DEVELOPMENT OF LOW-COST ARSENIC REMOVAL PROCESS AND PERFORMANCE EVALUATION OF ARSENIC-IRON REMOVAL PLANTS (AIRPs) IN NORTH 24 PARGANAS DISTRICT OF WEST BENGAL

A thesis submitted towards partial fulfilment of the
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Submitted by

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This work is devoted to arsenic oppressed populace.

Abstract

Arsenic is the most perilous element in the chemical world and excessive presence of arsenic in drinking water can cause disaster. Arsenic exists in organic as well as inorganic forms with varying valence states, (-) 3, 0, 3, and 5. The oxidized states, As(III) and As(V) are known as Arsenite and Arsenate respectively. The valence state of arsenic plays an important role in its behavior and toxicity in aqueous system. West Bengal is one of the worst arsenic affected regions in world arsenic scenario. 104 blocks of 11 districts in West Bengal are trashily affected by arsenic. Arsenic can be easily removed from groundwater by using of various technologies i.e. Co-precipitation, Adsorption, Ion-exchange and Membrane technique. In this study ion-exchange and adsorption technique is adopted for removal of arsenic. Different ion-exchange (Anionic-Cationic, Cationic and Anionic) resins were used for different experiments to evaluate the removal efficiency of arsenic. These experiments were carried out in a burette. This study revealed that using of anionic-Cationic resins for ion-exchange can remove the arsenic around 100%, but pH is affected badly. In case of Cationic resin, this study expressed that the arsenic removal efficiency of this resin is poor, around 49.30 to 65.61% and it also reduce the pH value from 7.74 to 0.98. Whereas the anionic resin can remove arsenic up to 97.43% without affecting the pH of treated sample. The adsorption experiment was carried out in a 75mm diameter PVC column. In this study 1500 gram rusted iron nails were used as an absorbent media and it was able to remove the arsenic 100% and other parameters (Iron, pH, Turbidity, TDS and Alkalinity, Hardness) of drinking water remained within the desirable limit of drinking water standard as per BIS-10500:2012. It is noted from this study that arsenic adsorption isotherm could be described by Freundlich equation. Performance evaluation of AIPRs in North 24 Parganas district of West Bengal is discussed in this study.

CONTENTS

Page No

Appendix A

List of Abbreviations

nm	nanometer	ng	nanogram
ppb	parts per billion	ppm	parts per million
mm	millimeter	µS/cm	microsiemens per centimeter
mg/l	milligram per liter	µg/l	microgram per liter
cm	centimeter	m	meter
g/l	gram per liter	kg	kilogram
g/hr	gram per hour	ml	milliliter
DD	Double Distilled	WHO	World Health Organization
TDS	Total dissolved solids	EC	Electrical Conductivity
As	Arsenic	Fe	Iron
BIS	Bureau of Indian Standard	EPA	Environmental Protection Act

Appendix B

List of Figures

Appendix C

List of Tables

INTRODUCTION

CHAPTER1

Arsenic is semi metallic in nature and broadly present in the earth-crust. In nature it is found in the forms of oxides, sulfides or as a salt of iron, sodium, calcium, copper etc. Arsenic and its compound are well known for its toxicity and carcinogenicity. Contamination of arsenic in ground water is the global problem and millions of people are at a risk of Arsenicosis. India, Bangladesh, China, Taiwan, Thailand, Chili, Romania are the foremost affected countries where inorganic arsenic present in the ground water with high concentration. It mobilized in the environment due to the combination of natural processes such as:

- Weathering Reactions
- Biological activity
- Volcanic emission

There are two major reasons behind the majority of environmental arsenic problems,

i. Natural conditions: Leaching of ambient arsenic in groundwater from sediments containing arsenic bearing minerals; leaching and percolation of arsenic in soils.
ii. Anthropogenic activities: These have an important impact through activities such as Mining, Combustion of fossil fuels, the use of arsenic-based pesticides, herbicides and crop desiccants

High exposure to arsenic through contaminated drinking water probably enchants the greatest threat to human health. Drinking water comes from a variety sources depending on local availability: Surface water (rivers, lakes, reservoirs, and ponds), groundwater and rain water. But most the cases, High concentrations of arsenic are mainly found in ground water.

The World Health Organization (WHO) lists arsenic as chemicals of major public health concern. Drinking water rich in arsenic over a long period lead to arsenic poisoning or Arsenicosis.

As per **BIS** (Bureau of Indian Standard) specifications, Indian standard of drinking water:

Table: 1.1 Standard specifications for drinking water

Parameters	**Desirable Limit (mg/l)**
Arsenic	0.01
Iron (as Fe)	0.3

1.1 Arsenic in environment

Arsenic is the 20th most abundant element in the earth-crust. The abundance of arsenic in the continental crust of the earth is generally given as 1.5 to 2 ppm. It is said to be essential at least for some animal species, but not for human. It is the king of poisons and has overwhelmed human beings since the days of antiquity. It h found as been well known as a carcinogen. It is a toxic chemical and may pollute air, soil, sediments and water and causing health hazards to both human and animal's life. Arsenic in nature as mineral forms, which may contaminated soil by the way of erosion and deposition.

Table 1.2: Approximate environmental concentration levels of arsenic and human exposure through the air, food and water

Medium		Concentration	Remarks
Air	Rural areas	0.4 – 4 ŋg/m³	Arsenic in ambient air is usually a mixture of arsenite and arsenate
	Urban areas	3 – 200 ŋg/m³	
	Industrial areas	>1000 ŋg/m³	
Food	Fish, shellfish and meat	0.4 – 120 µg/kg	70% is organic As and 25% is inorganic As
Water	Surface water	1 – 2 µg/L	Causing endemic illness
	Geothermal water	Mean 500 µg/L Max 25 µg/L	

1.2 Sources of Arsenic

1.2.1 Natural sources of Arsenic

As per several studies arsenic is component of more than 245 minerals. The most important ores are arsenopyrites (FeS), realger (As_4S_4), orpiment (As_4S_6), Ioelligngite ($FeAs_2$), nicoliote (NiAs), cobalt glance (CoAsS), Gersdroffite (NiAsS) and smaltite ($CoAs_2$). Within these minerals, arsenopyrite is probably the most common mineral in the environment.

Arsenic and its compounds are movable in the environment. Weathering of rocks converts arsenic sulfides to arsenic trioxide, which enters the arsenic as dust or by dissolution in rain, rivers or groundwater. Volatile forms of arsenic that is arsine (AsH_3) and trimethyl arsine (CH_3As) enter the atmosphere from land and water, are revisited by rain. By anaerobic processes the oxidized forms of arsenic are transformed back to sulfides, occurring on land and water sediments.

Table 1.3: Natural arsenic containing minerals and chemical formulas

Minerals	**Chemical Formula**	**Minerals**	**Chemical Formula**
Arsenite	As	Gersdorfifte	CoAsS
Arsenopyrite	FeAsS	Jordanite	$(Pb,Ti)_{13}As_7S_{23}$
Arsenogentite	Ag_3As	Loellingite	$FeAs_2$
Arsenolite	As_2O_3	Nicolite	NiAsS
Adamite	$Zn_2AsO_4(OH)$	Orpiment	As_2S_3
Antimony arsenide	AsSb	Pearcite	$Ag_{16}As_2S_{12}$
Beaudanite	$PbFe_3(AsO_4)SO_4$	Realgar	AsS
Coabalite	CoAsS	Scorodite	$(FeAl)AsO_4\ 2H_2O$
Domeykite	Cu-As	Sperrylite	$PtAs_2$
Enargite	Cu_3AsS_4	Tennantite	$Cu_{12}As_4S_{13}$

1.2.2 Anthropogenic sources

Recent studies have evaluate the ratio of natural to anthropogenic inputs of arsenic is 60:40. Arsenic may accumulate in soil through use of arsenical pesticides, application of fertilizers, irrigation, dusts from the burning fuels, and disposal of industrial and animal wastes. The global production rate of arsenic compounds is given below.

Table 1.4: Production rates of the main arsenical compounds.

Compound	**Production** (tons As/year)
Herbicides	8000
Cotton desiccant	12000
Wood preservatives	16000

1.2.3 Geological sources of Arsenic in West Bengal

In the region of alluvial sediment in West Bengal there is existence of pyrite and this pyrite is rich in arsenic. Due to heavy groundwater extraction and oscillation of water table from pre-monsoon and also due to many numbers of boreholes, the underground aquifer is aerated and the pyrite decomposes. The acid released due to this decomposition leaches out arsenic from pyrite. This is one of the main causes for arsenic contamination in West Bengal.

1.3 Chemistry of Arsenic

Arsenic is a chemical element in the nitrogen family (Group VA of the periodic table) existing in both grey and yellow crystalline forms. It is a semi metal element, odorless and tasteless also. Gray arsenic is more stable and more common than the softer yellow form and it is brittle type. 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.

Table 1.5: Properties 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:

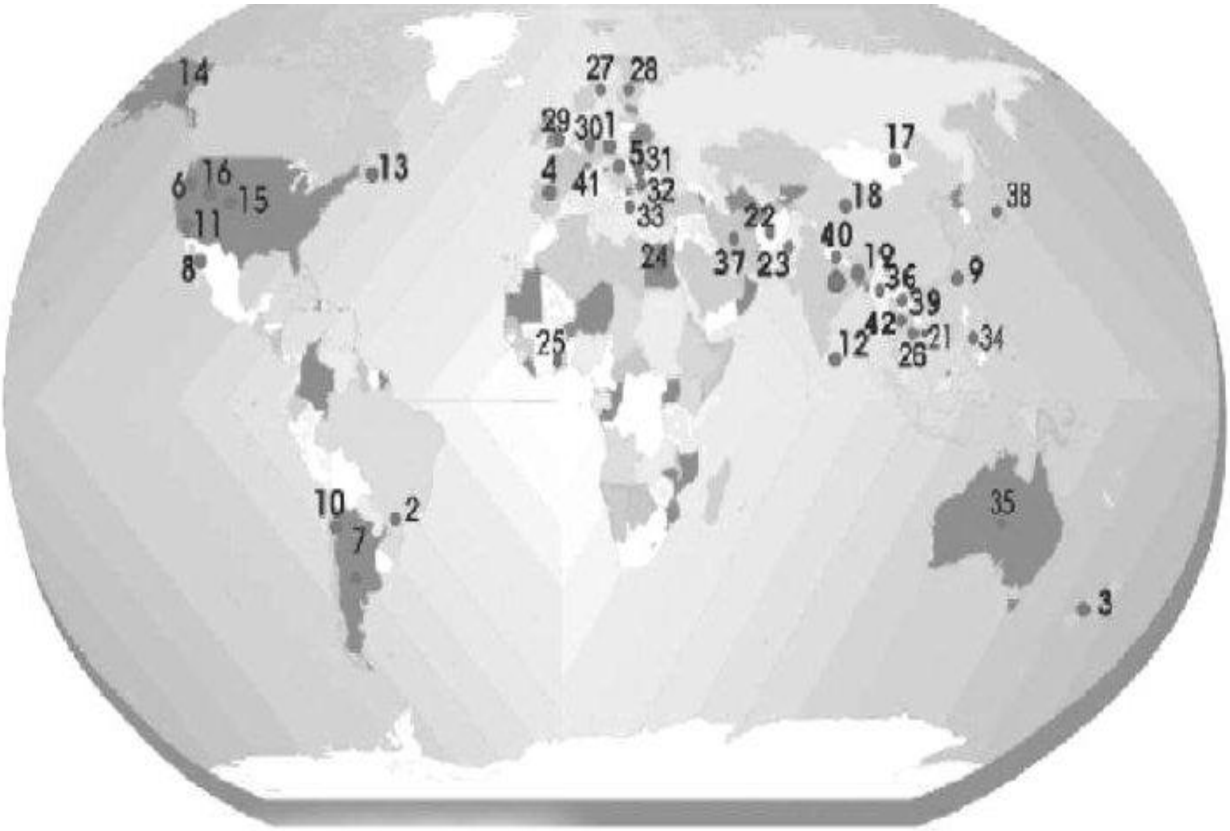
H_3AsO_4, $H_2AsO_4^-$, $HAsO_4^{2-}$, and AsO_4^{3-}

Similarly, arsenite exists in five forms:

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

1.4 Arsenic contamination of groundwater in global perspective

Over the past two or three decades, amount of high concentrations of arsenic in drinking-water has been documented as a major public-health concern in several parts of the world. With the discovery of newer sites in the recent past, the arsenic-contamination scenario around the world, especially in Asian countries, has changed considerably. A study found that over 137 million people in more than 70 countries are probably affected by arsenic poisoning of drinking water. Arsenic contamination of ground water is found in many countries throughout the world. 13 countries in Asia are poorly affected by arsenic in global arsenic scenario.



1. Poland
2. Brazil
3. New Zealand
4. Spain
5. Hungary
6. Lane County, Western Oregon, USA
7. Monte Quemodo, Cordoba, North Region Lagunera, Argentina
8. Region Lagunera, North Mexico
9. Taiwan
10. Antofagasta, Chile
11. Lassen county, California, USA
12. Sri Lanka
13. Nova Scotia, Canada
14. Fairbanks, Asaska
15. Millard County, Utah, USA
16. Fallon, Nevada, USA
17. Inner Mongolia, China
18. Xinjiang Uighur, China
19. Banglades
20. India
21. Viet Nam
22. Afghanistan
23. Pakistan
24. Egypt
25. Ghana
26. Cambodia
27. Sweden
28. Finland
29. United Kingdom
30. Germany
31. Romania
32. Bulgaria
33. Greece
34. The Philippines
35. Australia
36. Myanmar
37. Iran
38. Japan
39. Lao PDR
40. Nepal
41. Switzerland
42. Thailand

Fig 1.1: Arsenic affected countries (*source* - http://arsenic.pro4mation.com)

1.5 Extent of arsenic contamination in South-East Asia

In the South-East Asia Region, arsenic contamination of groundwater has been reported in India, Bangladesh and Thailand and to a limited extent in Nepal and Myanmar. Geological nature of arsenic is arising from the natural aquifers in India and Bangladesh, and possibly Nepal and Myanmar. However, in Thailand due to mining activities the contamination is anthropogenic in nature. In Bangladesh, India and Thailand, the concentrations in several groundwater samples range from 0.06 mg/L to 1.86 mg/L, which is in excess of the permissible value of 0.01 mg/L (as per WHO Drinking Water Guideline).

In West Bengal 14 million people are residing in areas where groundwater is contaminated with arsenic. Other arsenic affected states of India include Uttar Pradesh, Bihar, Jharkhand, Chattisgarh, Assam, and Manipur.

Bangladesh has been described as one of the worst cases of mass arsenic poisoning in world history. Exposure to arsenic in Bangladesh is through widely use of water obtained from 8-12 million tube wells distributed throughout the country. Most estimates put the number of people being exposed to arsenic concentration at around 25 million, exceeding the Bangladesh national standard of 0.05 mg/L.

Fig 1.2: Major arsenic affected regions in Asia (*source* https://www.semanticscholar.org)

1.6 Indian scenario of arsenic contamination

In India, the states of West Bengal, Jharkhand, Bihar, Uttar Pradesh, Assam, Manipur and Chhattisgarh are reported to be most affected by arsenic contamination of groundwater above the permissible level of 0.01 mg/L (as per WHO Drinking Water Guideline).

1. **West Bengal:** Unarguably, West Bengal is the most affected state in the country. Eleven districts are affected by high arsenic concentration. These are Malda , Murshidabad , Nadia, North 24 Paraganas, South 24 Paraganas, Burdwan , Howrah , Hoogly, Uttar Dinajpur, Dakshin Dinajpur, Coochbehar.

2. **Bihar:** According to a 2014 study, 18 districts of Bihar were affected by ground water arsenic. The worst affected districts were Bhojpur, Buxar, Vaishali, Bhagalpur and Samastipur

3. **Chhatishgarh:** Ground water arsenic contamination in a few villages in Rajnandgaon district of Chattisgarh was reported in 1999. The source of arsenic in groundwater is natural geologic and from rocky belt of Dongargarh-Korti zone of Rajnandgaon district.

4. **Jharkhand:** A detailed study in the Sahibganj district of Jharkhand state in the middle Ganga plain was carried out to determine the severity of groundwater arsenic contamination.

5. **Uttarpradesh:** hese districts are Ambedkarnagar, Baghpat, Budaun, Lucknow and Pilibhit. Three districts where arsenic level was detected around 0.01mg/litre are Kaushambi, Saharanpur and Sultanpur. According to the report, Ballia and Lakhimpur-Kheri are the worst affected districts

6. **Assam:** Assam has turned out to be another blip in the arsenic radar. 20 districts out of 24 districts are affected. These are Nalbari, Jorhat, Barpeta, Dhemaji, Golaghat, Darrang, Nagoan, Sonitpur, Dhubari, Lakhimpur, Cachar, Hailakandi, Karimganj, Goalpara, Kamrup, Sibasagar, Dibrugarh, Bongaigoan, Kokrajhar and Tinsukia districts.

7. **Manipur:** Thoubal district is affected by arsenic.

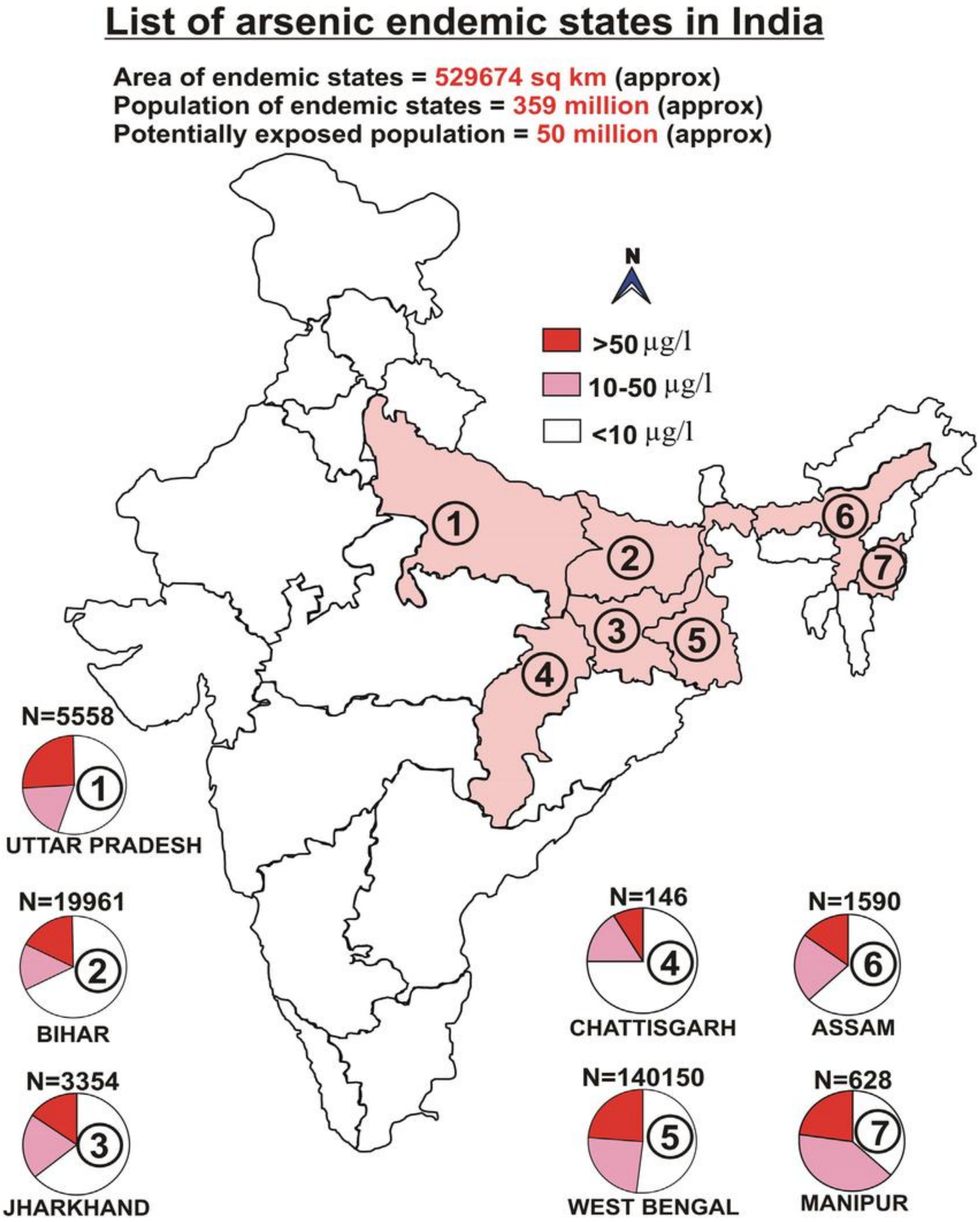


Fig 1.3: Arsenic affected areas in India (*source* https://www.researchgate.net)

1.7 Extent of arsenic contamination in West Bengal

The occurrence of arsenic in West Bengal, India was reported to be the biggest arsenic calamity in the world. In West Bengal, arsenic contamination in ground water came to light in early eighties when a villager of Gangarampur in South 24 parganas came to the School of Tropical Medicine, Kolkata, with infection in hands and legs in July, 1983. Doctor's report said that he had been suffering from Arsenicosis. Today the utterance of the word "Arsenic" causes panic amongst the people of 104 blocks of 11 districts in West Bengal namely Maldah, Murshidabad, Nadia, North 24 Parganas, South 24 Parganas, Bardhaman, Howrah, Hooghly, Uttar Dianjpur, Dakshin Dinajpur and Coochbehar.

