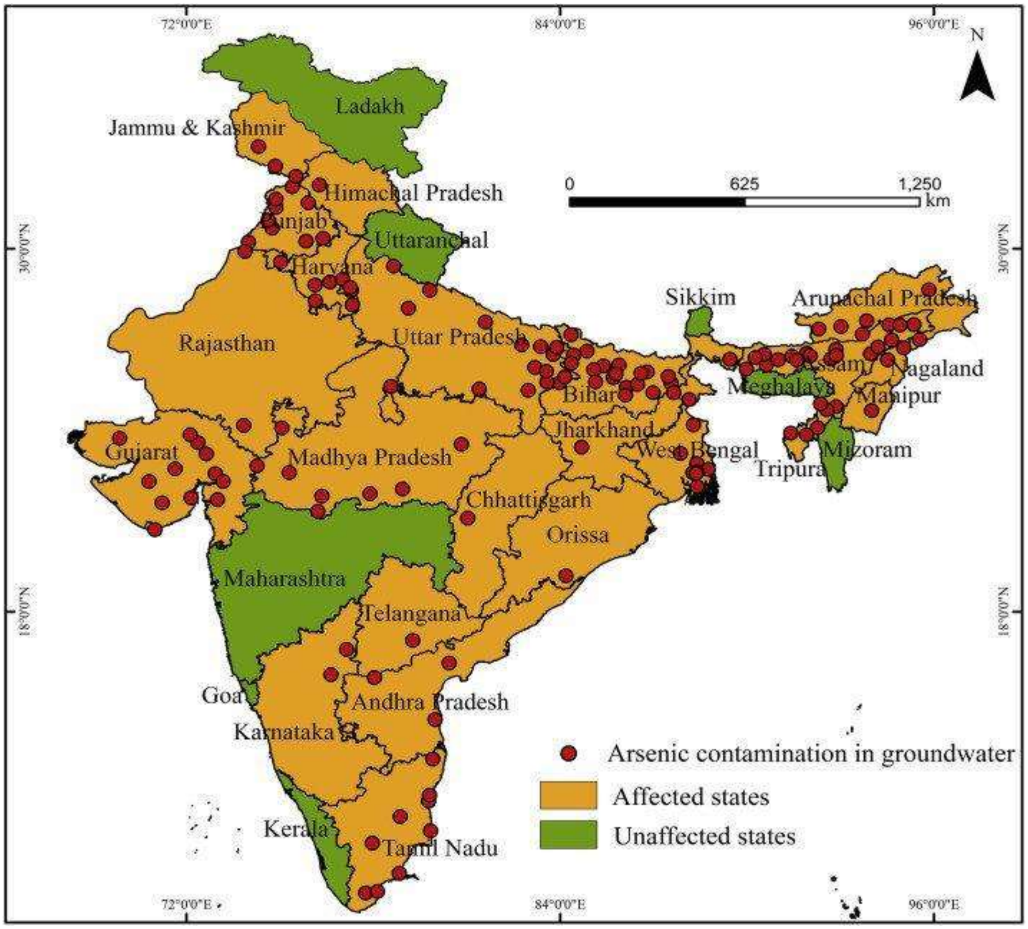


Fig: 1.2 Status of Arsenic Contamination in Water, Indian (Source www.researchgate.net)

1.7 Status of Arsenic Contamination in Water: West Bengal Scenario

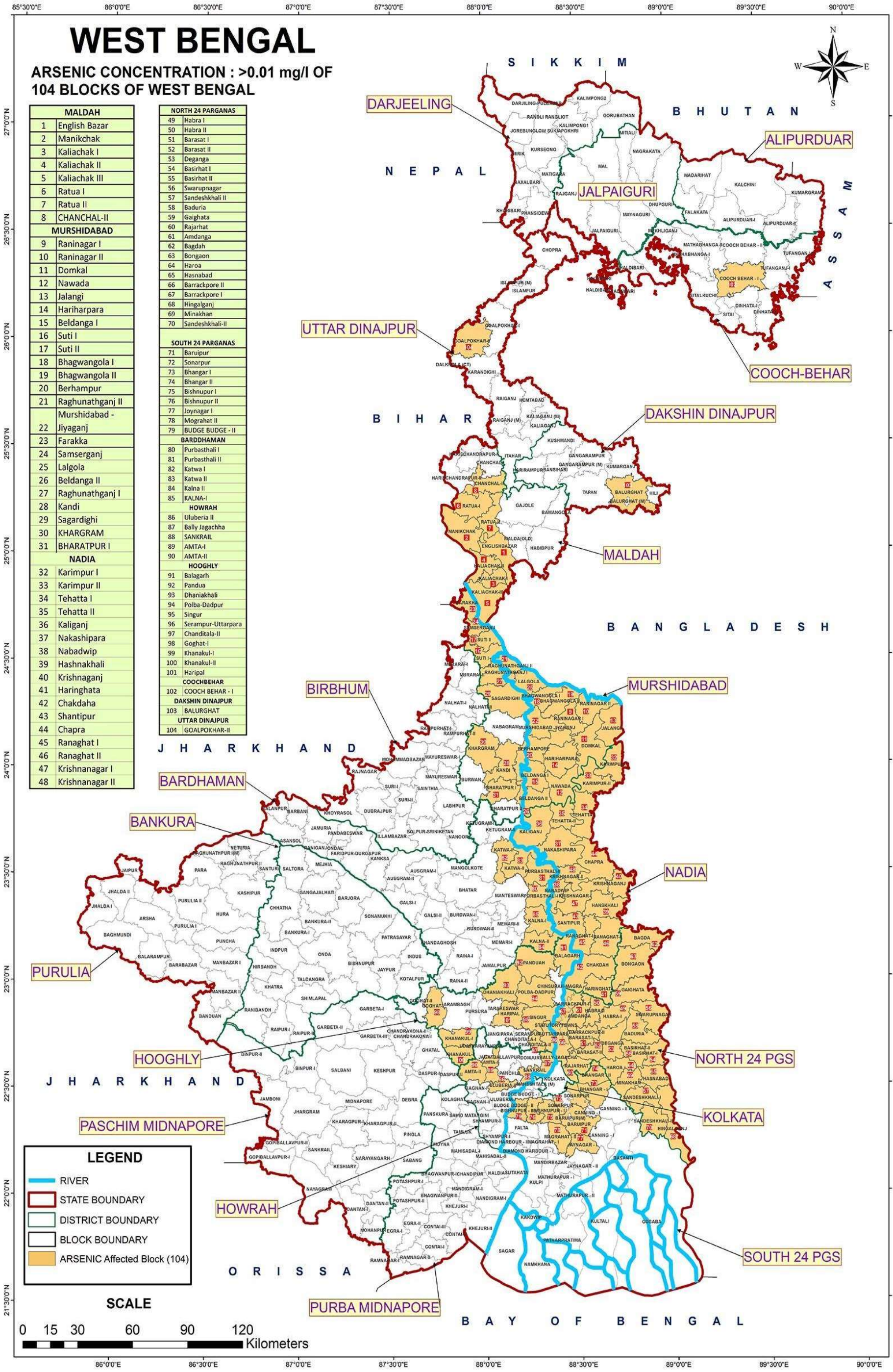
The primary source of fresh water in many parts of the world for meeting the requirements of daily purposes, including agriculture, is groundwater. The dependency on groundwater leads to approximately one-third of the world's population for drinking purposes. A large area of the world experiences massive contamination in groundwater due to the mixing of different toxic minerals and heavy metals, either naturally or unorganized, during the development of human civilization (Jain and Singh 2012). Arsenic is one of the essential minerals. The high concentrations of arsenic (As) in drinking water in inorganic form cause skin, liver, lungs and other organs damages in several parts of the world. More than 25% of domestic wells presented in alluvial aquifers of this state carry arsenic in drinking water beyond the permissible limit of WHO, 1993, 2017 (0.01mg/L). West Bengal lies within the Ganga–Brahmaputra delta basin and has high contamination of arsenic (<0.05mg/ml), mainly in groundwater. West Bengal can be divided into three arsenic prone zones-

1. Highly affected areas cover the eastern side of the Bhagirathi River
2. The affected areas include the northern part of the Bhagirathi River.
3. The unaffected region carries the western part of the state.

In West Bengal, a form of India and the fatal effect on human health due to arsenic toxicity. Groundwater is one of the most precious natural resources on our planet. It is being exploited extensively in many parts of the world, with a massive increase in extraction in the past few decades due to new and cheaper drilling and pumping technologies (Barbier 2019). Hydrogeologists refer to this drastic change in groundwater utilization as the silent revolution since it has occurred in many countries in an unplanned and uncontrolled manner (Stone et al. 2019). The demand for good quality groundwater has increased with increasing population and developmental activities across the globe. Providing safe drinking water to the world's 7.8 billion people is one of the most significant challenges of the century. At the beginning of the 20th century, the groundwater quality issues were minimal, and total dissolved solids and pH were the only parameters of concern. However, during the 21st century, there has been increased global attention on resolving groundwater quality issues. The chemical quality of groundwater varies significantly depending on the type of aquifers, duration of rock-water interaction and the inputs from various natural and non-natural sources. During the last decade, groundwater contamination from various chemical constituents has been reported from aquifers throughout the world. It often becomes non-potable as the components exceed the limits prescribed by WHO. Geochemical processes during and after aquifer recharge can either improve or cause a deterioration of water quality (Maliva 2020). In recent years, pollution by arsenic (As) has become a severe issue of concern because of its toxicity to humans. Arsenic contaminants in groundwater can also affect the health of the aquifers (Ngo et al 2012).

Groundwater plays a vital role in India, meeting the water demands of various sectors, such as domestic, industrial and irrigational needs (Saha and Ray 2019; Suhag 2019). The alluvial tracts of the Ganga and Brahmaputra rivers are the wealthiest groundwater province in the country. Most of the extraction occurs along the Indo-Gangetic basin in Northern and North-western India, which has resulted in significant drawdown and water table decline in many locations (Rodell et al. 2009; MacDonald et al. 2016). In India, it is reported that a population of over 50 million is currently at risk from groundwater arsenic contamination. Several workers carried out extensive work on arsenic contamination in groundwaters in India, especially in the Ganga basin (Chakraborti et al. 2018 and references therein). The Ganga River basin covers nearly 26% of India‘s landmass and is home to over 500 million (Chakraborti et al. 2018). The Ganga River basin is one of the most fertile and densely populated areas globally (Khan et al. 2016). Presently, the Ganga is one of the world‘s most polluted rivers, containing several toxins, including chromium, arsenic, cadmium, lead, copper and mercury, as well as pesticides and pathogenic microbes nearly 3000 times higher than the safe limit prescribed by the World Health Organization (WHO 2011; Tandon 2018). High arsenic (>10 ppb) groundwater has been reported in shallow aquifers in 10 states in India (CGWB 2018). However, the deeper aquifers of India (>100 m) are free from arsenic. Arsenic contamination in groundwater was first reported in the Chandigarh region of north India (Datta and Kaul 1976). The second case was reported in the lower Gangetic plain of West Bengal (Garat et al. 1984). It was followed by reports from several states, including West Bengal, Bihar, Uttar Pradesh, Jharkhand, Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, Punjab, Himachal Pradesh, Chhattisgarh and Andhra Pradesh (World Bank 2005;

Mukherjee et al. 2006; Chakraborti et al. 2018). In India, high arsenic groundwater occurs in (1) alluvial terrane and (2) hard rock terrane. Alluvial aquifers are the primary source (90%) of arsenic in India. Hard rock aquifers account for only 10%, including states like Karnataka and Chhattisgarh. In Karnataka, arsenic is associated with sulfide mineralization, especially arsenopyrite. It is mainly restricted to the gold mineralized areas covering parts of the Raichur and Yadgir districts. In Chhattisgarh, it has been reported that the acid volcanic is associated with Kotri lineament (Bhowmick et al 2014).



MALDAH	
1	English Bazar
2	Manikchak
3	Kaliachak I
4	Kaliachak II
5	Kaliachak III
6	Ratua I
7	Ratua II
8	CHANCHAL-II
MURSHIDABAD	
9	Raninagar I
10	Raninagar II
11	Domkal
12	Nawada
13	Jalangi
14	Hariharpara
15	Beldanga I
16	Suti I
17	Suti II
18	Bhagwangola I
19	Bhagwangola II
20	Berhampur
21	Raghunathganj II
22	Murshidabad - Jiyaganj
23	Farakka
24	Samserganj
25	Lalgola
26	Beldanga II
27	Raghunathganj I
28	Kandi
29	Sagardighi
30	KHARGRAM
31	BHARATPUR I
NADIA	
32	Karimpur I
33	Karimpur II
34	Tehatta I
35	Tehatta II
36	Kaliganj
37	Nakashipara
38	Nabadwip
39	Hashnakhali
40	Krishnaganj
41	Haringhata
42	Chakdaha
43	Shantipur
44	Chapra
45	Ranaghat I
46	Ranaghat II
47	Krishnanagar I
48	Krishnanagar II

NORTH 24 PARGANAS	
49	Habra I
50	Habra II
51	Barasat I
52	Barasat II
53	Deganga
54	Basirhat I
55	Basirhat II
56	Swarupnagar
57	Sandeshkhali II
58	Baduria
59	Gaighata
60	Rajarhat
61	Amdanga
62	Bagdah
63	Bongaon
64	Haroa
65	Hasnabad
66	Barrackpore II
67	Barrackpore I
68	Hingalganj
69	Minakhan
70	Sandeshkhali-II
SOUTH 24 PARGANAS	
71	Baruipur
72	Sonarpur
73	Bhangar I
74	Bhangar II
75	Bishnupur I
76	Bishnupur II
77	Joynagar I
78	Mograhat II
79	BUDGE BUDGE - II
BARDDHAMAN	
80	Purbasthali I
81	Purbasthali II
82	Katwa I
83	Katwa II
84	Kalna II
85	KALNA-I
HOWRAH	
86	Uluberia II
87	Bally Jagachha
88	SANKRAIL
89	AMTA-I
90	AMTA-II
HOOGHLY	
91	Balagarh
92	Pandua
93	Dhaniakhali
94	Polba-Dadpur
95	Singur
96	Serampur-Uttarpara
97	Chanditala-II
98	Goghat-I
99	Khanakul-I
100	Khanakul-II
101	Haripal
COOCHBEHAR	
102	COOCH BEHAR - I
DAKSHIN DINAJPUR	
103	BALURGHAT
UTTAR DINAJPUR	
104	GOALPOKHAR-II

Fig: 1.3 Status of Arsenic Contamination in Water: West Bengal Scenario (*source* http://wbphed.gov.in)

1.7.1 Distribution of arsenic polluted area in west Bengal

Arsenic contamination in groundwater in West Bengal first detected in 1978, and around 16.66 million people (according to the 2001 census) in 8 districts in West Bengal are at risk (Das, 2019). Das et al. (1996) and Chowdhury et al. (1999) reported that, in West Bengal, areas affected by arsenic contamination in groundwater are located in the upper delta plain and are primarily reported from the abandoned meander belt. The source of arsenic is geological. Bore-hole sample analyses show high arsenic concentrations only in soil layers rich in iron pyrites (Das, 2019). It has been reported that more than 50 million people living along the Ganga–Brahmaputra basins are affected by the high levels of arsenic in drinking water. High arsenic groundwater has been observed mainly in the districts of North 24 Parganas, Burdwan, Howrah, Hooghly, Kolkata, and Nadia (Singh, 2006). The highest concentration of arsenic in groundwater was reported in the Burdwan region, followed by Kolkata (Sen and Sarkar, 2019).

