Chapter 16
Arsenic and Excess Fluoride Removal in Public Water Supply: Key Issues and Challenges

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1 Introduction

Water is essential for our life, livelihood, food security and sustainable development. It is a scarce natural resource but renewable through cyclic process of the climate. India having one-sixth of world population and 2.4% of world's land area is to satisfy with only 4% of world's renewable water resources. The per capita availability of water is decreasing in the country and it has reduced to one-third today compared to water availability during independence. The demand of water is increasing at a faster rate due to growing population, growing agriculture, food production, rapid industrialization and economic development. Again climate change in recent time has resulted in alteration of rainfall pattern. It has been predicted that the climate change is likely to increase the variability of water resources affecting livelihood and human health. Spatial rainfall pattern of varying characteristic has resulted in uneven water resources and thereby developing water stress and water-scarce situation in many stretches of the country. The situation has aggravated due to natural and anthropogenic pollution of both groundwater and surface water sources.

Water is a public good and every person has the right to demand drinking water. To increase economic productivity and improve public health, there is an urgent need to enhance access to safe and adequate drinking water. Accordingly every water supply agency must ensure water security and safety for the consumers addressing the issue of potability, reliability, sustainability, convenience and equity.

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P. K. Sikdar (ed.), *Groundwater Development and Management*,
https://doi.org/10.1007/978-3-319-75115-3_16

In India 85% rural population depend on groundwater to fulfil their domestic requirement. The groundwater is extensively used for agriculture as well as to meet the industrial requirement. Over-abstraction of groundwater has resulted in depletion of groundwater level in many parts of the country. The quality of groundwater in certain regions has undergone a change to such an extent that the use of such water could be risky and hazardous. Increase in overall salinity of the groundwater and/or presence of high concentration of fluoride, arsenic, iron, nitrate, total hardness and few toxic metals have been noticed in large areas of several states in India. The problems associated with chemical constituents of drinking water arise primarily from their ability to cause adverse health effects after prolonged periods of exposure; of particular concern are contaminants that have cumulative toxic properties, such as heavy metals, and substances that are carcinogenic (WHO 1996).

Both arsenic and fluoride contamination of groundwater have emerged as a serious problem for public water supply in the country. Though surface water supply may be a good alternative to groundwater supply in arsenic and fluoride affected areas but it may not be feasible in many areas due to non-availability of acceptable surface water sources as well as cost. Removal of arsenic and fluoride from groundwater by adopting appropriate technology may be another solution for public water supply in affected areas. Today, installation of sustainable decentralized arsenic and fluoride removal units for the benefit of the rural community is a challenge to all stakeholders.

2 Arsenic in Groundwater

Arsenic is a chemical that is distributed widely in air, water, soil, rocks, plants and animals in variable concentrations. The source of arsenic in soil is mainly parent (or rock) materials from which it is derived (Majumder 2001). It gets introduced in water through dissolution of minerals and ores and through erosion from natural resources. Anthropogenic activities resulting from combustion of fossil fuels, mining, discharge of effluents from metallurgical, ceramic, dye and pesticides manufacturing industries, petroleum refinery, etc. may cause increased arsenic levels in surface water and groundwater. The cycling of arsenic in the environment is regulated by natural processes and human activities. Thus, humans all over the world are exposed to small amounts of arsenic, mostly through food and water.

Arsenic pollution in groundwater, used for drinking purposes has been envisaged as a problem of global concern. High arsenic concentrations recognized in many parts of Asia and elsewhere are dominantly found in groundwater, and many of the health consequences encountered have emerged in relatively recent years as a result of the increased use of groundwater from bore-wells for drinking and irrigation. In terms of numbers of groundwater sources affected by arsenic contamination and population at risk, the problem is of considerable proportion in several States of

India. The water quality monitoring study carried out by All India Institute of Hygiene and Public Health in 32 arsenic affected blocks in West Bengal ($n = 7680$ hand-pump fitted bore-wells) revealed presence of arsenic beyond 50 μg/L in 20% of bore-wells, arsenic up to 50 μg/L in 44% bore-wells. Arsenic was found to be absent in 36% of bore-wells (Ananthanarayanan and Majumder 2003). In West Bengal arsenic has been found in 83 blocks situated in Malda, Murshidabad, Nadia, North 24-Parganas, South 24-Parganas, Bardhaman, Hooghly and Howrah. However, most of the arsenic affected blocks are situated along eastern part of River Ganga. The groundwater in arsenic affected areas is characterized by high iron, calcium, magnesium, bicarbonate with low chloride, sulphate and fluoride. The surface water sources including dug-wells are not affected by arsenic contamination.

Long-term exposure to arsenic via drinking water may cause arsenicosis showing symptom of keratosis, hyperkeratosis, melanosis, disorder of digestive, urinary and nervous system. It may even cause cancer of skin, lungs, liver, urinary bladder and kidney. Arsenic has been detected as natural pollutant in groundwater in Ganga-Bramhaputra-Meghna River Basin. Inorganic arsenic can occur in the environment in several forms but in groundwater in India, it is mostly found as trivalent arsenite as well as pentavalent arsenate. The water quality monitoring result highlights presence of arsenic along with iron in groundwater. Millions of people in the States of West Bengal, Bihar, Uttar Pradesh, Jharkhand, Chhattisgarh, Assam and Manipur are at risk since they reside in arsenic affected areas.

Arsenic has been detected in paddy and vegetables cultivated in arsenic affected areas. Arsenic contaminated groundwater is used in these areas for cultivation. Presence of arsenic in rice grains and vegetables is considerably high causing risk of arsenicosis in human body (Ananthanarayanan and Majumder 2003).

In order to mitigate arsenic problem, safe water supply needs to be ensured for the people. Accordingly, alternative sustainable water sources free from arsenic contamination must be explored. Surface water sources are normally free from arsenic contamination and as such the water can be supplied after necessary purification. The arsenic contaminated groundwater can also be supplied after removal of arsenic from the water. The arsenic removal process should be technically feasible, economically viable and socially acceptable. The rejects from arsenic removal process should not cause deleterious effect to the environment and accordingly it must be disposed through eco-friendly manner causing no risk to the environment and public health.

