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Study Report under the Project
Concerted Action on Elimination/ Reduction of Arsenic in Ground Water, West Bengal, India
(Project: NC/IND/99/967)

(VOLUME II)

Executed by: United Nations Industrial Development Organization

New Delhi
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Concerted Action on Elimination/ Reduction of Arsenic in Ground Water, West Bengal, India (Volume II)

Contributions:

Don Ratanayaka- Water treatment and Technology.

CGWB (Easter Region) – Water Quality Analytical work.

Development Consultant Group – Socio-economic, Training & Privatization issues.

K S R N Sarma – Financial Appraisal

Report on Water Quality & Treatment

Prepared under the Project

Concerted Action on Elimination/Reduction of Arsenic in Ground Water, West Bengal, India

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Executed by: United Nations Industrial Development Organisation

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1 ARSENIC WATER CHEMISTRY

Arsenic is present in great variety of naturally occurring minerals primarily in the form of arsenates. It is present in ground and surface waters as a result of natural processes including dissolution, biological activity, complexing-chelation, ion exchange and adsorption. Factors affecting these processes are pH, redox potential and reaction kinetics (Welch et al 1988, Nickson et al; 2000). In some areas however arsenic may be derived from mine tailings or industrial sources due to the presence of arsenic in a waste stream from metallurgical processing of some metals. Manufacturing and the use of herbicides containing methyl arsenate ($CH_3AsO(OH)_2$) and dimethyl arsenate $(CH_3)_2AsO(OH)$, which are both very soluble, could introduce organic arsenates to natural waters (Akhter et al; 2000).

Arsenic can be introduced into drinking water directly from some chemicals employed in drinking water treatment where it is present as an impurity. Commonly used treatment chemicals include aluminium sulphate sodium hydroxide, sodium hypochlorite and potassium permanganate. Findings show that although the contributions from individual chemicals are small, the sum of the contribution from several chemicals could be about 0.25 Φg/l (Weng et al; 2000).

In natural waters arsenic is usually found in the oxidation states (also broadly known as valence states) +3 (Arsenite As(III)) or +5 (Arsenate As(V)) and can be present in various inorganic hydrolysed species depending on the pH and redox potential. In oxygen-saturated surface waters As(V) is the most common form present and the predominant hydrolysis species in the pH range 6 to 9 are $HAsO_4^-$ and $H_2AsO_4^{2-}$. Other species present are H_3AsO_4 and AsO_4^{3-} (Ferguson and Gavis; 1972). In anoxic waters such as some ground waters and the bottom waters of deep lakes and reservoirs, the predominant form is As(III) and the most common species is non-ionic H_3AsO_3 being present in the pH range 6-9. Other species present are $H_3AsO_3^-$ and $H_3AsO_3^{2-}$ (Ferguson and Gavis; 1972).

Organic arsenic species may be found in surface waters, but are not normally found in ground waters. Elemental arsenic is not normally present in waters.

2 RAW WATER QUALITY

Raw water samples were taken from several wells in five districts and analysed by the Central Ground Water Board. The results are given in the Annex.

MALDA DISTRICT

The ground water is exceptionally hard and slightly alkaline but with no excess of dissolved solids with respect to Indian Standards. The principal ions are calcium and magnesium bicarbonates with alkalinity values up to 560 mg/l as $CaCO_3$, a proportion of which is usually in the sodium form. Conductivity values vary from 580 to 1000 µS/cm, which is acceptable for potable water. Chloride, fluoride and sulphate concentrations are low. Silica (in reactive form) concentrations are quite high in ranging from 20 to 30 mg/l and as such may interfere with certain arsenic removal processes.

Arsenic concentrations in the two samples reported were 0.17 and 0.16 mg/l as As, that is significantly in excess of the Indian Standards of 0.05 mg/l. Iron was also present at very high values in the same samples with concentrations of 3.38 and 6.68 mg/l as Fe. The Indian Standard is 1.0 mg/l. In addition, eight samples were examined for heavy metals, of these aluminium, cadmium, chromium and copper were present in low concentrations and zinc at moderate but not excessive values. Lead was present at levels of up to 10 µg/l as Pb, which is less than the Indian Standard. Manganese is also present at excessive concentrations with average and maximum values of 875 and 1248 µg/l as Mn. The Indian Standard value is 0.5 mg/l. Dissolved oxygen concentrations are consistently low at less than 1.0 mg/l, a common characteristic of groundwater's containing iron and manganese.

MURSHIDABAD DISTRICT

The water is very hard and slightly alkaline with respect to pH, and contains high but not excessive levels of dissolved solids as indicated by conductivity values within the range 565 to 750 µS/cm. The principal ions are calcium and bicarbonate with typical values of 90 mg/l Ca and 280 mg/l $CaCO_3$ respectively. Chloride and sulphate values are consistently low, but silica (reactive) concentrations are moderately high at 18 to 24 mg/l.

Arsenic concentrations ranged from 0.266 to 0.3 mg/l as As in the three samples examined, and as such are in excess of the Indian Standard. Iron was present at exceptionally high concentrations up to 10.2 mg/l compared with the Indian Standard. Two samples were examined for heavy metals, the results indicate that aluminium, cadmium, chromium, copper and lead were present in trace amounts, while zinc was present at moderate, but not excessive levels, but manganese was present at 760 μg/l which is in excess of the Indian Standard. Dissolved oxygen concentrations were very low at less than 1 mg/l, a common characteristic of groundwater's containing iron and manganese.

NADIA DISTRICT

The groundwater is exceptionally hard and just on the alkaline side of neutrality with respect to pH value. It contains high, although not excessive, concentrations of dissolved solids, as reflected by conductivity values, which range from 770 to 1180 μS/cm. The principal ions are calcium and bicarbonate, together with moderate concentrations of magnesium, chlorides and sulphates. Silica is also present at a moderately high value in ranging from 23 to 25 mg/l.

Arsenic concentrations varied from 0.082 to 0.96 mg/l as As in the three samples examined and as such are in excess of the Indian Standard. Iron was present at exceptionally high concentrations up to 12.5 mg/l as Fe; this compares with the Indian Standard. Two samples were examined for heavy metals, the results indicate that aluminium, cadmium, chromium, copper, lead and zinc were either not detected or present at very low concentrations. Manganese was, however, present at values up to 870 μg/l as Mn which is in excess of the Indian Standard. Dissolved oxygen concentrations were low at less than 1 mg/l, a common characteristic of groundwater's containing iron and manganese.

NORTH 24 PARGANAS DISTRICT

The water is exceptionally hard and slightly alkaline with respect to pH value. It contains high but generally not excessive levels of dissolved solids as indicated by average conductivity values of 840 μS/cm. The maximum reported value of 1830 μS/cm equates to a TDS concentration of about 1200 mg/l. It is within the Indian Standard. The principal ions are calcium and bicarbonate with average values of 115 mg/l as Ca and 370 mg/l as $CaCO_3$ respectively. Chloride concentrations are moderately low while sulphate values rarely exceed 10 mg/l as SO_4. Silica (reactive) is present within the range 20 to 37 mg/l, which is considered to be moderately high.

Arsenic concentrations in community wells range from 0.05 to 2.34 mg/l and average 0.49 mg/l, this is greater than the Indian Standard. The equivalent values for arsenic in domestic well waters are 0.02 to 1.06 mg/l, with an average of 0.16 mg/l as As. Iron concentrations are very high in ranging from 1.38 mg/l to 15.98 mg/l as Fe (average 7.66 mg/l as Fe), this is significantly in excess of the Indian Standard.

Approximately 30 samples have been examined for a range of heavy metals, of these cadmium, chromium and copper were only present in trace or undetectable concentrations. Aluminium is consistently present at values in the range 20 to 150 μg/l as Al, with an average of 60 μg/l. Lead was generally undetectable; however, one sample contained 12 μg/l, which is still less than the Indian Standard.

Manganese was consistently present in each of the samples examined, with a concentration range from 27 to 1756 μg/l. The Indian Standard is 0.5 mg/l. Dissolved oxygen concentrations were very low at less than 1 mg/l, a common characteristic of groundwater's containing iron and manganese.

SOUTH 24 PARGANAS DISTRICT

The water is exceptionally hard and slightly alkaline with respect to pH value, and contains high but generally not excessive levels of dissolved solids as indicated by an average conductivity value of 940 μS/cm. Approximately 10% of the well waters have conductivity values slightly in excess of 1500 μS/cm. The increase in dissolved solids is probably due to an increase in saline constituents due to the proximity of the coast. The principal ions are generally calcium and bicarbonate with average values of 106 mg/l as Ca and 395 mg/l as $CaCO_3$ respectively. Chloride concentrations are high in some locations with average and maximum values of 42 and 152 mg/l as Cl. Silica (reactive) concentrations are also quite high with a range from 18 to 32 mg/l as SiO_2.

Arsenic concentrations in community wells range from 0.33 to 0.78 mg/l (average 0.50 mg/l) while in domestic supplies the variation is much greater being from 0.01 to 2.9 mg/l (average 0.52 mg/l). The Indian Standard is 0.05 as As respectively.

Iron concentrations are moderately high in varying from 0.01 to 5.38 mg/l with an average of 1.35 mg/l as Fe. The Indian Standard is 1.0 mg/l as Fe. Cadmium, chromium, copper and lead are present in trace concentrations, while aluminium is generally present at acceptable levels with an average value of 90 μg/l as Al. However, two samples were recorded at concentrations of 280 μg/l in comparison with the Indian Standard of 200 μg/l as Al. Manganese was present in each of the samples with a concentration ranging from 94 to 1156 μg/l as Mn and an average of 556 μg/l. The concentrations exceed the Indian Standard. Dissolved oxygen concentrations were low at less than 1 mg/l. Fluoride concentrations were in places higher than in other districts, with a maximum value of 0.96 mg/l which compares with an Indian Standard of 1.5 mg/l. Phosphate levels were also somewhat higher with a maximum of 1.1 mg/l as PO_4. Such values may be indicative of sewage pollution.