Groundwater in nine districts of West Bengal is severely affected, out of which, North 24 Paraganas, Nadia, and Murshidabad are in extreme conditions (Rahman et al., 2003; 2005a; b, 2014). Arsenic poisoning imposes different health hazards, including skin problems, respiratory troubles, cardiovascular diseases, nervous disorders, renal issues etc. (Mazumder, 2008). Being a group I carcinogen (IARC, 2012), exposure for a prolonged period causes cancer in different organs, increasing mortality (Abdul et al., 2015; Ng et al., 2003; Yunus et al., 2011). Twenty-five out of 26 blocks in the Murshidabad district were found to be As-affected, where As concentration in groundwater ranged from 3–3000 μg/l with a mean concentration of 240 μg/l (Chakraborti et al., 2009; Das, 2013). Lalgola, Raghunathganj-II, Bhagwangola-I & II, Raninagar-I & II, Berhampore, Hariharpara, Domkal, and Jalangi are some of the worst As-affected blocks. Rahman et al. (2005a)reported that approximately 53.8 % of the tube-well water samples (n = 29,612) analyzed from the district in the depth zone of 10–120 m contained As beyond its permissible limit in drinking water i. e. 10 μg/l. The inhabitants residing in Murshidabad have been suffering from chronic As toxicity for many years, including severe arsenical skin manifestations (Chakraborti et al., 2009; Rahman et al., 2005. The agricultural soil, plants, and cultivated foodstuffs in this district were also contaminated (Roychowdhury et al., 2002, 2005). Several mitigation strategies have been undertaken to conflict the As pollution in drinking water, such as pipeline water supply after proper treatment, installation of new and comparatively deeper hand pumps or establishment of numerous As removal plants, dug wells etc. (Halder, 2019).

In India, Arsenic contamination in groundwater was first reported in West Bengal, and it includes79 blocks in 8 districts among 26 districts where arsenic concentration in groundwater exceeded 50μg/L. According to Das, 2015, this problem is expanding rapidly, and in 2006 almost 3235 villages were affected, including North 24 Parganas, South 24 Parganas, Nadia, Murshidabad, Burdwan, Howrah, Hooghly and Maldah districts. The severely affected districts are Murshidabad, Maldah, Nadia, North and South 24 Parganas, Burdwan, Howrah and Hooghly. The values of arsenic-contaminated groundwater of the affected communities. In the study, the numbers of affected blocks under the affected districts were too high. Almost all sections contain over 50% to 100% arsenic-contaminated block.

Table: 1.2 Arsenic affect blocks in --West Bengal

District	**Arsenic affected blocks**	**No. of blocks**
Maldah	English Bazar, Manikchak, Kaliachak I, Kaliachak II, Kaliachak III, Ratua I, Ratua II, Chanchal II	8
Murshidabad	Raninagar I, Raninagar II, Domkal, Nawada, Jalangi, Hariharpara, Beldanga I, Suti I, Suti II, Bhagawangola I, Bhagawangola II, Berhampur, Raghunathganj II, Mrshidabad – Jiyaganj, Farakka, Saserganj, Lalgola, Bendanga II, Raghunathganj I, Kandi, Sagardighi, Kharagram, Bharatpur I,	23
Nadia	Karimpur I, Karimpur II, Tehatta I, Tehatta II, Kaliganj, Nakashipara, Nabadwip, Hashnakhali, Krishnaganj, Haringhata, Chakdaha, Shantipur, Chapra, Ranaghat I, Ranaghat II, Krishnanagar I, Krishnanagar II	17
North 24 Parganas	Habra I, Habra II, Barasat I, Barasat II, Deganga, Basirhat I, Basirhat II, Swarupnagar, Sandeshkhali II, Baduria, Gaighata, Rajarhat, Amdanga, Bagdah, Bongaon, Haroa, Hasnabad, Barrackpore I, Barrackpore II, Hingalganj, Minakhan, Sandeshkhali II	22
South 24 Parganas	Baruipur, Sonarpur, Bhangar I, Bhangar II, Bishnupur I, Bishnupur II, Joynagar I, Mograhat II, Budge Budge II	9
Barddhaman	Purbasthali I, Purbasthali II, Katwa I, Katwa II, Kalna I, Kalna II	6

Howrah	Ulluberia II, Bally Jagachha, Sankrail, Amta I, Amta II	5
Hoogly	Balagarh, Pandua, Dhaniakhali, Polba-dadpur, Singur, Serampur-Uttarpar, Chanditala I, Goghat I,Khanakul I, Khanakul II, Haripal	11
Coochbehar	Coochbehar I	1
DakshinDinajpur	Balurghat	1
Uttar Dinajpur	Goalpokhar II	1
11 Districts		**104 Blocks**

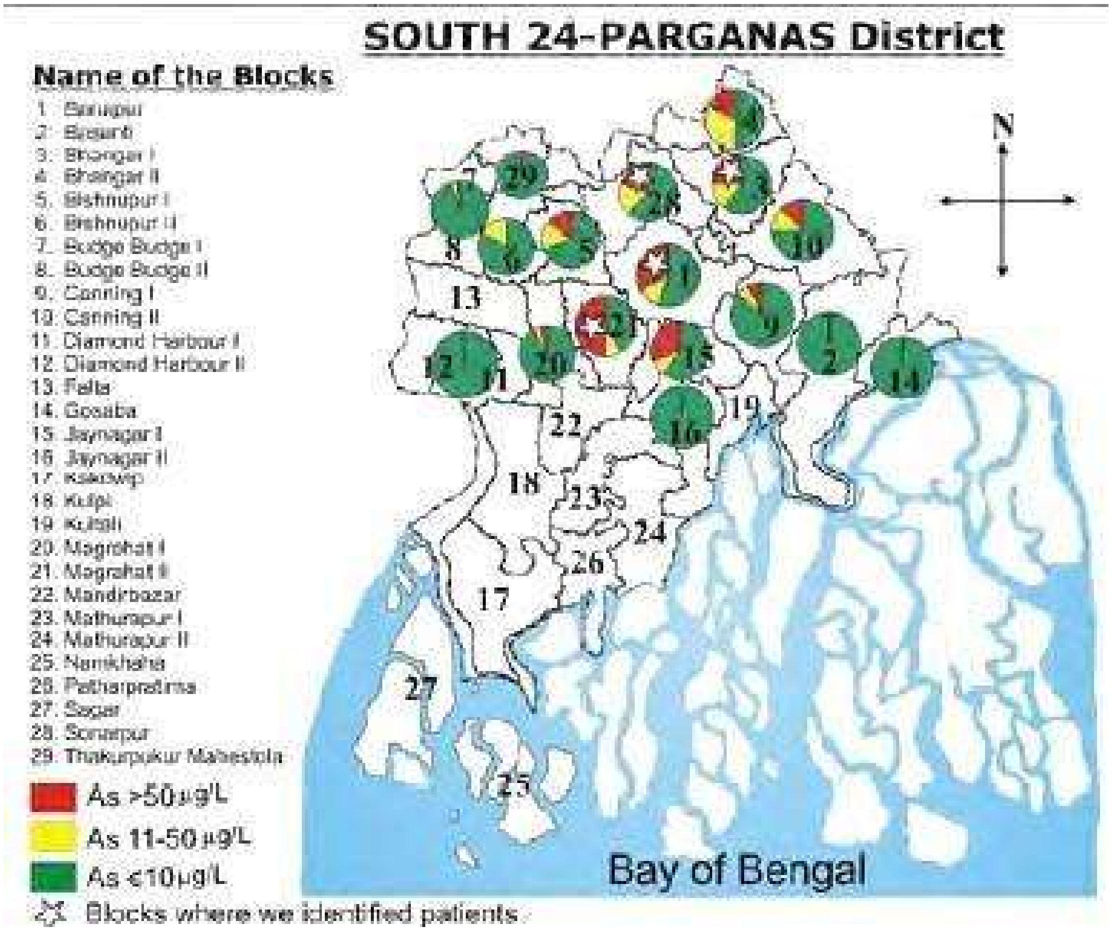


Fig: 1.4 Arsenic Condition In South 24-Parganas (*source* http://wbphed.gov.in)

1.8 Health Effects of Arsenic

As (III) and As(V) are both very toxic, with increased risk for cancer of the skin, lungs, urinary bladder, liver, and kidney butAs (III) is multiple times more harmful andversatile than As(V). Wellbeing impacts of arsenic depend upon different kind ofparameters.These include the type and amount of arsenic that has been allowed, how long you havebeen exposed to arsenic, and how the body reacts to arsenic. Unborn infants, children,and people with long sicknesses and the elderly are the weakest to arsenic exposure. Theimpacts of arsenic, when ingested even in limited quantities, show up gradually; it mighttake quite a long while for the harming effects to become obvious.Arsenic pollution in natural water is an overall issue, and has become a significantissue and challenge for world specialists, researchers, and even politicians. For instance,persistent arsenic poisoning due to drinking arsenic-polluted water has been one of theterrible wellbeing impacts influencing eight areas of West Bengal since the mid-1980s.
Itemized clinical assessment and investigation of 248 such patients showed the clinical signs of such harmfulness. Well beyond hyperpigmentation and keratosis, powerlessness,paleness, painful eyes, leg swelling, liver fibrosis, persistent lung ailment, gangrene of toes,neuropathy, and skin malignant growth were a portion of different symptoms. TheWorld Health Organization (WHO) and the U.S. Environmental Protection Agency (USEPA) have limited the As concentration level at 10 μg/L in 2001.

1.8.1 Human health effect (Arsenicosis)

The term arsenicosis to designate human health effect of chronic arsenic toxicity was first coined by our group and later used by the World Health Organization to imply a chronic disease caused by prolonged exposure of arsenic in humans. Previously, the condition was described as arseniasis, arsenism, arsenicism, and others. Most of the reports of chronic arsenic exposure in man focus attention on skin manifestations because of their diagnostic specificity. However, data derived from population-based studies; clinical case series; and reports relating to intake of inorganic arsenic through drinking water, medications, or occupational and environmental exposure, show that chronic arsenic exposure adversely affects multi organ system of human body.

1.8.1.1 Skin Manifestations

Pigmentation and keratosis are the specific skin diseases characteristic of chronic arsenic toxicity. To ascertain theprevalence of keratosis and pigmentation in relation to arsenic exposure, the first population-based survey wascarried out on 7,683 participants (4,093 females and 3,590males) in West Bengal with participant's arsenic-exposure data. The arsenic content of current water source of the participants ranged up to 3,400 mg/L; however, more than80% of the participants consumed water with arsenic level less than 50 mg/L. The age-adjusted prevalence of keratosis and pigmentation was strongly related to water arsenic levels, rising from 0 and 0.3 per 100, respectively, in the lowest exposure level (<50 mg/L), to 8.3 and 11.5 per 100,respectively, for females drinking water containing greater than 800 mg/L arsenic, and increasing from 0.2 and 0.4 per100, respectively, in the lowest exposure category, to 10.7and 22.7 per 100, respectively, for males in the highest exposure level (>800 mg/L). Calculation by dose per kilogram body weight showed that men had roughly two to three times the prevalence of both keratosis and pigmentation compared with women apparently ingesting the same dose of arsenic from drinking water. Participants who were less than 80% of the standard body weight for their age and sex had a 1.6-fold increase in the prevalence of keratosis, suggesting that malnutrition may play some rolein increasing susceptibility. However, the survey examined only the participants' primary current drinking-water source. Results of a nested case control study using detailed lifetime (at least 20 years) exposure assessment showing low dose of arsenic exposure (<50 mg/L) among the aforementioned study population were further available. The exposure assessment incorporated arsenic concentration data from current and past water sources used in households and work sites. The lowest peak arsenic level ingested by a confirmed case was 115 mg/L. Strong dose response gradients with both peak and average arsenic water concentrations were also observed. In another cross-sectional study, conducted in Bangladesh, 430 out of1,481 participants aged were found to have arsenical skin lesions. Arsenic water concentrations ranged from10 mg/L to 2,040 mg/L, and the crude overall prevalence rate for skin lesions was 29%. This study also showed higher prevalence rate of arsenical skin lesions in males than in females with clear dose response relationship.

Fig: 1.5 Affect of Arsenic in Human Bodies(Source internet)

1.8.1.2 Systemic Manifestations

Chronic arsenic toxicity produces various systemic manifestations over and above skin lesions. It needs to be noted that although systemic manifestations occur mostly in association with arsenical skin lesions, symptoms do occur in significantly higher number of cases in arsenic-exposed people even in the absence of arsenical skin disease compared with arsenic-unexposed people.

1.8.1.3 Respiratory Disease

Initial report of nonmalignant lung disease was available from a study of 180 residents of Antofagasta, Chile, exposed to drinking water containing arsenic (800 mg/L).About 38% of the 144 participants with abnormal skin pigmentation complained of chronic cough, compared with

3.1% of 36 participants with normal skin. Symptoms of chronic lung disease were present in 89 (57%) out of 156cases of chronic arsenic toxicity caused by drinking arsenic contaminated water in West Bengal. Lung function tests carried out on 17 patients showed features of restrictive lung disease in nine (53%) and combined obstructive and restrictive lung disease in seven (41%) cases. To ascertain the relationship of chronic arsenic exposure with occurrence of lung disease, an analysis of data of cross-sectional epidemiological survey of nonsmokers (6,864 participants) was carried out in West Bengal. The study participants included those who had arsenic-associated skin lesions and who were also highly exposed at the time of the survey (arsenic water concentration _ 50 mg/L).Participants with normal skin and low arsenic water concentration (<50 mg/L) were used as the reference group. In participants with skin lesions, the age-adjusted prevalence odds ratio (OR) estimates for cough, crepitation, and shortness of breath for females were and for males respectively. In an epidemiological study carried out on 218 nonsmokers (94 exposed to arsenic, 136e1,000 mg/Land 124 unexposed cases) in Bangladesh.

Participants without skin lesions were studied in an arsenic endemic population in West Bengal. The median highest level of arsenic in drinking water was 330 mg/L [standard deviation (SD)Z_881 mg/L] in participants with skin lesions compared with 28 mg/L (SDZ_147 mg/L) in those without such lesions. Thirty-eight study participants who reported at least 2 years of chronic cough underwent high-resolution computed tomography. The mean bronchiectasis severity score was 3.4 in the 27participants with skin lesions in the 11participants without these lesions (controls). In participants who reported chronic cough, high-resolution computed tomography evidence of bronchiectasis was found in 18(67%) cases with skin lesion and in three (27%) controls. Adjusted OR was found to be. This study showed that drinking high-arsenic-contaminated water was associated with increased incidence of bronchiectasis in man. Many other investigators also reported chronic respiratory disease in the form of chronic cough orchronic bronchitis because of prolonged drinking of arsenic contaminated water.

1.8.1.4 Cardiovascular disease

Blackfoot disease (BFD), a form of peripheral vascular disease, has been reported to be one of the important complications of chronic arsenic toxicity in Taiwan. The prevalence of BFD has been reported to be 8.9 per 1,000among 40,421 inhabitants studied in Taiwan. Comparable peripheral vascular disorders with varying degrees of severity, including Raynaud's syndrome and acrocyanosis,have also been reported among people drinking arsenic contaminated water by others. The incidence of peripheral vascular disease was found to be low in West Bengal. Out of 246 arsenicosis patients who attended referral hospital in Kolkata, three cases (1.2%) of peripheral vascular disease were found. However, out of 4,865cases surveyed in a village population of West Bengal, one case (0.02%) of gangrene was detected. Similarly, low incidence has been found in Chile and Bangladesh, whereas there is no report from Mexico and Argentina. An epidemiological study reported an increased prevalence of hypertension among residents in the endemic area of BFD and a dose response relationship between ingested inorganic arsenic and prevalence of hypertension. An association of cumulative arsenic exposure in drinking water was also found with increased risk of hypertension in a study of 1,595 people in Bangladesh. Increased prevalence of hypertension was also reported in 6.2% patients affected with arsenic-induced skin lesions (144) compared with none without skin lesion in Antofagasta, Chile. Mortality rates from ischemic heart disease with endemic arsenicosis (from 1973 through1986) were correlated with the arsenic level in drinking water among residents of 60 villages in Taiwan.

1.8.1.5 Gastrointestinal disease

Dyspepsia was observed in 60 out of 156 (38.4%) cases of chronic arsenic toxicity studied in West Bengal. However, in an epidemiological study carried out in the affected population, there was no difference in the incidence of pain in abdomen among people drinking arsenic-contaminated water and the control population. Gastroenteritis was reported in a study of 1,447 cases of chronic arsenicosis caused by drinking arsenic-contaminated water with a concentration greater than 50 mg/L in the Inner Mongolian Autonomous Region of China. Many investigators variously reported symptoms, such as nausea, diarrhea, anorexia, and abdominal pain in cases of chronic arsenic toxicity.