2.1 Action Plan Suggested for Mitigation of Arsenic Problem

Arsenic mitigation action plan is to be adopted for undertaking several activities so that people are prevented from the exposure of arsenic ingestion as well as extending curative medical services to the people who are under the threat of arsenicosis disease. The following action plan is suggested for mitigation of arsenic problem (Ananthanarayanan and Majumder 2003):

(a) Supply of river water through piped water supply system after conventional treatment.
(b) Adoption of roof-top rainwater harvesting system and supply of safe water for drinking and cooking.
(c) Collection of rainwater in ponds or impounding reservoirs as surface run-off and supply of safe water for drinking and cooking after appropriate treatment.
(d) Supply of groundwater from arsenic-free deeper aquifers by installing bore-wells.
(e) Supply of arsenic-safe water after removal of arsenic from contaminated groundwater.
(f) Regular water quality monitoring of all water sources including mapping and making the information available in public domain.
(g) Development of infrastructure and services for proper diagnosis and treatment of arsenicosis patients.
(h) Provision of nutritional support to the villagers in arsenic affected areas.
(i) Organize mass awareness and motivation campaign, and development of Information, Education and Communication (IEC) materials

2.2 Treatment Technologies for Arsenic Removal

Arsenic occurs in aquifers in trivalent (arsenite) or pentavalent (arsenate) form and these forms are considered to be most important in selecting removal methodology (Majumder 2001). The following criteria may be considered for selection of technology for removal of arsenic from contaminated groundwater (Majumder 2014):

(i) Higher arsenic removal efficiency
(ii) Ensuring arsenic in treated water below 10 μg/L
(iii) Simple operation and maintenance
(iv) Economic viability
(v) Least risk from arsenic-rich rejects

2.2.1 Technology Options for Arsenic Removal

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

(i) Oxidation and co-precipitation
(ii) Adsorption
(iii) Ion-exchange
(iv) Reverse osmosis

Technology Park for demonstrating various mechanisms for arsenic removal was initiated by All India Institute of Hygiene & Public Health under ICEF Project in Baruipur, South 24 Parganas. In all, 17 hand-pumps attached arsenic removal units were installed in the villages and the performance of the units were monitored on weekly basis. Different technologies were followed with the use of different chemicals and media for arsenic removal. Based on field performance and evaluation of arsenic removal units working under the principle of co-precipitation, adsorption and ion-exchange in Technology Park, critical review has been presented hereunder.

2.2.1.1 Oxidation and Co-precipitation

In groundwater arsenic is present in both arsenite and arsenate forms in varying proportion. Arsenic removal by co-precipitation process necessitates oxidation of arsenite to arsenate. This can be achieved by prolong aeration, chlorination, application of U-V ray etc. In groundwater, arsenic is present with iron of varying proportion but mostly having iron content more than 1.0 mg/L. In natural process with overnight detention period, a considerable quantum of arsenic gets removed after standard filtration process. In this process while dissolved iron gets oxidized in contact with oxygen to ferric hydroxide the arsenate gets adsorbed over ferric hydroxide facilitating removal of arsenic from contaminated groundwater. The arsenic removal process by co-precipitation thus gets strengthened by adding proper dose of oxidizing agent (average chlorine dose @ 0.5 mg/l) and chemical coagulant (aluminum sulphate/ferric sulphate/poly aluminium chloride etc.). The process requires rapid and slow mixing of chemicals, settling and filtration. The reject sludge requires proper treatment and disposal.

The oxidation and co-precipitation process is simple and economically viable. This process can be used in developing household model (Fig. 16.1), hand-pump attached model (Fig. 16.2) and also power-pump attached piped water supply

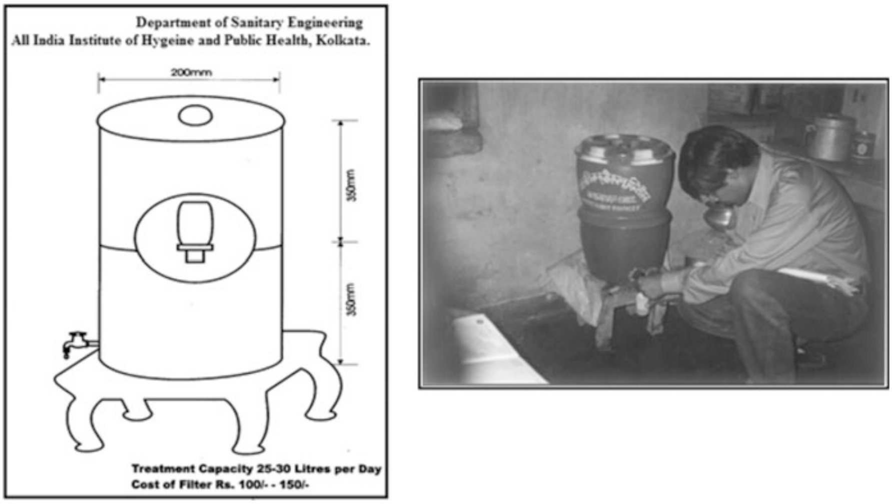

Fig. 16.1 Domestic arsenic removal unit operated with co-precipitation and filtration process

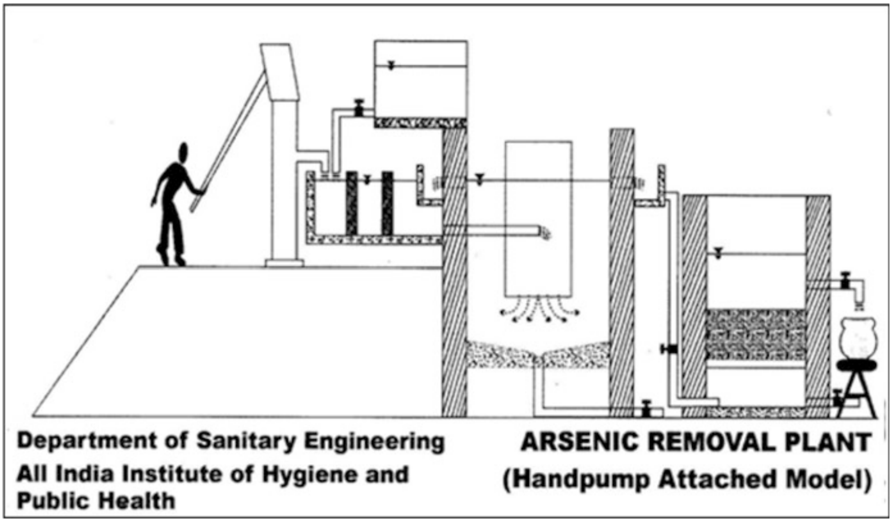

Fig. 16.2 Hand-pump attached arsenic removal unit operated with co-precipitation and filtration process

scheme. Since it is a single-stage treatment unit, it cannot bring arsenic in treated water below 10 μg/L. All India Institute of Hygiene and Public Health developed both domestic as well as hand-pump attached arsenic removal units and distributed in the villages for use (Figs. 16.1 and 16.2) (Ananthanarayanan and Majumder 2003). Critical review on the performance of both domestic and hand-pump attached models are furnished below.