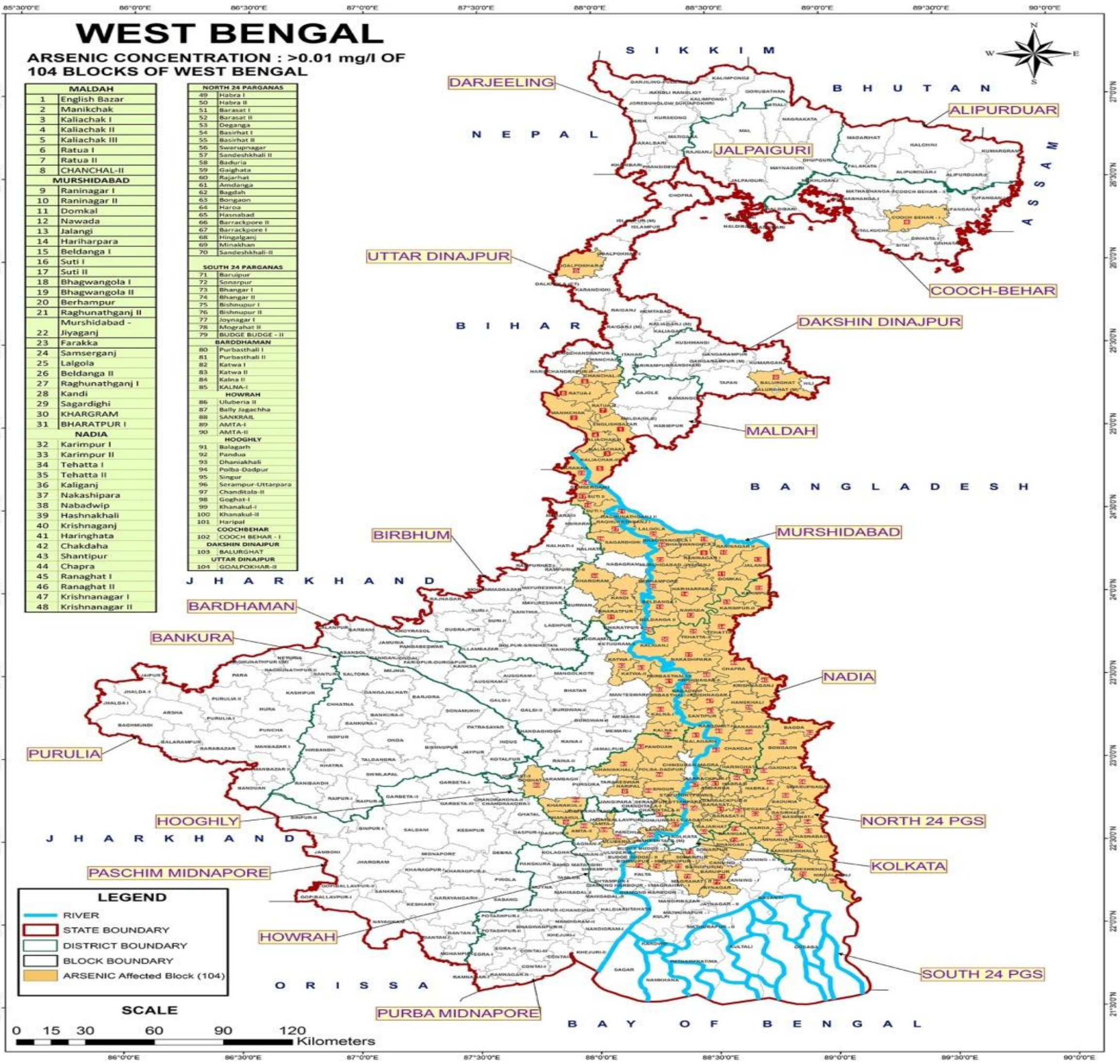


Fig 1.4: Arsenic affected areas in West Bengal (*source* http://wbphed.gov.in)

Table 1.6: Arsenic affected blocks of West Bengal, India

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
Dakshin Dinajpur	Balurghat	1
Uttar Dinajpur	Goalpokhar II	1
11 Districts		**104 Blocks**

1.8 Effects on human health

Inorganic arsenic is a confirmed carcinogen and it is the most significant chemical contaminant in drinking-water globally. Arsenic can also occur in an organic form. Inorganic arsenic compounds (such as those found in water) are highly toxic while organic arsenic compounds (such as those found in seafood) are less harmful to health.

- Severe Effects: The immediate symptoms of severe arsenic poisoning include vomiting, abdominal pain and diarrhea. These are followed by numbness and tingling of the extremities, muscle cramping and death, in extreme cases.
- Long term Effects: The first symptoms of long-term exposure to high levels of inorganic arsenic, through drinking-water and food, are usually observed in the skin and include pigmentation changes, skin lesions and hard patches on the palms and soles of the feet (hyperkeratosis). These occur after a minimum exposure of approximately five years and may be a precursor to skin cancer.
  In China (area of Taiwan), arsenic exposure has been linked to “Blackfoot disease”, which is a severe disease of blood vessels leading to gangrene. This disease has not been observed in other parts of the world.

Fig 1.5: Arsenic affected Patients (*source* https://scroll.in)

Table 1.7: Clinicopathological findings in Severe and Long term arsenic poisoning

	Severe	Chronic
Dermatologic	Capillary flush, contact dermatitis, folliculitis. Hair: delayed loss. Nails: Aldrich – Mees' lines (4-6 weeks post ingestion)	Melanosis, Bowen's disease, facial edema, Palmoplantar hyperkeratosis, cotaneous malignancies, hyper pigmentation, desquamation.
Neurologic	Hyperpyrexia, convulsions, tremor, coma, disorientation	Encephalopathy, headache, peripheral polyneuropathy, axonal degeneration.
Gastro-intestinal	Abdominal pain, dysphagia, vomiting, bloody or rice water diarrhea, garlicky odor to breath and stools, mucosal erosions, fatty liver.	Nausea, vomiting, diarrhea, anorexia,weight loss, hepatomegaly, jaundice, pancreatic, crihosis
Renal	Tubular and glomerular damage, liguria, uremia	Nephritic findings, proteinuria
Hematologic	Anemia, thrombocytopenia	Bone marrow hyperplasia, anemia, leucopenia, thrombocytopenia, impaired folate metabolism, basophilic stippling and karyorrhexis.
Cardio-vascular	ST-T wave abnormalities, QT prolongation, Ventricular fibrillation, atypical ventricular tachycardia.	Arrhythmias, pericarditis, accrocyanosis, Reynaud's gangrene (Blackfoot Disease)
Respiratory	Pulmonary edema, ARDS, bronchial pneumonia, tracheobronchitis.	Cough, pulmonary fibrosis, lung cancer.

1.9 Standards of Arsenic in drinking water in different countries

Different Countries have fixed different standards of arsenic content for drinking-water quality. In the year 1958, the international Standard for drinking-water was established at 200 μg/L as an acceptable concentration for Arsenic (as per WHO's norms). In 1963 the standard was re-evaluated and reduced to 50μg/L. The WHO guidelines have been revised during the recent past and the permissible limits have been reduced from 50μg/L to 10μg/L (10 ppb) in year 1993 due to adverse health reports arising from different parts of the world.

Table 1.8: Standard of arsenic in drinking water set by different countries

Country	**Permissible limit of Arsenic**
USA	10 μg/L
Australia	7 μg/L
Canada	25 μg/L
India	10 μg/L
Bangladesh	50 μg/L
China	50 μg/L
Chili	50 μg/L
New Zeland	10 μg/L
Vietnam	10 μg/L

SCOPE AND OBJECTIVE OF THE STUDY

CHAPTER 2

2.1 Objective of the study

The overall objective the study is to evaluate the effectiveness of ion-exchange resins (Cationic & Anionic) and rusted iron nails in removing of arsenic from contaminated 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
- Strategies for alleviation of arsenic contamination problem in groundwater
- To study arsenic removal from contaminated water by ion exchange resins
- To study arsenic removal by using rusted iron nails as an absorbent
- To develop lab scale models for arsenic removal
- To study the performance efficiency of AIRPs in North 24 Parganas district inWest Bengal

2.2 Scope of work

- To evaluate the arsenic removal efficiency of ion-exchange resins (Anionic-Cationic, Cationic and anionic) burette filter
- To determine the arsenic removal efficiency of Iron-nails adsorption filter.
- To evaluate the effects of various parameters (i.e. initial concentration of arsenic, pH, Alkalinity, Hardness, Iron, Chloride, TDS, Turbidity)
- To study of arsenic adsorption isotherms
- To evaluate the performance of 3 AIRPs
- Collection of samples from different units
- To prepare a report based on water quality

2.3 Deliverables

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

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

METHODOLGY

CHAPTER 3

3.1 Methodologies for this study

In this study ion-exchange and adsorption technique are adopted for removal of arsenic from contaminated water.

Arsenic in groundwater is generally found in as negatively charged ionic form ($H_3AsO_4^-$,$HAsO_2^-$) and also uncharged form. Anionic resin and cationic resin attract the negatively charged ions and positively charged ions respectively. In this study of ion-exchange process anionic and cationic resins are used as different possibilities in a burette filter (i.e. anionic-cationic resin bed, cationic resin bed and anionic resin bed) to evaluate the performance of arsenic removal 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.

Several studies noted that metal oxide or hydroxide is the good absorbent of arsenic. In this study of adsorption rusted iron nails are used as absorbent to remove the arsenic from contaminated water. A bench scale model is developed by using of 75cm PVC column as a filter. This experiment is done without oxidation and any pre-treatment of 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.

LITERATURE REVIEW

CHAPTER 4

4.0 Literature Review

Leupin X. et al. (2005) discussed on their article that arsenic removal from groundwater in Bangladesh is very challenging caused by the presence of As(III), phosphate and silicate at high concentration. Their article shows that application of zero-valent iron is a promising method for removal of arsenic from contaminated groundwater containing 500 ppb As(III), 2-3ppm Phosphate, 20ppm Silica, 8.2mM HCO_3^-, 2.5mM Ca^{++}, 1.6mM Mg^{2+} and pH 7.0. In a cycle of experiments, 1L was constantly passed through a mixture of 1.5g iron flakes and 3-4g quartz sand in a 10 mm dia. vertical glass column, allowing water to re-aerate between filtration. At a flow rate of 1L/h, up to 8ppm dissolved Fe(II) was released. During this subsequent Fe(II) is oxidized by dissolved oxygen and forms hydrous ferric oxide(HFO) which absorbed As(V). HFO is retained in the next filtration step and was removed by shaking of the sand-iron mixture with water. Four filtration lead to almost complete As(III) oxidation and removal of total Arsenic below 50 ppb. In a prototype, treatment with a succession of four filters, containing 1.5g iron and 60g sand, 36L could be treated to below 50 ppb in one continuous filtration, without adding oxidant.

Rao P. R. et al, (2015) studied on efficiency of arsenic removal by ion exchange, electro-membrane and electrochemical ion-exchange (EIX) process in laboratory. Batch experiments are carried out with chloride as well as hydroxyl exchangeable forms of anion exchange resins (AER), whereas, column experiments are done with only hydroxyl exchangeable AER to calculate its performance on arsenic removal. A plate and frame type electrolytic cell with ruthenium dioxide coated titanium plates as anode, and stainless steel plates as cathode, is fabricated to do experiment to evaluate the performance on arsenic removal by electro membrane and EIX processes. Removal of As(V) is important during batch studies, As(III) removal is poor by both the AER. Breakthrough curves are developed by passing As(V) contaminated water at a flow rate of 5ml/min through different bed depths of 5cm, 7.5cm and 10cm of modified chloride columns having 1cm internal dia. The columns can efficiently eliminate 500ppb of As(V) contaminated water to below 10ppb. EIX process was found to be inefficient in removing As(V) from contaminated water.

Richard J. et al. (2017) described on some technologies for arsenic removal. According to their study coagulation is the most common methodology for removal of arsenic.In Bangladesh groundwater is initially required oxidation with chlorine or permanganate just because of high arsenite concentration. Coagulation with $FeCl_3$ is most excellent at pH below 8.. Ion exchange resins are commercially produced synthetic materials that can only remove As(V). Where activated alumina, is commercially available in coarse grains which gives a longer run than ion-exchange resin and it works at pH 5-6 membrane methods include RO and nanofiltration. Currently available membranes are more expensive than other arsenic removal options.

Hesami F. et al. (2012) investigate the effect of arsenite and arsenate removal in synthetic water by coagulation using ferric chloride ($FeCl_3$) as coagulant and chitosan as coagulant aid. A conventional jar test apparatus is used to evaluate this process. The effects of various condition of pH (5.5-9), coagulation does of $FeCl_3$ (0-60mg/l), arsenic speciation (Arsenite and arsenate), chitosan as coagulant aid and initial arsenic concentration (0.2-2 mg/l) to arsenic removal is evaluated by considering the residual arsenic and iron after coagulation. Their article shows that the optimum pH for $FeCl_3$ as a coagulant to total arsenic removal was 7. Arsenate removal efficiency of 90% or higher by $FeCl_3$ alone are achieved for initial arsenate concentration 0.2-2 mg/l at optimum dosages (15-30 mg/l, it is reduced at low concentration arsenic) but in comparable conditions As(III) removal is about 60%. The chitosan is used as coagulant aid with $FeCl_3$ at a optimal does of 0.5 mg/l. then the efficiency of removal of As(III) and As(V) is almost 80% and 100% respectively. This method can be used where the initial concentration of arsenic in water is less than 100 ppb.

Ratnaweera H. et al. studied about the composite adsorbents based on zirconium oxyhydroxide(ZOH) with adding of Al_2O_3, Fe_2O_3 and Mn_3O_4 are synthesized by a sol-gel method to remove of As(V) and As(III) from contaminated water. Based on adsorption experiment without stirring they are chosen most effective composition (Zr-Mn). The equilibrium adsorption capacity of these adsorbents was achieved within 8 hours with a value of arsenic removal 96-98.5%. The experimental data they fitted is pseudo-second-order model. In this article more effective arsenic removal was observed at lower pH, but even at natural pH the efficiency of treatment is about 96-97%.

Barakat M.A et al (2010) discussed about the adsorption method of arsenic removal from contaminated water by strong base anion-chloride. In this study As(III) concentration of 20 ppm was used with a resin concentration of 1g/L, for adsorption times of 1 and 3 hour, but it is observed that As(III) was poorly absorbed even after increase the contact time 1 hr to 3 hr. In case of As(V) removal efficiency is high. At a concentration of 8ppm, As(V) can be totally adsorbed within 30minutes. In this process the As(V) removal decreased with increasing of As concentration and reactions are time depended. The removal attained its maximum after 90 min. of treatment at any As(V) concentration. Max removal efficiency values of 99.2%, 96%,78% and 68.5% are achieved for As(V) concentration values of 16, 32, 48 and 64ppm, respectively.

Pramanik B. K. et al. (2015) investigated to remove iron and arsenic contaminants from drinking water by biological activated carbon (BAC), biological aerated filter (BAF), alum coagulation and Moringa oleifera coagulation. They observed that at an initial dose of 5 mg/L, the removal efficiency for arsenic and iron was 63% and 58% respectively using alum, and 47% and 41% respectively using Moringa oleifera. The removal of both contaminants increased with the increase of coagulant dose and decrease of pH. According to their study biological processes are more useful in elimination of these contaminants than coagulation. Compare to BAF, BAC produce better removal efficiency of arsenic and iron, 85% and 74%, respectively. Longer contact time for both processes can reduce the greater concentration of arsenic and iron contaminants. The addition of coagulation (at 5 mg/L dosage) and a biological process (with 15 or 60 min contact time) can appreciably increase removal efficiency, and the maximum removal was observed for the combination of alum and BAC treatment (with 60 min contact time), with 100% and 98.56% for arsenic and iron respectively.

Halim M.A. et al. (2008) studied on adsorption filtration method to evaluate the efficiency of removing arsenic from contaminated water by laterite soil samples in laboratory condition. In this study, they Prepare 10 mg/L solution of As(III) and As(V) which is passed through the six soil samples. At room temperature, a batch of three different samples adsorbs 1010, 925 and 932.5 mg/kg of arsenic and their removal efficiency are found to be 58.74, 65.32 and 65.39%, respectively. At 100 °C temperature, the three soil specimens are studied and it shows that the adsorbed capacity is 54.40, 63.47 and 58.69%, while the respective amount adsorbed was calculated 848, 694 and 760 mg/kg. This study can be undoubtedly used to get better performance for low level arsenic contamination.

Roy et al. (2014) discussed on an efficient cost effective method to remove arsenic from groundwater. Their study area was Jyot Sujan village of Jiagunge-Murshidabad block in Murshidabad where arsenic concentration is high. Their objective is to elaborate on research of new and existing arsenic removal technologies or upgrading new or alternative system. They discuss that the use of dual treatment method including of oxidation-coagulation-filtration and adsorption by activated alumina is most economic as compared to other arsenic removal technologies.

Guzman A. et al. (2015) discussed about the process of electro coagulation (EC) for removal of arsenic and fluoride from ground water by using aluminum as the sacrificial anode in continuous filter-press reactor. They collected ground water from Bajio region in Mexico at a depth of 320m and found the concentration of As 43 ppb, fluoride 2.5 ppm, sulphate 89.6 ppm, hardness 9.8 mg/l, alkalinity 31.3 mg/l and pH 7.6. They are using 1 mg/l hypochlorite as a oxidizing agent to oxidize arsenite to arsenate. The EC test exposed that at current densities of 4.5 and 6 mA/cm^2 and flow velocities of 0.91 and 1.82 cm/sec, arsenate is decreased and residual fluoride concentration satisfies the WHO standard.

Audit Report, WBPHED discussed in their report that arsenic is a natural element mostly found in the earth layer in both of its oxidation state which are trivalent arsenite (As III) and pentavalent arsenate (As V). Both the forms of arsenic are poisonous. Arsenic contamination in groundwater has led to widespread condition of arsenic poisoning in Eastern India, Bangladesh and neighboring countries. Presently in the state of West Bengal there are 83 blocks are badly affected due to contamination of arsenic in the groundwater and authority was facing problem in context of supplying safe drinking water to those villagers in an economically feasible way. Arsenic can be removed from groundwater by different procedure i.e. Co-precipitation, Adsorption, Ion-exchange, Membrane Separation etc.

Siddiqui I. S. et al. (2019) discussed about the graphene oxide (GO) and its composites have attracted prevalent attentions as novel adsorbents for the adsorption of various water pollutants due to their unique physicochemical characteristics. This study represents advances made in the synthesis of graphene oxides and their composites, and summarizes the application of these materials as a better adsorbent for the removal of arsenic from water. The adsorption affinity in terms of contact time, pH, and temperature has been discussed in this chapter. Competitive ion effect and regeneration are included within the study. Moreover, the challenges for the commercial uses are discussed.

Loganathan P. et al. (2019) showed that the using granular activated carbon (GAC) (zero point of charge (ZPC) pH 3.2) and iron incorporated GAC (GAC-Fe) (ZPC pH 8.0) are very effective of arsenic removal from As(V) solutions. The batch study confirmed that GAC-Fe had higher Langmuir adsorption capacity at pH 6 (1.43 mg As/g) than GAC (1.01 mg As/g). Adsorption data of GAC-Fe fitted the Freundlich model better than the Langmuir model, thus indicating the presence of heterogeneous adsorption sites. The column adsorption study revealed that 2–4 times larger water volumes can be treated by GAC-Fe than GAC, reducing the arsenic concentration from 100μg/L to the WHO guideline of 10μg/L. The volume of water treated increased with a decrease in flow velocity and influent arsenic concentration. The study indicates the high potential of GAC-Fe to remove arsenic from contaminated drinking waters in practical column filters.