1.8.1.6 Arsenicosis and cancer

The evidence of carcinogenicity in humans from exposure to arsenic is based on epidemiological studies of cancer in relation to arsenic in drinking water. The working group of International Agency for Research on Cancer evaluated data from ecological, cohort, and case control studies

From many countries and observed that arsenic was chromosomal aberration (CA), and challenge assays. DNA damage and CA was significantly higher in the arsenicexposedparticipants compared with those in unexposed participants. Within the exposed group, there was no significant difference of DNA damage ($p > 0.05$), but CA was significantly higher in the exposed group with keratosis than in that without exposure (p <

0.01). Challenge assay showed that, on induction of DNA damage, the repair capacity in the exposed group with keratosis was significantly less (<0.001) than that of participants without skin lesion, although the basal level of DNA damage was similar in both. The results of the study suggested that deficiency in DNA repair capacity may be involved in arsenic-induced carcinogenesis.

1.9 Arsenic in Food Chain

An important research area in the environmental field is the trophic transfer of hazardous metals and metalloids in the food chain or food webs. They are transferred from water or soil to biota and consequently to animals and humans and contaminate food chains (Ali and Khan, 2018). Arsenic is a metalloid that is known for its hazardous effects at all trophic levels. As arsenic is highly toxic, there have been concerns for many years regarding its presence in surface water and groundwater (Missimer et al., 2018). Human exposure occurs both by drinking water that contains arsenic and by consumption of foods of both terrestrial and aquatic origins (Barral-Fraga et al., 2020). As reported by some groups, in the USA and Japan, arsenic exposure occurs via ingestion of various foods containing arsenic (Uneyama et al., 2007). Drinking water, soil, or air exposures of arsenic are significantly lower and limited when compared to exposure due to foods (Mondal et al., 2021). Approximately ~90% of arsenic consumption in the USA is mainly due to the consumption of arsenic-containing meat, fish, and poultry. Marine life forms contain arsenic in the form of arsenobetaine (AB), arsenocholine (AC), and arsenosugars (Popowich et al., 2016). Freshwater and terrestrial arsenic accumulations also reach humans via different food chains and food webs and can lead to toxicity. To date, the awareness of arsenic trophodynamics in all environments is insufficient and is, in fact, dubious. Arsenic amounts and speciation in aquatic and terrestrial environments are reviewed, but information regarding arsenic transfer at different trophic levels in food chains has not been summarized until now.

Major developments have taken place in the recent past for understanding arsenic accumulation in the food chain and its environmental effects, especially on plants. Arsenic exposure via water, soil, and air is known to cause large-scale toxicity in plants and animals and has become a substantial threat to our environment. A variety of factors are responsible for controlling the environmental arsenic fate. The biogeochemical cycle of arsenic affects the food chain. The inorganic forms of arsenic are not only found in the hydrosphere but are also accumulated in biological organisms including plants, animals and humans. The amount of arsenic reaching the biological system does not depend on the external arsenic concentration but the bioavailability of the arsenic in the living organism. Arsenic enters microbes and plants from the soil via numerous transporters which then enter the invertebrates, vertebrates and ultimately reaches humans. Humans are also directly exposed to several anthropogenic factors adding to the toxicity. Once it is in the body it leads to a lot of detrimental effects on the organism.

Several remediation strategies have been taken into account to combat the absorption and transportation of arsenic in the living being. Alterations and manipulations in the expression of transporters that are involved in the uptake, mobilization, and elimination need to be targeted, which can lead to an arsenic reduction in aerial plant parts. Bioremediation, which primarily consists of phytoremediation of arsenic-contaminated water and soil, is an effective and environmentally friendly option to minimize the adverse health effects of arsenic; however, research work in this area still needs to achieve a workable model (Mateo et al., 2019). Phytoremediation comprises phytoextraction where hyperaccumulator has effectively removed arsenic from contaminated soil; phytovolatilization where arsenic is removed as volatile species into the atmosphere through transpiration process limiting its presence in the plant body; phytostabilisation and phytoimmobilisation do not allow absorption of arsenic in the plant, thus reducing the bioavailability for human exposure.

Arsenic presents several complications to humans, animals, and plants. The physiology of plants and their growth and development are affected by arsenic. Arsenic is known to cause cancer and several types of organ toxicity, such as cardiotoxicity, nephrotoxicity, and hepatotoxicity. In the environment, arsenic exists in variable forms both as inorganic and organic species. From arsenic containing compartments, plants can absorb and accumulate arsenic. Crops grown on these contaminated soils pose several-fold higher toxicity to humans compared with drinking water if arsenic enters the food chain.

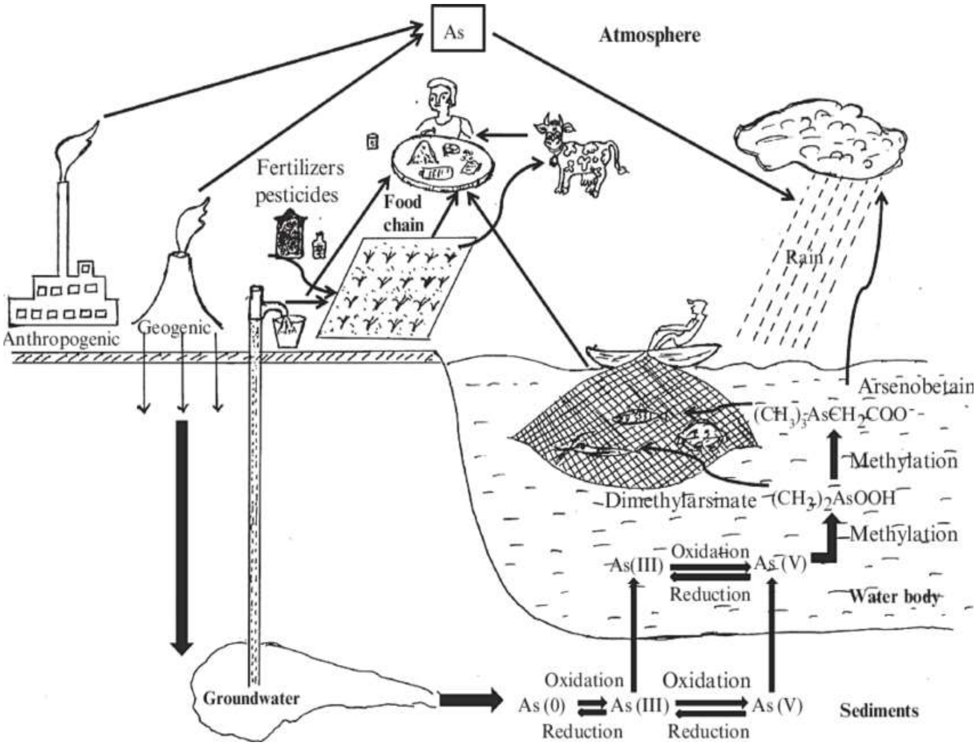


Fig: 1.6 Affect Of Arsenic In Food Chain (Source:researchgate.net)

Source:

1. **Status of Arsenic Remediation in India**

Anuja Bhardwaj*,a, Rakhee Rajput†,a, Kshipra Misra*

***Department of Biochemical Sciences (DBCS), Defence Institute of Physiology and Allied Sciences**

(DIPAS), Delhi, India, †Department of Chemistry, University of Delhi, Delhi, India

2.Development of Low-Cost Arsenic Removal Process by Using Ion-Exchange Resins

Priyabrata Mondal, Pankaj Kumar Roy, Nil Sadhan Mondal,Saurabh Kumar Basak, and Arunabha Majumder

CHAPTER 2

OBJECTIVE AND SCOPE OF WORK

2.0 OBJECTIVE

2.1 Objective of Study

The overall objective the study is to determine the effectiveness of ion-exchange resins (Anionic) and removing of arsenic from Ground water and as well as to achieve the technically viable, cost-effective and communally suitable method for arsenic removal. Also provides information on:

- Occurrence of arsenic in ground water
- Extent and enormity of arsenic problem
- Impact of arsenic contamination on human health and environment
- To study arsenic removal from ground water by ion exchange resins
- To develop lab scale models for arsenic removal
- To deliver arsenic safe drinking water.

2.2 Scope of work

- To evaluate the arsenic removal efficiency of ion-exchange resins (anionic) burette filter.
- To determine the iron removal efficiency of ion-exchange resin adsorption filter
- To evaluate the effects on various water quality parameters.
- To evaluate the adsorption capacity of the resin.

2.3 Deliverables

All arsenic removal technologies have their own advantages and disadvantages and should be reformed as appropriate and viable for a particular condition. The modifications should be based on the implementation of the technologies with objectives to:

- Improve the efficiency of arsenic removal
- Make it cost effective and technically viable.
- Make it user friendly
- Impact of arsenic safe water supply on people

CHAPTER 3

LITERATURE REVIEW

3.0 LITERATURE REVIEW

Audit Report, WBPHED discusses in their report that arsenic is a natural element mostly founding the earth crust in both of its oxidation state which are trivalent arsenite (As III) and pentavalent arsenate (As V). Arsenic in both the forms is poisonous in nature. Arsenic contamination of groundwater has led to endemic condition of arsenic poisoning in Eastern India, Bangladesh and neighbouring countries. Presently in the state of West Bengal there are 104 blocks are affected due to arsenic contamination in the groundwater and authority was facing problem in context of supplying safe drinking water to those villagers in an economically viable way. Arsenic can be removed from groundwater by different procedure i.e. Co-precipitation, Adsorption, Ion-exchange, Membrane Separation etc.

Natural dumping phenomena such as earthquakes, volcanos, storms, algae blooms, etc., cause significant changes in the ecological status of water and water quality. Statistics exemplify the scale of the problem that adulterated water like chemicals discharged from factories or washed down drains can cause [D. Mohan et al. (2007). About half of the ocean pollution is due to sewage and polluted water dumping. Every year, the world produces beyond 40, 00,000 lakh tons of industrial sludge, whose maximum proportion is dumped directly into oceans, rivers and other waterways. In India, around 4 00,000 factories take freshwater from streams and rivers, and polluted waters are pumped back into their place. However, significant improvements have recently been made in wastewater treatment [C. Su et al. (2001). The most common valence states of arsenic are As(V) and As(III). Arsenate (As(V)) is commonly found in aerobic surface water, and Arsenite As(III) is more common in anaerobic ground waters. Arsenic in groundwater is mainly due to mineral precipitation, leaking out of geological materials or dissolving of unstable arsenic ores, desorption- adsorption, chemical transformations and input from pesticides, fertilizers and geothermal sources. As(III) is the reduced form of inorganic arsenic, which is exceptionally poisonous[Mandal et al. (1997)]. It is highly toxic, soluble and mobilized than inorganic arsenic (As-V). The disadvantageous presence of As in the environment is of great concern. Arsenic forms 0.0006% of the entire mass of the earth's crust. Consumption of contaminated water, whose arsenic concentration is above 0.05ppm, is detrimental to human health. In West Bengal, arsenic poisoning by drinking tube well water was first reported in 1980[Kundu et al. (2002)]. Long-term intake of arsenic adulterated water may cause pigmentation and hyperkeratosis on the palms and soles of the feet. Black foot disease, skin cancer, bone marrow depression, cardiovascular disorder and cirrhosis are instigated by long term exposure to arsenic. Because of the catastrophic effects within Asia due to As intake, Bangladesh is at the top tailed by West Bengal (India), Cambodia and Vietnam, where more than 15 crores of people are in danger in West Bengal and Bangladesh alone. In all these areas, arsenic happens to be in deltaic soil deposits constituting shoal aquifers

Source(Audit Report, WBPHED),D. Mohan et al. (2007),C. Su et al. (2001),Kundu et al. (2002)

[J. Pattanayak et al. (2000)]

Arsenic (As) contamination of soil and groundwater systems is a significant health issue worldwide. Elevated As concentrations have been found in groundwater from As-contaminated areas, and geothermal influences can also increase As levels (Basu et al., 2014; Ungureanu et al., 2015). Arsenic can exist as organic and inorganic species in surface water or groundwater; inorganic species are more toxic than organic. The toxicity of As depends on its speciation, and the most effective forms for natural exposure of As in groundwater are its inorganic forms, including arsenite (As(III)) and arsenate (As (V)) **(Abid et al., 2016; Niazi et al., 2017)**. Arsenic concentrations in groundwater have been found at chronic levels affecting over 250 million individuals worldwide (e.g., China, Taiwan, Indonesia, Vietnam, Brazil, Canada, India, Bangladesh, Mexico, USA, Hungary and Pakistan). Out of 250 million people, about 100 million live in the Southeast Asian countries, which are potentially exposed to As toxicity **(Shakoor et al., 2015; Shahid et al., 2017; Waqas et al., 2017; Shakoor et al., 2018)**. Intake of Ascontaminated groundwater is responsible for carcinogenic and non-carcinogenic effects in humans (Shakoor et al., 2016; Waqas et al., 2017). The carcinogenic health problems include malfunctioning of the stomach, breast, head, colon, and neck (Rahman et al., 2010; Niazi et al., 2012; Khan et al., 2013). Elevated risk due to As exposure may cause liver, bladder, and skin cancers (Mahimairaja et al., 2005; Niazi et al., 2011a). Non-carcinogenic health issues are diabetes mellitus, cardiovascular problems, keratosis, and severe congenital disabilities in humans (Niazi et al., 2011b; Bhowmick et al., 2013; Niazi and Burton, 2016). Various sorbents have been developed to decrease As concentration below the recommended limit of the World Health Organization (WHO; 10µg/L used for drinking in many regions (Boddu et al., 2008; Shahid et al., 2018). Conventional treatment methods (e.g., precipitation, ion exchange, reverse osmosis) have been employed to eliminate As from contaminated water supplies (Mohan and Pittman, 2007; Niazi et al., 2018a). Although these methods successfully remove As from aqueous media, their high energy, chemical and operational costs, and toxic sludge creation are the critically-important hurdles in broad applicability for drinking water and wastewater treatment (Khaskheli et al., 2011; Chiban et al., 2012).

In recent years, biosorption has been considered a promising As removal method from water. In contrast to conventional methods, biosorption has the advantages of being low-cost, high efficiency, negligible sludge production, the chance of recovery of As and regeneration of biosorbent (Okafor et al., 2012; Pontoni and Fabbricino, 2012; Luqman et al., 2013). Significant efforts have been devoted to exploring the use of different biowastes originating from agriculture and the food industry as potential biosorbents to eliminate toxic elements, including As, from drinking water and wastewater (Tian et al., 2011; Shakoor et al., 2016). While biowastes have been successful for As(V) and As(III) immobilization from contaminated water, natural (untreated) biosorbents have some setbacks (such as low sorption potential, colouration issue and release of soluble organic substances in water) (Tariq et al., 2010; Taha et al., 2011; Sumathi and Alagumuthu, 2014). Recent studies have shown a progressive approach for developing modified biosorbents to remediate As-contaminated water. Pretreatment/modification of biosorbents with a range of acids and alkali solutions (e.g., NaOH, H2SO4, HCl) and impregnation with iron oxides (e.g., ferrihydrite, magnetite) could enhance their stability, thus increasing As removal capacity of the biosorbents. Furthermore, modified biosorbents could reduce the colouration problem and release soluble organic substances in water after treatment (Rahaman et al., 2008; Aryal et al., 2010; Shakoor et al., 2016. In a few studies, xanthation has been used to increase the sorption potential of rubber leaf powder to remove lead (Pb) from contaminated water (Khalir et al., 2011). These authors observed that xanthate rubber leaf powder successfully depleted Pb (Qe: 80 mg g−1) from water. Homagai et al. (2011) revealed that the xanthate sugarcane bagasse sorbed 225 mg g−1 of Cd, 178 mg g−1 of Cu, 318 mg g−1 of Pb, 144 mg g−1 of Ni and 164 mg g−1 of Zn from aqueous solutions. Notably, xanthation of the biosorbent could bear sulfur (S) compounds which can attach to As or make complexes with As in water due to the inherent ability of As to associate with S groups (Liang et al., 2009; Homagai et al., 2010). Citric acid has also been implied as a modifying agent to enhance the sorption potential of rice straw, which led to Pb sorption up to 5 mg g−1 from contaminated water (Guo et al., 2015). The citric acid modification can result in the generation of\\COOH groups on the surface of bio sorbents which could help to enhance the sequestration of As from water on biomass (Guo et al., 2015). However, to our knowledge, xanthation and citric acid modification of bio sorbents have not been investigated and compared to explore their efficiency for removing As(III/V) from aqueous solutions and drinking well water. Watermelon is one of the most abundant and low-cost fruits available in many South and Southeast Asian countries, including Pakistan, with an average production of 350,000 tons per year (FAO, 2013). Watermelon rind (WMR), a typical agricultural by-product, is a natural and abundant source of non-essential amino acids, citrulline, carotenoids, cellulose, pectin, and proteins. These types of biopolymers are large in functional moieties such as \\COOH (pectin), \\OH (cellulose) and amino\\(NH2) (protein) groups which can easily bind and replace As from contaminated water) (Urik et al., 2009; Niazi et al., 2018a; Niazi et al., 2018b). A few studies have reported the use of WMR for the sorption of some toxic elements in aqueous solutions, such as for Cu, Ni, Co and Pb (Banerjee et al., 2012; Lakshmipathy and Sarada, 2013; Lakshmipathy and Sarada, 2015; Lakshmipathy and Sarada, 2016). However, to our knowledge, this is the first study investigating the efficiency of natural WMR and chemically modified WMR as biosorbents to remove As from aqueous solutions and drinking well water/groundwater.