(i) Availability of chemicals to the users. Addition of chemicals as per prescribed dose is to be ensured.
(ii) No mechanized system; so does not require power.
(iii) Both arsenic and iron are removed in the process.
(iv) 90% treated water ensures arsenic <50 μg/L.
(v) Iron in treated water remains to be less than 0.3 mg/L.
(vi) Arsenic in treated water ranges between 20 and 45 μg/L.
(vii) Sludge is to be stored, treated and properly disposed.
(viii) Risk of arsenic re-entering in the environment if not taken proper care.
(ix) Domestic candle filter is to be cleaned once a week.
(x) Hand-pump attached arsenic removal unit is to be cleaned once a month. It may require 3/4 h for cleaning.
(xi) Less recurring cost.

Fig. 16.3 Arsenic removal unit operated with adsorption process

(xii) Community participation is to be ensured for operation and maintenance of hand-pump attached units.

(xiii) Institutional development with capacity building is to be ensured for extending support to the users.

2.2.1.2 Adsorption

Arsenic from groundwater can be removed by the adsorption process. The process is simple and user-friendly. Because of its ease of handling, regeneration capability of the media and sludge-free operation, the fixed bed operation using adsorption technique has secured place as one of the popular methods of arsenic removal. Activated alumina and ferric hydroxide have been found to be excellent adsorbent for removal of arsenic. Both the media have been extensively used in the development of domestic model as well as hand-pump attached model (Fig. 16.3). Activated alumina can be regenerated 4–5 times by washing with acid and alkali solutions. Iron oxide coated sand, iron-nail, bauxite, hematite, laterite etc. can also be used for removal of arsenic.

Removal of arsenic is higher in adsorption process than co-precipitation. Different adsorbents have different capacities of arsenic adsorption; so, arsenic removal efficiency varies with different adsorbent. It is difficult to achieve arsenic <10 μg/L in 100% of treated water after single stage adsorption process. Presence of iron in groundwater causes clogging of fixed bed of adsorbent and accordingly regular cleaning of the media by backwashing is a necessity for proper operation of the arsenic removal units. Often two columns in series filled with media are installed with the objective to remove iron in the first column and arsenic in the second column packed with adsorbent. Critical review of the performance of arsenic removal units operated with adsorption process is presented below.

(i) Granular activated alumina/ferric hydroxide/hematite were used as adsorbent.
(ii) Better performance compared to co-precipitation method.
(iii) 90% treated water showed arsenic <50 μg/L.
(iv) 75% treated water showed arsenic <10 μg/L.
(v) Twice a week backwashing was necessary.
(vi) On an average 45 min time was necessary for backwashing.
(vii) Risk of arsenic present in backwash water.
(viii) In general, arsenic removal units were user-friendly.
(ix) Operation and maintenance (O&M) cost was more than O&M cost of units operated with co-precipitation method.
(x) O&M cost was affordable to the consumers.
(xi) Media needed change/regeneration after exhaustion.
(xii) Community participation was necessary for O&M.
(xiii) Technical support and well-knit infrastructure was the necessity for proper O&M of the units.

2.2.1.3 Ion Exchange

Ion exchange is a physico-chemical process in which ions are exchanged between solution phase and solid resin phase. The solid resin is typically an elastic hydrocarbon network containing a large number of ionized groups electro-statically bound to the resin. These groups are exchanged for ions of similar charge in solution that have a stronger exchange affinity for the resin. Critical review of arsenic removal units packed with ion exchange resins are presented below.

(i) Bucket of resin was used as media.
(ii) Resin oxidized as well as exchanged arsenic during treatment.
(iii) Performance of arsenic removal units was not satisfactory.
(iv) 65% of treated water showed arsenic <50 μg/L.
(v) 25% of treated water showed arsenic <10 μg/L.
(vi) Resin was required to be disposed in a eco-friendly manner after being exhausted.
(vii) Twice a week cleaning was necessary.
(viii) Community participation was necessary for O&M.

(ix) O&M cost appeared higher than the units operated with adsorption process.
(x) Infrastructure development was a necessity for extending technical support to the community.

2.2.1.4 Reverse Osmosis

Reverse osmosis process removes most of the impurities from water. Membrane is used in the process and water is forced through the membrane resulting in elimination of dissolved solids (impurities) including arsenic from water. However, reject management is very important in the application of reverse osmosis.

2.2.2 Two-Stage Arsenic Removal Unit

Field monitoring study revealed that single stage arsenic removal process could not produce treated water having less than 10 μg/L. arsenic at all times for any input arsenic concentration. Two-stage arsenic removal processes have an advantage to overcome such problem. It has been found that oxidation-co-precipitation process followed by adsorption could ensure to conform to desirable limit (<10 μg/L) of arsenic in treated water at all times for any arsenic input concentration. Public Health Engineering Department, Government of West Bengal has adopted two-stage arsenic removal processes for installation of arsenic removal units in different places in West Bengal. The single stage arsenic removal unit (oxidation, co-precipitation-filtration) developed by All India Institute of Hygiene and Public Health has been modified successfully to two-stage arsenic removal unit (oxidation, co-precipitation, adsorption, filtration) by School of Water Resources Engineering (SWRE), Jadavpur University under DST Project (Figs. 16.4 and 16.5).

2.3 Sludge/Exhausted Media Disposal

In co-precipitation process considerable quantum of sludge is generated. The sludge should not be disposed in drain or open land. The sludge must be stored in a leak proof chamber or container. The arsenic-rich sludge is hazardous. There may be health risk as well as environmental risk if the same is not handled, stored and disposed properly. Similarly, the exhausted media used in the adsorption process for removal of arsenic must be disposed safely. Following disposal options are suggested for adoption (Majumder 2014):

(i) Disposal of sludge in on-site sanitation pit or septic tank for anaerobic digestion.