Xiong X. et al. (2011) evaluated that the efficiency of a novel and low-cost adsorbent, iron-modified bamboo charcoal (BC-Fe), for arsenic removal from contaminated water. The BC-Fe was synthesized by loading iron onto bamboo charcoal via soaking in a ferric salt solution. The BC-Fe possessed a porous structure with a surface area of 277.895m^2/g. In batch studies the adsorption characteristics of arsenic onto BC-Fe are investigated at various pH, contact times, arsenic concentrations, and adsorbent doses. The corresponding optimum equilibrium pH ranges for As (III) and As (V) removal are 4–5 and 3–4, respectively. The equilibrium times for As (III) and As (V) adsorption are 30 and 35.5 h, respectively. This chapter expressed that the arsenic removal was strongly dependent on the initial adsorbate concentration and adsorbent dosage and the maximum arsenic removal capacities of BC-Fe under the experimental conditions were 7.237 and 19.771 mg/g for As (III) and As(V), respectively.

Vigneswaran S. et al (2014) discussed about the treatment of arsenic waste. Management of arsenic waste is now becoming the major problem due to its very harmful effects on the environment. The aim of this study is to review the characteristics of arsenic waste produced by arsenic treatment systems and the treatment and disposal methods of this waste. Currently, encapsulation of arsenic waste through solidification/stabilization (S/S) techniques is considered to be the most attractive solution and this method is the focus of this review. A number of studies have used cement by itself and in combination with additives such as lime, iron, silicates, or fly ash in the S/S process.

Ghosh M. et al. (2014) expressed that the Bengal Delta Plain is contaminated with natural arsenic, basically the eastern part of river Hooghly. This study notified that the people of this region depend on groundwater at the depth of 20m to 80m for drinking and cooking. Study area was Shantipur block of West Bengal. In this study area arsenic in soil ranged between 2.02 and 21.08 mg/kg whereas arsenic in groundwater used for paddy cultivation ranged between 0.012 and 0.121 mg/L. Straw, husk and rice grains of paddy were analyzed and magnitude of arsenic was found as straw> husk> rice grain. Arsenic in paddy ranged between 1670 μg/kg and 2500μg/kg.

Banerji T. et al. (2017) reported that many researchers have also shown that the corrosion of Zero Valent Iron (ZVI) forms Hydrous Ferric Oxide (HFO) which can act as an adsorbent for arsenic and the oxidation of Fe to Fe has also been reported to oxidize As(III) to As(V). Using this information a ZVI based Arsenic Filter has been developed by Indian Institute of Technology, Bombay. Test units of the IITB-Arsenic Filter have been installed in the field in four villages in West Bengal. They expressed that the filter is able to consistently achieve arsenic levels around 10μg/L for initial arsenic concentrations ranging from 0.06 to 0.4 mg/L. They maintained the flow rate of the filtered water is approx 600 L/hr. Thereby the IITB-Arsenic Filter is able to consistently supply drinking water for about 200 families on a daily basis. The IITB-Arsenic Filter does not require frequent backwashing/cleaning (cleaning frequency is once in 3 months, and is done by the villagers) and therefore has low operation and maintenance costs. Moreover, it does not require monitoring of flow parameters and is easy-to-operate by unskilled personnel. The Fe/As ratio used in the filter is around 20. Low Fe/As ratios mean lesser sludge generation. Thus it is felt that the IITB Arsenic filter is a suitable technology for rural India.

Khan et al.(2000) showed a simple three-pitcher (locally known as '3-kalshi') filtration assembly made entirely from readily available local materials is tested for its efficacy in removing arsenic from the groundwater of Bangladesh. In a 3- kalshi assembly, the first kalshi has iron chips and coarse sand, the second kalshi has wood charcoal and fine sand, and the third kalshi is the collector for filtered water.They filter about 240 lit of arsenic contaminated groundwater and groundwater spiked with high concentrations of both As(III) and As(V). They measure arsenic and 24 other metals before and after filtration using Atomic absorption spectrometry with graphite furnace and Zeeman background correction (AASGF-Z) and inductively coupled plasma atomic emission spectrometry (ICPAES).They found that As(III) can be removed from 800 ppb to below the detection limit of 2 ppb and As(total) can be removed to a concentration below 10 ppb for most samples even at the highest input concentration of 1100 ppb As(total) and dissolved iron concentration decreased from an average 6000 ppb to 200 ppb. Although the role of metallic iron was difficult to quantitate, it provided excess soluble iron in the filtering media of the second kalshi. The wood charcoal was used to remove any organic impurities that may be present in groundwater. The filtered water remained crystal clear for months and free from most toxic metal ions. They showed daily capacity of the 3-kalshi system varies from 42 -148 L/day and found final water quality meets and exceeds the guideline values suggested by USEPA, World Health Organization and Bangladesh.They suggest the use of this simple setup to make potable water.

Das et al.(2000) developed a household device for removal of arsenic from contaminated water in 1993. The system consists of a filter, tablet, two earthen jars or plastic jars. Tablet contains iron salt, oxidizing agent and activated charcoal and the filter is made of mainly purified fly ash with binder. One tablet is sufficient for 20 liters of contaminated water having arsenic in the maximum range 1000 µg/l. The sludge produced after removal of arsenic which is rich in arsenic disposed to soil with cow dung and arsenic is eliminated from the sludge as volatile arsenic species through the microbes in the cow-dung. After their successful laboratory testing several units were taken to arsenic affected villages in six districts of West Bengal and tested with contaminated hand tube-wells (arsenic range 300-950 µg/l) from about 100 families and they found that the efficiency was 93 to 100%.They believed that this "Filter- Tablet System" to be used in emergency in affected villages for West Bengal-India and Bangladesh

Pakzadeh.B. et al., (2011) stated that brine disposal is a serious challenge of arsenic (V)removal from drinking water using ion-exchange (IX). Although arsenic removal with ferric chloride ($FeCl_3$) from drinking waters is well documented, the application of $FeCl_3$ to remove arsenic (V) from brines has not been thoroughly investigated. In contrast to drinking water, IX brines contain high ionic strength, high alkalinity, and high arsenic concentrations; these factors are known to impudence arsenic removal by $FeCl_3$. Surface complexation modeling and experimental coagulation tests were performed to investigate the impudence of ionic strength, pH, Fe/As molar ratios, and alkalinity on the removal of arsenic from IX brines. The model prediction was in good agreement with the experimental data. Optimum pH range was found to be between 4.5 and 6.5. The arsenic removal efficiency slightly improved with higher ionic strength. The Fe/As ratios needed to treat brines were significantly lower than those used to treat drinking waters. For arsenic (V) concentrations typical in IX brines, Fe/As molar ratios varying from 1.3 to 1.7 were needed.

Sludge solid concentrations varying from 2 to 18 mg L^{-1} were found. The results of this research have direct application to the treatment of residual wastes brines containing arsenic.

Mathieu et al.(2010) describe describe laboratory and field results of a novel arsenic removal adsorbent called ‘Arsenic Removal Using Bottom Ash’ (ARUBA).ARUBA is prepared by coating particles of coal bottom ash, a waste material from coal fired power plants, with iron (hydro)oxide. ARUBA is used for removing arsenic via a dispersal-and-removal process, and they envision that ARUBA would be used in community-scale water treatment centers. They show that ARUBA is able to reduce arsenic concentrations in contaminated Bangladesh groundwater to below the Bangladesh standard of 50 ppb. They show that ARUBA’s arsenic adsorption density (AAD), defined as the milligrams of arsenic removed at equilibrium per gram of ARUBA added, is linearly dependent on the initial arsenic concentration of the groundwater sample, for initial arsenic concentrations of up to 1600 ppb and an ARUBA dose of 4.0 g/L. This makes it easy to determine the amount of ARUBA required to treat a groundwater source when its arsenic concentration is known and less than 1600 ppb. Storing contaminated groundwater for two to three days before treatment is seen to significantly increase ARUBA’s AAD. ARUBA can be separated from treated water by coagulation and clarification, which is expected to be less expensive than filtration of micron-scale particles, further contributing to the affordability of a community-scale water treatment center

Bhargav.S et al.(2013) discussed removal of heavy metals like As (V) and Cu (II) from the contaminants in municipal water supply by the process of adsorption to make it safer for domestic purpose. They assigned magnetite nanoparticles (Fe_3O_4) with size less than 30 nm separating and removing contaminants in wastewater by applying external magnetic fields. At optimized pH they obtained Fe_3O_4 nanoparticles are coated with coating agents which develop surface functionalized groups. These form miniature aggregates in aqueous suspensions.

TREATMENT TECHNOLOGIES FOR ARSENIC REMOVAL

CHAPTER 5

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.

5.1 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

5.1.1 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 pretreatment 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

5.1.2 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.

5.1.3 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, sulfates 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.

5.1.4 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, sulfates 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 sulfate.
- 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.

5.1.5 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
- Nanofiltration
- Electro dialysis
- Reverse Osmosis

Two types of membrane processes microfiltration (MF) and ultra filtration (UF) remove contaminants through physical sieving while two others; nanofiltration (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.

ANALYTICAL PROCEDURE FOR TESTING OF DIFFERENT WATER QUALITY PARAMETERS

CHAPTER 6

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. Alkalinity
4. Total Hardness
5. Chloride
6. pH
7. Turbidity
8. TDS and Electrical conductivity

Test procedures are given below:

6.1 Total Arsenic

6.1.1 Laboratory Methods

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

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

6.1.3 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.

6.1.4 Apparatus

- Spectrophotometer for use at 520 nm.
- Gutzeit generator

6.1.5 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

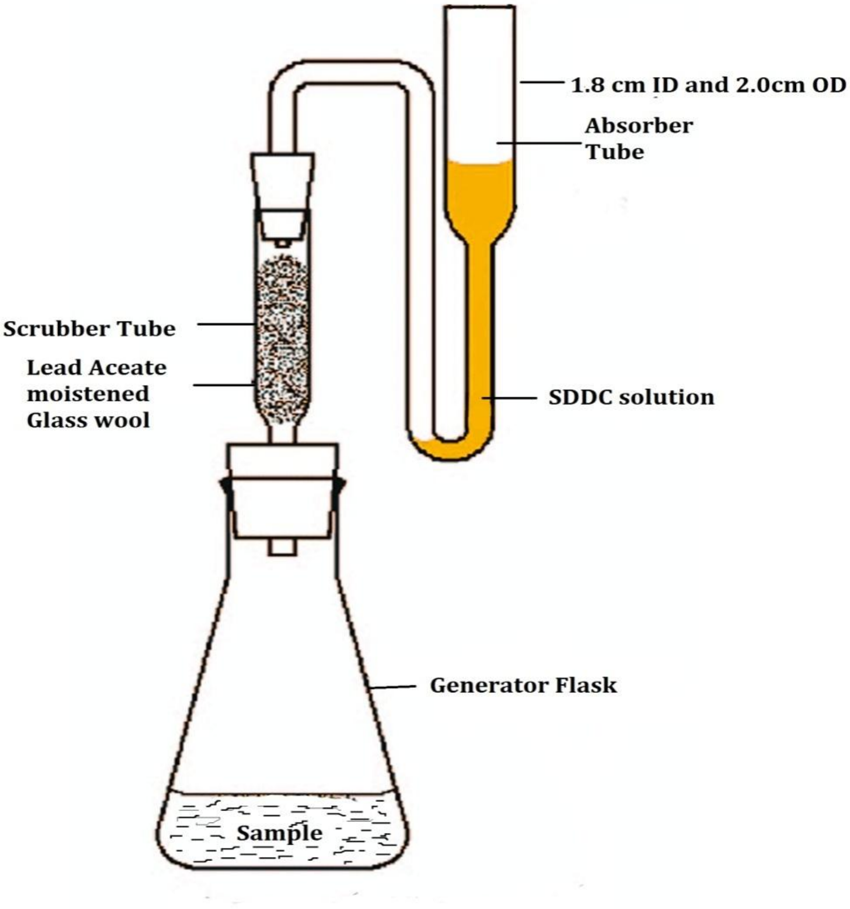


Fig 6.1: Arsine generator and absorber assembly

6.1.6 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.

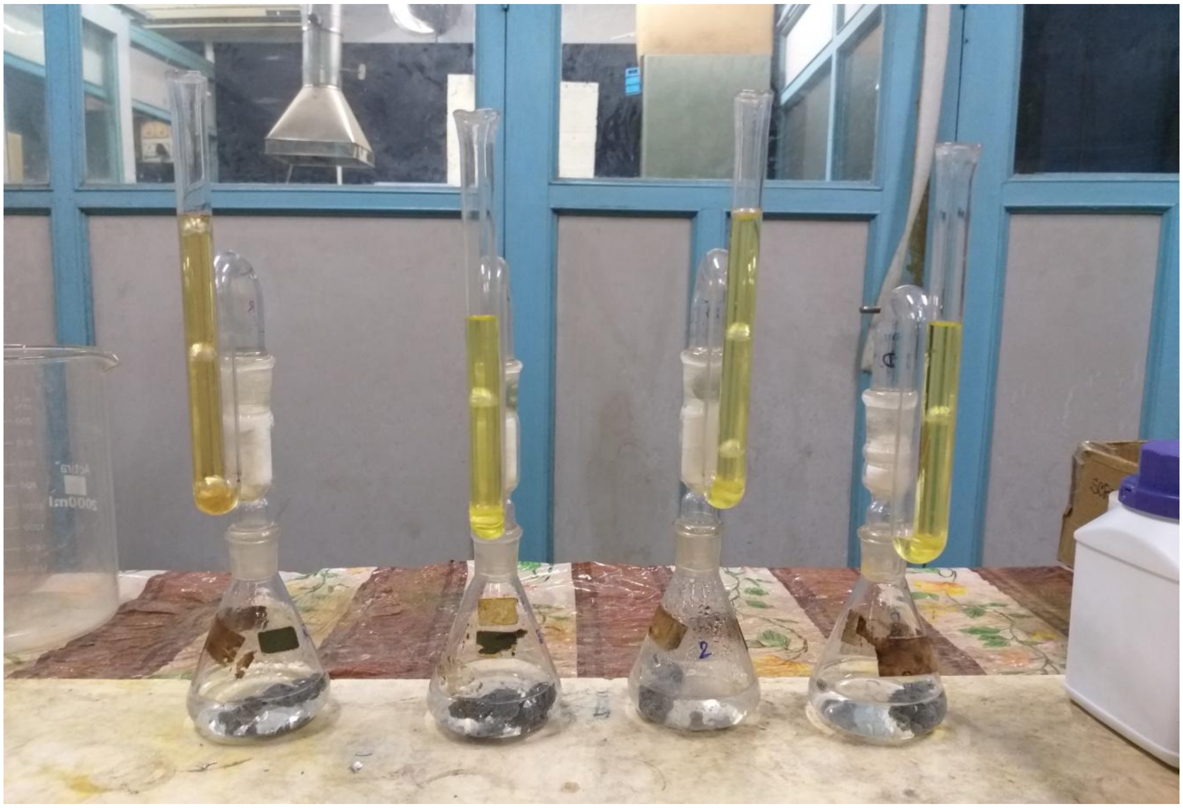


Fig 6.2: Testing of experimental samples in laboratory

6.2 Total Iron

6.2.1 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

6.2.2 Apparatus

Spectrophtometer, use at 510 nm.

6.2.3 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.

6.2.4 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.

6.3 Alkalinity Test

6.3.1 Introduction

Alkalinity of the water is a determination of its acid neutralizing capacity. Bicarbonates represent the major form of alkalinity. Samples are titrated with standard acid using an acid base indicator.

Total Alkalinity (T-Value) is the quantity which is measured by titration adding mixed bromocresol green-methyl red indictor in samples.

6.3.3 Reagents

1. Standard sulphuric acid or hydrochloric acid, 0.1N: Standardize daily against standard alkali
2. Standard sulphuric acid or hydrochloric acid, 0.02N: Dilute 200ml of 0.1N solution to 1000ml
3. Mixed bromocresol green-methyl red indicator: 100mg bromocresol green sodium salt and 20mg methyl red sodium salt in 100ml distilled water.

6.3.4 Procedure

Take an aliquot of sample (50-250 ml) in a conical flask, add 2-3 drop of mixed bromocresol green-methyl red indicator and titrate with 0.02N acid until the colour changes from green to red.

6.3.5 Calculation

Alkalinity (as $CaCO_3$), mg/l = $\frac{\text{A} \times \text{N} \times 50000}{\text{ml of Sample}}$ Where, A= ml of standard acid used

N= Normality of standard acid

Fig 6.3: Alkalinity test of experimental samples in laboratory

6.4 Total Hardness

6.4.1 Principle

The principal of this experiment is to determine the hardness of the water sample by measuring the total amount of calcium and magnesium present.

6.4.2 Introduction

All natural waters have salts dissolved in them and these salts are helped to produce a unique taste in water. Sometimes the water can contain too much of these salts and can cause problems when the water is used for drinking or washing. These problems are caused mainly by the presence of calcium and magnesium ions in the water.

Sodium salt of EDTA forms chelating soluble complex with calcium and magnesium ions. If small amount of Erichrome Black T (EBT) indicator is added to water samples at pH 10, the solution becomes wine red. If the solution is titrated with EDTA, the calcium and magnesium ions will be complexes with EDTA and when all the ions have composited the solution turns from wine to red.

6.4.3 Reagents

1. Buffer solution: Dissolve 16.9g ammonium chloride (NH_4Cl) in 143 ml conc. Ammonium hydroxide (NH_4OH) and dilute to 250ml with distilled water.
2. EBT indicator solution: Dissolve 0.5g solid EBT in 50ml ethyl alcohol then add 4.5g of hydroxylamine hydrochloride.
3. Standard EDTA, 0.01N: Weigh accurately 3.723g analytical grade disodium EDTA, dissolve in distilled water, and dilute to 1000ml with metal ion free distilled water.

6.4.4 Procedure

Take 25ml of sample in a 100ml conical flask. Add 1or 2ml of buffer solution and 1 or 2 drops of EBT indicator solution. Titrate with EDTA until the colour changes from Red wine to Blue.

6.4.5 Calculation

Hardness (as $CaCO_3$) = $\frac{\mathrm{A} \times 1000}{\mathrm{ml\ of\ sample}}$ Where, A = ml of EDTA used in titration

Fig 6.4: Hardness test of experimental samples in laboratory

6.5 Chloride

6.5.1 Principle

It is one of the major anions present in water and wastewater. Chloride is determined in a neutral or slightly alkaline solution by titration with standard silver nitrate solution using potassium chromate as indicator.

6.5.2 Reagents

1. Potassium chromate indicator solution: Dissolve 5g K_2CrO_4 in a little distilled water. Add $AgNO_3$ solution drop wise until a definite red precipitate is formed. Let stand for 12h, filter and dilute to 100ml with distilled water
2. Standard silver nitrate solution 0.0141N: dissolve 2.395g $AgNO_3$ in distilled water and dilute to 1000ml.
3. Standard sodium chloride,0.0141N: Dissolve 0.824 g NaCl (dried at 140° C) in distilled water add dilute to 1000ml
4. Aluminium hydroxide suspension: Dissolve 125g aluminium potassium sulphate, aluminium ammonium sulphate in 1liter distilled water. Warm 60° C and 55 ml conc. aluminium hydroxide slowly with stirring. Let stand for 1hr, transfer to abottle

and wash precipitate by successive additions, with through mixing and decanting with distilled water until free from chloride.

6.5.3 Procedure

Sample preparation: Take 100ml or portion diluted to 100 ml. if the sample is highly coloured add 3 ml aluminium hydroxide suspension. Let settle it and filter. If sulphide, sulphate or thiosulphate is present, add 1ml H_2O_2 and stir for 1 min.

Titration: Titrate the samples without pH adjustment in the pH range 7 to 10. Adjust sample pH 7.0 to 10.0 using dilute H_2SO_4 or NaOH if it is not in this range. Add 1ml K_2CrO_4 indicator and titrate with standard $AgNO_3$ to a pinkish yellow end point.

Standardize $AgNO_3$ and established a reagent blank by titration using distilled water instead of sample.

Calculation [Chloride, as Cl mg/l] = $\frac{(A-B)\times N\times 35450}{\text{ml of sample}}$

Where A= ml of $AgNO_3$ for sample, B= ml of $AgNO_3$ for blank, N= normality of $AgNO_3$

6.6 pH

6.6.1 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.

6.6.2 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 6.5: pH test of experimental samples

6.7 TDS & EC

6.7.1 Principle

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

6.7.2 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. Take 25-50 ml of water sample in a clean and dry beaker(100 ml)
3. Immerse the electrode into sample for measurement
4. Press MEAS button for measuring the TDS, waits for the stable reading in display.
5. TDS result shows in mg/l

6. Then press MODE button for measuring the EC of the sample.
7. Wait for a second until the reading is stabled in screen.
8. EC results shows in ms/cm

Fig 6.6 Conductivity meter for measuring the TDS & EC

6.8 Turbidity

6.8.1 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.

6.8.2 Proedure

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 6.7: Turbidity meter

EXPERIMENTAL STUDY ON THE REMOVAL OF ARSENIC BY ION-EXCHNAGE AND ADSORPTION METHOD

CHAPTER 7

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 and adsorption method is adopted for the removal of arsenic from contaminated water.