Over the past, the natural anthropogenic presence of toxic arsenate or arsenite ions in groundwater has been acknowledged as a chief public health substance in different parts of the world. Substantial contamination of As has been ascertained in more than 40 other countries worldwide, including West Bengal, India and Bangladesh and their adjacent counties, which shows its catastrophic exposure. Earlier, the allowable contamination of As in drinking water was 50ppb [Safe Drinking Water, WHO, 1984]—realising its carcinogenic effect on human health all across the globe and that the exposure is mainly through food and drinking water, which reviewed the permissible levels and provided a guideline of 10ppb [Arsenic Contamination in Groundwater, WHO, 1993]. Duration and dosage of exposure are two crucial parameters of the severity of the arsenic effect. It starts with a change in pigmentation, hyperkeratosis, and following terrible diseases like skin cancer, lungs, etc. In India, the unwellness due to arsenic consumption is most common in rural areas where groundwater is used directly for drinking, bathing, cleaning, and other household works without proper treatment. It is most likely due to the absence of services from the government [Chowdhury U.K., Biswas B.K., Chowdhary T. R. (2000)].

The water required for domestic supply in India (including West Bengal) is derived from rivers or canals. Deep tube well serves as one of the most significant groundwater sources, which are pretty lesser in number. Because of the small number of deep tube wells, the threat of arsenic intoxication in West Bengal is lesser than in Bangladesh. According to a study performed by W.H.O, it is estimated that approximately 5.2 crores of people worldwide are drinking groundwater whose arsenic level is above 10 ppb (or 0.01ppm). The government of both India and Bangladesh have allowed the contagion limit of arsenic at a marginally higher rate of 0.05ppm [I.S. 10500. 2012]. The World Health Organisation has categorised the pretentious areas of West Bengal under threat into three classes: Out of the nineteen districts of West Bengal, nine of them have been testified to have above 0.05 ppm of arsenic level. The total populace of those nine districts is above 3.4 crores, and the number of people using arsenic-rich water coarsely goes above 10 lakhs (above 0.05 ppm). That amount rises to 13 lakhs when the concentration level is set above 0.01 ppm [Chowdhury U.K., Biswas B.K., Chowdhary T. R. (2000)]. More than 13 districts of Bihar have been reported to have As contamination levels above the Indian standards. All these districts are located near large rivers like The Ganga and The Gandak [Biharprabha News, 25 September 2013].

Some reports are on arsenic removal using mixed bacterial culture from lab-made mining and metallurgical industrial effluents added with arsenic and iron (Altun et al., 2014; Battaglia-Brunet et al., 2012). Some are on the use of pure bacterial culture on simultaneous removal of arsenic and nitrate from the synthetic medium in the presence of iron (Li et al., 2015, 2016). Li et al. (2015) utilized anaerobic Fe(II) oxidation denitrifies (AFODN) bacteria. They achieved 44% and 28% nitrate and arsenic removal from an initial concentration of 8 mM and 13.65 mM, respectively, in the presence of iron. Although Rodriguez-Freire et al. (2014) reported complete arsenic removal after 9 days in the fact of 2 mg/L of FeCl3, the paper is entirely silent about iron removal efficiency. The addition of iron during arsenic removal by most researchers could be due to the co-occurrence of both most often. However, several hundred mg/L of arsenic alone (without iron) in several parts of India have been reported (CGWB, 2010; Venkataraman and Uddameri, 2012). The significant disadvantages of using such systems are the use of unrealistic (concerning treatment for drinking water purposes) high arsenic concentration and their dependency on the presence of iron in contaminated groundwater.
Additionally, pure culture often imposes several limitations in practice to dealing with large amounts of contaminated water (Kleerebezem and van Loosdrecht, 2007). Upadhyaya et al. (2010) also added 10 mg/L of iron and 22.4 mg/L of sulphate in a sulfidogenic bioreactor consisting of 2 identical columns in a series operated at the maximum of 40 min (20 þ 20 min) EBCT to remove 200 mg/L of arsenic but failed to meet drinking water standards for arsenic and iron. It could be due to insufficient sulphate addition and EBCT (20 min) maintained in the first column, resulting in only 1.5 mg/L of sulphate removal. Although biological arsenic removal in the absence of iron as arsenosulphides has been reported (in the form of orpiment and realgar), not more than 80% removal can achieve from an initial of 100 mg/L in the presence of 1800 mg/L of sulphate and 32 h HRT (Battaglia-Brunet et al., 2012). Altun et al. (2014) reported only 8e9% of arsenic removal from an initial arsenic concentration of 0.5e20 mg/L in the absence of iron but presence of 2000 mg/L of sulphate at an HRT of 9.6 h. Thus, none of the above two reactors could meet the drinking water standards due to very high initial

arsenic concentration (100 mg/L) and high sulphate concentration (1800e2000 mg/L). Sulphate bioreduction resulted in high bicarbonate alkalinity that can prevent precipitation of arsenosulphide in the form of realgar and orpiment (Henke, 2009).

In 2013, two previous Minor Field Studies (MFS) had carried out in this project. In both cases, the adsorbents were studied by laboratory column experiments. Natural water has been collected from the affected tube wells in northern Burkina Faso to mimic the natural conditions as closely as possible. Lundin and Öckerman (2013) presented a complementary study to Competition for Adsorption Sites on Iron Oxyhydroxide Based Column Adsorbents for the Removal of Arsenic Oxyacid Species (Paper IV in Mähler, 2013). These procedures evaluated the properties of the commercial material Granular Ferric Hydroxide (GFH) as an adsorbent for arsenic in natural water. Frid and Haglind (2013) continued the study on GFH at a larger scale and also researched the possibility of using natural lateritic soil from Burkina Faso for the same purpose. While the experiments with GFH in both studies showed promising results (~106-463 µg/cm3), it was concluded that the laterite tested had a low arsenic removal capacity (~7 µg/cm3), approximately 66 times lower than the GFH (Frid and Haglind, 2013).As lateritic soil from Burkina Faso showed a low adsorption capacity, a recent study in this project has examined the properties of GFH and laterite gathered from Lâm Dông Province, Vietnam, respectively (Sanou et al., 2016). This study indicated the laterite to have a good arsenic removal capacity. However, the work has been done with high arsenic concentrations (mg/L) and enriched deionized water rather than natural water. The results might not be comparable with earlier results in Burkina Faso.Recently, another Minor Field Study in this project was carried out by Ambjörnsson et al. (2016) in Ouagadougou, collaborating with another Uppsala team. This time, the iron oxyhydroxide material ferrihydrite was studied for arsenic removal. Both column and batch experiments have been made. While the adsorption capacity was very high in the batch experiment in Uppsala, both groups concluded by both groups that the set-up for the column needed to be improved.In 2013, Mähler and Persson studied ferrihydrite-coated quartz sand as a potential treatment method for arsenic-enriched water in developing countries. The study was done with deionized water, evaluating the effect of parameters such as empty bed contact time (EBCT), flow rate, initial pH and arsenic oxidation state. Additionally, Mähler (2013) studied the impact of competing ions. The two studies revealed that ferrihydrite-coated sand has good adsorption capacity (~79-349 µg/cm^3) and is a possible candidate for a low-cost full-scale system in the rural areas of developing countries such as Burkina Faso.

Source:Abid et al., 2016; Niazi et al., 2017,Shakoor et al., 2015; Shahid et al., 2017; Waqas et al., 2017; Shakoor et al., 2018, WHO,Niazi et al., 2011b; Bhowmick et al., 2013; Niazi and Burton, 2016,Okafor et al., 2012; Pontoni and Fabbricino, 2012; Luqman et al., 2013,Khaskheli et al., 2011; Chiban et al., 2012,Tariq et al., 2010; Taha et al., 2011; Sumathi and Alagumuthu, 2014,Rahaman et al., 2008; Aryal et al., 2010; Shakoor et al., 2016,Urik et al., 2009; Niazi et al., 2018a; Niazi et al., 2018b,Banerjee et al., 2012; Lakshmipathy and Sarada, 2013; Lakshmipathy and Sarada, 2015; Lakshmipathy and Sarada, 2016,Safe Drinking Water, WHO, 1984,Arsenic Contamination in Groundwater, WHO, 1993,Chowdhury U.K., Biswas B.K., Chowdhary T. R. (2000),I.S. 10500. 2012,
Chowdhury U.K., Biswas B.K., Chowdhary T. R. (2000),Biharprabha News, 25 September 2013,

Altun et al., 2014; Battaglia-Brunet et al., 2012,CGWB, 2010; Venkataraman and Uddameri, 2012,Kleerebezem and van Loosdrecht, 2007,Battaglia-Brunet et al., 2012,Paper IV in Mähler, 2013,

Nirav P. Raval et al. (2021) have observed that the bilayer NPS (core-shell) adsorbent was successfully synthesized and first time, practised for the sequestration of toxic As(V) from the aqueous environment. Compared to bare FeO NPs, the bilayer-coated NPs exhibited properly separated particles, leading to the high uptake capacity for As(V). After coating NPs. By enabling the formation of a polar shell, a secondary layer makes the hydrophilic surface containing the large number of –COOH groups available for the adsorption. The maximum sorption capacity for As(V) was obtained at neutral (7.0) pH with 1 g dosage of bilayer NPs in 120 min of reaction time. As(V) adsorption on the proposed adsorbent followed a pseudo-second-order rate model and was well described by a three-step intraparticle diffusion process. The isotherm studies demonstrated that As(V) adsorption on sorbent followed the Freundlich > Langmuir > Temkin models with higher R2 and lowered χ 2 values, suggesting the formation of consecutive multilayer/monolayer coverages. The potential to regenerate the adsorbent was excellent up to 5 cycles with 0.1 M NaOH. Furthermore, the adsorbent showed an efficient As(V) removal efficiency from the co– contaminants' binary and cocktail mixture. The acquired results validate the sustainable utilization of bilayer NPS as a promising adsorbent for removing metalloid contaminants from the water. Further research is required to study the efficiency of the proposed adsorbent on the real groundwater in the complex water system together with the bacterial consortium. These findings would open a new research direction in developing an effortless adsorbent material suitable for As(V) removal, which can also inhibit the growth of gram-positive/harmful bacteria via in–situ application of the adsorbent.

Source:Nirav P. Raval et al. (2021)

Manoj Kumar Yadav et al. (2021) emphasize the sources, occurrence, health effects of arsenic, and treatment methods employed to remove arsenic from aqueous media. The global arsenic mapping revealed that the arsenic contamination in groundwater is prominent in Asia, and North and South America, with the scattered regional spread in many river basins. Arsenic exposure to human beings from various pathways, especially water, food, air, and occupational hazards, creates chronic health effects. The consumption of arsenic leads to multiple health issues and can even cause cancer in different human organs, such as lung and skin cancer. The formation of methylated arsenic species from the inorganic arsenic by enzymatic activity is considered the major detoxification route of arsenic in the human body. The various arsenic removal techniques have been explored, among which adsorption, coagulation-precipitation, oxidation, and membrane methods gained significant attention. The issues and challenges in the field-scale implementation of arsenic removal plants lie in the inherent characteristic of popular technologies. The major challenge for aqueous arsenic management lies in its field application of technologies, the operation and maintenance of the treatment plants for large scale water treatment systems, and the management of arsenic laden sludge/waste. Arsenic recovery is not preferable due to less demand for arsenic compounds.

Furthermore, the stringent standard of arsenic as 10 µg/L enforced in most countries and the financial burdens evokes the necessity of a sustainable field-scale treatment system. A framework of qualitative assessment of technical, economic, environmental, and social sustainability has developed, and an extensive evaluation with 18 important treatment parameters has been addressed for various technologies. It has been observed that LCA can be used as an effective decision-making tool to provide a reliable assessment of targeted treatment system sustainability.

Source:Manoj Kumar Yadav et al. (2021)

Aminul Islam et al. (2021) observed different carbon structured carbon materials for arsenic adsorption are successfully synthesized from locally available low-cost biomass mixture by the environmentally friendly chemical activation with H3PO4 and subsequently pyrolysis. Of the three different microstructures of activated carbons tested, one activated carbon, C2, seemed to be the most effective for adsorption. Energetically favorable space for adsorption generated from the alignment of carbon nanorods (carbons, C2) and high strength of acidity might be advantageous for arsenic adsorption. Parametric observation revealed that the adsorption of As was found under the optimum reaction time of 60 min, carbon dosage (1g), temperature (25 C) and pH 3. The adsorption of carbon C2 has further improved by developing a complex functional group by impregnating iron oxyhydroxide. Adsorption experiments of As-contaminated groundwater revealed that the iron oxyhydroxide impregnated carbon nanorods (C2) have been found to remove 80% of As after the reaction time of 60 min. Treatment with these activated carbons met drinking water standards (0.01 mg/L). Adsorption of As(V) was also found to depend on the strength of the medium's acidity, microstructure, and pH. These findings represent a promising way to remove As from wastewater using structured carbon. Further study should focus on structured carbon with stable surface functions to accomplish adequate adsorption capacities at low temperatures and a wide pH range.

Source:Aminul Islam et al. (2021)

A.Y. Goren et al. (2021) have concluded that the aerated EC process with 3D Al electrodes can remove the arsenic from groundwater in the presence of anions. The arsenic removal efficiency increased with increasing operating time. On the other hand, there was a negative effect on the arsenic removal efficiency, as phosphate, silicate, boron, and bicarbonate concentrations decreased the arsenic removal efficiency. The competitive effects of silicate and phosphate on arsenic removal efficiency ($C_{f. As}$> 10 mg L^{-1}) were observed when silicate and phosphate concentrations were higher than 50 and 7.5 mg L^{-1}, respectively. The effect of fluoride on the arsenic removal efficiency did not have a significant effect. Quadratic regression model equations also indicated that the anions significantly influence arsenic removal. Furthermore, the results showed that the treatment process could simultaneously remove arsenic and other anions from groundwater. According to BBD, the optimal operating conditions were 1.0 mg L^{-1}, 26.0 mg L^{-1}, 651.5 mg L^{-1}, 2.0 mg L^{-1}, 9.9 mg L^{-1}, and 10.5 min for phosphate and silicate bicarbonate, fluoride, boron, and operating time, respectively. Under these optimal conditions, the experimental values of $C_{f.As}$, Re , ENC, ELC, OC, and we were found to be 2.819 mg L^{-1} , 98.6%, 0.411 kWh m^{-3} , 0.0124 kg m^{-3}, 0.098 \$ m^{-3} , and 17.65 µg As (mg Al)1 , respectively. In conclusion, this study offers significant benefits as one of the limited numbers of studies that investigated the combined effect of anions on arsenic removal efficiency using the EC process.