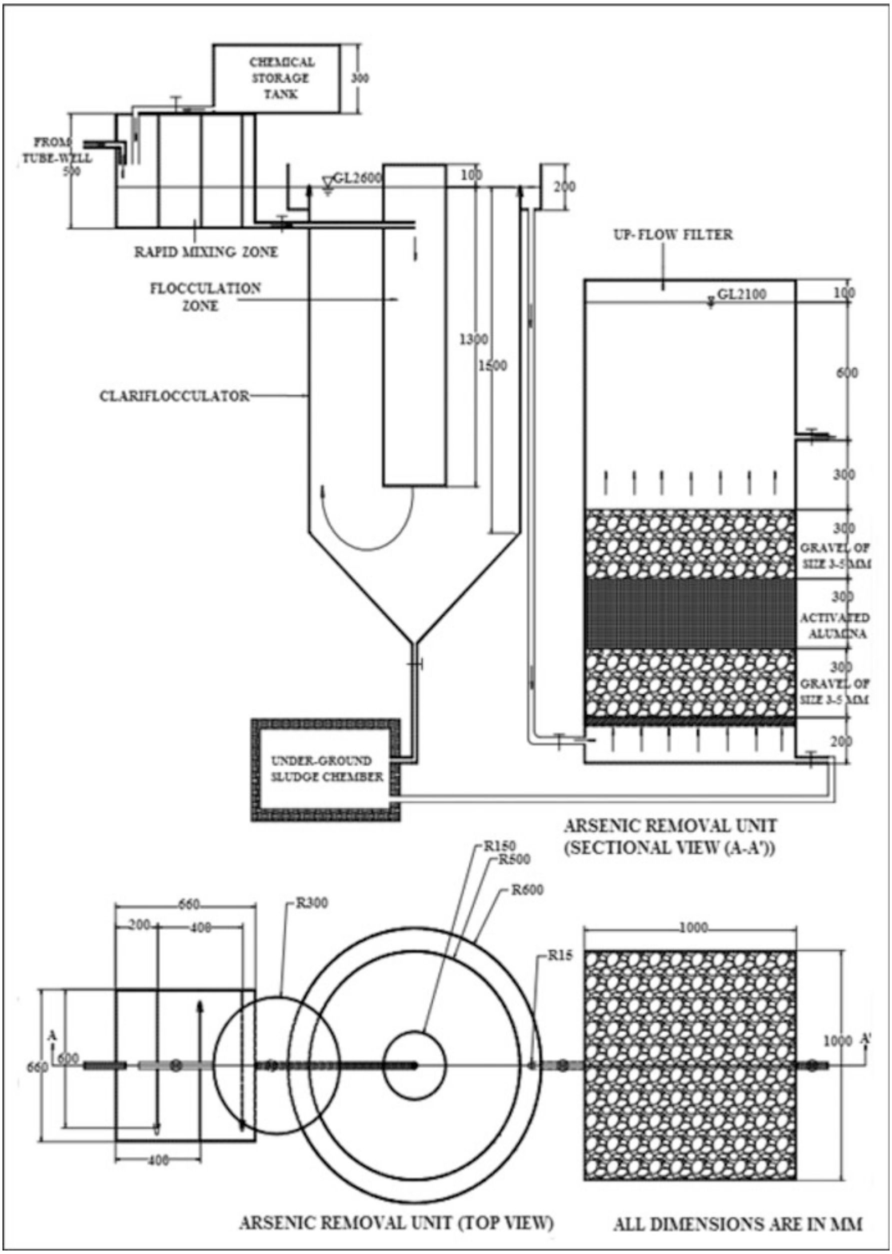

Fig. 16.4 Process diagram of two-stage arsenic removal unit of SWRE, Jadavpur University (DST Project)

Fig. 16.5 Arsenic removal unit operated with two-stage treatment at Malatipur village, Lalgola block, Murshidabad district, West Bengal of SWRE, Jadavpur University (DST Project)

(ii) Mixing of arsenic-rich sludge/grinded media with concrete in prescribed proportion.
(iii) Mixing of arsenic-rich sludge/grinded media with clay for preparation of brick and burning in kiln.

Environmental monitoring plan must be adopted around arsenic removal units during operational phase. This includes monitoring of arsenic in nearby surface water sources, sub-surface groundwater and soil.

2.4 Performance of Arsenic and Iron Removal Plants Attached to Big-diameter Borewells: Case Study

A study carried out by the All India Institute of Hygiene & Public Health, Government of India indicated that around 64% hand pump fitted wells ($n = 7680$) were contaminated by arsenic (>10 μg/L) in arsenic affected areas. In the contaminated tube-wells concentration of arsenic was mostly between 10 and 50 μg/L and sometimes even more. Based on this study Public Health Engineering Department (PHED), Government of West Bengal has implemented many surface water supply schemes based on the River Ganga water after conventional treatment to supply arsenic-free water in arsenic affected areas. Many more are in the process of execution. But in some affected areas, which cannot be covered under the existing or proposed surface water based piped water supply schemes, groundwater based piped water supply schemes were envisaged. Accordingly a good number of groundwater based mini piped water supply schemes have been implemented. Since groundwater in such areas contain

Fig. 16.6 Jasaikathi arsenic and iron removal plant

concentration of arsenic and iron beyond the desirable limit as per BIS 10500 (arsenic: >10 µg/L; iron: >300 µg/L), PHED has installed arsenic and iron removal plants (AIRP) to provide potable water to the village communities. The treatment plants have been installed by different agencies and are working under different principles and procedures with different operation and maintenances approaches. Mostly the implementing agencies are operating and maintaining the AIRP.

There are three AIRPs in North 24 Parganas District in West Bengal. They are (i) Jasaikathi Water Supply Scheme (Zone II) in Baduria Block; (ii) Bajitpur Water Supply Scheme in Baduria Block; and (iii) Kola Water Supply Scheme in Bagdah Block. A brief description of each of these AIRPs is given below.