7.1 ION-EXCHANGE METHOD

7.1.1 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, $\mathrm{R-SO_3H}$)
II. Weakly acidic (carboxylate, $\mathrm{R-COOH}$)
III. Strongly Basic (quaternary amine, $\mathrm{R-N^+OH^-}$)
IV. Weakly Basic (tertiary amine, $\mathrm{R-NH_3OH}$)

Cationic exchange resins: These are negatively charged and attracted by the positively charged ions in the water (e.g. Na^+). Widely used cation exchange resin is that obtained by copolymerization of styrene and a small portion of diviylbenzene followed by sulphonation ($\mathrm{-SO_3H}$).

Mechanism of cation exchange Process:

$\mathrm{R^-H^+ + A^+ \rightarrow R^-A^+ + H^+}$

Where, R = Ion exchanger
A^+ = Positive charged ions

Classification: There are two types of cation exchange resins.

a) Weak acidic (cationic exchange) resin, WAR:
    - Most weak acidic exchangers have carboxylic groups ($\mathrm{-COOH}$). These resins behave likes weak organic acids.
    - The degree of dissociation of WAR is strongly influenced by pH of the solution.

b) Strong acidic resins (SAR) :
  - Behaves like a strong acid.
  - Sulfonic groups are contained by this resin.
  - This resin is used for water softening in sodium form, helped in the removal

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 polymers with quaternary 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 cationic and anionic resin are used as ion exchange media to remove the arsenic from water.

Fig 7.1: Anionic resin and cationic resin

7.1.2 Removal of arsenic by Anionic-cationic Resin

7.1.2.1 Materials required

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

7.1.2.2 Chemical required

- Arsenic stock solution (concentration of 100mg/l)
- Concentrated hydrochloric acid

7.1.2.3 Methodology

7.1.2.3.1 Sampling

Chemicals are used AR/GR 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 and the low concentration arsenic solutions are freshly prepared from primary stock solution for each experiment. Glass and plastic-ware are acid washed before use. Low concentrated stock solutions are prepared in a 500ml beaker. Before collecting the sample, the container is rinsed three-four times by the water is to be filled.

7.1.2.3.2 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 2cm Gravel layer
  15cm Coarse sand layer
  12.5 cm Anionic resin layer
  1 cm sand layer
  12.5 cm cationic resin layer
  2cm sand layer

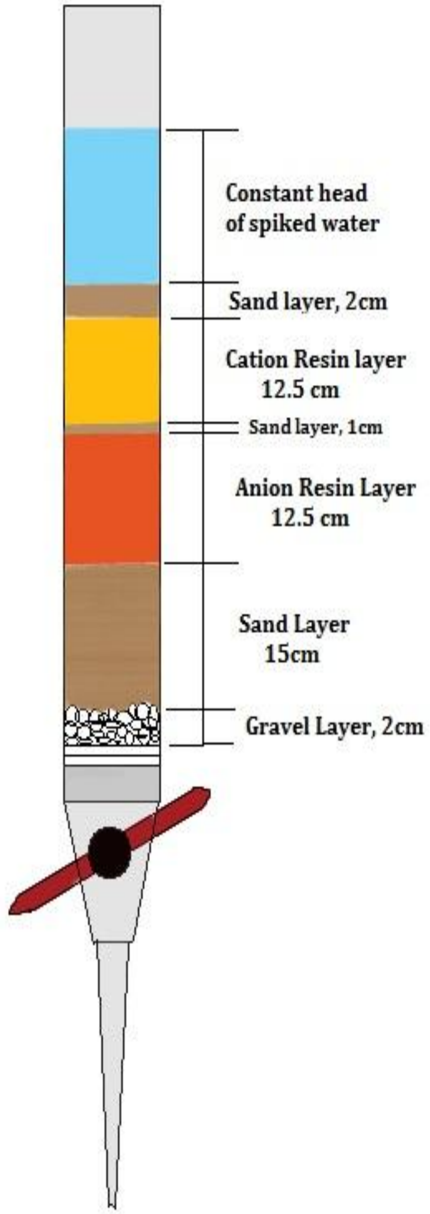


Fig 7.2: Design of anionic-cationic resin filter

Fig 7.3: anionic-cationic resin burette filter

7.1.2.3.3 Experimental Procedure

All the experiments are carried out with ground water without any pH adjustment or any pretreatment.

- Take 0.35 ml, 0.50 ml and 1ml volume of 100 mg/l primary stock solution dilute up to 500ml ground water in measuring cylinders as arsenic concentration will be 0.70 mg/l , 0.100mg/l, 0.200mg/l respectively for each trail.
- The spiked water is passed through the filter bed in a down flow pattern and maintaining the hydraulic flow rate at the outlet is 535 L/hr/m^2 or 14 drops/min
- About 500ml of spiked water is passed through the filter bed in each trail.
- After filtration 100ml of sample is collected in plastic container.
- All the necessary tests are analyzed on the day of this experiment.

7.1.2.3.4 Results, Analysis and Discussion

7.1.2.3.4.1 Results and Analysis

Table 7.1: Removal of Arsenic and effects on pH by anionic-cationic resin filter

Parameters	**Trial 1**		**Trial 2**		**Trial 3**	
	Raw	**Filtered**	**Raw**	**Filtered**	**Raw**	**Filtered**
Arsenic in mg/l	0.075	0.000	0.112	0.000	0.192	0.000
pH	7.95	3.19	6.87	3.12	6.62	3.16

Table 7.2 Percentage removal efficiency of arsenic in each trial

No. of Trials	**Concentration of Raw water**	**Concentration of Filtered water**	**Percentage of Removal**
Trail 1	0.075	0.000	100%
Trial 2	0.112	0.000	100%
Trial 3	0.192	0.000	100%

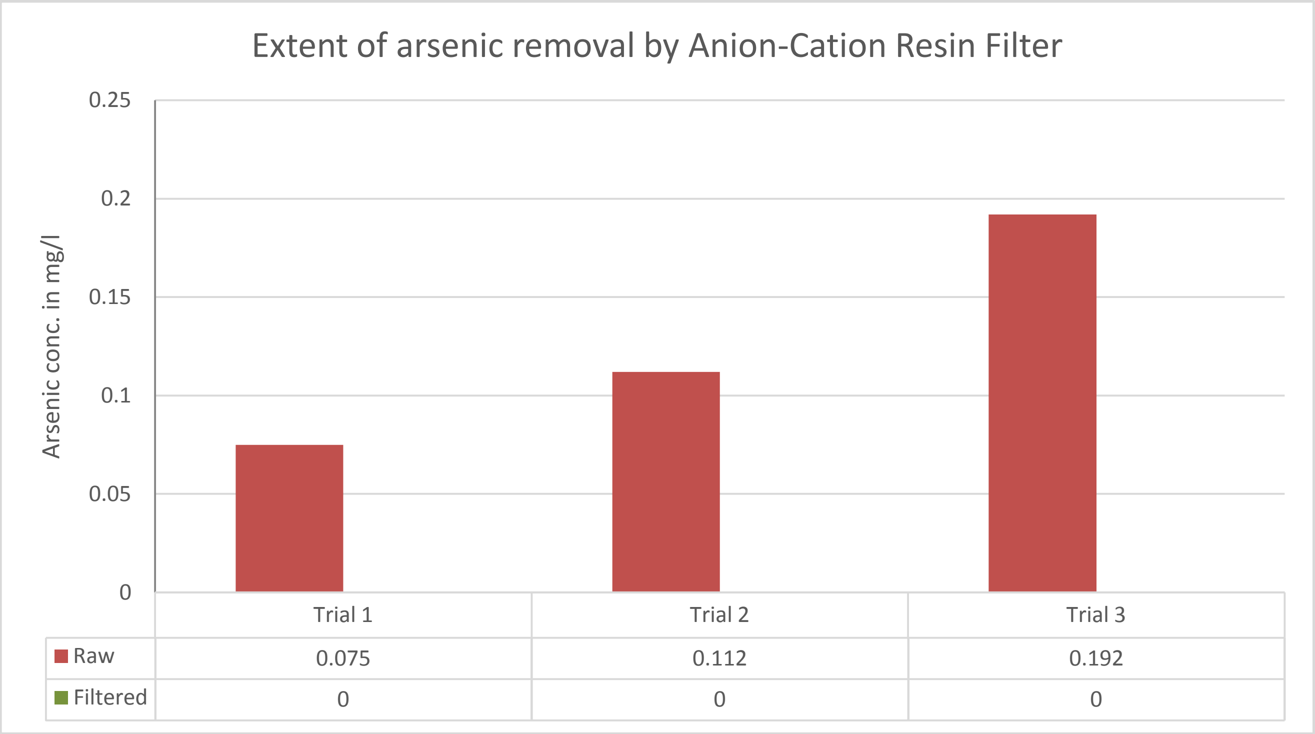


Fig 7.4: Arsenic concentrations varying with spiked water

7.1.2.3.4.2 Discussion

- With maintaining the constant flow rate of 535 lit/hr./m^2, various concentration is applied for the experiment.
- From **Fig7.4** and **Table 7.2** we can see that anionic-cationic resin filter can produce the arsenic free water and percentage removal of arsenic in each trial is 100%
- **Table 7.1** shows that pH is getting very low in the filtered water 3.19, 3.12 & 3.16 from 7.95, 6.87 & 6.62 respectively.

7.1.3 Ion exchange process of arsenic using Cationic resin

7.1.3.1 Materials required

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

7.1.3.2 Chemical required

- Arsenic stock solution (concentration of 100mg/l)
- Concentrated hydrochloric acid

7.1.3.3 Methodology

7.1.3.3.1 Sampling

Chemicals are used AR/GR 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 and the low concentration arsenic solutions are freshly prepared from primary stock solution for each experiment. Glass and plastic-ware are acid washed before use. Low concentrated stock solutions are prepared in a 500ml beaker. Before collecting the sample, the container is rinsed three-four times by the water is to be filled.

7.1.3.3.2 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 2cm Gravel layer
  15cm Coarse sand layer
  30cm Cationic resin layer
  7 cm sand layer

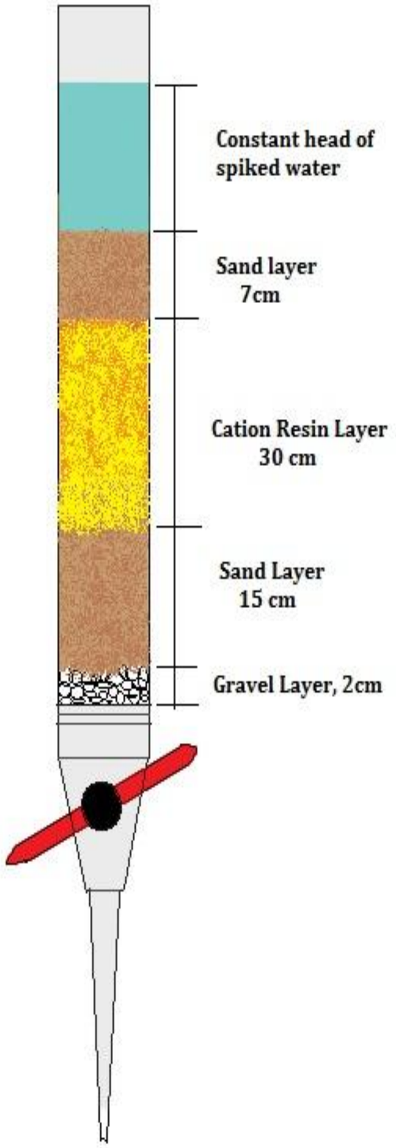


Fig 7.5: Design of cationic resin filter

7.1.3.3.3 Experimental Procedure

This experiment is carried out with ground water and Garden Reach water without any pH adjustment or any pretreatment.

- Take 1.25 ml and 1ml volume of 100 mg/l primary stock solution dilute up to 500ml of Garden reach water and Jadavpur Ground water in measuring cylinders as arsenic concentration will be 0.250mg/l, 0.200mg/l respectively for each trail.
- The spiked water is passed through the filter bed in a down flow pattern and maintaining the hydraulic flow rate at the outlet is 535 L/hr/m^2 or 14 drops/min
- About 500ml of spiked water is passed through the filter bed in each trail.
- After filtration sample is collected in a 100ml plastic container.
- All the necessary tests are analyzed on the day of each trial.

Fig 7.6: Sample collection from cationic resin filter outlet

7.1.3.4 Results, Analysis and Discussion

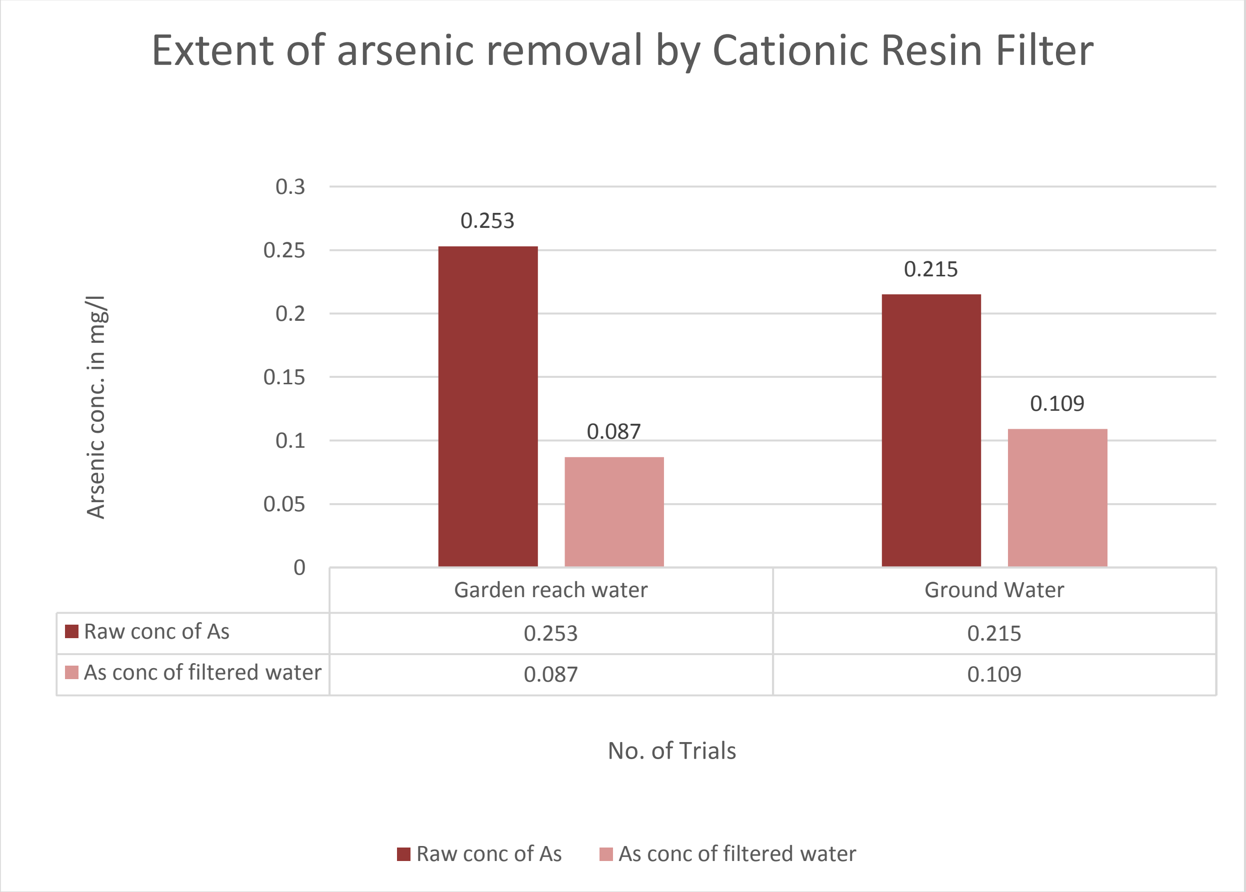
7.1.3.4.1 Results and Analysis

Table 7.3: Removal of Arsenic and effects on others parameter by using of anionic-cationic resin filter

No of Trials	Trial 1 Garden Reach Water		Trial 2 Ground water	
Parameters	Raw	Filtered	Raw	Filtered
Arsenic, in mg/l	0.253	0.087	0.215	0.109
pH	6.75	2.51	7.74	0.98
Total Dissolve Solid, in mg/l	112.6	274	1830	6840
Electrical conductivity, in us/m	188	447	3005	11370
Total alkalinity, as $CaCO_3$ in mg/l	134	0	362	0
Total Hardness, as $CaCO_3$ in mg/l	148	20	728	30
Chloride as Cl, in mg/l	31.99	49.98	979.69	4998.45

Table 7.4 Percentage removal efficiency of arsenic in each trial

No. of Trials	Concentration of Raw water	Concentration of Filtered water	Percentage of Removal
Trail 1 with Garden reach water	0.253	0.087	65.61%
Trial 2 with Groundwater	0.215	0.109	49.30%



	Garden reach water	Ground Water
Raw conc of As	0.253	0.215
As conc of filtered water	0.087	0.109

Fig 7.7: Arsenic concentrations varying with Garden Reach and Ground Water

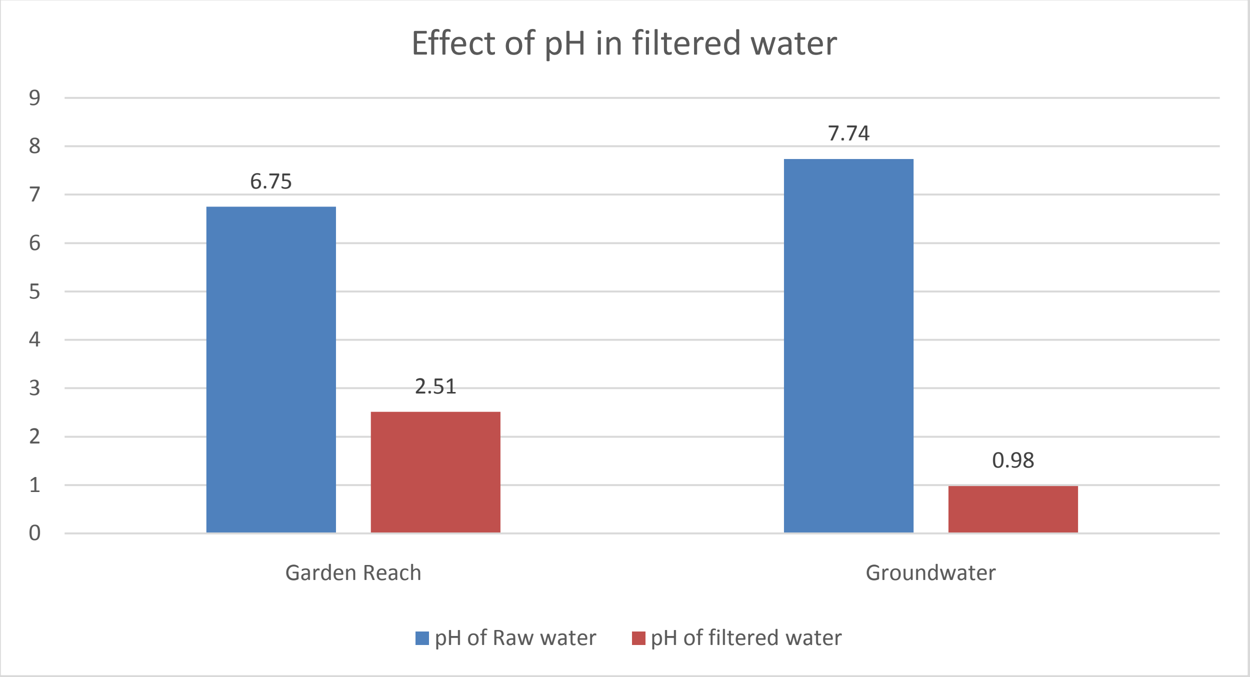


Fig 7.8: pH of Filtered water varying with Raw water

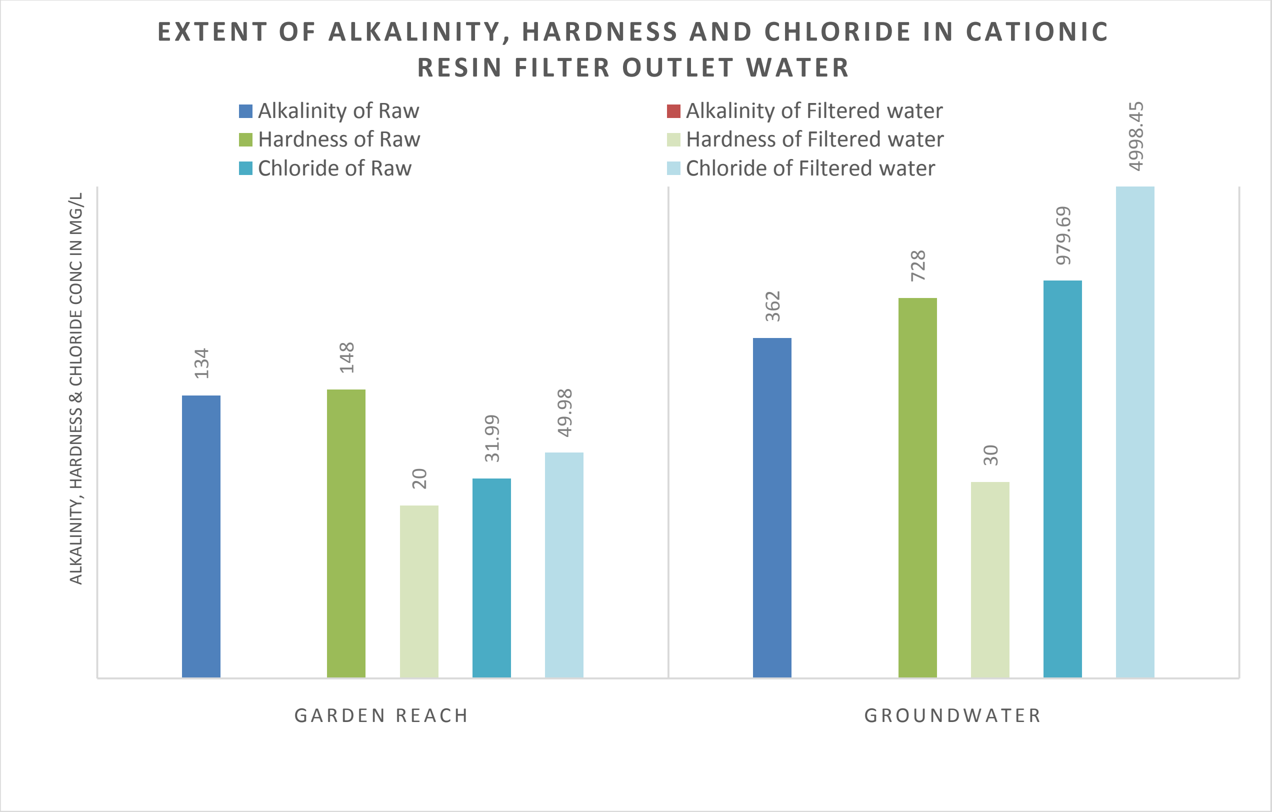


Fig 7.9: Varying of Alkalinity, Hardness & Chloride conc. in Filtered water with Raw water