Source:A.Y. Goren et al. (2021)

Jeffrey Paulo H. Perez (2020) examined the potential of GR for the natural attenuation of arsenic using natural groundwater from a former wood preservation site. Thermodynamic calculations based on the water chemistry of collected samples from the contaminated site show that GR can form in these anoxic subsurface environments. The author performed long-term batch experiments by ageing synthetic GRSO4 in anoxic groundwater, with or without added As, at ambient (25°C) and low (4°C) temperatures. Arsenic was removed entirely (>99%) from the natural groundwater after 120 days of ageing at ambient temperatures. The As removal rate was lower at lower temperatures, and complete removal has only been achieved after one year of ageing. The stability of GRSO4 during ageing in natural groundwater was greatly affected by temperature and the presence of adsorbed As species. Under ambient temperature, GRSO4 transformed to GRCO3 and ultimately to magnetite within one month of ageing in pristine groundwater. The addition of As to the groundwater significantly slowed down these mineral transformation rates due to the adsorption of As onto GRSO4. A similar stabilization effect was achieved when GRSO4 was aged in pristine groundwater at 4°C. Remarkably, GRSO4 remained stable for up to one year when aged in As-spiked groundwater at 4°C. Overall, the results highlight the importance of GR in removing As species from groundwater and their potential as critical host phases for As in natural attenuation processes in contaminated subsurface environments.

Source:Jeffrey Paulo H. Perez (2020)

Samuel B. Adeloju et al. (2021) have demonstrated that arsenic contamination of groundwater impacts the availability of safe and sound quality water for domestic use (drinking and cooking) and agriculture in under-developed countries such as Bangladesh and India, Pakistan and Nepal, as well as the USA. It can have dire consequences on human health, agriculture, and economic and social well-being. The need for a good understanding of the chemistry of arsenic and its fate in the environment has also been demonstrated to be very important for dealing with or minimising the consequences of groundwater contamination by arsenic. The case study about Bangladesh focused on the direct products and impact of groundwater contamination by arsenic with serious health, agricultural, social and economic impacts. Furthermore, it highlights that when groundwater contamination by arsenic is identified, rapid efforts need to be directed to reducing/minimising the associated effects by adopting and utilising appropriate treatment and removal strategies and seeking alternatives for drinking water sources where possible. Socio-economic factors will also play a significant role in adopting safer drinking water options. A recent study in Bangladesh illustrated the need for public education combined with the provision of alternative drinking water sources to overcome attitudes and the reluctance of people to switch to better alternatives. The adoption of many of these strategies in the development of various filter systems for arsenic removal has had a significant impact on the ability of people to access safe drinking water in some parts of the affected countries and communities. Many of the available potable treatment systems effectively remove and minimise arsenic in groundwater-dependent communities to acceptable local standards.

However, there are still issues with the long-term maintenance of these systems, especially in ensuring ongoing effective removal of arsenic, disinfection, filter replacement and sludge disposal. Ongoing education of local communities on how to maintain these systems, including how often the filters have been replaced and disinfection protocols, is necessary to ensure safety, particularly where there is no alternative water source to groundwater. Therefore, there is still a need for ongoing research on developing more robust and highly effective filter systems for arsenic removal from groundwater for use for domestic consumption, to further reduce capital and operation costs, improve user-friendliness, minimise maintenance requirements, and resolve or eliminate the need for sludge management and disposal. Also, portable devices for household and community monitoring of arsenic concentrations in drinking water are now available.

Source:Samuel B. Adeloju et al. (2021)

Das et al. have developed two low-cost field test kits to detect arsenic in water. These kits can detect as low as 10 µg/L of total arsenic in groundwater within 7 min. In addition, there are commercially available quick test systems for arsenic detection in water within 12 min. If adopted, these devices will ensure communities can adequately assess their water safety and, thus, minimize the incidences of arsenic poisoning. Furthermore, the use of various nanomaterials will play a significant role in developing a next-generation efficient filter system. In the long-term, the development of a more affordable version of Arsenic Water Filtration System, which is maintenance-free, will go a long way to addressing the various issues with existing filters if it can be designed to suit the arsenic levels found in groundwater in the under-developed countries and remote communities at a reasonable capital cost.

Source:Das et al.

Santanu Mukherjee et al. (2021) stated that the agricultural biomass-derived mesoporous pyrolyzed char (RSBC) was successfully prepared and applied for the removal of toxic As (V) from the aqueous solution. Among the different dosages of the biochar (RSBC) used in this study (0.5–5 g L-1), it has been found that 2 g L-1 exhibited high uptake capacity for As (V) (~45% higher) compared to 0.5 and 5 g L-1. The maximum removal efficiency of As (V) (>3.43%) has obtained at the near-neutral pH (6.0–6.5). Increasing the initial As (V) concentrations from 10 to 100 µg L-1, the adsorption capacity increased from 4.53 to 13.1 µg g-1. In contrast, removal efficiency decreased from 64.5 to 9.23% resulting from increasing diffusion path length and collision among individual char particles. Adsorption to functionalized char material followed pseudo-second-order ($R2 \geq 0.96$) and Langmuir ($R2 \geq 0.99$) kinetic and isotherm models, respectively. Such a high correlation with the pseudo-second-order rate model provides a vital insight into chemisorption kinetics for As (V) adsorption, which is also well described by the intra-particle diffusion model. Incorporating organic functionalized char particles drives the As (V) removal process through hydrogen bonding, pore filling, electrostatic interaction or inner-sphere complex formation. The obtained results validate the sustainable utilization of such pyrolyzed waste material as a promising novel electron exchanging adsorbent for removing metalloid contaminants from water. Further research is required to study the efficacy of the proposed adsorbent on actual groundwater in the complex PRB system and bacterial consortium to check its antifouling/biocidal activity. In addition, the research focus should be based on the handling of spent adsorbents for the significant scale decontamination of wastewater samples.

SourceSantanu Mukherjee et al. (2021)

Payel Singh et al. (2021) concluded that the S–nZVI was synthesized and was employed for As removal. Characterization of the synthesized particles revealed different morphology of S–nZVI and nZVI. Unlike nZVI, which has an inner Fe0 core and a smooth outer layer of Fe oxide, the core-shelled structure of S–nZVI nanoparticles consist of an inner Fe0 core and an outer distorted flaky shell of iron oxide and FeS. Batch adsorption studies showed sulfide modification promoted As removal by nZVI, and the fast removal rate for both As(III) and As(V) followed pseudo-second-order reaction kinetics. The extent of sulfidation of nZVI influenced the rate of As removal, and the highest removal capacity of As was achieved with an S/Fe molar ratio of 0.1 at acidic pH. The adsorption isotherm results were well described by Langmuir isotherm, with the maximum adsorption capacity of 89.29 mg-1 and 79.37 mg-1 for As(III) and As(V), respectively. While ageing substantially decreased the reactivity of nZVI for As(III) and As(V), the surface FeS layer of S–nZVI decreased the surface passivation and prolonged the lifetime of S–nZVI as demonstrated by the maintenance of high As(III) and As(V) removal rate by S–nZVI even after ageing for 2 weeks. Moreover, sulphur amendment of nZVI had a profound effect on the kinetics of As removal and altered the As sequestration mechanism. The dominant uptake mechanism of As by nZVI involves adsorption and reduction of the adsorbed As(III) and As(V) to a lower valence state, including As(0). In contrast, As(III) and As(V) are primarily removed by S–nZVI through adsorption as arsenite and arsenate surface species, respectively, with additional precipitation of As2S3 – like phase. Overall, the results of this study improved our understanding of the kinetics and mechanism of As removal by S-nZVI and demonstrate that sulfide amendment of nZVI can be a promising strategy for enhanced removal of inorganic As from contaminated water with significant improvement on most of the limitation of nZVI; however the long term feasibility of S–nZVI application and its environmental behaviour needs further investigations.

Source:Payel Singh et al. (2021)

Mohan & Pittman (2007) published a review on the arsenic removal from water/wastewater focused on the adsorbent's use. They concluded that adsorption could be a valuable tool for controlling the extent of aqueous arsenic pollution. However, the most used adsorbent activated carbon has some drawbacks, such as:

- It can only remove a few milligrams of metal ions per gram of activated carbon (30 – 400 mg/g).
- Some regeneration problems exist, which brings up the cost of the process.
- Arsenites must be pre-oxidized to arsenates before adsorption to ensure high efficiencies.

Source:Mohan & Pittman (2007)

Tonoy K. Das et al. (2020) have compared four frequently reported iron-based nanomaterials for arsenic removal under the same experimental conditions and selected the best candidate for potential field application to remove arsenic from water. The nanoscale zero-valent iron (NZVI)-based material showed better removal performance over a wide range of pH (3-9) for both As(III) and As(V). The authors explored the potential mechanisms of arsenic removal by NZVI-based nanomaterials and opined that electrostatic forces and surface complexation controlled arsenic removal. The magnetite (M)-based nanomaterials worked better (>90%) at low pH ($pH < 4$) only for As(V), with the removal being controlled by electrostatic interactions. On the other hand, As(III) removal by M-based nanomaterials increased with increased pH as the process was overseen by ligand exchange and surface complexation. The deposition of nanoparticles on GO surface (to form nanohybrids) improved arsenic removal significantly in both the nanohybrids (GNZVI and GM) compared to their base counterparts (NZVI and M), and this happened because of better dispersion of iron nanoparticles on GO surface providing better interaction between arsenic species and nanomaterial reactive surfaces. GNZVI nanohybrids were the most efficient in terms of arsenic removal per unit mass of iron used. The authors would promote GNZVI as a potential candidate for future field applications (e.g., pump and treat and point-of-use treatment) to remove arsenic from groundwater. It is, however, essential to recognize that nano-based adsorbents with high arsenic adsorption capacity always pose a concern for secondary contamination through the release (desorption) of arsenic from the adsorbed phase. Additional experiments should be conducted to evaluate the long-term stability of the adsorbed arsenic in arsenic saturated nanomaterials in an actual groundwater environment. Further, the potential reuse of the adsorbent should be determined.

Source:Tonoy K. Das et al. (2020)

CHAPTER 4

TREATMENT TECHNOLOGIES FOR ARSENIC REMOVAL

4.0 ARSENIC REMOVAL TECHNOLOGY

Arsenic occurs in aquatic environment in trivalent (Arsenite) or pentavalent (Arsenate) form and these forms are considered to be most important in selecting removal methodology. The requirements for an acceptable technique for removal of arsenic from drinking water are:

- High efficiency
- Safe technology to ensure the maintaining of the maximum contaminant level
- Simple operation
- Minimum residual mass

4.1 Methods of arsenic removal

Arsenic can be removed from ground water by the application of following techniques:

- Oxidation
- Co-precipitation
- Adsorption
- Ion exchange
- Membrane separation

4.1.1 Oxidation of Arsenic

The common valency of Arsenic in raw water sources are (+)3 (arsenite) and (+)5 (arsenate). In geogenic arsenic the above mentioned two valence forms are probably the only species of concern. Different studies have indicated that pentavalent arsenic can be more effectively removed than trivalent arsenic. Thus, oxidation of As (III) to As (V) is thus required as a pre-treatment for efficient removal.

Oxidation of As (III) by dissolved oxygen in water is a very slow process. In oxygen free ground water, a part of arsenic may be present in arsenite form. But effective removal of arsenic from water requires complete oxidation of As (III). Thus, following oxidizing agents could be used for conversion of arsenite to arsenate.

- **Oxygen**: Aeration process may help in oxidizing arsenite; but the process is very slow.
- **Powdered Active Carbon and Dissolved Oxygen**: Catalytic oxidation; the process require very high quantum of powdered active carbon and also 20 to 30 minutes time. Finally carbon needs to be removed from water.
- **UV-Radiation**: Requires high pressure mercury lamp; the process is very fast. Natural organic compounds, if present in water may get oxidized. Application of this process in domestic unit as well as in community models is not feasible, in rural areas.

- **Chemicals:** Free chlorine, hypochlorite, bleaching powder, ozone, permanganate and hydrogen peroxide. Bleaching powder solution or sodium hypochlorite could be used for oxidation of arsenite. Natural organic matter if present may also get oxidized. Bleaching powder is cheap and readily available in common market. Application of ozone would be very costly. Potassium is very effective for oxidation of arsenite, but it may develop a faint colour.
- **Sunlight:** In the presence of light and naturally occurring light-absorbing minerals, the oxidation rate of arsenic (III) by oxygen can be increased by ten thousand fold.

Advantages

- Relatively simple and rapid process.
- Low capital cost.
- Oxidizes other impurities and kills microbes.

Disadvantage

- The process removes only a part of arsenic

4.1.2 Co-precipitation technique

Arsenic occurs in aquatic environment in trivalent (Arsenite) and pentavalent (Arsenate) forms. In order to remove arsenic from ground water by this method, complete oxidation of Arsenite to Arsenate is necessary. After converting Arsenite to Arsenate by using an oxidizing agent (like bleaching powder, calcium hypochlorite, sodium hypochlorite; chlorine dose 0.5mg/L approximately), a coagulant (like alum, ferric sulphate, ferric chloride etc.) is added to water at 40-65mg/L (depending on arsenic concentration in raw water) by rapid mixing for 1 min. Thereafter, slow mixing may be done for approximately 7 minutes. The whole quantity of water is allowed to stand for 2 hours. The supernatant is filtered to obtain arsenic free water. Any type of filter (candle filter, sand-gravel filter) can be used for filtering the supernatant.

Advantages

- Lowest capital costs for larger systems.
- Lowest overall operating costs for larger systems.
- Proven and reliable.
- Most effective for Arsenate

Disadvantages

- Not appropriate for smaller systems.
- Operator care required with chemical handling.
- Produces high As-contaminated sludge volume.
- High or low pH reduces treatment efficiency; secondary treatment may be required.

4.1.3 Adsorption technique

In adsorption processes, arsenic is concentrated on the surface of the adsorbent, thereby reducing its concentration in water. The adsorption media are usually packed into a column. Fixed bed adsorption is probably the most prospective technology for removal of arsenic. The following media may be used for removal of arsenic through adsorption technique:

- Activated alumina
- Metal oxide or hydroxide
- Granular ferric hydroxide
- Activated carbon
- Bauxite, Haematite, Feldspar
- Iron oxide coated sand, etc.

Among these Activated alumina end Ferric hydroxide are commonly used as media for adsorbing arsenic. Activated alumina is a low cost chemical. At lower pH, however, activated alumina works better in adsorption of arsenic. Activated alumina can be regenerated after its adsorption capacity has been exhausted. It can be regenerated by washing with alkali or acid solution. Ferric hydroxide is also an excellent adsorbent for removal of arsenic.

The main factors affecting adsorption performance are fouling the media with suspended or precipitating solids and competition for adsorption sides with other water constituents like silica, fluorides, sulphates and phosphates. All adsorption processes produce wastes from regeneration or spent media that might require treatment or disposal.

Advantages

- Well established.
- Suitable for some organic chemicals, some pesticides, and THMs.
- Suitable for home use, typically inexpensive, with simple filter replacement requirements.
- Improves taste and smell; removes chlorine.

Disadvantages

- Effectiveness is based on contaminant type, concentration, and rate of water usage.
- Bacteria may grow on alumina surface.
- Adequate water flow and pressure required for backwashing/flushing.
- Requires careful monitoring.

4.1.4 Ion Exchange

- Ion exchange is physical and chemical processes in which ions are held electro statically on the surface of a solid are exchanged for ions of similar charge in a solution. For arsenic removal strong base anionic exchange resins are used. The process is effective treatment only for Arsenate therefore pre-oxidation step is usually necessary. During flow through resin Arsenate is bound effectively on resin whereas arsenite is passed through column of anion exchange resin.
- Different categories of resins could be used for arsenic removal. Strong base anionic resin is found to be a good agent in removing of arsenic. Iodized resins also have been found to be an excellent agent in removing not only arsenic but also iron and pathogenic organisms. However, the resins need to be replenished after use and renewal interval is dependent on the quantity of arsenic in water.
- The main factors affecting ion exchange performance are fouling the resins with suspended or precipitating solids and competition with other water anions, particularly, sulphates and phosphates.

Advantages

- Anionic exchange can be very effective at removing arsenic from water if conditions are just right.
- Anionic exchange requires very little maintenance, only the addition of salt every few weeks. It's very easy for a homeowner to use. Systems are typically installed to treat an entire house

Disadvantages

- Other constituents in water can compete with resin sites, reducing the effectiveness of the system. EPA recommends the influent water have less than 500 mg/1 total dissolved solids and less than 25 mg/1 sulphate.
- Treated water can have a very low pH (in case of strong acidic resins) and high levels of chloride, which will cause the water to very corrosive.