2.4.1 Jasaikathi Water Supply Scheme

In Ramchandrapur village of Baduria block groundwater contains arsenic and iron which are more than the permissible limit prescribed by BIS. The arsenic concentration ranges between 37 and 80 µg/L. Since surface water is not available PHED implemented a groundwater based water supply scheme known as Jasaikathi Water Supply Scheme in February, 2015 to serve a population of 16315 (Fig. 16.6). This

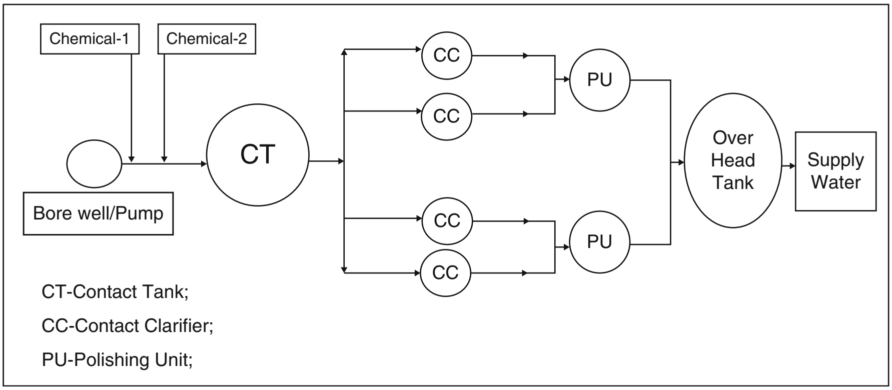

Fig. 16.7 Process flow diagram for arsenic and iron removal in Jasaikathi Water Supply Project. The plant was evaluated by School of Water Resources Engineering, Jadavpur University, and manufactured and installed by Odissi Innovation

water supply scheme has an AIRP attached to a borewell to remove arsenic and iron from the groundwater. The techniques used to remove arsenic and iron are chemical coagulation, precipitation, filtration and adsorption.

The process flow diagram of the plant is given in Fig. 16.7. The contact tank (CT) facilitates mixing of sodium aluminate and sodium sulphide with the raw water. The contact clarifier (CC) is packed with sand and gravel. Part of the arsenic is removed in the contact clarifier. Remaining part of arsenic is removed in the polishing unit (PU) where ferric hydroxide is packed to adsorb arsenic. Monochloramine is added for disinfection of water. Underground sludge tank allows storage of arsenic-rich sludge. The contact tank and contact clarifier is cleaned regularly (twice a week) by backwashing.

The treatment capacity of the plant is 110 m^3/hr and the plant is operated for 7 hr/day. After treatment the arsenic concentration reduces to <10 μg/L in 70% occasion. In the rest 30% occasion the concentration ranged between 10 and 17 μg/L. The iron concentration was reduced to <0.3 mg/L. This technology is suitable for low arsenic concentration in groundwater (<100 μg/L) but is doubtful for higher concentration of arsenic in raw water (>300 μg/L) in bringing down arsenic below 10 μg/L in treated water. Sludge management is also not satisfactory. Mixing of the sludge in nearby pond has been detected.

2.4.2 Bajitpur Water Supply Scheme

In Bazitpur village of Baduria block groundwater contains arsenic and iron which are more than the permissible limit prescribed by BIS. The arsenic concentration ranges between 300 and 400 μg/L. Since surface water is not available PHED implemented a groundwater based water supply scheme known as Bajitpur Water

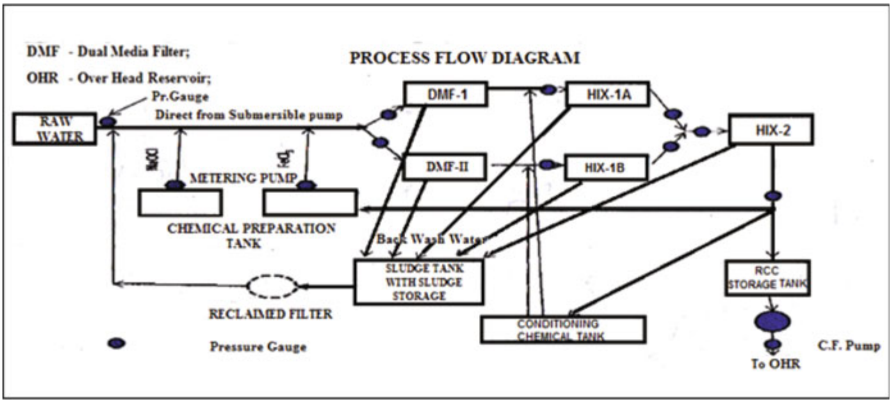

Fig. 16.8 Process flow diagram of arsenic and iron removal plant in Bajitpur Water Supply Project. The plant was evaluated by School of Water Resources Engineering, Jadavpur University, and manufactured and installed by Rites Water Solution (India) Pvt. Ltd

Supply Scheme in April, 2016 to serve a population of 16,335. This water supply scheme has an AIRP attached to a borewell to remove arsenic and iron from the groundwater. The AIRP is operated under the principle of chemical addition, oxidation, co-precipitation, dual-media filtration, two-stage ion-exchange for removal of arsenic and iron. The DMFs are required to be cleaned daily by backwashing. The back-washed water is re-circulated in the system for treatment. Media (ion-exchange) regeneration is done through chemical treatment as and when required. Sludge is stored in separate tank at AIRP site.

The process flow diagram of the plant is given in Fig. 16.8. The treatment capacity of the plant is 1464 m^3/day but the present operational rate is 91.5 m^3/hr and the plant is operated for 6 hr/day. The volume of water treated per day is 546 m^3. Performance of physico-chemical treatment is found to be satisfactory. Sodium hypo-cholorite, ferric chloride and HAIX (adsorbent) are showing encouraging result in arsenic removal process. After treatment the arsenic concentration reduces to <10 μg/L. Sludge management is not satisfactory.

2.4.3 Kola Water Supply Scheme

In Kola village of Bagdah block groundwater contains arsenic and iron which are more than the permissible limit prescribed by BIS. The arsenic concentration is <100 μg/L. Since surface water is not available PHED implemented a groundwater based water supply scheme known as Kola Water Supply Scheme in March, 2015 to serve a population of 2515 (Fig. 16.8). This water supply scheme has an AIRP attached to a borewell to remove arsenic and iron from the groundwater. The AIRP is operated under the principle of oxidation, flash mixing, coagulation and settling. The unit consists of oxidation chamber (OC), slow mixing flocculation tank (SMFT),