All waters are suitable for arsenic removal treatment by chemical precipitation using aluminium sulphate and ferric chloride. In the case of the former, an excess of aluminium sulphate would be necessary to achieve the optimum pH for precipitation. All of the waters contain exceptionally high concentrations of iron, some of which will be oxidised when the water is exposed to air. To maximise iron removal water should be properly aerated. A proportion of As(V) would be removed with iron by co-precipitation. The addition of an oxidant such as chlorine in sufficient concentrations would help not only to oxidise any As(III) present to As(V), but also reduce iron concentrations to very low values. Chlorine would also oxidise any manganese perhaps in conjunction with catalytic media filtration. With such concentrations of iron and manganese, a settling or filtration stage, or both, would be necessary in particular to remove the precipitate derived from iron. With a filter alone, it could require very frequent backwashing. In the case of adsorption processes without a pre-filter, the adsorbent would become clogged in a short period.

The pH values of the waters are within the acceptable operating range for most adsorption processes, in particular using activated alumina or granulated ferric hydroxide. The presence of silica would however, reduce the performance of the activated alumina process if operated at the ambient raw water pH values. The concentration of phosphates in the raw waters is not sufficiently high to influence the performance of either of the absorption processes. The total dissolved solids concentration of all the waters are too high for ion exchange processes to operate economically, even though the proportion of sulphates in the waters are very low.

3 TREATMENT OBJECTIVES

Water containing arsenic should be treated in order to reduce the concentrations to the values defined in the Indian drinking water quality standards. These are published in Manual on Water Supply and Treatment (MOUD, 1999). There are two values: 'Acceptable' - 0.01 mg/l as As, the limit up to which water is generally acceptable to the consumers and 'Cause for rejection' - 0.05 mg/l as As, the value in excess of that mentioned under 'Acceptable' which render the water not acceptable, but still may be tolerated in the absence of an alternative, better source, but up to the limits indicated, above which the source will have to be rejected.

Indian standards like the drinking water quality standards of many countries are set on the basis of values defined by World Health Organisation (WHO). These values have become more stringent with time due to a better understanding of the toxicological effects of various chemicals and substances and developments in analytical methods, which permit the accurate determination of much lower concentrations. For example values for arsenic have varied from 0.2 mg/l as As in 1958 (WHO; 1958); 0.05 mg/l as As in 1984 (WHO; 1984) and 0.01 mg/l as As in 1993 (WHO; 1993). The value given in 1993 'Guideline Values for Drinking Water' is only a provisional value.

The toxicity of arsenic depends on the oxidation state and in descending order the toxicity from most to least toxic is as follows: -
arsine (a gas) > inorganic As(III) > organic arsenites (As(III)) > inorganic As(V) > inorganic arsonium compounds > elemental arsenic.

Toxicity of As(III) is about 10 times that of As(V) (Pontius et al; 1994). The most toxic arsines have not been reported in natural waters. Elemental arsenic is poorly absorbed in the body and removed almost unchanged, whilst organic arsenic compounds are known to be rapidly and completely eliminated from the kidneys. Inorganic arsenic may accumulate in skin, bone and muscle (WHO; 1996).

The WHO Guideline value for arsenic in drinking water is based on the 'provisional maximum tolerable daily intake' of inorganic arsenic assuming 20% is from drinking water. This would vary from country to country and even from region to region within a country depending on the climate, dietary habits of the local population and socio-economic factors. Therefore when applying WHO Guideline Values to local situations, these issues should be given consideration. Studies should be undertaken to establish the maximum tolerable arsenic concentration in drinking water that is acceptable to the population in West Bengal. Until such values are established, the immediate objective is to treat the water to an arsenic concentration below 0.05 mg/l as As.

In addition to India there are about 20 other countries where arsenic is found in drinking water concentrations in excess of about 0.5 mg/l, they include Bangladesh, Japan, Thailand, Australia, Austria, Jamaica, Germany, Canada, Mexico, New Zealand, USA Vietnam, Chile, China, Inner Mongolia, Taiwan and Argentina. In some developed countries it has recently become a water quality parameter of concern because of the very low values specified in updated national drinking water quality standards.

For comparison, standards for arsenic in drinking water set by countries with a serious arsenic problem, various regulatory bodies of other countries and some international agencies are given below in Table 1.1: -

Table 1.1: Standards for arsenic in drinking water

Country/regulatory body/ international agency	Concentration as As/remarks
India (Bureau of Indian Standards)	0.01 mg/l (acceptable) 0.05 mg/l (cause for rejection)
Bangladesh	0.05 mg/l
Japan	0.01 mg/l
Finland	0.01 mg/l
Chile	0.05 mg/l (0.01 mg/l is being considered) (Kercher, 1999)
China (National Standard GB5749-85)	50 Φg/l
Taiwan	50 Φg/l
Argentina (Argentine Food Codex)	0.05 mg/l (maximum authorised concentration (Madiec, 2000)
Mexico	0.05 mg/l (maximum contaminant level) (Simeonova, 2000)
UK (Water Supply (Water Quality) Regulations, 1983)	50 Φg/l 10 Φg/l (compliance scheduled for end of 2003)
Germany (DIN, 1996)	10 Φg/l (Jekel, 2000)
US Environmental Protection Agency, (US EPA; 1975)	50 Φg/l (maximum contaminant level) (Proposed for June 2001 to reduce MCL to 5 Φg/l with comments requested at 3, 10 and 20 Φg/l) (Pontius, 2000); 5 Φg/l value has been recommended
Council of European Communities (CEC; 1998)	50 Φg/l 10 Φg/l (compliance scheduled for end of 2003)
WHO (1993)	0.01 mg/l (provisional)
Australia (National Health and Medical Council; 1996)	0.007 mg/l
New Zealand (Ministry of Health; 2000)	0.01 mg/l

4 ARSENIC REMOVAL METHODS

Ease of arsenic removal depends on the form that it is present in the waters. As(III), which is much more prevalent in ground waters, is difficult to remove because it exists predominantly in the non-ionic form H_3AsO_3. Whereas with As(V) which is the dominant form in surface waters, removal is relatively easy as it exists as the mono-valent $H_2AsO_4^-$ ion or bi-valent $H_2AsO_4^{2-}$ ion. Therefore the oxidation of As(III) to As(V) would improve the effectiveness of As(III) removal.

There are several treatment methods available for the removal of arsenic in waters for potable use. They include:-

(a) Chemical precipitation;
(b) Adsorption;
(c) Membrane processes; and
(d) Biological processes.

Since As(V) is the easier of the two forms to remove, when As(III) is present an oxidation stage usually precedes most of the recognised treatment processes.

Oxidation

The kinetics of the oxidation of As(III) by aeration or other similar oxygen addition processes are very slow and could take several weeks to complete. Strong alkaline and acid conditions, copper salts, carbon and high temperature are some of the agents known to increase the rate of reaction (Ferguson; 1972). The rate of reaction is also reported to increase rapidly in the presence of iron or manganese oxides and hydroxides; this principle is used effectively in the subterranean removal of arsenic (Roff and Firedel, 2000). In this method a part of the delivered ground water is treated with oxygen and recycled to the aquifer. Oxygen transfer efficiency is high due to high pressure and chemical reaction is fast with pure oxygen because of its better absorption kinetics than oxygen in air. Arsenic removal is considered to be by co-precipitation with iron. The oxidation products of iron, manganese and arsenic are retained in the aquifer, thus eliminating the requirement for aboveground sludge disposal. It is reported that the deposited oxidation products do not appear to clog the underground aquifer. The process.removes not only arsenic, but also iron and manganese. Results produced in field trials at two sites are tabulated below.

Table 1.2 : Subterranean Removal of Arsenic, Iron and Manganese

Parameter	German Guideline Value (GV)	Plant A			Plant B		
		Raw water	Time to reach GV (months)	After about 2.5 years	Raw water	Time to reach GV (months)	After about 2.5 years
Dissolved oxygen (mg/l)	-	1.2			0.3		
Iron (mg/l Fe)	0.20	0.94	2	0.06	0.35	3	0.002
Manganese (mg/l Mn)	0.05	0.15	>2		0.11	>3	0.014
Arsenic (mg/l As)	0.01	0.015	2	0.005	0.019	3	0.002

(Roff and Firedel; 2000)

As(III) was successfully oxidised by oxygen on manganese coated quartz sand filter medium. Precipitation was achieved either by iron (III) or iron (II) oxidised by oxygen. In a full scale plant operating on this principle As(III) and As(V) concentrations were reduced to less than 1 and 3 Φg/l respectively (Borho and Wilderer; 1996). Other agents which have been shown to catalyse the oxidation reaction are copper oxide, solar or UV radiation and activated carbon.

The method utilising solar radiation known as 'solar oxidation and removal of arsenic' (SORAS) has been developed for application at household level, i.e. point of use (POU) (Wegelin et al; 2000). It is based on the photochemical oxidation of water containing As(III) in the presence of Fe(III) and citric acid, brought about by irradiation with sunlight in a UV-A transparent bottle such as polyethylene terephthalate (PET) bottles. The process is most suitable for well waters containing iron. Lemon could be used as a substitute for citric acid. Shaking the partly filled bottle helps to aerate the water and oxidise Fe(II) to Fe(III). For best results the water should be irradiated throughout the day under a clear sky. Finally the settled precipitate containing ferric hydroxide with adsorbed As(V) should be separated either by decanting or filtration through a muslin cloth. Arsenic removal is limited to about 50 to 75%; therefore water containing up to 100 to 150 Φg/l arsenic could be treated by this method.