7.1.3.4.2 Discussion

- With maintaining the constant flow rate of 535 lit/hr./m^2, various concentration is applied for the experiment.
- Only cationic resin can't reduce the arsenic concentration up to its permissible limit (0.01 mg/l).
- From **table 7.3** we can see that Alkalinity in filtered water becomes zero in both Garden Reach and Groundwater of Jadavpur.
- Total Chloride of filtered water is increased. From **fig 7.9** we can see that the total chloride in filtered Garden Reach water is increased from 31.99mg/l to 49.98mg/l. Where in Jadavpur groundwater it changes rapidly from 989.69mg/l to 4998.45mg/l.
- pH is getting very low, in Garden reach water pH drops off from 6.75 to 2.51. Where in Jadavpur groundwater pH drops off from 7.74 to 0.98.
- **Fig 7.9** shows that the hardness of both Garden reach and Jadavpur groundwater are getting low, from 148mg/l to 20mg/l and 728mg/l to 30mg/l respectively.

7.1.4 Ion exchange process of arsenic using Anionic resin

7.1.4.1 Materials required

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

7.1.4.2 Chemical required

- Arsenic stock solution (concentration of 100mg/l)
- Concentrated hydrochloric acid

7.1.4.3 Methodology

7.1.4.3.1 Sampling

Chemicals are used AR/GR 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 and the low concentration arsenic solutions are freshly prepared from primary stock solution for each experiment. Glass and plastic-ware are acid washed before use. Low concentrated stock solutions are prepared in a 500ml beaker. Before collecting the sample, the container is rinsed three-four times by the water is to be filled.

7.1.4.3.2 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 2cm Gravel layer
  15cm Coarse sand layer
  30cm Anionic resin layer
  7 cm sand layer

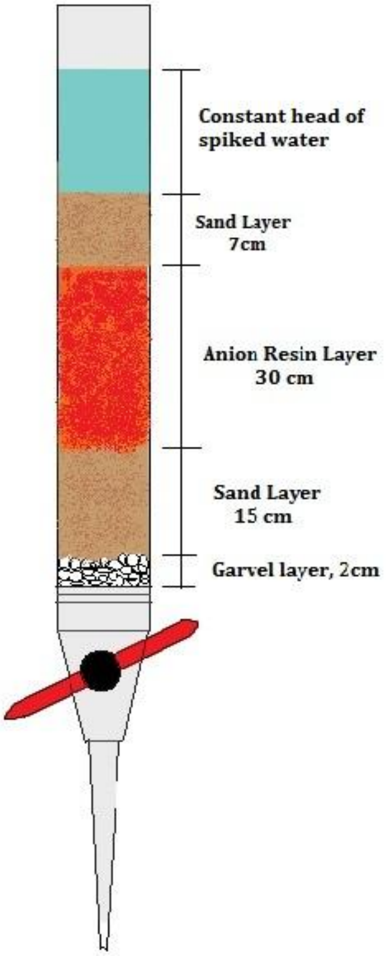


Fig 7.10: Design of anionic resin filter

7.1.4.3.3 Mechanism

The spiked water passes through the chloride form resin bed (RCl) during which the chloride arsenate ion-exchange reaction takes place to yield resin in the arsenate form ($R_2H_3AsO_4$).

$$2RCl + H_3AsO_4^- = R_2H_3AsO_4 + 2Cl$$

$$RCl + HAsO_2^- = RHAsO_2 + Cl$$

7.1.4.3.4 Experimental Procedure

All the trials of this experiment are carried out with ground water without any pH adjustment or any pretreatment.

- Take 0.4ml, 0.75ml, 1ml and 1.25 ml volume of 100 mg/l primary stock solution dilute up to 500ml Ground water in measuring cylinders as arsenic concentration will be 0.80mg/l, 0.150mg/l, 0.200mg/l, 0.250mg/l respectively for each trail.
- The spiked water is passed through the filter bed in a down flow pattern and maintaining the hydraulic flow rate at the outlet is 375 L/hr/m^2
- About 250ml of spiked water is passed through the filter bed in each trail.
- After filtration sample is collected in 100ml plastic container.
- All the necessary tests are analyzed on the day of every trial.

Fig. 7.11: anionic resin burette filter

7.1.4.4 Results, Analysis and Discussion

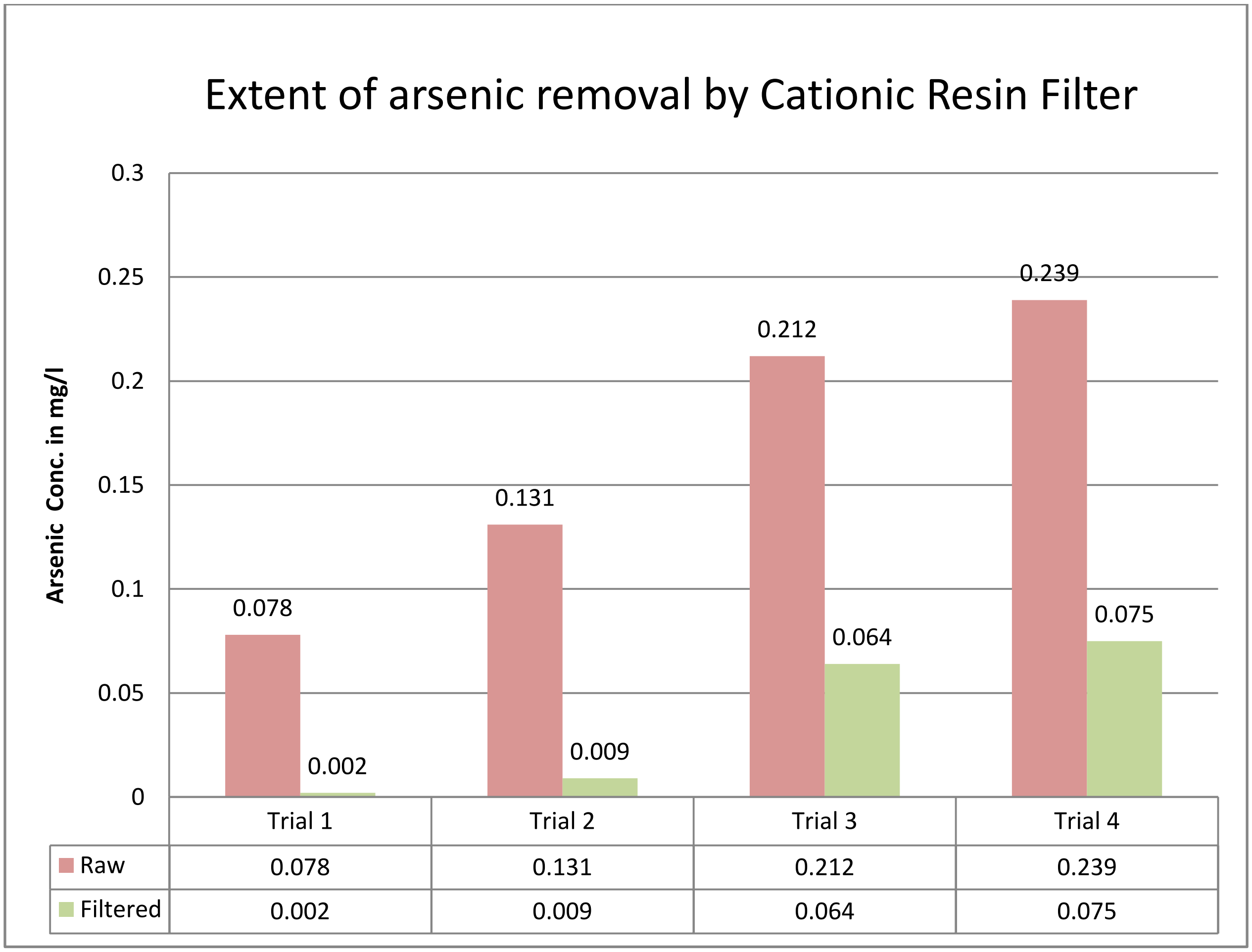
7.1.3.4.1 Results and Analysis

Table 7.5: Removal of Arsenic and effects on others parameter by using of anionic resin filter

No of Trials	**Trial 1**		**Trial 2**		**Trial 3**		**Trial 4**	
Parameters	**Raw**	**Filtered**	**Raw**	**Filtered**	**Raw**	**Filtered**	**Raw**	**Filtered**
Arsenic (in mg/l)	0.078	0.002	0.131	0.009	0.212	0.064	0.239	0.075
Iron (in mg/l)	0.34	0.01	0.26	0.01	0.36	0.02	0.36	0.09
pH	7.62	7.31	7.48	6.95	7.74	7.25	7.48	7.20
TDS (in mg/l)	1732	1769	1709	1788	1703	1759	1748	1803
E.C (in mS/cm)	2860	2910	2870	2950	2870	2920	2910	3010
Alkalinity (As $CaCO_3$ in mg/l)	296	224	325	125	312	272	320	145
Hardness (As $CaCO_3$ in mg/l)	672	708	605	760	700	752	650	725
Chloride (As Cl in mg/l)	1009.68	1193.62	959.7	1059.67	1039.67	1075.66	1064.67	1129.14

Table 7.6: Percentage removal efficiency of arsenic in each trial

No. of Trials	Raw	Filtered	Percentage of Removal
Trial 1	0.078	0.002	97.43 %
Trial 2	0.131	0.009	93.12 %
Trial 3	0.212	0.064	69.81 %
Trial 4	0.239	0.075	68.62 %



	Trial 1	Trial 2	Trial 3	Trial 4
🟥 Raw	0.078	0.131	0.212	0.239
🟩 Filtered	0.002	0.009	0.064	0.075

Fig 7.12: Arsenic concentration varying with spiked water

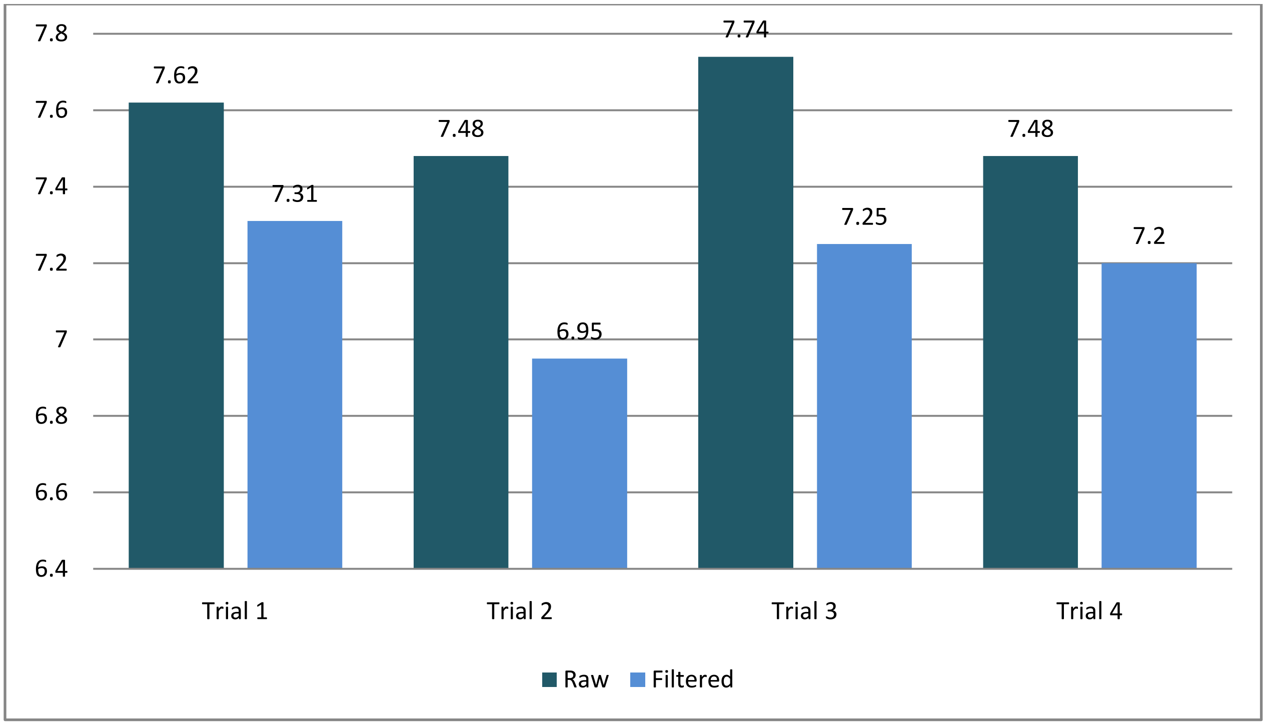


Fig 7.13: pH of Filtered water varying with Raw water

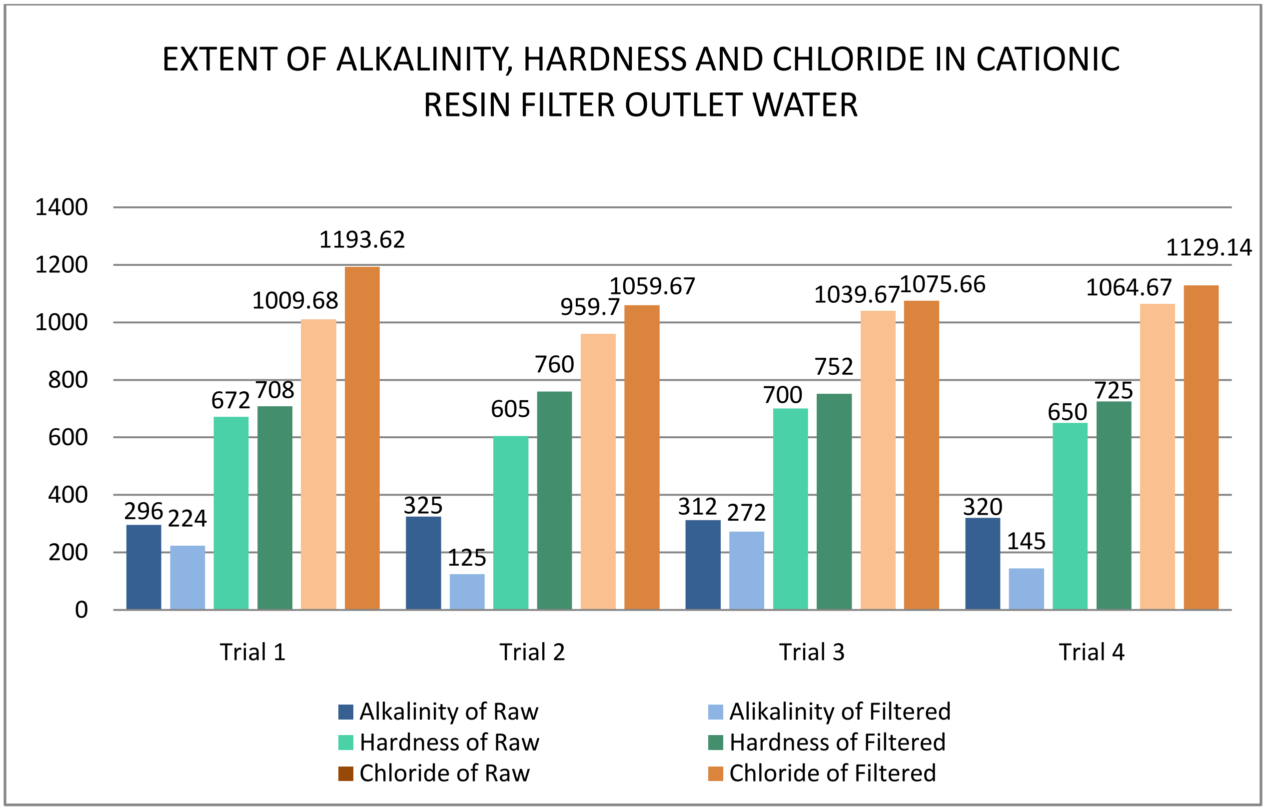


Fig 7.14: Varying of Alkalinity, Hardness & Chloride conc. in Filtered water with Raw water

7.1.4.4.2 Discussion

- With maintaining the constant flow rate of 375 L/hr/m^2, various concentrations is applied for this experiment.
- **Table 7.6** shows that, arsenic is removed by this method up to 97.43%
- From **Fig 7.14** we can see that total alkalinity in filtered water are (224mg/l , 125mg/l, 272mg/l, 145mg/l) in the permissible limit (600mg/l) of drinking water as per BIS-10500:2012.
- In case of Hardness in filtered water are (708mg/l, 760mg/l, 752 mg/l, 725 mg/l) just exceeds the permissible line of drinking water (600mg/l).
- Chloride of the filtered water slightly increased from raw water, which is also not in the permissible limit (1000mg/l) of drinking water standard. (From **fig 7.14**).
- **Fig 7.13** shows that the pH values of filtered water are (7.31, 6.95, 7.25, and 7.20) in the acceptable limit (6.5-8.5) of drinking water standard.
- From **table 7.6** we can see that total dissolved solids in filtered water are in the permissible limit (2000mg/l) of drinking water standard as per BIS-10500:2012.

7.1.5 Conclusion

- Anionic ion-exchange by anion resin is most effective process to remove the arsenic from contaminated water than cationic resin or anionic-cationic resin process.
- In anionic-cationic resin process total arsenic can be removed (100%) but pH of filtered water is affected badly, so a pre treatment of pH in raw water is needed. But in anionic process there is no need of pretreatment in pH and arsenic can be removed by 97.43% and others parameter on drinking water remained in there permissible limit of drinking water standard as per BIS-10500:2012.
- In ground water arsenic presents as oxy anions: monovalent, $H_3AsO_4^-$ and divalent, $HAsO_2^-$, these are attracted by only anionic resin. So, only anion resin can remove the arsenic.
- This process is very economical. Some simple operation and maintenance process is required.
- Exhausted Resin can be regenerated by using NaCl solution.
- Cationic exchange resin is generally used for water softening. The experimental results show that hardness of the filtered water is getting low than the raw water.

7.2 ADSORPTION METHOD

7.2.1 Introduction

In adsorption process solid is used as medium for removal of objects from gaseous or liquid solutions. Adsorption phenomenon is feasible in most natural, physical, biological and chemical system. For removal of arsenic activated alumina, metal oxides are used in commercial base. This technique is very popular and effective for removal of arsenic from contaminated water. In this study arsenic is removed by using only Iron nails as an absorbent.

7.2.2 Removal of arsenic by iron nails

Several studies confirmed that, common rust or iron oxide is a good the absorbent of arsenic. It is also a cheap material and easily available in market.