Fig. 16.9 Kola arsenic and iron removal plant

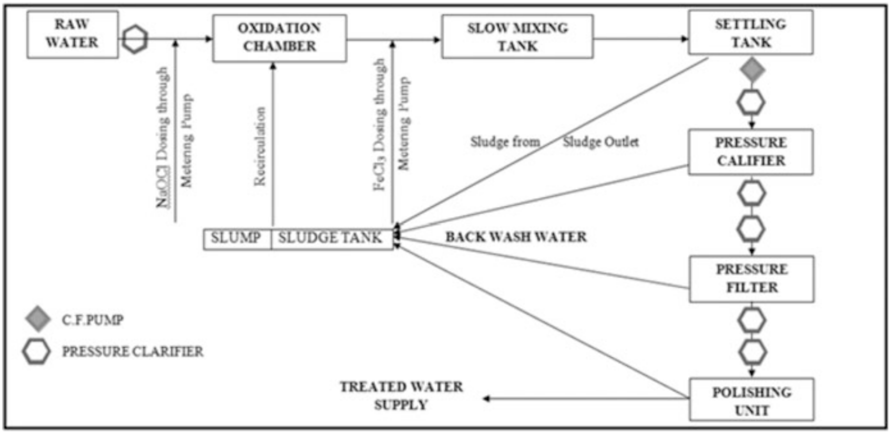

Fig. 16.10 Process flow diagram of arsenic and iron removal plant in Kola Water Supply Scheme. The plant was evaluated by School of Water Resources Engineering, and manufactured and installed by M/s Puspsa Enterprise

settling tank (ST), clarifier tank (CT), pressure filter (PF) and polishing unit (PU) (Fig. 16.8). Initially sodium hypochlorite is added for oxidation of arsenite. Ferric chloride as coagulant is added with flash mixing. The settling tank facilitates co-precipitation for removal of arsenic and iron. The polishing unit is packed with activated alumina which removes remaining arsenic from water by adsorption. The activated alumina will be regenerated as and when required. The AIRP also has sludge separation bed and sludge tank (Figs. 16.9 and 16.10). The treatment capacity of the plant is 240 m^3/day but the present operational rate is 30 m^3/hr and the plant is operated for 4 hr/day. The volume of water treated per day is 120 m^3. Performance of physico-chemical treatment is found to be satisfactory and the treated water contains <10 µg/L. As sludge management is not satisfactory.

2.5 Sustainability of Arsenic Removal Units

The feasibility of arsenic removal units is to be assessed before installation. The feasibility depends on existing basic water supply system in the area, amount of arsenic in groundwater and percentage of arsenic to be removed, level of managerial and technical capacity to install and maintain the arsenic removal units, community participation in managing the units, willingness and level of income to contribute towards O&M. Public Health Engineering Department installed around 2400 hand-pump attached arsenic removal units in arsenic affected habitations as per recommendation of All India Institute of Hygiene and Public Health based on study of different arsenic removal processes in Technology Park. But majority of hand-pump attached arsenic removal units did not function properly due to lack of participation of the community for O&M. It was observed that beneficiaries were not motivated for O&M of the units, lack of initiative for O&M from Gram Panchayet, funds were not collected from the beneficiaries for O&M, often units remained idle for want of minor repair, no-availability of media regeneration facility and sense of ownership of units was not generated amongst the beneficiaries.

But there are instances where arsenic removal units are functioning very well with community involvement for O&M. In each of these, users committee was formed at beginning with the leadership of women to look after the operation and regular maintenance of arsenic removal unit. Subscriptions were collected from the user-families and the money was kept in Post Office or Bank. The success story indicates that sustainability of arsenic removal units depend on how efficiently the units are managed by the community with affordable resources of the community.

AIRPs attached to big-diameter bore-well are operated and maintained by the agency that manufactured and installed the unit. Safe water is supplied through pipeline system via over-head reservoir. PHED is looking after the water supply scheme with support from the local Gram-Panchayet. Departmental monitoring and surveillance strategy has been developed towards sustainability of the AIRPs.

3 Fluoride in Groundwater

In India drinking water supply is provided from groundwater and surface water sources. The rural water supply is predominantly dependent on groundwater sources. The selections of aquifers are based on geo-hydrological conditions of the area. The aquifers below thick impervious clay layers are usually free from bacteriological contamination. Generally, groundwater contains higher dissolved solids than surface water. While recharging, rain water passing through soil grains are enriched with different dissolved solids (remaining as molecules or ionic forms). Higher concentrations of calcium and magnesium salt (causing hardness) and also iron are very common in groundwater sources. In coastal areas higher concentration chloride are found in aquifers. Fluoride is usually present in groundwater, but presence of fluoride beyond permissible level (1.5 mg/L) has been found in 20 states. In West Bengal, fluoride in groundwater has been detected beyond permissible level (1.5 mg/L) in 43 blocks of seven districts.

In India, fluorosis is considered to be one of the major environmental health problems. Though prevalence of fluorosis was detected more than 60 years ago, the progress of understanding fluorosis and its clinical manifestation was slow (Susheela 2001). Further rural water supply agencies (mostly Public Health Engineering Department) focused only on quantitative aspect with little emphasis on bacteriological quality and the aspect of chemical quality was ignored.

The risk of fluorosis in the country was found to be increasing rapidly in 70's and 80's. The medical professionals working with fluorosis diagnosis and treatment did not interact with water supply agencies and vice versa. The two groups worked in isolation and as a result suffering of the people were not properly attended. It was only in 1986 that National Drinking Water Mission, Government of India launched Mini-Mission Programme on control of fluorosis, removal of excess iron, desalination of water, eradication of guinea-worm, and conservation of water and recharging of groundwater (RGNDWM 1993).

In order to mitigate problem of fluorosis one has to ensure fluoride-safe water supply to the community. This involves selection of area specific appropriate methodology for fluoride- safe water supply as well as sustainability of the programme through active participation of the user community.

During the last 25 years with active support of Central Government, various State Governments have taken up action programmes for mitigation of excess fluoride problem in drinking water. UNICEF, WHO, UNDP etc. have also stretched their hands to supplement governmental efforts. Various non-governmental organizations are also in the fray to mitigate fluoride problem.

3.1 Extent and Magnitude of the Problem

All groundwater contain varying concentrations of fluoride due to universal presence of fluorides in earth's crust. However, there can be major differences within a relatively small area and different depths of boreholes. Fluoride in untreated groundwater is one of the most chronic toxic substances which have affected a considerable number of rural populations causing dental, skeletal and non-skeletal fluorosis. Contamination of groundwater with fluoride is severe in Rajasthan, Andhra Pradesh, Gujarat, Haryana, Karnataka and Punjab. In addition, such problems also exist in certain areas of Madhya Pradesh, Chhattisgarh, Maharashtra, Orissa, Tamil Nadu, Uttar Pradesh, Kerala, Bihar, Jharkand, Delhi and Jammu & Kashmir. In 90s fluoride concentrations beyond permissible limit in groundwater have been reported from Assam and West Bengal. In affected areas, majority of fluoride concentration varies between 1.5 and 8 mg/L. However, fluoride concentrations in much higher proportion have also been reported from many areas (10–18 mg/L). In India, 200 districts in 20 states are endemic to fluorosis due to excess fluoride in drinking water. It has been estimated that around 66 million rural populations are residing in excess fluoride prone risk areas of the country (Susheela 2001).