Laboratory tests have demonstrated that UV at 254nm was not very effective in As(III) oxidation unless doses as high as 46,000 $mW.sec/cm^2$ are used (Ghurye et al; 2000). Even at such extreme doses the oxidation was limited to 76%.

The oxidising agents most effective in As(III) oxidation to As(V) are chlorine, sodium or calcium hypochlorite, chlorine dioxide, potassium permanganate, ozone and hydrogen peroxide in the presence of ferrous, ions, the so-called Fenton's reagent. Hydrogen peroxide forms hydroxyl free radicals in the presence of ferrous ions, which is known to promote the oxidation reaction. The oxidation reaction does not require the presence of oxygen (Lauf and Waer; 1993, Oscardson et al; 1981). The use of chlorine or hypochlorites for oxidation could result in the formation of trihalomethanes (THM) from reactions with natural organic matter. These chlorine by-products are known to be harmful. In the case of ground waters where As(III) normally predominates, the risk is small as THM precursors are usually absent. Surface waters could pose a risk of THM formation if both As(III) and THM precursors are present in appreciable concentrations. In such cases an alternative oxidant should be used.

Chloramines do not oxidise As(III). Therefore when ammonia is present in the water, oxidation by chlorine or hypochlorite should be preceded by breakpoint chlorination to remove ammonia and to ensure free chlorine is present for the oxidation stage. Typically the chorine dose required for breakpoint chlorination is about 10 times the ammonia concentration expressed as NH_3. Chlorine dioxide is produced on site by the reaction between sodium chlorite and chlorine, or hydrochloric acid or aluminium sulphate. The reaction also produces chlorates and chlorites by disproportion, these by-products are considered to be harmful. The applied dose should therefore be kept low to minimise their concentration in the water. Chlorine dioxide does not react with natural organic matter to form THM. It could also be used when ammonia is present as it does not react with ammonia.

Potassium permanganate is an effective oxidant, but it forms a brown, muddy precipitate of manganese dioxide, which should be removed by filtration. Care should be taken to control the dose accurately as over dosing would add a pink coloration to the water. Ozone is not known to be used solely for arsenic oxidation because of its high capital and operating costs. The weight of oxidant required per unit weight of As(III) depends on the presence of Fe (II) and organic matter as they would also have an oxidant demand. By using potassium permanganate to oxidise As(III), satisfactory results have been achieved with 1.26 mg potassium permanganate for 1 mg of As(III) (Lauf and Waer; 1993). The reaction was rapid and oxidation was independent of pH in the range 6 to 8.

Laboratory studies by Ghurye et al have concluded that chlorine, potassium permanganate and ozone were very effective in oxidising As(III) to As(V) in the pH range 6.3 to 8.3 in the presence of dissolved iron and manganese. Chlorine dioxide was not very effective; three times the stoichiometric dose produced only about 20 to 30% reduction in As(III) concentration and 100 times the stoichiometric dose produced only about 76% reduction in the As(III) concentration in 5 minutes. In-situ produced chloramines oxidised only 40% of As(III) using three times the stoichiometric dose. With both chlorine dioxide and in-situ produced chloramines the observed oxidation could be due to the presence of chlorine since pre-formed chloramines failed to produce any measurable As(V) (Ghurye et al; 2000). These studies also demonstrated that the presence of sulphide retarded the oxidation process using chlorine, permanganate or ozone, although greater than 95% oxidation was still possible. Total organic carbon had no effect on chlorine and permanganate oxidation. Ozone oxidation was delayed due to the reaction with total organic carbon; 40% oxidation of As(III) was achieved after 5 minutes.

Chemical precipitation

Chemical precipitation is the most effective and widely practised method for removing arsenic, particularly in large-scale water treatment plants. Best removals are achieved for As(V). Both ferric and aluminium salts are considered to be suitable. Removal is known to be by co-precipitation and adsorption with freshly precipitated aluminium or ferric hydroxides. Iron salts perform better than aluminium in arsenic removal. This is considered to be because all of the Fe added precipitates as the hydroxide whereas not all of the Al dosed forms aluminium hydroxide. This difference is due to the effect of pH on the precipitation reaction.

The process is typical of the coagulation process used in surface water treatment and, in the same way, removal is pH dependent. In fact in the treatment of surface water by coagulation using iron or aluminium salts for turbidity and natural organic water removal, arsenic is also removed. The coagulation process would also remove particulate arsenic, which usually forms a high proportion of total arsenic in surface waters. The capacity of iron (III) and aluminium (III) hydroxides to remove arsenic could be reduced by other ions, in particular phosphates in the water. Then a higher dosage of aluminium or iron salt would be necessary to achieve equivalent removal efficiencies.

Since only the metal hydroxide precipitate formed brings about arsenic removal, pH is an important parameter in the process. Aluminium and iron salts form insoluble hydroxides over a range of pH values specific to the salt. Outside these ranges, the soluble fraction of the metal in the water increases. Similar to coagulation processes therefore, soluble residual aluminium or iron should be kept to a minimum by operating the process at the optimum pH for precipitation. Aluminium hydroxides are sensitive to pH changes. The normal pH range for aluminium hydroxide precipitation is about 6.5 to 7.5. Outside this pH band aluminium hydroxide dissolves to form soluble aluminates (pH>7.5) and other soluble salts such as chlorides and sulphates (pH <6.5). Ferric hydroxide is less sensitive to pH changes and precipitation reaction could be carried out over a wider pH range (pH 4 to 10). Ideally 'jar tests' should be carried out to optimise treatment chemistry (i.e. aluminium or iron salt dose and pH) to ensure low soluble aluminium or iron residual in the water and therefore to maximise arsenic removal.

Removals of As(V) with aluminium and ferric salts would be equally effective (on a molar equivalent basis) at pH below about 7.2; at pH values greater than about 7.0 removals with aluminium salts decreased (Edwards; 1994, Cheng et al; 1994, Pontius; 2000, Hering et al; 1996).

The higher the metal salt dose, the greater the arsenic removal, in a manner somewhat similar to organic removal by enhanced coagulation. The US Environment Protection Agency (EPA) defines enhanced coagulation as the addition of excess coagulant, a change in type of coagulant or a change in coagulation pH for improved total organic carbon removal. The influence of the increase in dose applied on arsenic removal was demonstrated in a full scale plant which showed average arsenic removals of 82, 89, 86, 94 and 96% using ferric chloride doses of 3, 4, 5, 6.5 and 10 mg/l respectively, whilst aluminium sulphate doses of 6, 10 and 20 mg/l produced removal efficiencies of 23, 24 and 69% respectively. On the same plant turbidity removal averaged

93.9% in the ferric chloride test and 97.1% in the aluminium sulphate test (Scott et al; 1995). Increase in As(V) removal by increasing the coagulant dose has been reported by many workers (Sorg and Logsdon; 1978, Hathaway and Rubet; 1987, Shen; 1973, Gullidge and O'Connor; 1973).

In general As(V) removal efficiencies greater than 90% can be achieved by aluminium salts at pH values <7 and by ferric salts at pH values <8.5 (AWWA; 1988). The effectiveness of ferric salts was not pH dependent between 5.5 and 7.0 (Cheng et al; 1994) but removal could be as high as 99% at a pH of about 8.5. It is reported that As(V) adsorption on to ferric hydroxide decreased at pH values greater than 9.0 (Edwards; 1994). Chilean experience shows that on a full scale plant with oxidation, pH adjustment and precipitation using ferric chloride followed by filtration, it was impossible to reduce arsenic concentration below about 0.02 to 0.03 mg/l (Sancha; 2000).

It is reported that a works in Australia treating a stored water, changed coagulant from aluminium sulphate to the more efficient ferric sulphate during periods of high arsenic contamination. Arsenic concentrations were reduced from values in the range 20 to 50 Φg/l to less than 5 Φg/l (Murray et al; 1999). High removal efficiencies are reported in laboratory tests when ferric chloride was used with hydrated lime; on a full scale plant comprising clarification and granular activated carbon adsorption removal efficiencies of 97 to 98% were obtained (Harper; 1992). Arsenic removal by either ferric or aluminium salts is much reduced when the metal is present as As(III), with ferric salts being by far the most effective. An 80% removal of 300 Φg/l of As(III) was achieved by 5 mg/l of Fe (III) over a pH range of 5.5 to 9.0. Whereas a molal equivalent concentration of Al (III) removed on the average of only about 40% of As(III) (Edwards; 1994). Removals could be maximised by oxidising As(III) to As(V).