4.1.5 Membrane Separation

Membrane processes separate contaminants from water by passing it through a semi-permeable barrier or membrane. The membrane allows some constituents to pass through, while blocking others. It is very effective method and very much suitable for providing arsenic free water. Different common methods of membrane separation are as follows:

- Ultra filtration
- Microfiltration
- Nano filtration
- Electro dialysis
- Reverse Osmosis

Two types of membrane processes microfiltration (MF) and ultra filtration (UF) remove contaminants through physical sieving while two others; nano filtration (NF) and reverse osmosis (RO) remove them through diffusion across the permeable membrane. MF and UF have been used with precipitation/co-precipitation to remove solids containing arsenic. NF and RO are used as sole treatment of dissolved arsenic. Generally, RO is more efficient then NF in removing dissolved arsenic but cost of the treatment is higher. Typically, RO can reduce arsenic concentration to below 0.010 mg/1. The main problem with membrane treatment is fouling of membrane. Therefore pretreatment of water using filtration or chemical treatment are necessary. Regular cleaning of membranes with chemicals is also necessary. NF and RO processes generate rejected wastewater with elevated arsenic concentrations that require additional treatment or disposal.

Recently, advances in nanoscience and nanotechnology have paved the way to the development of various nanomaterials for the remediation of contaminated water. Due to their high specific surface area, high reactivity, and high specificity, nanoparticles have been given considerable environmental attention as novel adsorbents of contaminants, such as heavy metals and arsenic, from aqueous solutions. The most widely used and investigated nanoparticles for the treatment of arsenic-contaminated water are

- Carbon nanotubes and Nanocomposites
- titanium-based nanoparticles
- iron-based nanoparticles, and other metal-based nanoparticles.

Advantages

- Produces highest As removal; produces highest quality water.
- Can effectively treat wide range of dissolved salts and minerals, turbidity, health and aesthetic contaminants, and certain organics; some highly-maintained units are capable of treating biological contaminants.
- Low pressure (<100 psi), compact, self-contained, single membrane units are available for small installations.

Disadvantages

- Relatively expensive to install and operate.
- Frequent membrane monitoring and maintenance; monitoring of rejection percentage for arsenic removal.
- Pressure, temperature, and pH requirements to meet membrane tolerances.

CHAPTER - 5

DETERMINATION OF WATER QUALITY PARAMETER

5.0 GENERAL WATER QUALITY PARAMETER TEST

In this study various parameters of water quality, which are tested in laboratory of School of Water Resources Engineering, are given below.

1. Arsenic
2. Iron
3. pH
4. Turbidity
5. TDS and Electrical conductivity

5.1 Test procedures are given below:

5.1.1 Total Arsenic

Laboratory Methods

- Spectorophotometric Silver Diethyldithiocarbomate ($C_5H_{10}NS_2Ag$) Method.
- Hydride generation Atomic Absorption Spectrophotometric Method.
- Electro thermal Atomic Absorption Spectrophotometric Method.

Spectrophotometric Silver Diethyldithiocarbomate($C_5H_{10}NS_2Ag$) Method:

Principle

Total arsenic in ground water mostly found in forms of inorganic arsenates (AsO_3^{3-}) and arsenates (AsO_4^{3-}). In Gutzeit generator Zinc, Hydrochloric (HCl) acid and Stannous Chloride ($SnCl_2$) all are used as reducing agent where Stannous Chloride is used for complete evolution of Arsine gas (AsH_3) by reducing Arsenate, As(V) to Arsenite, As(III). The Arsine gas is passed though scrubber tube containing absorbent cotton with lead acetate [$(CH_3COO)_2Pb$] to remove sulfide interference (Sulfureted Hydrogen, H_2S). The arsine gas is absorbed in Silver Diethyldithiocarbomate (SDDC) solution and it gives a orange-red colour. Then it is measured by spectrophotometer at 520 nm.

Apparatus

- Spectrophotometer for use at 520 nm.
- Gutzeit generator

Reagents

a) Concentrated hydrochloric acid.
b) 15% Potassium Iodide (KI) solution: Add 100ml D/D water with 15gm KI
c) 40% Stannous chloride ($SnCl_2$) solution: Dissolve 40gm $SnCl_2,2H_2O$ in 25ml conc. HCl and dilute to 100ml hydrochloric acid ,conc.
d) 10% lead acetate [$(CH_3COO)_2Pb$] solution: Dissolve 10g $(CH_3COO)_2Pb.3H_2O$ in 100ml D/D water.
e) Zinc Flakes, Arsenic free.
f) Silver Diethyldithiocarbomate (SDDC) solution: Dissolve 1ml morpholine in 70ml chloroform, $CHCl_3$. Add 0.30gm SDDC, $AgSCSN(C_2H_5)_2$; shake in a stoppered flask until most is dissolved. Dilute to 100ml with chloroform. Then filter with a whatman filter paper in moisture free container and store in a refrigerator.
g) Standard arsenic stock solution: Dissolve 0.17876gm sodium arsenite (Na_2AsO_2) salt in 1000ml D/D water

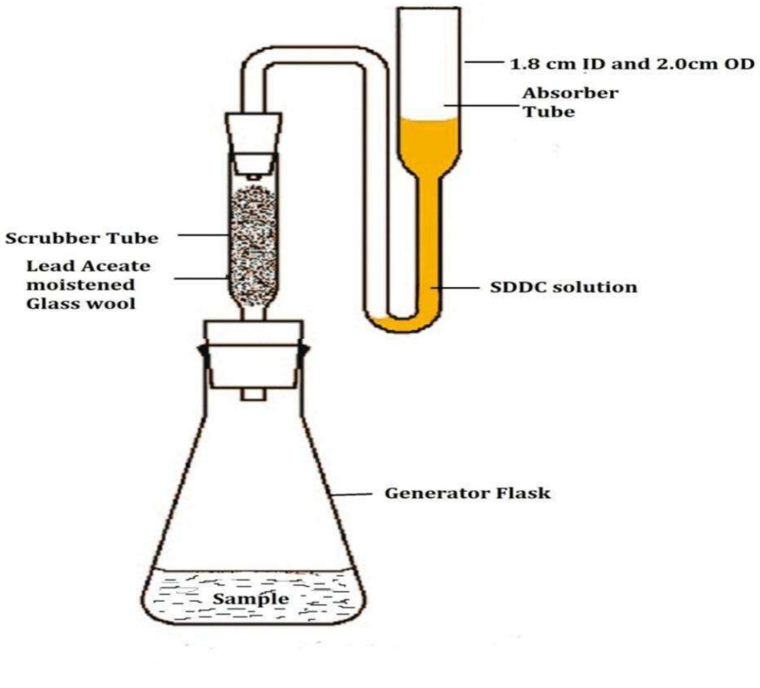


Fig:5.1 Arsine generator and absorber assembly

Procedure

- Sample preparation: 35ml of water sample is taken by 100ml measuring cylinder into a clean generator flask, add 5ml conc. HCl, 2ml KI solution and 0.5ml $SnCl_2$ solution successively with proper mixing. Kept it for 15minutes for reduction of Arsenic in arsenate, As(V) to As(III)
- Preparation of Scrubber tube and absorber: In the scrubber tube glass wool is impregnated with lead acetate solution. 10ml of SDDC solution was pipette out into the absorber tube or U-tube.
- Arsine generation and measurement: 3-4 grams of zinc flakes is added to sample water in generator flask and scrubber-absorber assembly is connected immediately. 30 minutes is allowed for the complete evolution of arsine. The solution is directly poured in a clean 20mm cuvette /cell and absorbance was measured in spectrophotometer at 520 nm.
- Preparation of calibration curve: Treat standard arsenic solution containing 0.0, 1.0, 2.0, 5.0, 10.0 and 20.0 μg. Plot the absorbance vs. microgram of arsenic in the standard solution in Spectrophotometer.

Fig:5.2 Testing of experimental samples in laboratory

5.1.2 Total Iron

Introduction

Iron is brought into solution, reduced to ferrous state by boiling with acid and hydroxylamine and treated with 1, 10-phenanthroline at pH 3.2 to 3.3. Minimum detectable concentration is 10 ug/l Fe

Apparatus

Spectrophtometer, use at 510 nm

Reagents

a) Concentrated hydrochloric acid
b) Hydroxylamine solution: Dissolve 10g $NH_2OH.HCl$ in 100ml water.
c) Ammonium acetate buffer: Dissolve 100mg 1, 10-phenantroline monohydrate, $C_{12}H_8N_2.H_2O$ in 100 ml water by stirring and heating to $80°C$. Do not boil it. Discard solution when it darkens. Heating is not required if 2 drops of HCl is added.

Procedure

Total iron:

a) Take 50ml sample into a 125 ml conical flask.
b) Add 2ml concentrated HCl and 1ml $NH_2OH.HCl$ solution and add few glass beads and heat to boil.
c) Continue boiling until volume is reduced to 15-20ml
d) Cool to room temperature and transfer to a 50ml volumetric flask.
e) Mix thoroughly and allow at least 10-15 min for maximum colour development.
f) Then check the reading in Spectrophotometer using at 510nm wavelength.

5.1.3 pH

Principle

The basic principle of the pH meter is to measure the concentration of hydrogen ions. A pH meter provides a value as to how acidic or alkaline a liquid is. The pH varies with temperature.

Procedure

Electromagnetic Method:

- At first switch on the pH meter and given it 15mins for warm up.
- Then for calibration press CAL button.
- Dip electrode into pH buffer solution 1 (pH 10.01), press AR & then run ENTER
- Rinse electrode with distilled water & wipe clean, display shows insert Buffer 2 (pH 7.00)
- Dip electrode into pH Buffer 2 (pH 7.00), press AR & then run ENTER
- Again, display shows insert Buffer 3 (pH 4.01), rinse electrode with distilled water & wipe clean with tissues.
- Calibration is done.
- Immerse electrode into experimental sample and press MEAS For measurement
- Wait for the stable reading in display of pH meter.
- Rinse electrode with distilled water & wipe clean with tissues

Fig:5.3 pH test of experimental samples

5.1.4 TDS & EC

Principle

A TDS meter displayed the concentration of total dissolved solids in a solution.

Procedure

Ion selective Electrode method

Immerse the conductivity electrode in water sample and measure electrical conductivity (E.C) as well as total dissolved solid (TDS) concentration.

1. At first switch on the conductivity meter.
2. Immerse the electrode into sample for measurement
3. Press MEAS button for measuring the TDS, waits for the stable reading in display.
4. TDS result shows in mg/l
5. Then press MODE button for measuring the EC of the sample.
6. Wait for a second until the reading is stabled in screen.
7. EC results shows in ms/cm
8. Take 25-50 ml of water sample in a clean and dry beaker (100 ml)

Fig:5.4 Conductivity meter for measuring the TDS & EC

5.1.5 Turbidity

Principle

The main principle of turbidity meter is based on the comparison of the intensity of light a sample with the intensity of light scattered by a standard suspension. The intensity of scattered light is sensed by a photocell kept at 90° to the beam.

Procedure

Nephelometric Method:

1. Switch on the Turbidity Meter
2. Press CAL for calibrate it, insert 800 NTU, 100 NTU, 20.0 NTU, 0.02 NTU standard bottles and press READ respectively for each.
3. Turbidity meter shows the exact value for each standard sample that means the calibration is done correctly.
4. For sample analysis, shake the sample bottle, fill the sample vial till the mark and clean it with dry tissue and kept it in the photocell.
5. Press READ and wait for the stable result is shown in screen.
6. Turbidity results shows in NTU
7. Wash the sample vial with distilled water & wipe with a clean tissue before filling the next sample.

Fig:5.5 Turbidity meter

CHAPTER-6

EXPERIMENTAL METHODOLOGY ON THE REMOVAL OF ARSENIC BY ION- EXCHANGE METHOD

6.0 Methodologies for this study

In this study Anionic resin is used as an ion exchanger media in Burette to evaluate the arsenic removal efficiency from contaminated ground water.

Arsenic in groundwater is generally found in as negatively charged ionic form($H_3AsO_4^-$,$HAsO_2^-$) and also an uncharged form. Anionic resin exchanges the negatively charged ions. In this study Anionic resin is used as an ion exchanger media to evaluate the arsenic removal efficiency from contaminated ground water of each experiment. Arsenic concentration of spiked and treated water is measured by Spectrophotometric Silver Diethyldithiocarbomate Method (SDDC) and other water quality parameters are tested in the laboratory also.

In this study of adsorption Anionic resin are used as adsorbent to remove the arsenic from contaminated ground water. Arsenic concentration of spiked and treated water is measured by Spectrophotometric Silver Diethyldithiocarbomate Method (SDDC) and other water quality parameters are tested in the laboratory also.

Various technologies have been urbanized for the deletion of high concentrations of arsenic from the drinking water (mainly ground water). Most used technologies are oxidation, coagulation-flocculation, adsorption, ion-exchange and membrane techniques. In this study Ion-exchange method is adopted for the removal of arsenic from contaminated water.

6.1 Ion-Exchange Method

Introduction

Ion-exchange process for removal of arsenic has been found to be most convenient for use in field. These resins are rooted in a cross-linked polymer skeleton and it is composed of polystyrene cross-linked with divinylbenzene and charged functional groups are attached to this through covalent bonding. There are four groups according to their charge.

I. Strong acidic (sulfonate,$R - SO_3H$)
II. Weakly acidic (carboxylate,$R - COOH$)
III. Strongly Basic (quaternary amine,$R - N^+OH^-$)
IV. Weakly Basic (tertiary amine,$R - NH_3OH$)

Anionic Exchange Resin: These are positively charged resin attracts negatively charged ions presents in water. In groundwater arsenic is mainly found as negatively charged ($H_3AsO_4^-$,$HAsO_2^-$). That's why it is most effective to remove the arsenic from groundwater. The basic character is due to the presences of amino groups. Those polymerswithquaternary ammonium groups and amino or substituted amino groups are respectively having strong basic and weak basic properties. A widely used anion exchange resin is prepared by co-polymerization of styrene and a little divinylbenzene.

In this experiment anionic resin are used as ion exchange media to remove the arsenic from water.

Fig: 6.1 Anionic resin

Ion exchange process of arsenic using Anionic resin

Materials required

- Glass burette
- Glass funnel
- 500 ml beaker
- 100 ml Measuring cylinder for calculate the flow rate by using stopwatch
- 10 gm anionic resin
- Coarse sand
- Gravel
- 100ml Glass bottles for sampling

Chemical required

- Arsenic stock solution (concentration of 200mg/l)
- Concentrated hydrochloric acid

Methodology

Sampling

Chemicals are used AR graded without any added purification. All the solutions are prepared with D/D water in the laboratory of School of Water Resources Engineering. 100 mg/l Primary stock solution is prepared by sodium arsenate diluted with D/D water in the laboratory of School of Water Resources Engineering. Spiked groundwater concentrated 200 µg/L is prepared from primary stock solution for the experiment. Glass are acid washed before use. Before collecting the sample, the container is washed three-four times by the water is to be filled.

Experimental set-up

- Diameter of the burette = 1cm

Height of the burette = 75cm

Cross-sectional area of the burette = 0.78571 cm^2

Height of the bed = from bottom 5cm Gravel layer
15cm Coarse sand layer
15 cm Anionic resin layer

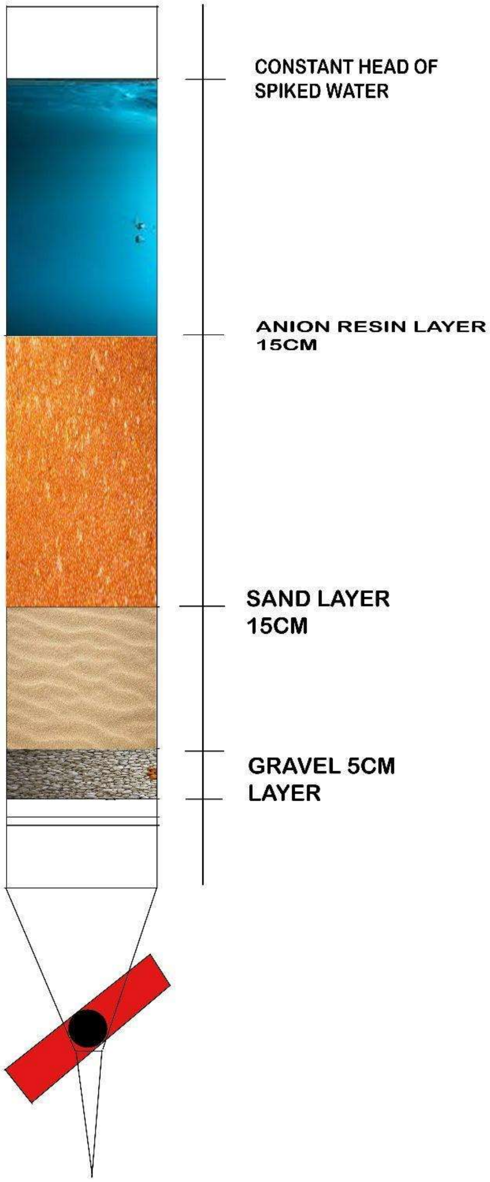


Fig:6.2 Design of anionic resin filter

Experimental Procedure

All the experiments are carried out with ground water without any pH adjustment or any pre-treatment.