7.2.2.1 Mechanism

Iron nails are placed in contact with air and water so that they are rusted quickly by forming ferric hydroxide. When arsenic spiked water pass through the filter bed, arsenic fragments are come in contact with rusted iron nails for surface-complex reaction and arsenic is absorbed over rusted nails. Then arsenic loaded iron particles are settled on top of the sand layer and arsenic free water go through the sand-gravel layer to produce high quality water.

The Possible chemical reaction:

$\mathrm{Fe(OH)_3 + H_3AsO_4 \rightarrow FeAsO_4.2H_2O + H_2O}$ Where, $\mathrm{FeAsO_4}$ = Iron Arsenate

$\mathrm{Fe(OH)_3 + HAsO_2 \rightarrow FeAsO_3 + 2H_2O}$ $\mathrm{FeAsO_3}$ = Iron Arsenite

7.2.2.2 Materials required

- 20 liter plastic container for storing of spiked water
- Specially fabricated PVC pipe (used as column filter)
- Tripod steel stand for holding up the column filter
- Rubber pipes
- 100 ml Measuring cylinder for calculate the flow rate by using stopwatch
- Gravels
- Sand
- 1500gm of Rusted Iron nails
- 100ml plastic bottles for collection of water samples

7.2.2.3 Chemicals required

- Arsenic stock solution (concentration of 100mg/l)
- Concentrated hydrochloric acid

7.2.2.4 Methodology

7.2.2.4.1 Sampling

Chemicals are used AR/GR 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 and the low concentration arsenic solutions are freshly prepared from primary stock solution for each experiment. Glass and plastic-ware are acid washed before use. Low concentrated stock solutions are prepared in a plastic container, capacity of 20 liters. Before collecting the sample, the container is rinsed three-four times by the water is to be filled.

7.2.2.4.2 Experimental Set-Up

- Diameter of the column filter = 0.075 m
- Height of the column filter = 0.86 m
- Height of the bed = 0.35 m of iron nails
  0.30 m of sand
  0.10 m of gravels

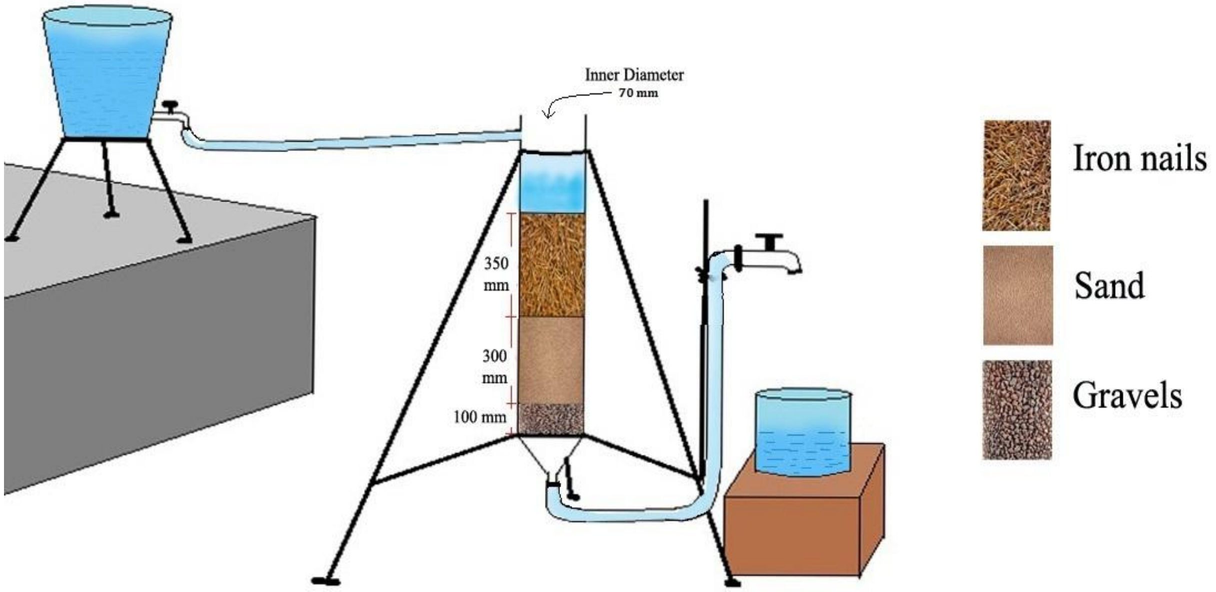


Fig 7.15: Detail configuration of the filter using iron nails as absorbent media

7.2.2.4.3 Experimental procedure

Experiment trials are carried out in a 20 liters plastic bucket with 16liters arsenic spiked groundwater without any pre-treatment.

- Take 40ml volume of stock solution from primary arsenic stock solution of 100 mg/l in a 100 ml measuring cylinder and diluted with 16 liters groundwater in the plastic bucket as the arsenic concentration of spiked water would be 0.250 mg/l
- With maintaining the constant flow rate of 1.2 lit/hr, the spiked water passed through the filter bed with downward flow pattern.
- About 112 liters of spiked water is passed through the adsorption filter without oxidation.
- After filtration treated samples are collected in 100ml plastic container in the interval of 4liters.
- Samples are acidified by concentrated hydrochloric acid for storage and analyzed within a week.

Fig 7.16: (i) Experimental set up in laboratory (ii) rusted iron nails which are used for adsorption.

7.2.2.5 Results, Analysis and Discussion

7.2.2.5.1 Results

Table: 7.7 Removal of arsenic and Iron by rusted iron nails

		RAW WATER QUALITY		TREATED WATER QUALITY		PERCENTAGE REMOVAL	
Serial No.	Water treated (in Liters)	Conc. of As in Raw (mg/l)	Conc. of Fe in Raw (mg/l)	Conc. of As in Treated (mg/l)	Conc. of Fe in Treated (mg/l)	Percentage removal of As (in %)	Percentage removal of Fe (in %)
1	4	0.245	0.34	0	0.006	100	98.23
2	8	0.245	0.34	0	0.006	100	98.23
3	12	0.245	0.34	0	0.006	100	98.23
4	16	0.253	0.39	0	0.005	100	98.71
5	20	0.253	0.39	0	0.005	100	98.71
6	24	0.253	0.39	0	0.005	100	98.71
7	28	0.276	0.45	0.004	0.009	98.55	98.00
8	32	0.276	0.45	0.007	0.010	97.46	97.77
9	36	0.276	0.45	0.009	0.010	96.73	97.77
10	48	0.255	0.36	0	0.015	100	95.83
11	60	0.242	0.31	0	0.012	100	96.12
12	72	0.266	0.42	0.004	0.019	98.49	95.47
13	78	0.232	0.29	0	0.015	100	94.82
14	84	0.232	0.29	0.002	0.020	99.13	93.10
15	88	0.255	0.36	0.002	0.025	99.21	93.05
16	92	0.255	0.36	0.002	0.030	99.21	91.66
17	96	0.255	0.36	0.003	0.036	98.82	90.00
16	100	0.238	0.26	0.011	0.068	95.37	73.84
17	108	0.238	0.26	0.012	0.071	94.95	72.69
18	112	0.262	0.28	0.025	0.086	90.45	69.28
19	116	0.262	0.28	0.033	0.090	87.40	67.85

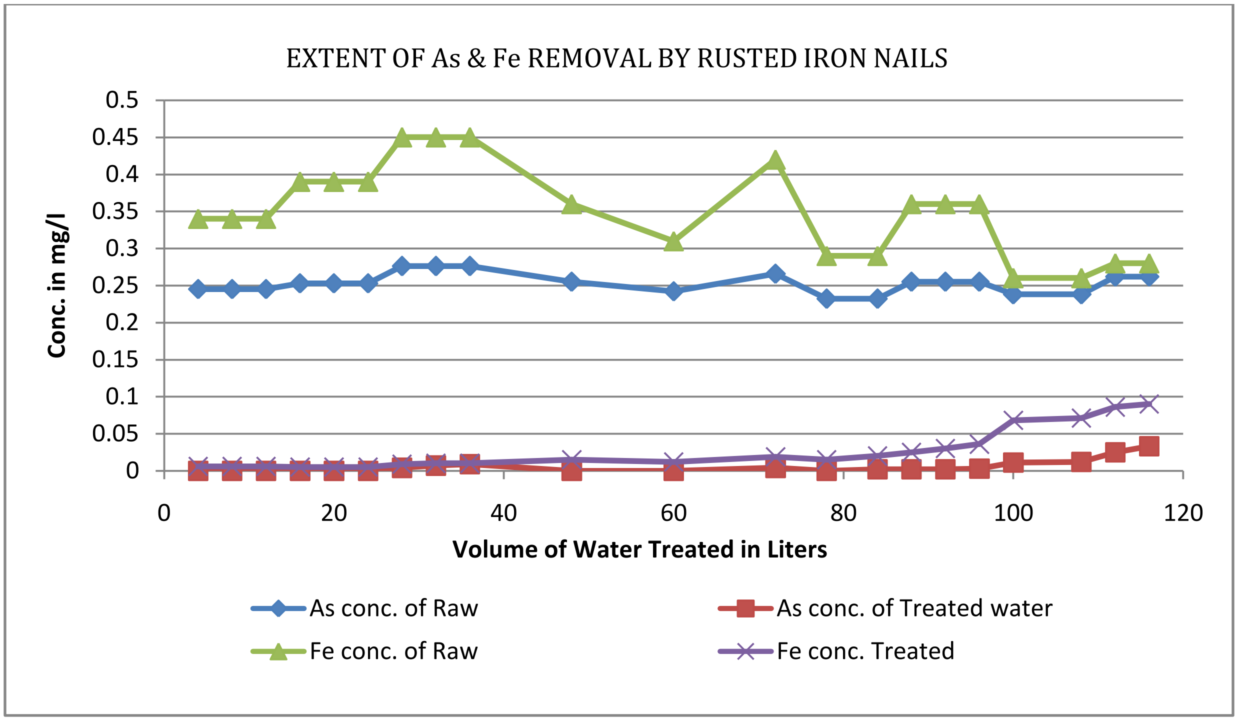


Fig 7.17: Removal of arsenic & iron from contaminated water with respect to volume of treated water

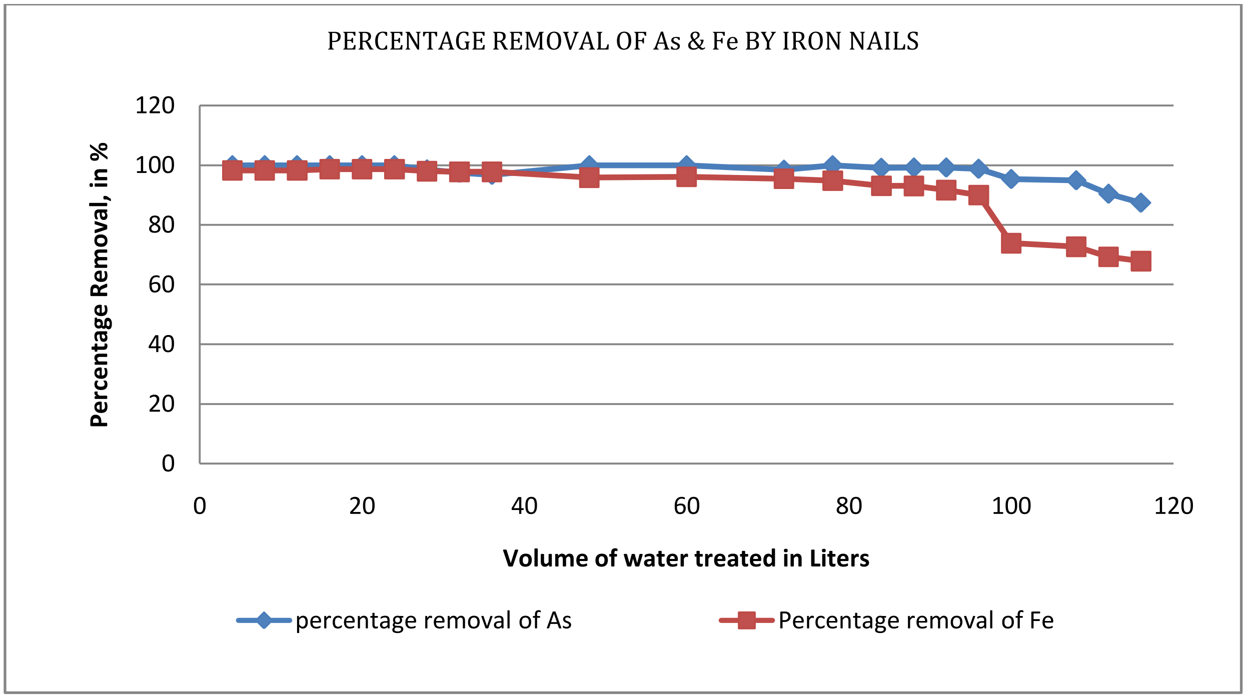


Fig 7.18: Percentage removal of arsenic & iron with respect to the volume of water treated

Table 7.8: Varying of pH with respect to the removal of As from Raw water

	Raw Water Quality		Treated Water Quality	
Volume of treated water in Liters	**As conc.** in mg/l	**pH**	**As conc.** in mg/l	**pH**
4	0.245	7.71	0.000	7.46
8	0.245	7.74	0.000	7.53
12	0.245	7.68	0.000	7.67
16	0.253	7.81	0.000	7.57
20	0.253	7.75	0.000	7.66
24	0.253	7.86	0.000	7.69
28	0.276	7.76	0.004	7.48
32	0.276	7.79	0.007	7.65
36	0.276	7.80	0.009	7.74
48	0.255	7.88	0.000	7.49
60	0.242	7.80	0.000	7.74
72	0.266	7.81	0.004	7.89
78	0.232	7.74	0.000	7.61
84	0.232	7.69	0.002	7.56
88	0.255	7.89	0.002	7.53
92	0.255	7.81	0.002	7.41
96	0.255	7.86	0.003	7.59
100	0.238	7.32	0.011	7.44
108	0.238	7.36	0.012	7.52
112	0.262	7.19	0.025	7.41
116	0.262	7.25	0.033	7.49

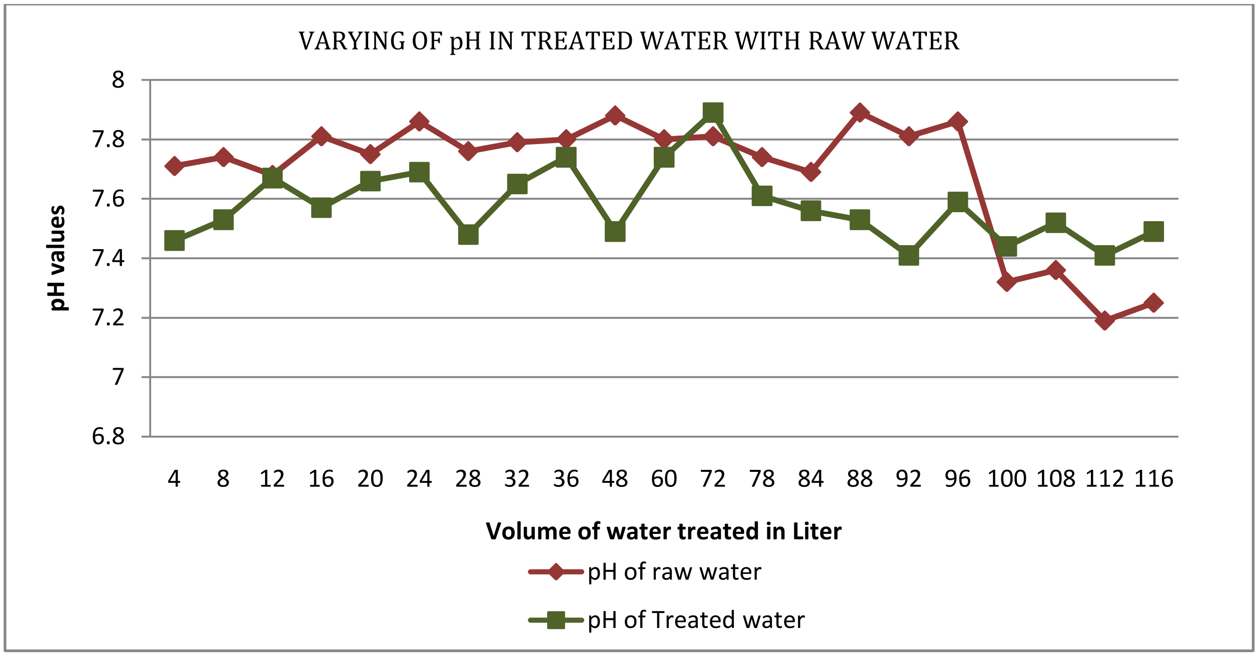


Fig 7.19: Varying of pH in treated water

Table 7.9: Effect of Turbidity in Treated water with removal of As

	Raw Water Quality		**Treated Water Quality**	
Vol. of treated water in Liters	**As concentration,** in mg/l	**Turbidity of Raw water**, in NTU	**As concentration,** in mg/l	**Turbidity of treated water**, in NTU
12	0.245	3.80	0.000	0.66
24	0.253	2.78	0.000	0.35
36	0.276	3.57	0.009	0.69
48	0.255	4.54	0.000	1.04
60	0.242	2.96	0.000	0.57
72	0.266	3.18	0.004	0.65
84	0.232	2.04	0.000	0.58
96	0.255	1.75	0.002	0.56
108	0.238	2.82	0.012	4.56
116	0.262	1.10	0.033	3.30

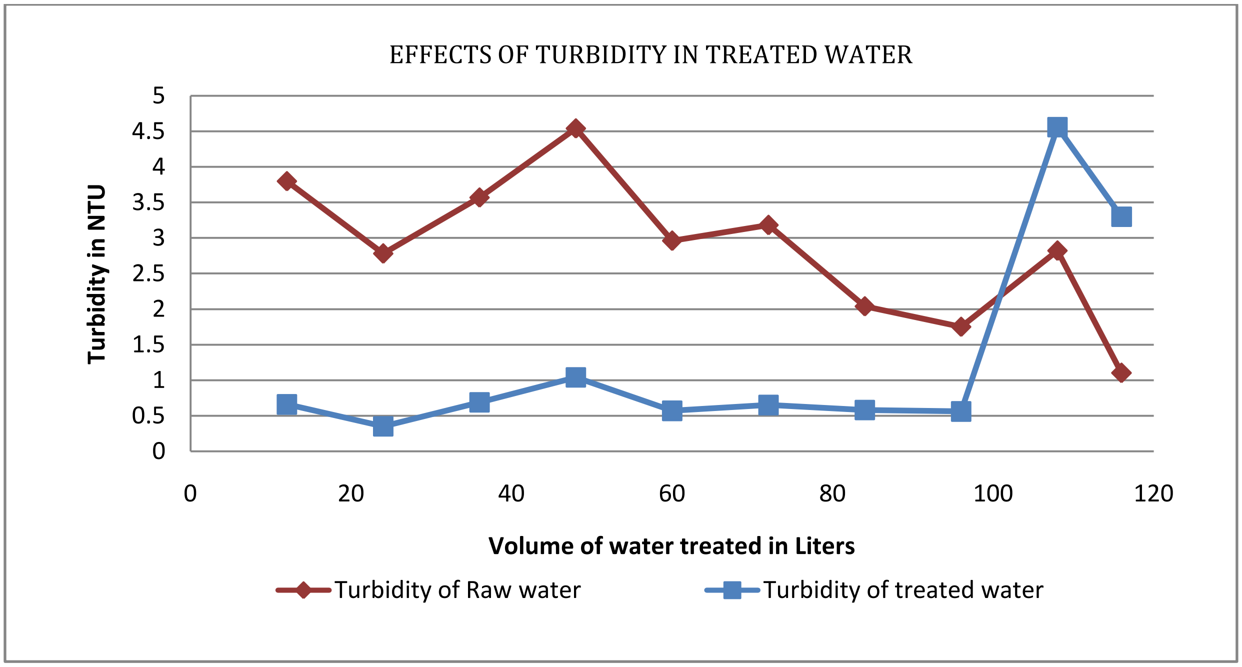


Fig 7.20: Varying of Turbidity in Treated Water with Volume of treated water

Table 7.10: Effect of Alkalinity and Hardness in Treated water

	Raw Water Quality			Treated Water Quality		
Vol. of treated water, in Liters	**As concentration** in mg/l	**Alkalinity** in mg/l	**Hardness** in mg/l	**As concentration** in mg/l	**Alkalinity** in mg/l	**Hardness** in mg/l
12	0.245	345	350	0.000	260	435
24	0.253	325	345	0.000	275	455
36	0.276	305	525	0.009	295	500
48	0.255	295	480	0.000	250	445
60	0.242	285	355	0.000	235	405
72	0.266	290	395	0.004	250	415
84	0.232	260	435	0.000	245	440
96	0.255	320	485	0.002	260	465
108	0.238	545	500	0.012	285	460
116	0.262	292	548	0.033	260	412