In ground waters As(III) usually co-exists with iron in the reduced form Fe (II). When water is exposed to air, Fe (II) is converted to insoluble $Fe(OH)_3$ (ferric hydroxide) which gives a reddish brown colouration to the water. Arsenic when present is removed along with iron by mechanisms of adsorption and co-precipitation. Soluble As(V) removal during oxidation of Fe (II) is expected to be very significant. At a full scale treatment plant, oxidation of Fe (II) at concentrations greater than 1.5 mg/l resulted in 80 to 95 per cent removal of As(V) (McNeill and Edwards; 1995). The US EPA studied arsenic removal at two iron removal plants over a two-year period. Plant A had an average iron concentration of 2.284 mg/l and the average total arsenic concentration was reduced from 20.3 Φg/l to 3.0 Φg/l; an 87% reduction. In plant B the reduction was 74% which represented a decrease in the average total arsenic concentration from 48.5 Φg/l, to 11.9 Φg/l, while the iron concentration in the raw water averaged 1.137 mg/l (Sorg; 2000a). The degree of arsenic removal in the two plants is probably reflected in the difference in the iron concentration. Laboratory tests have shown that As (III) removal increased in the pH range 5.0 to 8.0, with an increasing Fe (III) to As (III) ratio. Tests also demonstrated that manual mixing followed by prolonged settlement brought up to 92% As(III) removal (Mamtaz; 2000). An optimum Fe (III) to As (III) ratio of 11 at pH value of 9.0 was reported for maximum As (III) removal (Nenov; 1994).

However, when manganese is present in water, arsenic removal during Mn (II) oxidation was not significant. (Edwards; 1994, McNeill and Edwards; 1995). Using models it has been shown that 1 mg/l of manganese (II) reduced arsenic concentration of 5 mg/l by only 25%. However when the manganese (II) concentration was high (3 mg/l) arsenic removal was about 60% (Edwards; 1994), but such high manganese concentrations are rarely found in ground waters.

Removal efficiencies for As(V) by aluminium and ferric salts and As(III) by ferric salts are considered to be independent of the initial arsenic concentration (Hering; 1997). Of the ferric salts both ferric sulphate and ferric chloride have been successfully used in the removal process. The latter has the disadvantages that it is highly corrosive and therefore hazardous to handle, and it adds chlorides which could render the water corrosive. Materials in contact with ferric chloride should be made of glass, ceramic, plastics or steel lined with rubber. Ferric sulphate is less corrosive, does not add chlorides to water and unlined stainless steel can be used as a construction material. However ferric chloride is more commonly used because, being a by-product of the steel industry, it is cheaper than ferric sulphate. It has also been reported that ferric chloride is more effective because hydrogen ions formed in the hydrolysis reaction regulate the coagulation pH better (Chadha and Sinha Ray; 1999). Ferric salts contain manganese as an impurity with concentrations as high as 700mg manganese per kg of iron in the product. This could add sufficient manganese to the water to exceed the WHO Guideline value of 0.1 mg/l, particularly if manganese is also naturally present in the water.

Of the aluminium salts, work to date has concentrated primarily on aluminium sulphate. Removal efficiencies using polymerised aluminium salts such as polyaluminium chloride, polyaluminium silicate sulphate or polyaluminium chlorohydrate have not been thoroughly investigated. They may offer better prospects because of their wider operating pH band.

As(V) is also effectively removed by lime softening depending on the operating pH (Sorg and Logsdon; 1978). During softening at pH about 9.0 to remove calcium hardness only, As(V) removal was only up to 10%. At pH values in the range 10 to 11 when total softening to remove both calcium and magnesium hardness is affected, As(V) was reduced from values in the range 100 to 300 Φg/l to 1 to 5 Φg/l in laboratory tests and pilot plants

(Sorg; 1993); in a full scale treatment works the reduction varied in the range 60 and 95% (McNeil and Edwards; 1995). These tests also showed that removal increased with increased precipitation of magnesium in the softening process; 6 mg/l of magnesium showed 60 to 74% As(V) removal whilst more than 40 mg/l of magnesium produced over 94% As(V) removal. The removal mechanisms may be by adsorption on to calcium carbonate and magnesium hydroxide precipitates and by the formation of insoluble calcium arsenate. Jar tests and pilot plant work carried out on As(III) showed, once oxidised by chlorine, removal patterns were similar to those reported for As(V). Without oxidation, however, removal was limited to about 75% at pH values greater than 11.0 (Sorg and Logsdon; 1978).

In Hungary arsenic concentrations in contaminated ground water were reduced to less than 0.05 mg/l by co-precipitation with magnesium hydroxide produced by the action of magnesium oxide (MgO) or magnesium chloride ($MgCl_2$) and sodium hydroxide (NaOH), (Anon; 2000b).

Overall the process for arsenic removal by chemical precipitation comprises the following stages as outlined in Table 1.3:-

Table 1.3: Different process stages used in As removal

Process	Function
Oxidation (where necessary)	Converts As(III) to As(V)
pH adjustment	Facilitate Fe (III) or Al (III) hydroxide formation
	Adsorption and co-precipitation
Addition of Fe (III) or Al (III) salt	
Sedimentation (where necessary)	Removal of precipitates and other suspended solids
Filtration	Removal of precipitates and other suspended solids

Arsenic removal therefore depends on the efficiency of the individual process stages. Sub-processes such as mixing of chemicals in the water and the control of pH within optimum ranges (in particular for Al (III) salts), also become important. Mixing efficiency of oxidising, pH correction and precipitation chemicals in the receiving water are crucial to the removal process. Good mixing also helps to reduce the cost of chemicals. A good control parameter for optimum pH is the concentration of soluble aluminium or iron residuals present in the water before or after the solid-liquid separation stages. This should ideally be of the order of 0.02 mg/l as Al or 0.05 mg/l as Fe. Once co-precipitated, the efficiency of the downstream solid-liquid separation processes which could include direct filtration or clarification followed by filtration becomes important in the removal of arsenic.

The use of the optimum coagulating pH to minimise soluble residual aluminium or iron concentrations is essential to maximise, aluminium or ferric hydroxide precipitation. Efficient suspended solids separation is essential to minimise breakthrough of arsenic containing floc. Based on experience at operational plants, it is reported that there is a greater risk of arsenic breakthrough with aluminium salts than with ferric salts due to high aluminium solubility and floc stability (McNeill and Edwards; 1997).

In surface water treatment plant chemical precipitation would be a part of the coagulation process for turbidity and natural organic matter removal. In such plants coagulant aids such as activated silica or synthetic polyelectrolytes are dosed to improve the performance of the solid-liquid separation stages with respect to turbidity removal. The presence of turbidity had little or no influence on arsenic removal by chemical precipitation (Cheng et al; 1994). This was confirmed by tests using kaolin particles (Hering et al; 1996) however good turbidity removal is still an indication of optimum coagulation and efficient solids-liquid separation and hence good arsenic removal.

In Chile, where arsenic is found in surface waters, ferric chloride is used in preference to Al (III) salts. The latter required much higher doses; while Fe (III) doses were lower, the operating pH range of 6.5 to 8.0 was much wider and Fe (III) produced a large and denser floc which settled better. Chlorine was used to oxidise As(III). The chlorine and ferric chloride doses used were 1 and 30 mg/l respectively. Sedimentation tanks and filters (coal-sand) were operated at about $3m^3/h.m^2$ and $6m^3/h.m^2$ respectively. Chemical dose control was difficult due to daily and seasonal variations in raw water quality. The arsenic concentration in the treated water varied in the range 0.04 and 0.05 mg/l and the overall removal was about 90% on a raw water arsenic concentration of 0.4 to 0.6 mg/l (Sancha, 2000). A separate study carried out in Chile has concluded that with better control of the Fe (III) dose and a pH nearer the optimum values, removals as high as 95% could be achieved. However operating experience at a full scale plant shows that such demanding removal rates cannot be achieved consistently, primarily due to daily and seasonal variations in raw water quality (Sancha; 2000).

In ground water treatment the floc formed in the absence of turbidity would primarily be a chemical floc, therefore the floc would be fragile. It would therefore be more difficult to remove efficiently by conventional solid-liquid separation processes, which would normally be limited to a media filtration stage. In such cases, far more efficient membrane filtration of the microfiltration or ultrafiltration type should be considered (see Membrane Processes). For small-scale treatment cartridge filters could be used.

The use of a ferrous (Fe (II)) salt has been demonstrated at a plant in Germany where a well oxygenated ground water containing primarily As(V) at concentrations up to 21 Φg/l was treated by pressure filtration (at $7m^3/h.m^2$) in anthracite-sand media filters; an As(V) removal of 90% was achieved with a 1 mg/l of iron dose. At higher doses the degree of removal approached 98%. Test work at the plant concluded that both Fe (II) and Fe (III) salts produced similar removal efficiencies, but filter performance with respect to head loss development and filter run lengths was far superior with the Fe (II) salt. This behaviour is considered to be the result of small Fe (III) hydroxide flocs with good adsorption properties being formed in the filter media due to slow oxidation of Fe (II) by oxygen in the water (Jekel and Seith; 2000). The operating pH of 7.9 was in the optimum range for complete precipitation of the iron; residual iron in the filtered water was less than 3 Φg/l.

Adsorption processes

Arsenic can be removed by adsorption on to several types of material which include activated alumina, ion exchange resins, granulated ferric hydroxide, activated carbon, activated bauxite, hematite, laterite, iron or manganese coated sand, iron filings and greensand.

The processes consist of the passage of water containing arsenic through a column of the media. Arsenic is adsorbed on to the media and when the media is exhausted as indicated by rising concentration of arsenic in the effluent, it is regenerated for further use or replaced with fresh media. Adsorption processes are primarily applied to ground waters because they contain low turbidity which could otherwise clog the bed. When they are applied to surface waters or ground waters containing turbidity, pre-treatment, which should include filtration should precede the process.