- To produce 200 µg/L spiked groundwater 6 mL of primary arsenic stock solution (i.e., 100 mg/L) is diluted to 3 liters of groundwater.
- The groundwater is collected from a tube well located at purandarpur math in baruipur of south 24 parganas district,) is passed through the filter bed in a down flow pattern and maintaining the hydraulic flow rate at the outlet is 500 L/hr/m^2
- After filtration sample is collected in 100ml glass container.
- All the necessary tests are analysed on the day of every trial.

Fig:6.3 Anionic resin burette filter

6.2 Results, Analysis and Discussion

6.2.1 Arsenic Removal Efficiency

Table: 6.1 Arsenic Removal Efficiency

Treated Volume	Treated Volume(ml)	Time	Initial Conc. (mg/l)	Final Conc. (mg/l)	Removal %
0.1	100	142.86	0.203	0.004	98.03
0.15	150	214.29	0.203	0.003	98.52
0.2	200	285.71	0.203	0.004	97.85
0.25	250	357.14	0.203	0.004	98.03
0.3	300	428.57	0.203	0.004	98.03
0.375	375	535.71	0.203	0.005	97.54
0.45	450	642.86	0.203	0.006	96.85
0.5	500	714.29	0.203	0.007	96.72
0.55	550	785.71	0.203	0.007	96.58
0.6	600	857.14	0.203	0.008	96.06
0.65	650	928.57	0.203	0.007	96.32
0.7	700	1000.00	0.203	0.008	96.19
0.75	750	1071.43	0.203	0.008	96.06
0.8	800	1142.86	0.203	0.009	95.60
0.85	850	1214.29	0.203	0.010	95.14
0.9	900	1285.71	0.203	0.011	94.68
0.95	950	1357.14	0.203	0.012	94.22
1	1000	1428.57	0.203	0.013	93.76

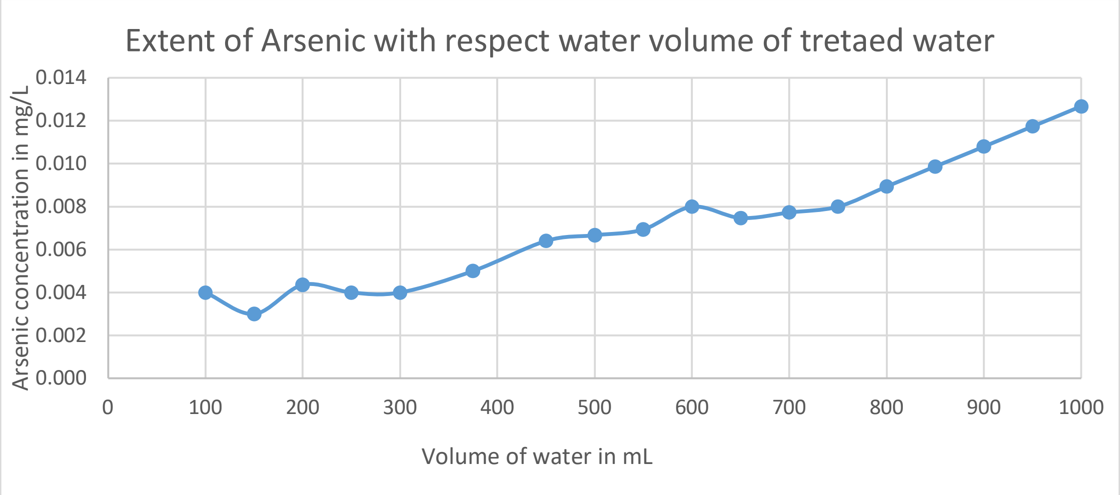


Fig:6.4 Final concentration versus volume of Treated water

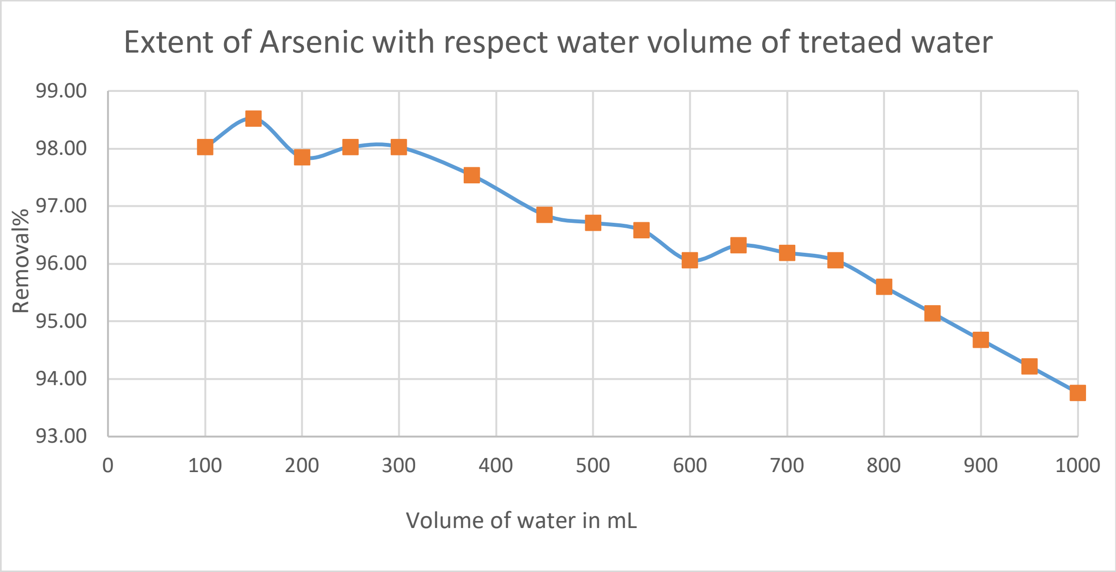


Fig:6.5 Removal % versus volume of Treated water

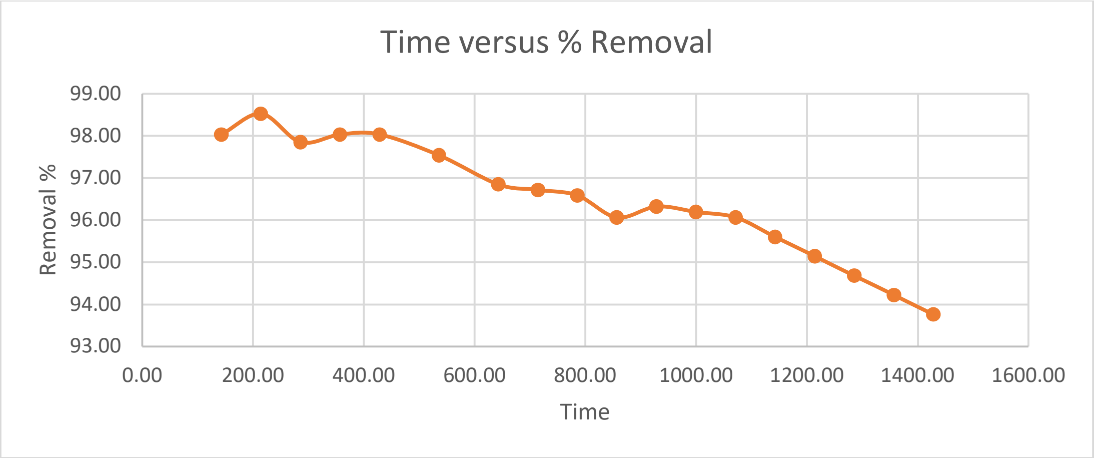


Fig:6.6 Removal % versus Time

Adsorption Capacity of Ion exchange resin:

$q_e = \frac{(C_0 - C_e)}{m} \times V$

where C_0 and C_e are the initial and equilibrium concentrations of the aqueous solution, respectively, in mg/L, m is the mass of the adsorbent in kg, and V is the volume of the arsenic solution in L.

$$q_e = \frac{(0.203 - 0.01)}{10} \times 0.85 = 0.016405 \frac{mg}{gm} \; or, 16.45 \; gm/kg$$

6.2.2 Iron Removal Efficiency

Table: 6.2 Iron Removal Efficiency

Sl No.	Treated Volume	Time	Initial Conc.	Final Conc.	Removal %
1	100	142.86	0.46	0.05	89.13043
2	200	285.71	0.46	0.05	89.13043
3	300	428.57	0.46	0.06	86.95652
4	400	571.43	0.46	0.07	84.78261
5	500	714.29	0.46	0.09	80.43478
6	600	857.14	0.46	0.09	80.43478
7	700	1000.00	0.46	0.105	77.17391
8	800	1142.86	0.46	0.112	75.65217
9	900	1285.71	0.46	0.158	65.65217
10	1000	1428.57	0.46	0.163	64.56522

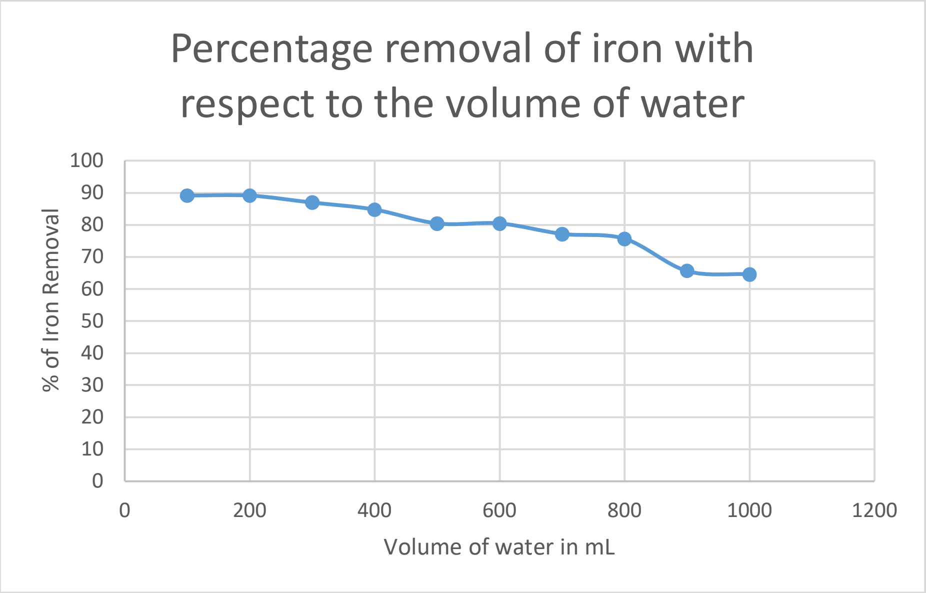


Fig:6.7 Removal % versus volume of Treated water

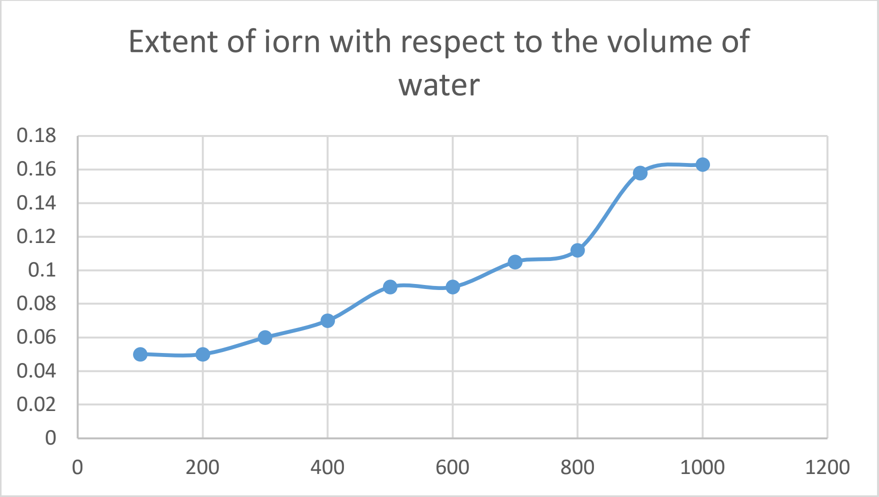


Fig:6.8 Final concentration versus volume of Treated water

6.2.3 Effect On pH

Table: 6.3 Effect on pH

Sl No.	Treated Volume	Time	Initial Conc.	Final Conc.
1	100	142.8571429	9.38	7.84
2	200	285.7142857	9.38	8.01
3	300	428.5714286	9.38	8.36
4	400	571.4285714	9.38	8.42
5	500	714.2857143	9.38	8.43
6	600	857.1428571	9.38	8.25
7	700	1000	9.38	8.35
8	800	1142.857143	9.38	8.48
9	900	1285.714286	9.38	8.27
10	1000	1428.571429	9.38	8.35

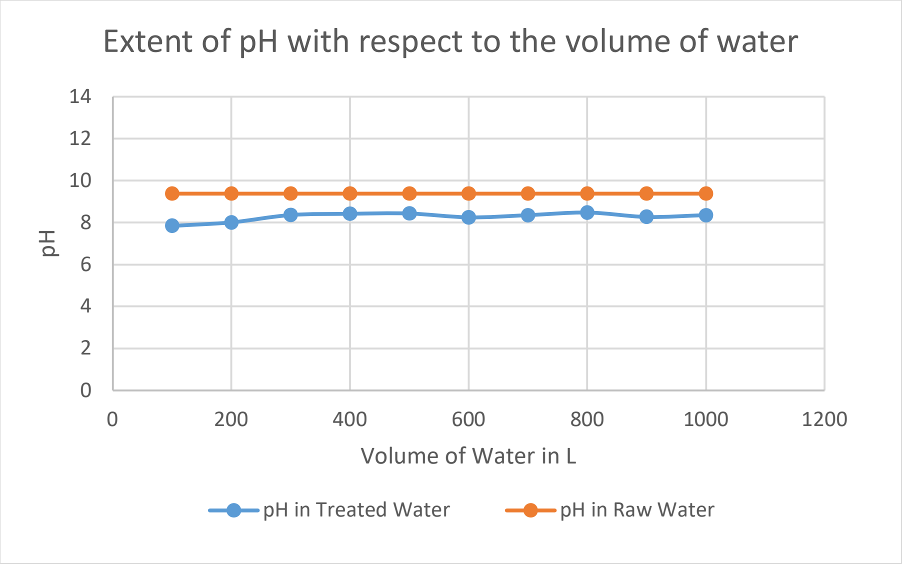


Fig 6.9: Extent Of pH With respect to the volume Of Water

6.2.4 Effect On Other Water Parameter

6.2.4.1 TDS

Table: 6.4 Effect On TDS

Sl No.	Treated Volume	Time	Initial Conc.	Final Conc.
1	100	142.8571	320	210
2	200	285.7143	320	496
3	300	428.5714	320	442
4	400	571.4286	320	439
5	500	714.2857	320	423
6	600	857.1429	320	481
7	700	1000	320	488
8	800	1142.857	320	510
9	900	1285.714	320	485
10	1000	1428.571	320	493