3.2 Action Plan to Mitigate Excess Fluoride Problem

A holistic approach should be taken to mitigate fluoride problem in the country. The following action plan is suggested in excess fluoride affected areas (Majumder 2004):

(i) Supply of fluoride-safe water to the community
(ii) Extensive water quality monitoring
(iii) Diagnosis and treatment of fluorosis affected people
(iv) Extending nutritional support
(v) Awareness, motivation and training

3.3 Alternate Fluoride-Safe Water Supply System

There would be various systems for supply of fluoride-safe water to the community. Such water supply system must be appropriate to suit area specific condition. The alternate fluoride-safe water supply system could be as follows (Majumder 2004):

(i) River water based piped water supply
(ii) Big-diameter tube well based piped water supply
(iii) Installation of deep tube well
(iv) Handpump attached excess fluoride removal unit
(v) Excess fluoride removal unit attached with big-diameter tubewell for piped water supply
(vi) Use of traditional water sources pond/lake water after treatment
(vii) Rain water harvesting
(viii) Household treatment for excess fluoride removal

3.3.1 River Water Based Piped Water Supply

River water usually does not contain excess fluoride. This water can be treated by conventional process (coagulation-flocculation-sedimentation-filtration-disinfection) and can be supplied in the excess fluoride affected villages through piped network system. This alternative water supply system has following advantages and constraints:

(i) Permanent/long term solution
(ii) Very expensive (capital cost)
(iii) Execution process lengthy
(iv) Difficulty in operation and maintenance.

3.3.2 Big Diameter Tubewell Based Piped Water Supply

Water of aquifers free from excess fluoride can be drawn through big-diameter tubewell and supplied through piped network system. Such type of tube wells need to be installed with required skilled by providing proper sealing avoiding risk of contamination of excess fluoride through vertical leaching. The following are the advantages and constraints:

(i) Comparatively easier to execute
(ii) Comparatively less expensive than river water based piped water supply
(iii) Operation and maintenance require skill
(iv) Risk of contamination (vertical leaching)

3.3.3 Installation of Deep Tubewell

Deep tube well for tapping excess fluoride safe aquifer can be installed as a spot source for supplying water. Installation of deep tube well requires meticulous skill for sealing against vertical leaching. Following are the advantages and constraints:

(i) Easier to execute and operate
(ii) Less expensive
(iii) Skilled driller required to seal contaminated aquifer zone
(iv) Risk of contamination
(v) Appearance of excess fluoride after a considerable time

3.3.4 Handpump Attached Excess Fluoride Removal Unit

The other alternative to supply fluoride safe water is by adopting defluoridation techniques. The standard methods for fluoride removal are:

(i) Co-precipitation
(ii) Adsorption
(iii) Ion-exchange
(iv) Reverse Osmosis

The three important factors that are to be considered for implementing defluoridation technique are (i) simplicity of application, (ii) applicability in case of small water supplies, and (iii) cost effectiveness.

In Nalgonda technique, co-precipitation principle is adopted for removal of excess fluoride. Nalgonda technique is a combination of several unit operations and the process incorporates rapid mixing, chemical interaction, flocculation, sedimentation, filtration and disinfection. Lime, bleaching and alum are added in this process for defluoridation. The cost of the process is very cheap but the process is not user-friendly. The process can be installed with handpump attached excess fluoride removal model or domestic model. Such units are usually non-mechanized and no electricity is required to run the unit.

Activated alumina can be used as a media for adsorption of fluoride. Capacity of activated alumina depends upon the basicity of water and decreases considerably with increasing basicity. Following information are essential for manufacturing of defluoridation unit with activated alumina:

- Operating characteristics
  - (i) Capacity curves
  - (ii) Exhaustion curves
  - (iii) Exchange capacity and corresponding regenerating chemicals requirement with concentration
  - (iv) Number of times regeneration of the adsorbent should be considered
  - (v) Back wash and rinse water quantity and rate of application
  - (vi) Loading rate
  - (vii) Attrition losses and replacement requirement
  - (viii) Anticipated cycles of operation
  - (ix) Impact of variation in Ca, Mg, Sodium bicarbonate in groundwater
- Waste water (wash) disposal
  - (i) Activated alumina regenerated waste water quantity and quality
  - (ii) Method and cost of effluent treatment and/or disposal
- Cost aspect
  - (i) Cost of activated alumina
  - (ii) Capital cost of the plant for various treatment rates
  - (iii) Life expectancy of plant and activated alumina
  - (iv) Operation and maintenance requirement and cost

Appropriate treatment and safe sludge disposal technique need to be adopted if defluoridation techniques are used by the community. The hand pump attaches unit needs to be operated and maintained by the community. A community group is to be formed for each of the unit for operation and maintenance. A subscription will be required from the user family to maintain the plant.

3.3.5 Excess Fluoride Removal Unit Attached with Big Diameter Tubewell for Piped Water Supply

Excess fluoride removal unit working with the principle of either co-precipitation or adsorption or both can be installed with big diameter tubewell for piped water supply. Such unit however needs to be operated and maintained meticulously by skilled operators and technicians.

3.3.6 Use of Traditional Water Sources (Pond and Lake Water) After Treatment

Traditional water sources like lake, pond etc is free from excess fluoride. The water can be upgraded by using horizontal roughing filter (HRF) – slow sand filter (SSF). Such unit can be maintained by the community at an affordable cost. The following are the advantages and constraints:

(i) Availability of sufficient quantum of water
(ii) The ponds should not be used for bathing and pisiculture
(iii) The pond must be free from external pollution
(iv) Sound technology available for up-gradation of water quality
(v) Protection of source difficult
(vi) Disinfection is necessary after treatment of water; ensuring regular disinfection often becomes difficult
(vii) Community response sometimes not positive
(viii) Total community participation needs to be ensured for the success of the program

3.3.7 Rain Water Harvesting

Rain water harvesting by roof top collection can provide fluoride safe water. However, sufficient quantity of water needs to be stored for use during dry period. The water is to be used for drinking and cooking only.