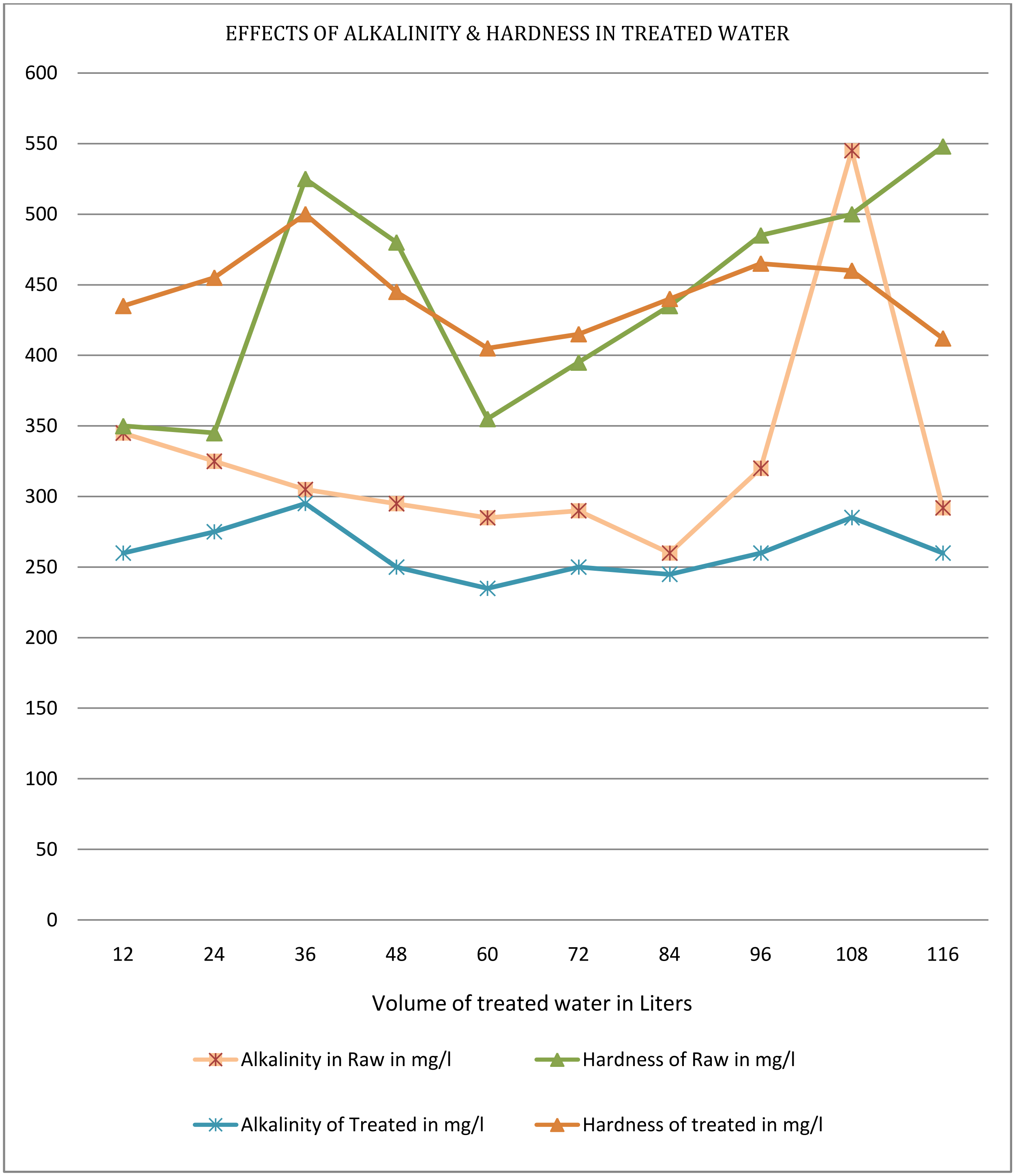


Fig 7.21: Varying of Alkalinity and hardness in treated water with spiked water

Table 7.11: TDS & EC of treated water varying with raw water with respect to the volume of treated water

	Raw Water Quality			**Treated Water Quality**		
Vol. of water treated, in Liters	**As concentration** in mg/l	**TDS** in mg/l	**EC** in uS/cm	**As concentration** in mg/l	**TDS** in mg/l	**EC** in uS/cm
12	0.245	1372	2290	0.000	1329	2120
24	0.253	1384	2290	0.000	1362	2220
36	0.276	1409	2270	0.009	1430	2310
48	0.255	1390	2250	0.000	1435	2290
60	0.242	1403	2280	0.000	1433	2320
72	0.266	1378	2190	0.004	1406	2280
84	0.232	1391	2210	0.000	1428	2330
96	0.255	1391	2260	0.002	1418	2220
108	0.238	1360	2250	0.012	1437	2260
116	0.262	1460	2350	0.033	1498	2440

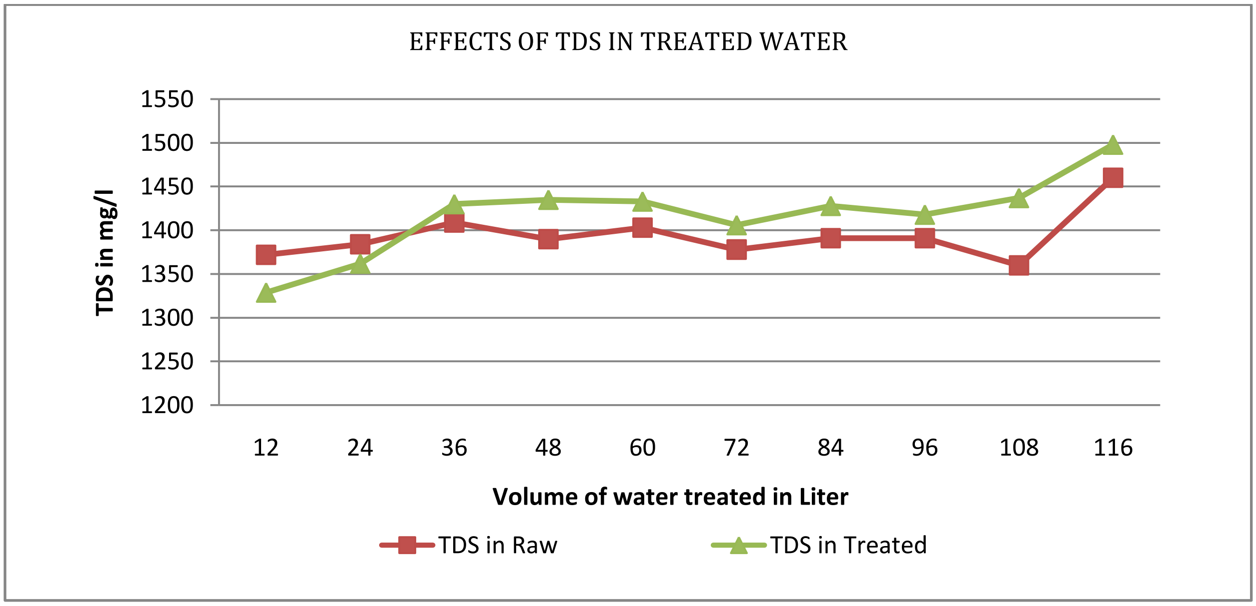


Fig 7.22: Varying of TDS in treated water with raw water with respect to volume of treated water

7.2.2.5.2 Discussion

- In this study of adsorption by rusted iron nails, 1500 gm rusted iron nails are used for absorbent media in filter bed.
- A constant flow rate of 1.2 lit/hr is maintained throughout the experiment.
- Table 7.7 shows that the 1500 gm of iron nails can reduce arsenic & iron concentration at its permissible limit (0.01mg/l & 0.3 mg/l respectively) and around 100 liters of contaminated water can be purified.
- Fig 7.18 and Table 7.7 show that the removal efficiency of arsenic is around 100% and Fe is around 98% from contaminated water.
- pH of treated water is getting slightly low from the pH of Raw water, Table 7.8 & Fig 7.19 shows that.
- Table 7.9 displayed that the turbidity of treated water is within the permissible limit (0.1-1 NTU) of drinking water, as per BIS-10500:2012. After purifying the 96liters of water the turbidity of the outlet samples is increasing with arsenic concentration as well.
- Table 7.10 expressed that the alkalinity & hardness are in their permissible limit (200-600 mg/l) of drinking water, as per BIS-10500:2012
- Adsorption capacity of iron nails is found that 294.97 mg/kg

7.2.3 ARSENIC ADSORPTION ISOTHERM

As we know the desirable limit of arsenic concentration in drinking water (as per BIS 10500:2012) is 0.01 mg/l, so for the establishment of adsorption isotherm the values of treated water concentration up to 0.01mg/l have taken for this study.

Table 7.7 shows that, after filtration of 100 liters of water, the concentration of arsenic reaches 0.011mg/l. So, by interpolation we get, arsenic concentration of treated water may reach 0.01mg/l after the filtration of 98.5 liters of water.

Table 7.12 Experimental data of arsenic adsorption isotherm during filtration with rusted iron nails

Cumulative of treated water, **V in Liters**	Wt. of absorbent (nails), **m in gm**	Influent concentration **C_0 in mg/**l	Equilibrium concentration **C_e in mg/l**	Amount of adsorbate adsorbed by nails, **X=(C_0-C_e)/m in mg**	Adsorbate to adsorbent ratio, **q in mg/g**
4	1500	0.245	0.0001	0.9796	0.000653
8	1500	0.245	0.0001	1.9592	0.001306
12	1500	0.245	0.0001	2.9388	0.001959
16	1500	0.253	0.0001	4.0464	0.002698
20	1500	0.253	0.0001	5.058	0.003372
24	1500	0.253	0.0001	6.0696	0.004046
28	1500	0.276	0.004	7.616	0.005077
32	1500	0.276	0.007	8.608	0.005739
36	1500	0.276	0.009	9.612	0.006408
48	1500	0.255	0.0001	12.2352	0.008157
60	1500	0.242	0.004	14.28	0.00952
72	1500	0.266	0.009	18.504	0.012336
78	1500	0.232	0.0001	18.0882	0.012059
84	1500	0.232	0.007	18.9	0.0126
88	1500	0.255	0.002	22.264	0.014843
92	1500	0.255	0.002	23.276	0.015517
96	1500	0.255	0.003	24.192	0.016128
98.5	1500	0.238	0.01	22.458	0.014972

7.2.3.1 Fitting of the experimental values to Langmuir & Freundlich Isotherm

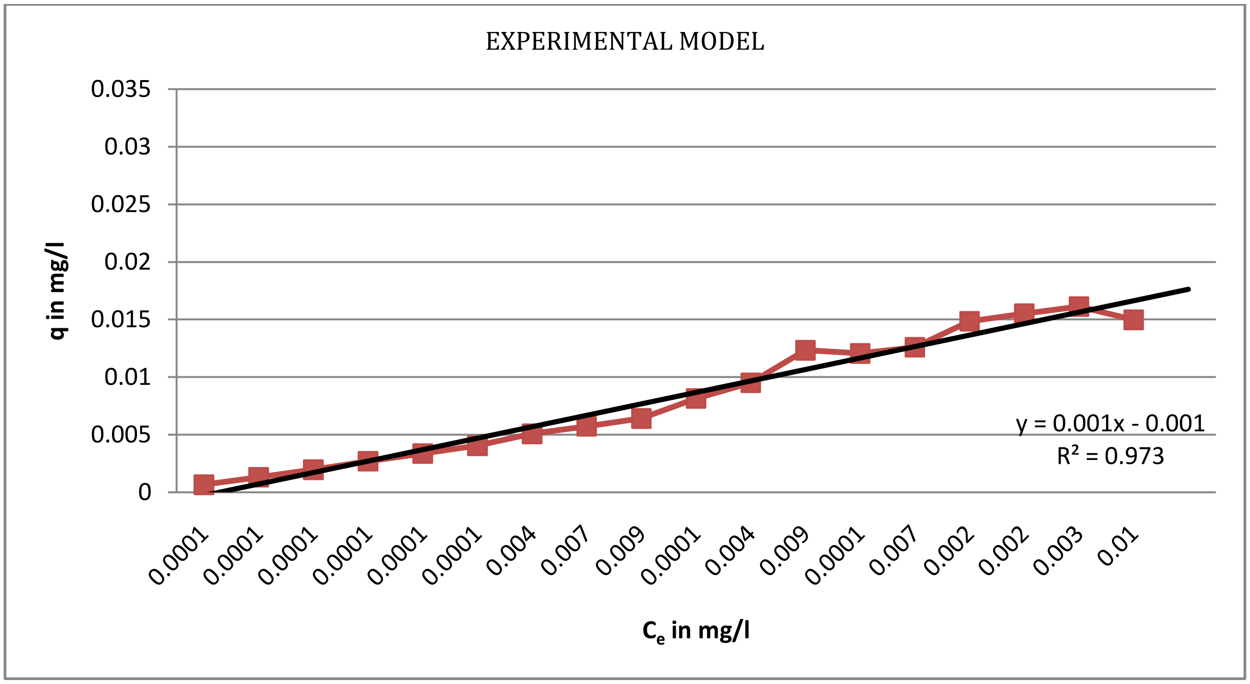


Fig 7.23: Experimental model for adsorption Isotherm

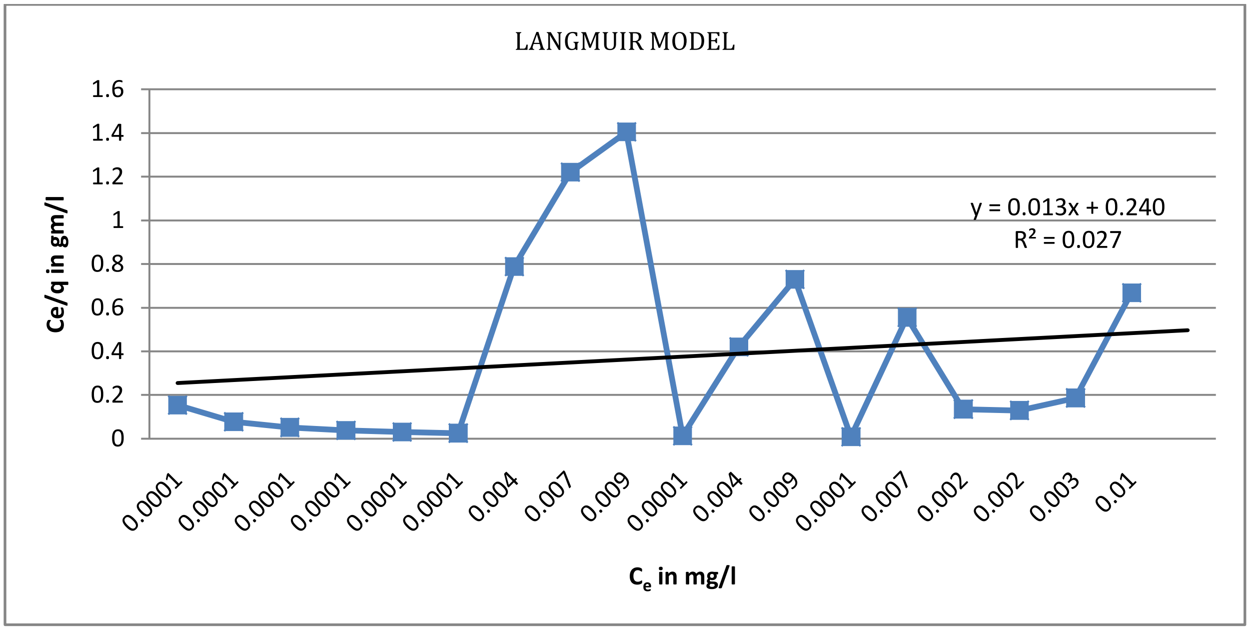


Fig 7.24: Langmuir isotherm model

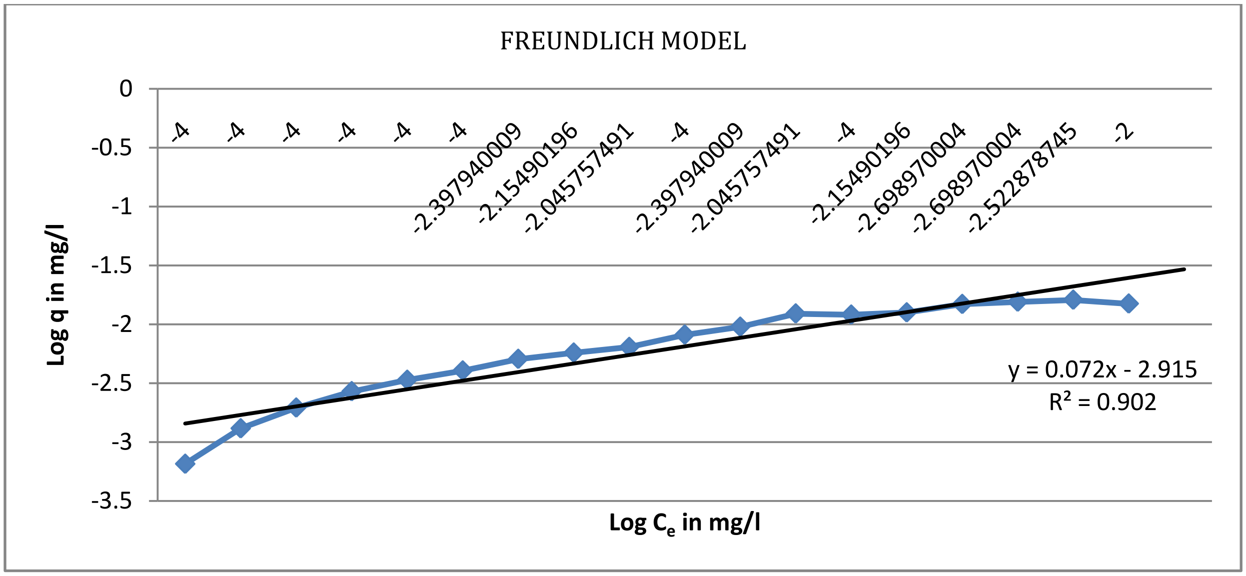


Fig 7.25: Freundlich isotherm model

Table: 7.13: Isotherms models with Correlation coefficient

Adsorption Isotherm models	X	Y	Linear equation	Correlation coefficient R^2
Experimental	C_e	q	y = 0.001x - 0.001	0.973
Langmuir	C_e	C_e/q	y = 0.013x - 0.240	0.027
Freundlich	Log C_e	Log q	y = 0.072x – 2.915	0.902

In this study, the equations of Langmuir and Freundlich are evaluated from the experimental data to explain the adsorption isotherm of arsenic removal by rusted iron nails. Experimental isotherm model (fig7.23) is relatively similar to the Freundlich isotherm model (fig 7.25) & table 7.13 shows that the overall arsenic adsorption is best described by Freundlich equation for this study of adsorption by rusted iron nails.

PERFORMANCE ANALYSIS OF AIRPs

CHAPTER 8

Arsenic is a major anxiety in the water quality scenario of West Bengal mainly in the districts of – Nadia, Maldah, Murshidabad & North 24 Parganas. The Public Health Engineering Department, Govt. of West Bengal being very serious about Arsenic Mitigation have installed Arsenic cum Iron Removal Plants in the Districts of Nadia, Malda, Murshidabad & North 24 Paraganas. The Arsenic iron Removal Plants (AIRPs) are designed to remove Arsenic & Iron from ground water. The implementation of these plants needs constant monitoring on a day to day basis to ensure the clarity of output water. Under the Arsenic Master Plan, 165nos. of Arsenic Iron removal plants (AIRPs) were proposed for implementation and the work is at an advance stage of completion. Apart from the Master Plan schemes, Public Health Engineering Department, Govt. of West Bengal has already implemented a good number of AIRPs.

Table 8.1: Details of Arsenic Iron removal plants (AIRPs) in West Bengal

District	Total no. of AIRPs	Ongoing	Commissioned	Under Trial Run
Maldah	11	8	3	-
Murshidabad	66	51	15	-
Nadia	65	23	42	-
North 24 Paraganas	33	18	14	1

Performance evaluations of three AIRPs with having different removal technologies, in North 24 Parganas district are going to discuss in this study.

Table 8.2: List of Groundwater based piped water Supply Schemes with AIRPs in North 24 Parganas.