Activated alumina

Activated alumina is an aluminium oxide prepared by thermal dehydration of an aluminium hydroxide (e.g. gibbsite, bayerite etc). The most common type of activated alumina used in adsorption processes is the γ(gamma)-alumina, which is prepared by dehydration at 450°C. Its zero-point discharge pH at 8.2 is higher than for most mineral oxides, it therefore has good adsorption properties towards several anions in water around pH 7.0. Activated alumina is a very effective agent for removing arsenic; As(V) is removed better than As(III) (Gupta; 1978). Some manufacturers have achieved very high removal of As(III) by using iron coated activated alumina. With these products therefore, a pre-oxidation stage may not be necessary. Major water quality parameters which influence the removal of arsenic are pH and competing ions in the following decreasing order of selectivity in the pH range 5.5 to 8.5 (Clifford; 1991):

$$OH^- > H_2AsO_4^- > H_3SiO_4^- > F^- > SO_4^{2-} > HCO_3^- > Cl^- > NO_3$$

The other competing ion, which is not included in the above sequence, is phosphate (PO_4^{3-}); which is considered to be as selective as $H_2AsO_4^-$ and F^-. Activated alumina is used to remove both phosphate and fluoride in water. Activated alumina is said to be amphoteric; being neutral at pH 9.5, positively charged at pH values less than 9.5 and negatively charged at pH values greater than 9.5. Therefore under acidic conditions, typically pH of 6.5 or less, As(V) which is predominantly present as negatively charged monovalent and divalent anions, is very effectively adsorbed with over 95% removal. At pH 5.5, As(V) reduction from values of 0.08 to 0.116 to less than 0.05 mg/l has been reported (Hathaway and Rubel; 1987). At such low pH however, some of the media could be dissolved and the cost of pH correction also becomes an important factor. The optimum pH range is therefore 6.0 to 6.5 (Simms and Azizan; 1998). The rate of removal of As(III) is known to show improvements with increasing pH.

Gosh and Yuan have reported that both mono-methyl and di-methyl arsenates, two principal ingredients in arsenic based herbicides, are removed effectively by activated alumina. Of the two the mono-methyl arsenate is better adsorbed (Gosh and Yuan; 1987).

Ground waters of high pH and high alkalinity will require large quantities of acid to lower the feedwater pH to values between 6 and 6.5. It is reported that at a treatment plant in Albuquerque the ground water of pH 8.5 and containing an alkalinity of 150 mg/l $CaCO_3$ required 57 litres of sulphuric acid or 186 litres of hydrochloric acid per $1,000m^3$ of water to lower the pH from 8.5 to 6.0 (Chwirka et al; 2000). The acidification process would increase the concentration of sulphates or chlorides in the treated water. Since sulphate is an interfering ion, hydrochloric acid is preferred for pH adjustment. Chlorides could however adversely influence the corrosivity of the water in particular if the alkalinity is low.

Of the competing anions silicates are the most influential in reducing the adsorption capacity of both As(V) and As(III). Silicates are known to adsorb preferentially on activated alumina with maximum effect at pH 9 (Hueng; 1975). At high pH values, silicic acid disassociates to produce $H_3SiO_4^-$ which competes with arsenic for adsorption sites (Chwirka et al; 2000). Therefore at the pH values of 6 to 6.5 used in the arsenic removal, interference from silicates is not appreciable. The effect of silicates on arsenite removal is considered to be independent of pH whilst that on arsenate decreases with decreasing pH (Azizan; 1999). Since activated alumina is also used for fluoride removal at pH values similar to those used for arsenic, its presence would interfere with arsenic adsorption. However fluorides are rarely present in sufficiently high concentrations to cause appreciable interference to arsenic adsorption. Sulphate and bicarbonate ions result in a marginal reduction in As(III) and As(V) adsorption at pH values less than 7. The presence of phosphate ions at concentrations greater than 5 mg/l as P is known to cause an appreciable reduction in As(III) adsorption at pH greater than 6 and in As(V) at pH greater than 7 (Azizan; 1999). Chlorides and nitrates concentrations are usually too low to have any influence on arsenic adsorption on activated alumina. The presence of calcium ions is known to enhance the adsorption of As(III) at pH values greater than 6 and of As(V) at pH values greater than 8 (Azizan; 1999). Activated alumina, unlike ion exchange does not show marked chromatographic peaking (see Ion Exchange).

A year long sampling and monitoring programme by the US EPA at two plants, A and B, using two columns containing modified activated alumina in series showed arsenic removal efficiencies of 87 and 98% respectively. Plant A contained a total arsenic concentration in the range 34 to 76Φg/l, of which the As(III) concentration was 0.3 to 28.8Φg/l, which was totally removed without pre-oxidation. Plant B source water contained only As(V) at a concentration in the range 53.3 to 87Φg/l. At both plants activated alumina was used on a single application basis and was exhausted and discarded after about 1 to 1.5 years, after treating approximately 9,600 bed volumes at Plant A and 5,260 bed volumes at Plant B (Sorg; 2000b).

When an activated alumina bed is exhausted with respect to arsenic it is regenerated to restore its adsorption capacity. The regeneration process usually consists of desorption of arsenic with sodium hydroxide in downflow mode, followed by a down flow water rinse and then an up flow acid wash to neutralise excess sodium hydroxide and for protonation, which is achieved by converting alumina to the chloride form, and finally by a water rinse. When the feed water contains suspended solids due to turbidity or oxidised iron, the regeneration cycle is usually preceded by a water backwash.

The concentration of sodium hydroxide used in regeneration is usually in the range 1 to 2% $^{w}/_{v}$ (10 to 20 g/l). Higher concentrations of 3 to 4% $^{w}/_{v}$ (30 to 40 g/l) are known to perform better, but loss of activated alumina is expected to be about 2 to 3% because of its solubility at high pH (Chwirka et al, 2000). The regeneration process is known to recover over 85% of the adsorptive capacity of virgin activated alumina with no further appreciable reductions in subsequent regeneration. Hydrochloric acid is preferred to sulphuric acid for the acid wash because interference from chloride ions is less than that from sulphate ions; the typical concentration of acid used is in the range 1 to 2% $^{w}/_{v}$ (10 to 20 g/l).

Activated alumina is commonly available in a fine sieve size of 28 to 48 (0.6 to 1.2 mm) and a coarse sieve size of 14 to 28 (0.3mm to 0.6mm). The finer media have a higher adsorptive capacity and are easier to regenerate due to the greater surface area per unit volume and better accessibility to the pores in the media. Pilot plant work has concluded that the adsorptive capacity of the finer media was 25% greater than that of the coarser media and that the former retained more adsorptive capacity than the latter after regeneration (Simms and Azizan; 1998). Another test programme has demonstrated that powdered activated alumina passing the sieve size 100 (<150 Φm) at a concentration of 1000mg/l used in conjunction with ultrafiltration membranes resulted in 55 to 98% removal of As(III); on this basis As(V) removal could be 20 times more effective (Yallaly and Kramer; 2000).

There are two types of activated alumina. The standard type is manufactured in many countries including India. Indian material is currently used in a design developed by Bengal Engineering College. US material is used by Apyron in West Bengal. Alcan Chemicals also manufacture a similar product in the UK. The adsorptive capacity of the standard product typically varies between 15 to 17g As/kg adsorbent.

Alcan Chemicals (UK) have developed an arsenic specific activated alumina (AAFS50) which is impregnated with ferric ions and it is claimed to give adsorptive capacities between 30 to 80 As/kg adsorbents and to remove both As(III) and As(V). Apyron Technologies Inc of USA also market a modified activated alumina and it is claimed to remove both As(III) and As(V), and used on a throwaway basis. The material is currently in use in West Bengal, India. There are other manufacturers offering similar modified aluminas with adsorptive capacities better than the standard products. Bed volumes treated to breakthrough at 10 Φg/l As depend on the initial arsenic concentration. It is reported that for an inlet concentration of 30 Φg/l at a pH value of 7.5 standard activated alumina gave about 8,000 bed volumes whilst AAFS50 gave over 60,000 bed volumes (Azizan; 1999). Run lengths to exhaustion up to 6,700 bed volumes have been estimated for a 8.7 Ml/d groundwater plant using standard activated alumina in Albuquerque in USA (Chwirka et al; 2000).

Increase in empty bed contact time (EBCT) (which is defined as the time required for a volume of solution equal to the bed volume of adsorbent to pass through the column) increases the adsorptive capacity of activated alumina. For example EBCT of 3, 6 and 12 minutes gave arsenic removal capacities of 0.19, 0.24 and 0.35g As/kg of activated alumina respectively (Hall; 2000a). The corresponding bed volumes to achieve 10 Φg/l arsenic were 9,000, 10,000 and 14,000 respectively. Typically an EBCT of 5 to 6 minutes is suggested.

Activated alumina is primarily used in the treatment of ground waters. When a water contains high turbidity or iron concentrations, pre-oxidation and filtration stages are desirable to remove turbidity or ferric hydroxide precipitate; alternatively activated alumina adsorbers need to be backwashed regularly to minimise rapid head loss development, particularly when using finer media. The presence of iron and its removal in a pre-filtration stage would supplement the removal of arsenic by activated alumina. Depending on the concentration of iron, removals up to 70% of As(V) could be achieved by co-precipitation and adsorption.

Activated alumina has a specific gravity of 2.6 and a bulk density of the order of 740 kg/m^3. The flow rate through the bed.usually varies between 6 to 12 bed volumes/h. For large plants a bed depth of 2 to 2.5m is used. Alkali, water and acid volumes used in the regeneration cycle typically vary between 5 to 10 bed volumes, 2 to 5 bed volumes and 5 bed volumes respectively (Twort et al, 2000). Activated alumina lost during regeneration is usually less than 2%, depending on the regeneration pH.
Treated water from the activated alumina process has a pH of about 6.0 and should be adjusted to give the water a Langelier Index (Saturation pH-pH) of about +0.2 to ensure that the water is not aggressive.