Rain water can also be stored in impounding reservoir or pond in village. However, such water needs up-gradation by installing HRF-SSF. The following are the advantages and constraints:

(i) Technology available
(ii) Strong awareness and motivation are required
(iii) Community based schemes are to be ensured
(iv) For roof top collection individual family members are to be motivated
(v) Expensive for individual household

3.3.8 Household Treatment for Excessive Fluoride Removal

Both co-precipitation and adsorption techniques can be used for household treatment unit. The cost of the unit must be affordable to the people. The co-precipitation technique is cheaper than the adsorption technique. The following are the advantages and constraints:

(i) Easy to maintain and handle
(ii) Different models are available
(iii) Efficient in removal of excess fluoride
(iv) Availability of chemical often becomes difficult in the villages
(v) Sludge disposal strictly to be followed

3.4 Case Study

A fluoride removal unit (installed jointly by WIST Inc. US and Rite Solutions Pvt. Ltd) is functioning at Laxmi Narayanpur A. J. Adibasi High School, Nalhati, Birbhum, West Bengal. Public Health Engineering Department, Government of West Bengal, had arranged for the site for demonstrating the technology for excess fluoride removal from groundwater as per the recommendation of the Fluoride Task Force, Government of West Bengal.

3.4.1 De-Fluoridation Unit: Technological Aspects

The de-fluoridation unit has been developed primarily focusing selective removal of fluoride through effective sorbent-based treatment technology. HIX–NanoZr in which nano particles of zirconium oxide are loaded within a polymeric support of ion-exchange resin offers selective fluoride removal from a background of other competing ions. The schematic diagram of fluoride removal unit installed at school is presented in Fig. 16.11. The sequence of water treatment may be as follows:

(i) Column 1 with appropriate ion-exchange (cations) materials for partial desalination and pH adjustment/reduction
(ii) Column 2 with HIX-NanoZr for fluoride removal
(iii) Column-3 with specific ion-exchange materials for passive pH control
(iv) Column-4 with granular activated carbon (GAC) media as a polishing unit
(v) Additional arrangement for application of UV irradiation for disinfection of treated water

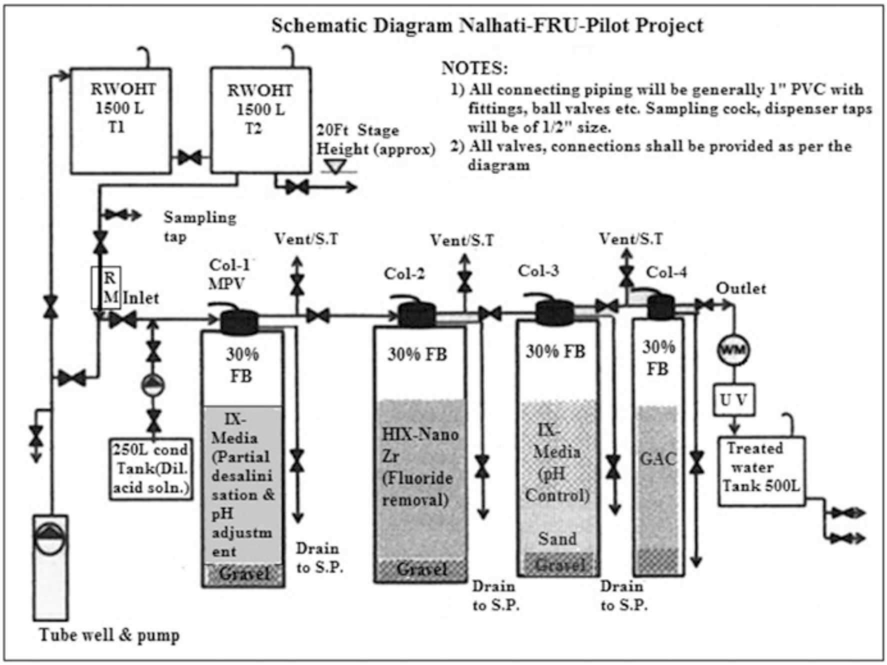

Fig. 16.11 A schematic diagram for the HIX-NanoZr fluoride removal plant installed at Nalhati, Birbhum

3.4.2 Operation

During de-fluoridation unit operation, column 1 and column 2 will need reconditioning. Ion-exchange media in column 1 needs reconditioning periodically depending on quantity and quality of groundwater. On an average, reconditioning interval may be seven days (weekly). The reconditioning is done by passing dilute hydrochloric acid. Reconditioning of HIX-NanoZr media in column 2 will be done at six monthly intervals (depends on raw water quality). Alkaline solution will be required for reconditioning of media in column 2 followed by rinsing with low pH/acid water.

In addition to above, regular back washing is required for column 1 (daily), column 2 (alternate day) and column 3 (twice a week).

The treatment capacity of the installed de-fluoridation unit is 500 L/h. Initially a 3000 L capacity tank is filled up with excess fluoride contaminated groundwater by pumping. Thereafter, the unit is operated in continuous mode till the raw water tank gets exhausted. At the most the de-fluoridation unit can treat 5000 L water daily. At present 400 students of the school are provided with the treated water. The treated water is also used for preparation of mid-day meal. The installed water-meter reading indicated that so far 57,500 L water has been treated.

3.5 Sustainability of Defluoridation Units

The technology to be adopted for removal of fluoride must be appropriate to actual groundwater quality of the site where the defluoridation unit will be installed. Presence of certain parameters on higher concentration or wide variation of pH may interfere with the operation of the unit and accordingly removal efficiency may vary. It is normally recommended to examine the groundwater quality before the installation of the defluoridation units. If necessary, treatability test may be carried out and modification in the model may be considered before installation. The manufacturer must assess the running time or bed-volume for the unit before regeneration of media or change of media. Regular surveillance as well as evaluation of the performance of the units will certainly help in achieving sustainability of the defluoridation units for the benefit of the rural community. Economic viability and social acceptability are the two other key issues to be considered for the success of defluoridation units.

4 Conclusions

Very many technologies have been developed for removal of arsenic and excess fluoride from contaminated groundwater. But in most of the cases treatability studies for different technologies at varying groundwater quality have not been carried out and as a result performance of different arsenic and excess fluoride removal units in the field condition are varying widely. Chemical dosages, quantity of adsorbents and quantity of ion-exchangers are not considered at field condition by the manufactures resulting in wide variation in the expected time for regeneration of the media. Again interference of certain water quality parameters present in excess in groundwater is posing problem in the contaminant removal process. Sludge management is often found to be poor in many water treatment plants. Thus, water quality monitoring and surveillance along with performance evaluation of arsenic and excess fluoride units should be planned and followed to achieve sustainability of the units.

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