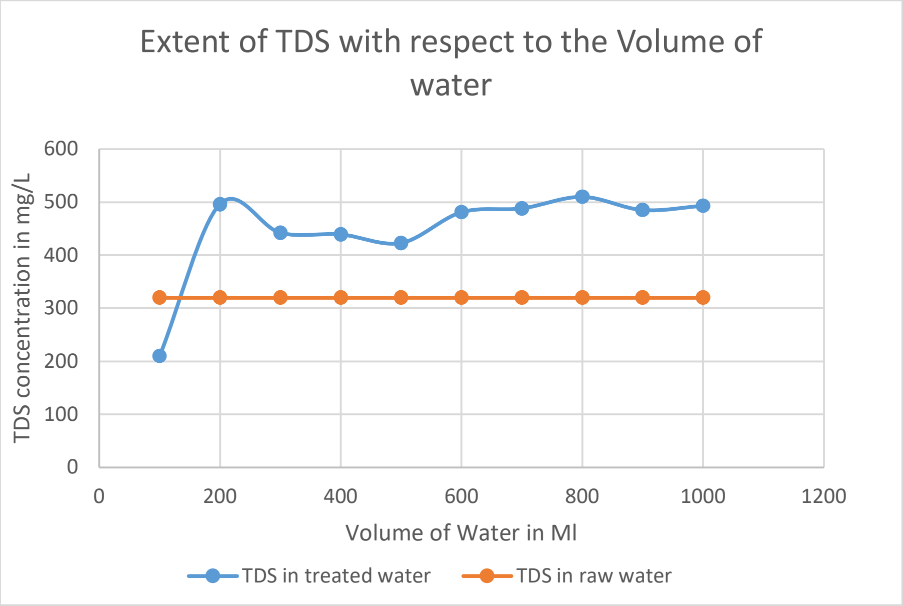


Fig 6.10: Extent of TDS With respect to the volume Of Water

6.2.4.2 Turbidity

Table: 6.5 Effect on Turbidity

Sl No.	Treated Volume	Time	Initial Conc.	Final Conc.
1	100	142.8571	1.05	0.49
2	200	285.7143	1.05	0.62
3	300	428.5714	1.05	0.65
4	400	571.4286	1.05	0.71
5	500	714.2857	1.05	0.77
6	600	857.1429	1.05	0.81
7	700	1000	1.05	0.85
8	800	1142.857	1.05	0.96
9	900	1285.714	1.05	1.02
10	1000	1428.571	1.05	0.96

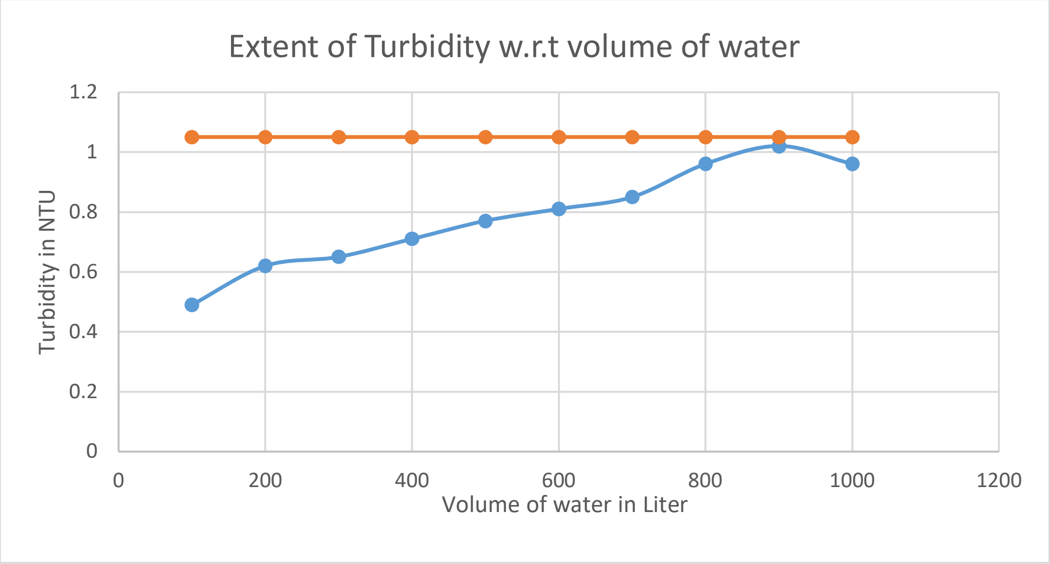


Fig 6.11: Extent of Turbidity With respect to the volume Of Water

CHAPTER-7

Discussion of Study

Discussion

Firstly I have prepare a filter which is shown in fig. number 6.3. this filter consists of gravel layer of 5cm, sand layer of 15cm, and anion resin layer of 15cm and constant head of spiked water 40cm respectively from bottom to top which is shown in fig. number 6.2. the diameter of the burette is 1cm and cross-sectional area is 0.78571cmsq.

The main objective for making this filter to determine arsenic removal efficiency, iron removal efficiency, measurement of ph, tds, turbidity,

From table number 6.1 we can see that from this filter 100ml of treated water takes 142.86mints whose initial arsenic concentration was 0.203mg/l and final concentration was 0.004mg/l so the removal efficiency is 98.03% after that when the treated volume is 700ml it took 1000min and final concentration 0.008mg/l and removal efficiency is 96.19% and lastly the 1000ml treated water took 1428.57mints and final concentration is 0.013mg/l and removal percentage is 93.76%. I represent these result by graphically figure numbers 6.4, 6.5 and 6.6.

From table number 6.2 we can see that from this filter 100ml of treated water takes 142.86mints whose initial iron concentration was 0.46 mg/l and final concentration was 0.05mg/l so the removal efficiency is 89.13% after that when the treated volume is 700ml it tooks 1000min and final concentration 0.105 mg/l and removal efficiency is 77.17 % and lastly the 1000ml treated water took 1428.57mints and final concentration is 0.163 mg/l and removal percentage is 64.56%. I represent these result by graphically figure numbers 6.7 and 6.8.

From table number 6.3 we can see that from this filter 100ml of treated water takes 142.86mints whose initial pH concentration was 9.38 mg/l and final concentration was 7.84mg/l after when the treated volume is 700ml it tooks 1000min and final concentration 8.35 mg/l and lastly the 1000ml treated water took 1428.57mints and final concentration is 8.35 mg/l .I represent these result by graphically figure number 6.9.

From table number 6.4 we can see that from this filter 100ml of treated water takes 142.86mints whose initial TDS concentration was 320 mg/l and final concentration was 210 mg/l after when the treated volume is 700ml it took 1000min and final concentration 488 mg/l and lastly the 1000ml treated water took 1428.57mints and final concentration is 493 mg/l .I represent these result by graphically figure number 6.10

From table number 6.5 we can see that from this filter 100ml of treated water takes 142.86mints whose initial Turbidity concentration was 1.05 mg/l and final concentration was .49 mg/l after when the treated volume is 700ml it took 1000min and final concentration .85 mg/l and lastly the 1000ml treated water took 1428.57mints and final concentration is .96 mg/l .I represent these result by graphically figure number 6.11

CHAPTER-8

Conclusion of Study

8.0 Conclusion

The existence of arsenite and arsenate in ground water is a serious problem across the world specially in West Bengal and detection of arsenic by appropriate technologies is one of the solutions to manage the arsenic problem.

1. The ion-exchange process by resin is a simple, reliable and cost-effective method of arsenic removal from contaminated Ground water. This process does not cause of sludge generation.
2. Resins can be regenerate by addition of salt (NaCl).
3. Excellent removal efficiency around 100% is achieved by using anionic resin as a filter bed, but pre adjustment of pH is to be needed because of getting low pH in treated water samples.
4. Only anionic resin also gives the excellent arsenic removal efficiency of 98.03% without requirement of any pre-treatment process, at a same time most of the parameters of treated water are remained in the desirable limit of the drinking water standard as per BIS-10500:2012.
5. So, Ion-exchange process of arsenic removal by anionic resin has been found to be very effective, economical and simple operation and maintenance process.
6. The beads shaped ion- exchange material are able to remove arsenic from synthetic contaminated Ground water. Anionic resin are easily available in local market.
7. It is very efficient system with respect to the arsenic removal (100%), On the other hand the adsorption capacity and maximum removal efficiency in Anionic resin filter bed is 93% to 98% respectively.
8. Ion- exchange process of the Anionic resin may be acceptable for arsenic removal than other removal technologies because of inconsiderable sludge generation and simple regenerating procedure of ion-exchange media.
9. This system may be applicable and adaptable for a house-hold which is cost- effective and user friendly too.

CHAPTER-9

Reference

9.0 Reference

- Adeloju SB, Khan S, Patti AF (2021) Arsenic Contamination of Groundwater and Its Implications for Drinking Water Quality and Human Health in Under-Developed Countries and Remote Communities—A Review. Appl. Sci. 11(4): 1926.
- Ali AH (2022) Review on Application of Low-Cost Adsorbents for Arsenic Removal. Eart & Envi Scie Res & Rev 5(2): 9-17.
- Ali MBS, Humrouni B, Bouguecha S et al (2004) Silica removal using ion-exchange resins. Desalination 167: 273-279.
- Bhardwaj A, Rajput R, Misra K (2019) Status of Arsenic Remediation in India. In: Ahuja S (Ed.) Advances in Water Purification Techniques, Elsevier, USA, 219-258.
- Bhowmick S, Halder D, Nriagu J et al (2014) Speciation of Arsenic in Saliva Samples from a Population of West Bengal, India. Environ. Sci. Technol. 48(12): 6973–6980.
- Das A, Joardar M, De A et al (2021) Pollution index and health risk assessment of arsenic through different groundwater sources and its load on soil-paddy-rice system in a part of Murshidabad district of West Bengal, India. Groundwater for Sustainable Development 15: 100652.
- Das TK, Bezbaruah AN (2021) Comparative study of arsenic removal by iron-based nanomaterials: Potential candidates for field applications. Science of The Total Environment 764: 142914.
- Dey TK, Banerjee P, Bakshi M et al (2014) Groundwater Arsenic Contamination in West Bengal: Current Scenario, Effects and Probable Ways of Mitigation. International Letters of Natural Sciences 8(1): 45-58.
- Gautam A (2014) Study of various methods for the removal of Arsenic Contamination in Groundwater. Bachelor of Technology Thesis in Civil Engineering, Department of Civil Engineering, National Institute of Technology, Rourkela.
- Goren AY, Kobya M (2021) Arsenic removal from groundwater using an aerated electrocoagulation reactor with 3D Al electrodes in the presence of anions. Chemosphere 263: 128253.
- Islam A, Teo SH, Ahmed MT et al (2021) Novel micro-structured carbon-based adsorbents for notorious arsenic removal from wastewater. Chemosphere 272: 129653.
- Israel S, Tredoux G, Engelbrecht P et al (2009) In-situ nitrate removal from groundwater to supply rural communities: experimental work and modelling. WIT Transactions on Ecology and the Environment 127: 427-436.

- Jain CK, Singh RD (2012) Technological options for the removal of arsenic with special reference to South East Asia. Journal of Environmental Management 107: 1-18.
- Jha SK, Mishra VK, Damodaran T et al (2017) Arsenic in the groundwater: Occurrence, toxicological activities, and remedies. Journal of Environmental Science and Health, Part C 35(2): 84-103.
- Joardar M, Das A, Chowdhury NR et al (2021) Health effect and risk assessment of the populations exposed to different arsenic levels in drinking water and foodstuffs from four villages in arsenic endemic Gaighata block, West Bengal, India. Environ Geochem Health 43: 3027–3053.
- Kobya M, Gebologlu U, Ulu F et al (2011) Removal of arsenic from drinking water by the electrocoagulation using Fe and Al electrodes. Electrochimica Acta 56(14): 5060-5070.
- Mazumder DG, Dasgupta UB (2011) Chronic arsenic toxicity: Studies in West Bengal, India. Kaohsiung Journal of Medical Sciences 27: 360-370.
- Melin T, Jefferson B, Bixio D et al (2006) Membrane bioreactor technology for wastewater treatment and reuse. Desalination 187(1-3): 271-282.
- Mohanty D (2017) Conventional as well as Emerging Arsenic Removal Technologies—a Critical Review. Water Air Soil Pollut 228: 381.
- Mondal NS, Mondal P, Roy PK et al (2022) Adsorption kinetics and isotherm modeling of arsenic removal from groundwater using electrocoagulation. J IRAN CHEM SOC 19: 1445–1456.
- Mondal P, Majumder CB, Mohanty B (2006) Laboratory based approaches for arsenic remediation from contaminated water: Recent developments. Journal of Hazardous Materials 137(1): 464-479.
- Mondal P, Roy PK, Mondal NS et al (2021) Development of Low-Cost Arsenic Removal Process by Using Ion-Exchange Resins. In: Roy PK, Roy MB, Pal S (eds) Advances in Water Resources Management for Sustainable Use. Lecture Notes in Civil Engineering, 131, Springer, Singapore.
- Moreira VR, Lebron YAR, Santos LVS et al (2021) Arsenic contamination, effects and remediation techniques: A special look onto membrane separation processes. Process Safety and Environmental Protection 148: 604-623.

- Moreira VR, Lebron YAR, Santos LVS et al (2021) Arsenic contamination, effects and remediation techniques: A special look onto membrane separation processes. Process Safety and Environmental Protection 148: 604-623.
- Mukherjee DC, Chowdhury SB, Paul A (2012) A review on arsenic pollution in West Bengal and Bihar · Cause, effects and remedial measures following latest technology. J. Indian Chern. Soc. 89: 9-18.
- Mukherjee S, Thakur AK, Goswami R et al (2021) Efficacy of agricultural waste derived biochar for arsenic removal: Tackling water quality in the Indo-Gangetic plain. Journal of Environmental Management 281: 111814.
- Nasorallahi N, Ghalamchi L, Vatanpour V et al (2021) Photocatalytic-membrane technology: a critical review for membrane fouling mitigation. Journal of Industrial and Engineering Chemistry 93: 101-116.
- Ngo HH, Guo W, Surampalli RY, Zhang TC (2016) Green Technologies for Sustainable Water Management. ASCE Library
- Perez JPH, Schiefler AA, Rubio SN et al (2021) Arsenic removal from natural groundwater using ‘green rust’: Solid phase stability and contaminant fate. Journal of Hazardous Materials 401: 123327.
- Raval NP, Kumar M (2021) Geogenic arsenic removal through core–shell based functionalized nanoparticles: Groundwater in-situ treatment perspective in the post–COVID Anthropocene. Journal of Hazardous Materials 402: 123466.
- Rehman MU, Khan R, Khan A et al (2021) Fate of arsenic in living systems: Implications for sustainable and safe food chains. Journal of Hazardous Materials 417: 126050.
- Roy PK, Majumder A, Banerjee G et al (2015) Removal of arsenic from drinking water using dual treatment process. Clean Techn Environ Policy 17: 1065–1076.
- Shaji E, Santosh M, Sarath KV et al (2021) Arsenic contamination of groundwater: A global synopsis with focus on the Indian Peninsula. Geoscience Frontiers 12(3): 101079.
- Shakoor MB, Niazi NK, Bibi I et al (2018) Arsenic removal by natural and chemically modified water melon rind in aqueous solutions and groundwater. Science of The Total Environment 645: 1444-1455.

- Shakya AK, Ghosh PK (2018) Simultaneous removal of arsenic and nitrate in absence of iron in an attached growth bioreactor to meet drinking water standards: Importance of sulphate and empty bed contact time. Journal of Cleaner Production 186: 304-312.
- Singh P, Pal P, Mondal P et al (2021) Kinetics and mechanism of arsenic removal using sulfide-modified nanoscale zerovalent iron. Chemical Engineering Journal 412: 128667.
- Usman M, Katsoyiannis I, Rodrigues JH et al (2021) Arsenate removal from drinking water using by-products from conventional iron oxyhydroxides production as adsorbents coupled with submerged microfiltration unit. Environ Sci Pollut Res 28: 59063–59075.
- Yadav MK, Saidulu D, Gupta AK et al (2021) Status and management of arsenic pollution in groundwater: A comprehensive appraisal of recent global scenario, human health impacts, sustainable field-scale treatment technologies. Journal of Environmental Chemical Engineering 9(3): 105203.
- Yenial U, Bulut G, Sirkeci AA (2014) Arsenic Removal by Adsorptive Flotation Methods. Clean Soil Water Air 42(11): 1567-1572.
- Yeo KFH, Li C, Zhang H et al (2021) Arsenic Removal from Contaminated Water Using Natural Adsorbents: A Review. Coatings 11(11): 1407.