Ion exchange resins

Arsenic is removed effectively by strong-base anion exchange resins of the chloride form. As with activated alumina As(V) which is present as monovalent $H_2AsO_4^-$ and divalent $H_2AsO_4^{2-}$ in the pH range 6 to 9 is removed by ion exchange resins; removal of As(III) occurs only at a pH greater than 9.2 when monovalent arsenite ion $H_2AsO_3^-$ predominates. At neutral pH, As(III) is present as H_3AsO_3 (arsenous acid) which is non-ionic and is poorly adsorbed.

In this process arsenic is exchanged for chloride and therefore the competition by other anions present e.g. sulphates, bicarbonates, nitrates in the water is extensive. The selectivity of major ions for adsorption by ion exchange in the decreasing order is as follows (Clifford; 1991):

$$SO_4^{2-}>HAsO_4^{2-}>CO_3^{2-}>NO_3^->Cl^->H_2AsO_4^->HCO_3^->>H_3AsO_3$$

Work carried out by Berdal et al. show carbonate after sulphate and $HAsO^2_4$ and $H_2AsO^-_4$ in the positions shown at pH values 7 to 8 and less than 5 respectively. The process is therefore considered to be uneconomical for waters containing total dissolved solids greater than 500 mg/l or sulphates greater than 25 mg/l (Clifford; 1991), although the process may be practical for sulphate levels up to 120 mg/l (Pontius; 2000). Increase in sulphate concentration from 20 to 80 mg/l is reported to have reduced run lengths by about 70% (Clifford et al; 1995). High sulphate concentrations in a water increase the potential for arsenic peaking, a phenomenon common in chromatography where one compound is displaced off the column by a preferentially adsorbed compound. The concentration of arsenic in water when displaced by sulphate is much greater than that resulting from the gradual breakthrough that would otherwise occur and the concentration of arsenic in the treated water would be several times greater than that in the feed water. Pilot plant trials have shown that for a feed water containing 12 to 25 Φg/l As, arsenic was displaced from the column to give a product water containing 50 Φg/l (Hall; 2000a). Therefore the columns must be removed for regeneration before arsenic breakthrough due to displacement by sulphates. Ion exchange produces nearly 100% As(V) removal. The presence of sulphates however reduces adsorption capacity significantly. The bed volumes required when 5, 20 and 100 mg/l sulphate ions are present have been reported to be 1500, 900 and 640 respectively (Perry et al; 2000). Ion exchange therefore tend to produce significantly lower volumes of treated water between regenerations than activated alumina.

The process also removed bicarbonates (HCO_3^-) from the water, giving a treated water with a lower pH in the early part of the adsorption process (Clifford; 1991). This effect could be minimised by having two or three vessels and running them out of phase. The treated water pH may also require elevation to reduce aggressive tendencies of the water.

The US EPA monitored the performance of two ion exchange plants (A and B). The results from the two plants demonstrated that the process was capable of reducing arsenic concentration to less than 5 Φg/l provided the columns were regenerated before breakthrough occurred. In Plant A 'chromatographic peaking' occurred after 3000 to 3200 bed volumes of water had been treated. Breakthrough was not observed on Plant B, which achieved 97% arsenic removal to give 0.8 to 0.45Φg/l in the treated water. The source water arsenic concentrations were 34 to 76Φg/l in Plant A and 53.3 to 87Φg/l in Plant B. The former had an As(III) concentration of 0.3 to 28.8Φg/l (Sorg; 2000b).

Studies carried out with the commercial resin Amberlite IRA900 have indicated that the optimum pH for As(V) removal is about 6 and the maximum As(V) uptake is about 75mg/g dry weight of resin (Anon; 2001).

Once exhausted the resin is backwashed and regenerated with a concentrated solution of sodium chloride followed by a water rinse to displace the regenerant. In the regeneration process the adsorbed As(V) ions are replaced by chloride ions. The minimum sodium chloride concentration is about 5% $^{w}/_{v}$ (50 g/l). Recycle of waste brine may be feasible up to 20 times (Pontius; 2000) with some make up to maintain the minimum salt concentration. The salt required for regeneration is reported to be of the order of 90 g/l of resin (Chwirka et al; 2000). Perry has listed typical design parameters for ion exchange as follows (Perry et al; 2000): Resin depth 1 to 1.5m, empty bed contact time 1.5 to 4 minutes, bed loading rate 5 to 10 m^3/h.m^2, regenerant volume 5 bed volumes and displacement rinse volume 2 to 6 bed volumes.

No arsenic selective ion exchange resins have yet been developed. Ion exchange resins activated with ferric chloride in the laboratory have been used in laboratory column studies (Viraraghavan et al; 1999). The performance of the column with about 37% of arsenic removal was not satisfactory. Chelating resins of the Fe(III) form have been successfully used for As(III) and As(V) removal (AWWA; 1993). As(III) was effectively removed in the pH range 8 to 11 and As(V) removal was effected in the pH range 4 to 7. The removal mechanism is considered to be complexion of arsenic with Fe(III) ions. Once exhausted the resin is regenerated with a solution of sodium hydroxide. Chelating resins of the Cu(II) type have also been successfully used in test work to remove As(V) (Sengupta et al; 1991).

The ion exchange process requires pre-treatment to remove turbidity and precipitated iron as they foul the resin and clog the columns resulting in the rapid development of head loss. Resins are also susceptible to residual chlorine, organic carbon and bacterial contamination. Chlorine, if used for oxidation of Fe(II), should be removed by sodium bisulphite or similar ahead of the ion exchange column. The removal of Fe(II) as Fe(III) by oxidation is known to remove up to 70% of As(V) through co-precipitation and adsorption.

Granular ferric hydroxide

Granulated ferric hydroxide is an adsorbent developed specially for arsenic removal. It has a larger capacity for arsenic compared to activated alumina in the same way as it has been demonstrated in the precipitation reactions where ferric salts remove arsenic better than aluminium salts. It is reported that arsenic is adsorbed on amorphous ferric hydroxide about 3 to 10 times more efficiently than on activated alumina (Pierce and Moore; 1982).

It is believed that the material is currently produced by three manufacturers, one in Germany (GEH Wasserchemie GmbH & Co), one in Canada (ADI Group, Inc) and the other in Finland (Kemira). Severn Trent Water (UK) are in the process of developing a similar material for the same application. It is usually prepared by precipitation of ferric hydroxide from a ferric salt such as ferric chloride using sodium hydroxide followed by dewatering of the precipitate. The active substance is ferric hydroxide and $-FeOOH. The German product has a specific surface area of 250 to 300m^2/g and a particle porosity of 75 to 80%. The grain size varies from 0.2 to 2mm and the bulk density when saturated with water is 1.32 g/cm^2. (Drichaus et al; 1998). The ferric hydroxide is a poorly crystalised form of $-FeOOH and contains 52 to 57% by weight with the remainder being moisture. Bed porosity is 22 to 28% and grain density is 1.59 g/cm^3 (Jekel and Seith; 2000). It is reported that since the preparation of the material does not include thermal drying, all the pores remain filled with water giving rise to a high adsorption capacity (Driehams and Jekel; 1998).

The mechanical strength of the granules is not comparable to that of activated alumina, but it is suitable to use in packed bed adsorbers and, if necessary, could be backwashed without significant attrition loss. Typical losses when using water only backwash at a rate of 8.5mm/sec are reported to be about 0.03% (Jekel and Seith; 2000). Others have reported 0.1% loss with a water wash and that an air scour preceding the water wash did not make a significant difference to these losses (Barnes et al; 2000).

The adsorption process is pH dependent, capacity decreases with increasing pH. The optimum operating pH range is 5.5 to 8 (Pal; 2000). Pilot studies have shown that at pH 6.5 the treated water arsenic concentration was 1 Φg/l after 150,000 bed volumes compared to 6 Φg/l at pH 7.5 (Hall; 2000b). Unlike activated alumina, anions, except orthophosphate do not interfere with the adsorption process. Orthophosphate starts to show a marked effect on arsenic adsorption at concentrations in excess of 0.05 mg/l as phosphate. This is due to the reaction with Fe(III) to form ferric phosphate, a method frequently used to remove phosphate in sewage effluent. Turbidity in a water is effectively removed in the adsorber but results in the rapid development of headloss because of the small particle size of the media used. Any iron present as ferric hydroxide would also be similarly removed. It is suggested that in order to minimise excessive mechanical loads the adsorber should be backwashed at head loss values not exceeding 500 mbar (Jekel and Seith; 2000). It would be desirable to use a pre-filter when turbidity and iron values in the raw water are high. When iron is present in the ferrous form oxidation using chlorine, potassium permanganate or ozone, followed by filtration through a filter containing a catalytic manganese dioxide media is usually used. The ferric hydroxide precipitate formed is removed in the filter. Oxidised iron could remove up to 70% of arsenic by coprecipitation and adsorption, depending on the concentration of iron in the raw water. Tests on the German material have shown that although the media can be used effectively for filtration and adsorption when Fe(II) is present in water, the rapid development of head loss due to the small size of the media would limit iron concentrations acceptable in the feed to less than 175 Φg/l (Selvin et al; 2000b). Therefore with the current generation of media, a pre-filtration stage would be necessary to remove turbidity and oxidised iron.

The use of larger sized particles for the granulated ferric hydroxide media would allow it to be used both for filtration and adsorption. Tests, however, have shown that media of particle size 1.0 to 2.0 mm reduced arsenic adsorption capacity by about 50% when compared to the media of particle size 0.4 to 2.0 mm. (Selvin; 2000b).