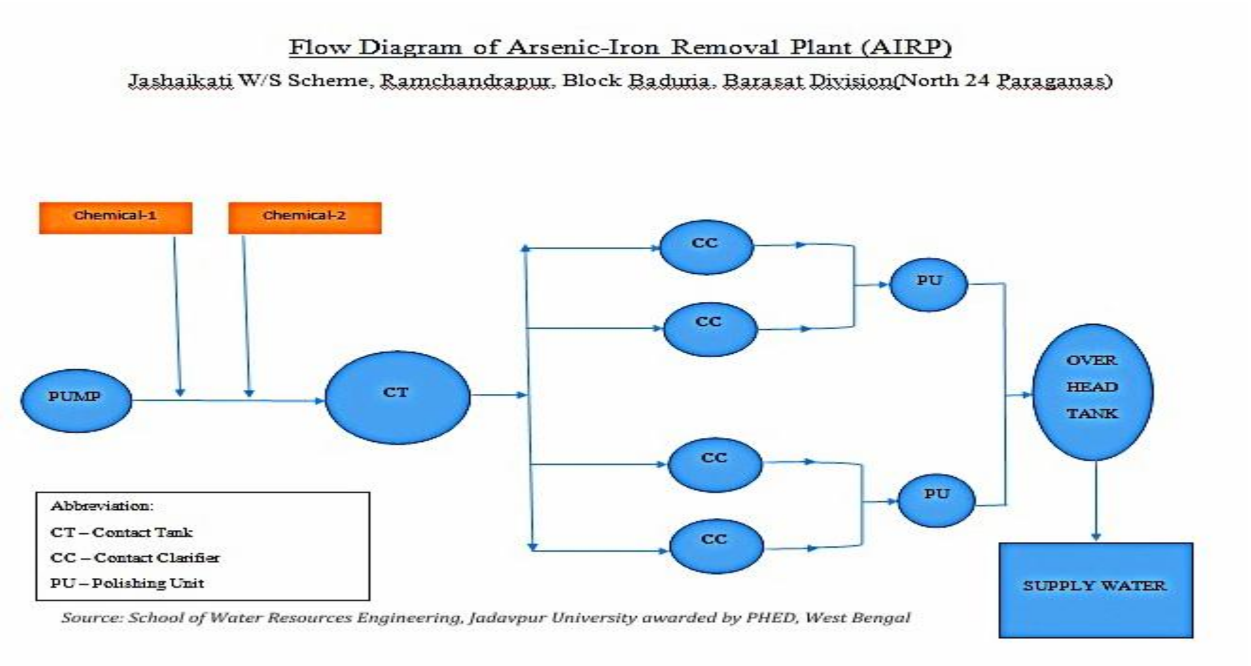
District	Blocks	Schemes
North 24 Parganas	Baduria	Jasaikhati W/S Scheme (Zone II)
	Baduria	Bazitpur W/S Scheme
	Bagdah	Kola W/S Scheme

8.1 AIRP for Jasaikhati W/S Scheme, Zone II

8.1.1 Details informations of Jasaikhati W/S scheme

Village Name	Ramchandrapur
Block	Baduria
District	North 24 Parganas
Date of commissioning	February,2015
Plant Manufacturer	Odissi Innovations
Population Served	16315
Treatment Technology	Chemical coagulation, Precipitation, Filtration and Adsorption
Treatment capacity	110.00 m^3/hr
Operation time	7 hours/day
Treatment Units	1 number of Contact Tank (CT); 4 number of Contact Clarifier (CC); 1 number of Polishing Unit (PU)

8.1.2 Flow diagram of Jasaikhati AIRP plant



Flow Diagram of Arsenic-Iron Removal Plant (AIRP)

Jashaikati W/S Scheme, Ramchandrapur, Block Baduria, Barasat Division(North 24 Paraganas)

Source: School of Water Resources Engineering, Jadavpur University awarded by PHED, West Bengal

Fig 8.1: Jasaikhati AIRP Plant, North 24 Parganas

8.1.3 Chemicals used in Jasaikhati AIRP

Sodium Aluminate ($NaAlO_2$); Dose: 5mg/L Concentration: 15% for Coagulation

Sodium Sulphide (Na_2S); Dose: 0.01mg/l Concentration: 7% for Oxidation,

Monochloramine (NH_2Cl); Dose: 0.20mg/l, Concentration: 6% for Disinfection

Ferric Hydroxide [$Fe(OH)_3$] for adsorption

8.1.4 Water quality test report:

All samples drawn and tested by School of water Resources Engineering

Date of sample collection: 03.10.2018

Sl. No.	**Parameters**	**Results**				
		RW	**CT**	**CC**	**PU**	**PW**
1	pH	7.64	7.61	7.59	7.54	-
2	IRON, mg/L as Fe	1.37	1.09	0.51	0.28	-
3	ARSENIC, mg/L as As	0.05	0.043	0.012	0.002	0.006

Date of sample collection: 26.12.2018

Sl. No.	**Parameters**	**Results**			
		RAW (GROUND WATER)	**OUTLET OF CONTACT CLARIFIER**	**OUTLET OF POLISHING UNIT**	**OUTLET OF PUBLIC STAND POST**
1	pH	7.27	7.28	7.27	7.29
2	IRON, mg/L	1.13	0.18	0.14	0.13
3	TOTAL ARSENIC, mg/l	0.028	0.007	0.004	0.005

Date of sample collection: 25.01.2019

Sl. No.	**Parameters**	**Results**			
		RAW (GROUND WATER)	**OUTLET OF CONTACT CLARIFIER**	**OUTLET OF POLISHING UNIT**	**OUTLET OF PUBLIC STAND POST**
1	pH	7.23	7.19	7.21	7.32
2	IRON, mg/L	1.38	0.72	0.38	0.35
3	TOTAL ARSENIC, mg/l	0.034	0.010	0.001	0.023

Date of sample collection: 09.04.2019

Sl. No.	**Parameters**	**Results**			
		RAW (GROUND WATER)	**OUTLET OF CONTACT CLARIFIER**	**OUTLET OF POLISHING UNIT**	**OUTLET OF PUBLIC STAND POST**
1	pH	7.55	7.52	7.55	NA
2	IRON, mg/L	0.74	0.49	0.28	NA
3	TOTAL ARSENIC, mg/l	0.046	0.011	0.006	NA

8.1.5 Discussion:

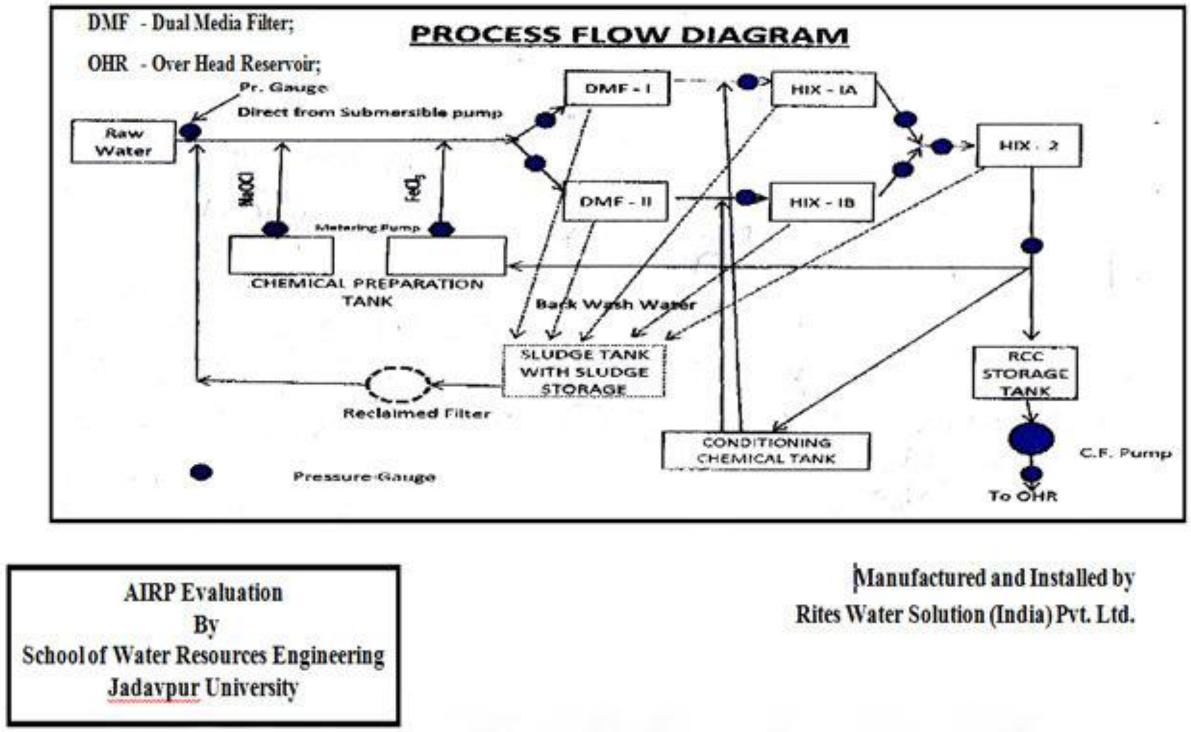
- ✓ It is found that, raw water concentration of arsenic in Jasaikhati AIRP is below 100ppb or 0.1 mg/l
- ✓ Arsenic concentration in Polishing Unit (PU) is found within the desirable limit in every test report, but at the stand post it is found to be more than desirable limit (0.01µg/l or 10 ppb) of arsenic in drinking water, in only the month of January'19.
- ✓ Iron concentration in raw water is found very high for every month.
- ✓ Iron concentration in final treated water is found within the permissible limit (0.3mg/l) of iron in drinking water
- ✓ A sludge tank is available in Jaisaikhati plant for disposal of arsenic rich sludge.

8.2 AIRP for Bazitpur W/S scheme

8.2.1 Details information of Bazitpur W/S scheme

Village Name	Bazitpur
Block	Baduria
District	North 24 Parganas
Date of commissioning	April’2016
Plant Manufacturer	Rites water solution (India) Pvt. Ltd.
Population Served	16335
Treatment Technology	Oxidation, Coagulation, Dual Media Filtration, Sorption through HIX1, Polishing through HIX2
Treatment capacity	91.5 m^3/hr
Operation time	4 hours/day
Treatment Units	2 numbers of Dual Media Filter (DMF) unit, 2 numbers of HIX-1 unit, 1 number of HIX-2 unit

8.2.2 Flow Diagram of Bazitpur AIRP



Source: Project of School of Water Resources Engineering, Jadavpur University awarded by PHED West Bengal

Fig 8.2 Sample collection from different units of Bazitpur AIRP

8.2.3 Chemicals used in Bazitpur AIRP

- Sodium Hypochlorite (NaOCl): Concentration of 4 mg/l; Dosing 10 lit/hr of 2%; used for oxidation
- Ferric Chloride ($FeCl_3$): Concentration of 8 mg/l; Dosing 10lit/ hr of 4%; used for coagulation

8.2.4 Water quality test report

All the samples are drawn and tested by School of Water Resources Engineering

Date of sample collection: 26.12.2018

Sl. No.	Parameters	Results			
		RAW (GROUND WATER)	OUTLET OF HIX-1	OUTLET OF HIX-2	OUTLET OF PUBLIC STAND POST
1	pH	7.16	7.12	7.13	7.19
2	IRON, mg/L	2.88	0.76	0.03	1.78
3	TOTAL ARSENIC, mg/l	0.242	0.025	0.001	0.151

Date of sample collection: 25.01.2019

Sl. No.	Parameters	Results			
		RAW (GROUND WATER)	OUTLET OF HIX-1	OUTLET OF HIX-2	OUTLET OF PUBLIC STAND POST
1	pH	7.13	7.21	7.19	7.08
2	IRON, mg/L	3.75	0.86	0.25	1.86
3	TOTAL ARSENIC, mg/l	0.238	0.025	0.001	0.162

Date of sample collection: 09.04.2019

Sl. No.	Parameters	Results			
		RAW (GROUND WATER)	OUTLET OF HIX-1	OUTLET OF HIX-2	OUTLET OF PUBLIC STAND POST
1	pH	7.54	NA	7.17	7.25
2	IRON, mg/L	2.87	NA	0.006	1.89
3	TOTAL ARSENIC, mg/l	0.266	NA	0.005	0.161

8.2.5 Discussion

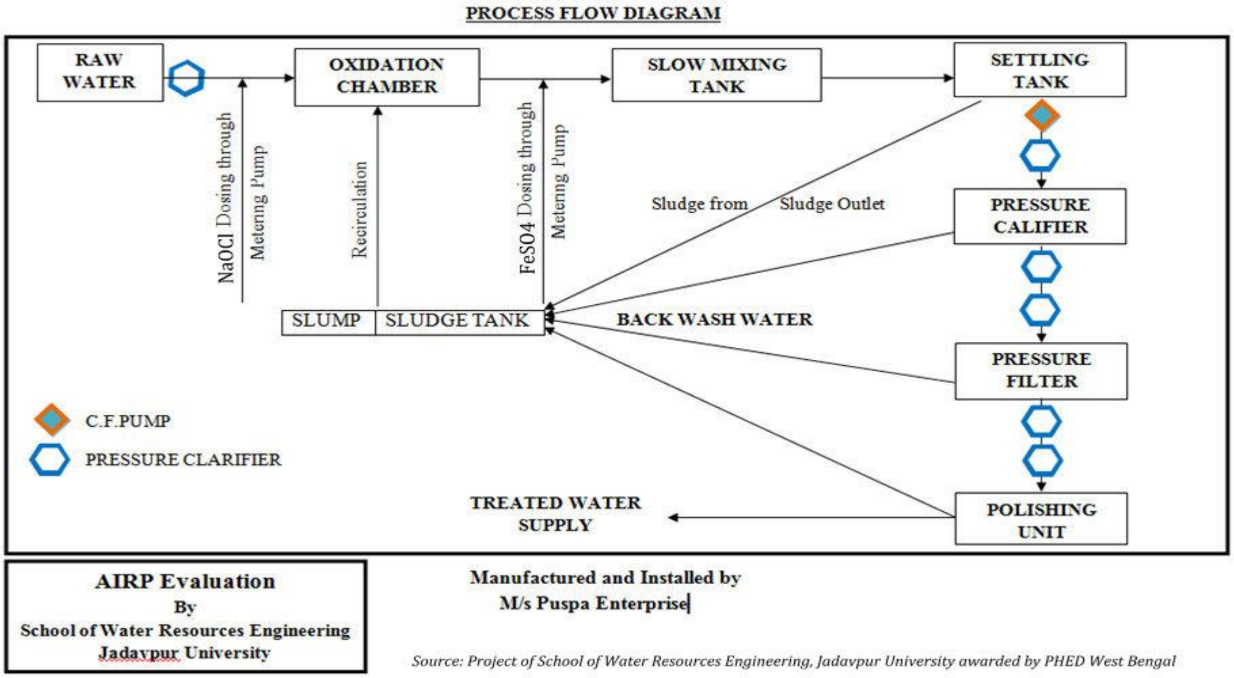
- ✓ Arsenic concentration in raw water is very high in this zone.
- ✓ In this study highest arsenic concentration is found 0.266 in the month of April’19
- ✓ Arsenic concentrations of outlet water in HIX-II unit are found very less, which is within the desirable limit (10 ppb) of arsenic in drinking water.
- ✓ But in stand post water arsenic concentrations are found to be very high (>10ppb) in last three different month. As concentrations in stand post outlet are 0.151mg/l, 0.162mg/l and 0.161mg/l in the month of December, January and April respectively.
- ✓ Test report shows that the iron concentration in raw water at Bazitpur zone is very high.
- ✓ Highest concentration of iron in raw water is found 3.75 mg/l in the month of January, in this study.
- ✓ According to test report, iron concentrations of outlet water of HIX-II unit are in the desirable limit (0.3 mg/l) of iron in drinking water.
- ✓ Similar to the arsenic concentration in public stand post water, the concentrations of iron are found very high compare to the concentration of outlet water of HIX-II unit in three different months.
- ✓ Iron concentrations in public stand post outlet are 1.78, 1.86 and 1.89 in the month of December, January and April respectively.
- ✓ Sodium Hypochlorite, Ferric chloride and HAIX (absorbent) are showing encouraging result in arsenic and iron removal process.
- ✓ The performance of adsorption unit HIX-I and HIX-II is found satisfactory.

8.3 AIRP for Kola W/S scheme

8.3.1 Details information of Kola W/S scheme

Village Name	Kola
Block	Bagda
District	North 24 Parganas
Date of commissioning	March’2015
Plant Manufacturer	M/s Puspa Enterprise
Population Served	2515
Treatment Technology	Oxidation, Flash mixing, Coagulation, Settling, Clarification by Pressure clarifier, Filtration by pressure filter, adsorption by Polishing unit
Treatment capacity	30 m^3/hr
Operation time	4 hours/day
Treatment Units	Oxidation Chamber, Slow mixing tank, Settling tank, Pressure Clarifier (PC), Pressure Filter (PF), Polishing Unit (PU)

8.3.2 Flow Diagram of Kola AIRP



Source: Project of School of Water Resources Engineering, Jadavpur University awarded by PHED West Bengal

Fig 8.3: (i) Kola Plant (ii) Sample collection (iii) Overflow of sludge tank

8.3.3 Chemical used for Kola AIRP

- Sodium Hypochlorite (NaOCl) : Concentration 3.5 mg/l; dosing 1.5 lit/hr of 7%
- Ferrous Sulphate ($FeSO_4$)

8.3.4 Water quality test report

All the samples are drawn and tested by School of Water Resources Engineering

Date of Sample Collection: 01.10.2018

Sl. No.	Parameters	Results			
		RAW WATER	PRESSURE CLARIFIER	PRESSURE FILTER	POLISHING UNIT
1	pH	7.8	7.66	7.61	7.57
2	IRON(as Fe), mg/L	1.43	1.12	0.37	0.26
3	TOTAL ARSENIC(as As), mg/L	0.038	0.031	0.012	0.009

Date of Sample Collection: 28.12.2018

Sl. No.	Parameters	Results			
		RAW (GROUND WATER)	AFTER PRIMARY FILTER	OUTLET OF POLISHING UNIT	OUTLET OF PUBLIC STAND POST
1	pH	7.31	7.39	7.33	7.30
2	IRON, mg/L	1.27	0.35	0.27	0.95
3	TOTAL ARSENIC, mg/l	0.039	0.020	0.008	0.055

Date of sample collection: 25.01.2019

Sl. No.	Parameters	Results			
		RAW (GROUND WATER)	AFTER PRIMARY FILTER	OUTLET OF POLISHING UNIT	OUTLET OF PUBLIC STAND POST
1	pH	7.23	7.39	7.33	7.30
2	IRON, mg/L	1.37	0.72	0.49	0.36
3	TOTAL ARSENIC, mg/l	0.022	0.008	0.005	0.001

Date of sample collection: 09.04.2019

Sl. No.	Parameters	Results			
		RAW (GROUND WATER)	AFTER PRIMARY FILTER	OUTLET OF POLISHING UNIT	OUTLET OF PUBLIC STAND POST
1	pH	7.21	7.26	7.21	7.39
2	IRON, mg/L	0.48	0.06	0.06	0.14
3	TOTAL ARSENIC, mg/l	0.036	0.024	0.012	0.009

8.3.5 Discussion

- ✓ Arsenic concentration in raw water is not more than 100ppb
- ✓ Polishing Unit outlet water concentration is found under the desirable limit of arsenic concentration in drinking water.
- ✓ In the month of December the arsenic concentration in public stand post water is found to higher than the Polishing unit outlet water, i.e. 0.055 mg/l
- ✓ Iron concentration in raw water is found very high.
- ✓ After the final treatment iron concentration is found higher than the desirable limit of iron concentration, in the outlet of Polishing Unit, in the month of October’18 & January’19
- ✓ In the month of the December’18 and January’19, concentration of iron in public stand post water is found to be more than the desirable limit (0.3 mg/l) of Fe concentration in Drinking water.
- ✓ It is found that the arsenic rich sludge is overflowing from the sludge tank.

CONCLUSION

CHAPTER 9

Conclusion

The existence of arsenite and arsenate in ground water is a serious problem across the world specially in West Bengal & Bangladesh and deletion 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 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 of both anionic and cationic 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 cationic resin cannot remove arsenic properly from the contaminated water. removal efficiency of this resin has been found around 50%
5. Only anionic resin also gives the excellent arsenic removal efficiency of 97.43% without requirement of any pretreatment 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
6. So, Ion-exchange process of arsenic removal by anionic resin has been found to be very effective, economical and simple operation and maintenance process.
7. Rusted iron nails have been found to be an excellent absorbent of arsenic. It is very cheap and easily available in market. Removal efficiency of iron nails through adsorption process has been found around 100%
8. Adsorption by rusted iron nails has been found to be most cost effective arsenic removal process, but back washing must be needed for sludge removal.
9. Arsenic and Iron concentration in treated water in Jasaikhati AIRP has found below their desirable limit. Performance of this AIRP is good.
10. In Bazitpur AIRP, arsenic and iron concentration in HIX-II unit outlet has found very less but in the stand post water it has found very high compare to HIX-II unit outlet in last three different months.
11. Performance of HIX-I and HIX-II unit has found satisfactory, but overall performance of this AIRP is not very satisfactory for the reason of serving high arsenic and contaminated water to the people.
12. Performance of the Kola AIRP has found adequate for people, but it is found that the arsenic rich sludge is overflowing from the sludge tank, proper maintenance needs to taken.

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