The process removes both As(III) and As(V). Trials carried out in the UK have shown that a source water containing 20% As(III) could be treated satisfactorily without the need for pre-oxidation; As(III) was not detected in the adsorber outlet (Barnes et al; 2000). The process can be used to reduce arsenic concentration to values of less than 10 Φg/l independent of the influent concentration. The German manufacturer claims a maximum adsorptive capacity of 25g As/kg of adsorbent. Published results from test plants show that arsenic breakthrough at 10 Φg/l occurred well before the full capacity is utilised; 2.6g As/kg (Barnes et al; 2000), 2g As/kg (Jekel and Seith; 2000) and 1.4g As/kg (Pal; 1998). The number of bed volumes treated up to breakthrough depends on the raw water arsenic and phosphate concentrations. The results from the test plants are given in the Table 1.4.

Table 1.4 : Bed volumes treated to arsenic breakthrough

Feed water Arsenic (Φg/l)	Bed volumes to breakthrough	Treated water arsenic (Φg/l)	Reference
22	190,000	10	Barnes et al; 2000
16	110,000	5	Selvin et al; 2000b
16	25,000	3	Selvin et al; 2000b
21	70-80,000	10	Jekel & Seith; 2000
21	40-60,000	10	Pal; 1998

The process is suitable for point-of-use treatment and is currently used in households in West Bengal, India and Bangladesh. Test carried out using chlorinated water with an arsenic concentrations of 20 Φg/l and a point of use unit containing one litre of the medium treated 50,000 bed volumes or litres with an EBCT of 45 seconds or 33,000 bed volumes or litres with an EBCT of 25 seconds (Selvin et al; 2000b). However, intermittent use of the point of use unit showed a bed life increase of 33% for 45 seconds. EBCT and 82% for 25 seconds EBCT.

The adsorber is normally operated at volumetric surface loading rates in the range 15 to 20 m^3/hr m^2. The empty bed contact time is usually 3 to 6 minutes depending on the inlet and outlet arsenic concentrations, required bed-life to exhaustion and cost. Once exhausted, the media cannot be readily and economically regenerated and is therefore discarded.

Activated carbon

Granular activated carbon (GAC) is known to remove arsenic to some degree depending on the pH of raw water. As(V) is best removed at low pH values typically 4 to 5 when arsenic is negatively charged and GAC is positively charged (Gupta and Chen; 1978). As(III) is removed at pH values above 9.2 when it is negatively charged. Tests carried out by The All India Institute of Hygiene and Public Health using GAC showed that although GAC could be used to remove arsenic, it is not economically viable due to the large quantity required. A filter column containing 100g GAC operating at a surface loading rate of 1.2m^3/h.m^2 removed 0.48mg of arsenic in a total filtered volume of 6 litres over a period of 10 hours to breakthrough. The initial arsenic concentration was 0.08 mg/l (Nath and Majumber; 1997). Adsorption and the rate of removal of As(V) could be improved significantly in the presence of ferrous ions. The mechanism of arsenic removal was postulated to be by the formation of ferrous-arsenate complexes rather than by co-precipitation (Huang and Vane; 1989). Tests on a small water filtering system comprising oxidation by chlorine, chemical precipitation by ferric chloride at an Fe:As ratio of 4:1 at pH 7 showed 90% arsenic precipitation. Complete removal was achieved by filtering through a media containing Fe(II) treated activated carbon granules (Arrykul et al; 2001). GAC is regenerated by stripping the adsorbed arsenic with a strong acid or a strong base and further treatment with a ferrous salt (Huang and Fu; 1984).

The use of purpose made iron oxide impregnated carbon of mesh size between 200 and 400 (0.075 and 0.375mm) increased As(III) and As(V) removal by about one and two orders of magnitude respectively compared to non-impregnated activated carbon. Removal of As(V) decreased with decrease in pH whilst removal of As(III) was most efficient at pH about 7.0 (Reed et al; 2000). Cu(II) activated carbon is reported to have reduced arsenic concentrations by up to 100% (Simeonova; 2000). Powdered bituminous coal (2 g/l) has been used with a lime dose of 800 mg/l operating at pH 11.5 to reduce arsenic levels to less than 0.05 mg/l (Dutta and Chandhuri; 1991).

Jadavpur University in Calcutta used activated charcoal in combination with a ferric salt and an oxidising agent to prepare a tablet, which would remove arsenic in 'point-of-use' applications. It is reported that when the tablet is added to arsenic containing ground water, it turned black due to the breakdown of the tablet. The contents, when filtered through a special candle filter, where the candle is made from fly ash, clay and charcoal, gave 95 to 100%

arsenic removal. The presence of black specs in the filtered water was an indication of a leaking filter (Jadavapur; 2000). Whether activated charcoal plays a role in the removal of arsenic is not evident; arsenic being primarily removed by the ferric salt. Field trials in West Bengal with household units have shown arsenic removal from less than 1.0 mg/l in raw water to less than 0.01 mg/l in the treated water. The tablets have also been shown to reduce concentrations of heavy metals including cadmium, cobalt, chromium, lead, iron, manganese and zinc at micro-gram values. An aluminium salt may be used in place of the ferric salt in the tablets.

Coconut husk carbon impregnated with copper sulphate has been evaluated for its ability to remove As(III). Maximum adsorption was reached at pH 12. The adsorbent once saturated was regenerated with hydrogen peroxide in nitric acid and reused (Manju et al; 1998).

Other iron based material

Iron oxide coated or manganese oxide coated sand or manganese greensand removes arsenic by adsorption. It has been shown that manganese greensand outperforms iron oxide coated sand in As(III) removal (Viraraghavan et al; 1999). For optimum performance the former required an Fe : As ratio of 20:1; an As(III) concentration was reduced from 100 Φg/l to 25 Φg/l. The results of the laboratory study showed continuous regeneration of the manganese greensand column with potassium permanganate produced better results than intermittent regeneration.

The US EPA has estimated 50% arsenic removal by manganese greensand and that it may be very pH sensitive (Pontius; 2000). High removal of arsenic concurrently with ferrous ions on manganese greensand filters is reported for some well waters in Ontario, Canada (AWWA; 1993). The use of manganese dioxide-coated sand showed promise for As(III) and As(V) removal from ground water. Arsenic concentrations of 0.5 mg/l of each As(III) and As(V) were reduced to less than 0.01 mg/l of total arsenic with 153 to 185 bed volumes per cycle. Regeneration using 0.2 N (8 g/l) sodium hydroxide produced 85% recovery after the first cycle and 94.6 to 98.3% recovery in the subsequent cycles (Bajpai and Chaudhuri; 1999).

A fluidised bed reactor which adsorbs heavy metals including arsenic on to iron oxyhydroxide or manganese dioxide granules has been developed by Krhger A/S in Denmark (Nielsen and Chirstensen; 1996). Laboratory studies have shown that removal efficiencies in excess of 99.5% could be obtained for As(V) and by adding sufficient Fe(II) irons into the water, As(V) concentrations in the treated water could be reduced to less than 10Φg/l. As(III) removal was low; the addition of hydrogen peroxide as an oxidising agent improved the removal efficiency and also the surface loading rate.

The feasibility of using hematite (an iron ore containing "-Fe_2O_3) has been studied for As(III) removal. A 96% removal was reported with an influent concentration of 1.0 mg/l at pH 7.0 and 20°C (Singh et al; 1988). Almost total arsenic removal has been reported in field trials carried out in Mexico (Simeonova; 2000). The hematite used had a particle density of 3.89 kg/l and size 0.88 to 1.0mm. The hematite column was followed by a manganese zeolite column to remove any arsenic slippage. The water tested contained 0.62 to 0.875 mg/l arsenic, about 0.5 mg/l iron and up to 0.4 mg/l manganese. During the initial run depletion of the haematite adsorption capacity was rapid. However, following regeneration using 4% $^{w}/_{v}$ (40 g/l or 1 N) sodium hydroxide 0.02% $^{w}/_{v}$ (2 g/l or 0.05 N) hydrochloric acid, the performance of the hematite improved, giving almost 100% removal, and arsenic values between 0.003 to 0.03 mg/l over run lengths of 31 to 59 hours. The zeolite column was able to add a further 21 hours to the run length until breakthrough from the zeolite column occurred at 0.05 mg/l. Initially the haematite column was operated at pH 5.5, but this resulted in iron solubilisation from the column. This was overcome by operating the column in the pH range 6.0 to 7.0. The haematite column was allowed to run to reduce iron to values in the range 0.05 to 0.15 mg/l because of the downstream zeolite column. The zeolite column achieved almost 100% iron removal, irrespective of the influent concentration. During the test the empty bed contact time and loading rate were optimised for the two beds operating in series at 12 minutes and 2 $m^3/h\ m^2$ respectively. The high concentration of total dissolved solids (268 mg/l), sulphates (71 mg/l as SO_4), silicates (17 mg/l as SiO_2) and fluoride (0.85 mg/l as F) gave poor results from an activated alumina column evaluated on the same source.

A two stage adsorption/filtration system consisting of a coarse sand and iron chip filter followed by a wood charcoal and fine sand filter has been successfully tested in Bangladesh (Khan et al; 2000). Results show that As(III) was almost completely removed from an initial concentration of 0.8 mg/l and the total arsenic concentration was reduced from about 1.0 mg/l to less than 0.01 mg/l. The dissolved iron concentration was reduced from an average value of 6.0 mg/l to 0.2 mg/l. No chemicals including oxidising or pH-correcting agents were used in the process. Wood charcoal helped to remove any organic matter in the ground water. The two filter units took the form of two pitchers placed one on top of the other with the third pitcher used to collect the filtrate. A flow rate up to 100 ml/min was used and the daily capacity was identified to be about 42 to 148 litres.

Laterite soil (composed mainly of hydrated iron and aluminium oxides and hydroxides) has been used in a filter column together with Fe_2O_3/MnO_2 in an adsorption/filtration process developed by Jahangirnagar University

(British Geological Society; 1999), Total arsenic removal was achieved at feed water concentrations in the range 0.05 to 2.0 mg/l, but after a month's use the column showed signs of clogging. This was overcome by using a granular filter medium developed from a mixture of laterite soil/Fe_2O_3/MnO_2. The mixture was treated in a furnace to a temperature of 1400°C and the resulting bricks were broken down to suitable size granules and chemically treated to maximise its arsenic removal properties for a feed water containing 1.8 mg/l arsenic at 250 ml/min. It is reported that the column has a daily capacity of 30 litres and theoretical life to exhaustion of 2 years, after which the media is thrown away. It is claimed to remove both As(III) and As(V).

Some of the other adsorbents studied for arsenic removal include china clay (Yadava et al; 1988), fly ash (Diamatopoulos et al; 1993) Chitosan/Chitin mixture (Elson et al; 1980), Ganga sand (Vaishya and Agarwali; 1993), carbonate Bauxite (Gupta and Chen; 1978) and basic yttrium carbonate (Wasay et al; 1996).

A disadvantage with the use of naturally occurring materials is their limiting adsorptive capacity unless they are modified to improve the adsorption properties.

Membrane processes

In membrane processes a semi-permeable membrane is used to separate materials in accordance with their physical and chemical properties when a pressure differential or electrical potential difference is applied across the membranes. Pressure driven processes are broadly classified according to the membrane pore size and size of particles removed. Microfiltration and ultrafiltration are micro-porous and remove particles by physical separation and are therefore low pressure processes; feed pressure varies in the range 0.5 to 3.5 bar. Reverse osmosis and nano-filtration, which is also known as low pressure reverse osmosis, employ the osmosis principle to separate ions. In arsenic removal both types of membrane systems could be applied in different ways. Micro or ultrafiltration systems are used as a solid-liquid separation stage in chemical precipitation methods and reverse osmosis or nanofiltration systems can be used to remove As(III) and As(V) ions.

Chemical precipitation with iron or aluminium salts followed by microfiltration or ultrafiltration can remove arsenic more efficiently than conventional solid-liquid separation processes because of their much higher efficiency in particulate removal. Pontius has reported removal to less than 2 Φg/l by low pressure membrane processes (Pontius; 2000). When precipitation of arsenic with aluminium or iron salts is used in conjunction with micro or ultrafiltration processes, micro flocs are preferred to the larger flocs used in conventional solid-liquid separation processes. Flocculation should therefore be of the high-energy type. Membranes remove virtually all floc particles and other particulate matter including turbidity. They also remove viruses, E.Coli, cysts and occysts.

Membrane processes are probably better suited for aluminium salts, since with iron salts any residual soluble iron present could precipitate in the membrane pores during chemical cleaning using oxidants, and block the pores. A similar situation could occur with soluble iron and manganese when present in raw water or when manganese is added to the water with the iron salts in which it is usually present as an impurity. However this phenomenon has not been observed in practice; ferric salts have been successfully used in pilot plant work. Primary design parameters are membrane flux, trans-membrane pressure and backwash and chemical cleaning frequencies. Membrane flux for micro and ultrafiltration systems ranges between 80 to 200 l/h.m^2 and trans-membrane pressure varies in the range 0.1 to 1.0 bar, depending on the type of membrane and feed water quality. Membranes are operated in the cross-flow or dead-end mode and either outside-in or inside-out.

Once a layer of particles has formed on the membrane surface, it must be cleaned by water backwash. In practice, depending on the feed water quality, backwash frequency ranges from 30 minutes to 3 hours and the duration ranges between 3 seconds to 3 minutes. Feed water recovery varies between 85 and 98% depending on the feed water quality. Fouling in membrane pores cannot be removed by backwashing and therefore membranes should also be subjected to occasional chemical cleaning. Typical cleaning agents used are: oxidants (chlorine solution, hydrogen peroxide) for bacterial fouling, alkali for bacterial fouling, acids for carbonate scaling and sometimes detergents are also used for bacterial fouling.

Membranes are commonly made of polyethersulphones, cellulose acetate, polypropylene, or polyvinylidine difluoride. Of these all but polypropylene have a high chlorine tolerance and all are suitable for operating at pH values normally found in raw waters. Cellulose acetate has the narrowest operational pH range (4 to 8.5). The low chlorine tolerance of polypropylene membranes would preclude its use in applications where As(III) is required to be oxidised to As(v) using chlorine, unless all residual chlorine is removed by a dechlorinating agent such as sodium bisulphite or granular activated carbon.

Pilot plant trials at Albuquerque, USA with a microfiltration membrane using ferric chloride coagulant at pH 7.3 reduced the As(V) concentration to less than 2 Φg/l (Chiwrika et al; 2000). Since the alkalinity of the water was high, excess ferric chloride was used to reduce the pH from the initial value of 8.5. The design parameters used on the pilot plant are listed in Table 1.5 below:

Parameter	Value
Ferric chloride dose	23 mg/l
Rapid mix velocity gradient	1000 seconds
Detention time	20 seconds
Membrane flux rate	115 l/h.m^2
Time between backwashes	20 minutes

An 8700m^3/d plant where microfiltration is employed with chemical precipitation is planned for the City of Albuquerque (Chiwrika et al; 2000). The flux rate and the backwash frequency used on the pilot plant would be repeated on the main plant.

Yallaly and Kramer investigated removal of As(III) from surface water by adsorption on to powdered activated alumina followed by the removal of the powder by ultrafiltration membranes. Polysulphone and cellulose acetate membranes were tested. As(III) removal was better at 55 to 98% over raw water pH values from 6.6 to 9.5. Since As(V) adsorbs 20 times more efficiently than As(III), they theorised that As(V) removal would be almost complete. Polysulphone membranes performed the better of the two types (Yallaly and Kramer; 2000).

Nanofiltration and reverse osmosis achieve arsenic removal by ionic separation. In nanofiltration rejection of monovalent ions (Na$^+$, K$^+$, Cl$^-$) is poor (40 to 70%), whereas rejection of multivalent ions (Ca^{2+}, Mg^{2+}, SO$_4^{2-}$) or ionic compounds is comparatively high (85 to 95%). Reverse osmosis rejects all dissolved salts at an efficiency of 90 to 98%. The removal of As(V) by reverse osmosis is almost proportional the efficiency of sodium chloride removal (Kang et al; 2000). Early work has shown reverse osmosis membranes of cellulose acetate or aromatic polyamide thin-film composite construction reject As(V) more efficiently (90 to 99%) than they reject As(III) (46 to 75%) (Clifford et al; 1986) (Schneiter and Middlebrook; 1983). Similar rejections have been reported recently for As(V) (95%) (Amy and Brandhuber; 1998) and As(II) (40 to 60%) (Sorg; 2000). Kang et al demonstrated that the removal of arsenic was pH dependent and As(V) was removed far more efficiently than As(III) over the pH range 3 to 10 (Kang et al; 2000).

Test work carried out on ground waters in Finland on point-of-use reverse osmosis devices at a site which contained mostly As(V) at a concentration of 50Φg/l, showed that acetate membranes achieved only 30% removal efficiencies whereas thin film composite membranes gave good results. At another site which contained 350Φg/l As(V) and 150Φg/l As(III) the removal with thin film composite membrane was only 60 to 75% (FEI; 2001).

As(III) removal by reverse osmosis was independent of raw water concentration whilst concentration of less than 0.1mg/l adversely affected the removal of As(V) (Waypa et al; 1997). Fox found that low pressure reverse osmosis rejected about 50% of arsenic in ground water and membrane renewal was required after six months (Fox; 1989). Removal efficiencies by nanofiltration have only recently been investigated and show up to 97% removal of As(V) (Thompson and Chowdhury; 1993).

There is very little published data on recoveries and their effect on performance of ion separation membranes. To a large extent recoveries would depend on the concentration of sparingly soluble salts such as sulphates and carbonates in the water. Therefore nanofiltration membranes which are primarily used for water softening would be better suited. For reverse osmosis Fox quotes recoveries up to 59% (Fox; 1986); Sorg has reported recoveries of the order 75 to 80% (Sorg; 2000c).

Reverse osmosis and nanofiltration membranes require feed water of high quality. The presence of turbidity, organic matter, iron, manganese and bacteria could foul the membranes irreversibly, and unlike micro or ultrafiltration membranes they cannot be backwashed. Chemical cleaning is used to remove calcium carbonate scale and organic solutes. These membranes are therefore more appropriate for groundwater treatment because of the better raw water quality. Also they would be more usefully employed for ground water treatment as arsenic is mostly present as As(III). This would eliminate the need for chlorination for oxidation of As(III), which would otherwise damage those membranes made of materials susceptible to chlorine. Precipitation of calcium sulphate and calcium carbonate could be minimised by the addition of sequestering agents and pH adjustment. Iron and manganese, when present, should either be totally removed upstream of the membranes or maintained in their reduced states by maintaining the feed water anaerobic until the water has passed through the membranes. Organic matter should be removed by granular activated carbon adsorption.

With reverse osmosis and nanofiltration, usually only a proportion of the water is treated and blended with the remainder. The ability to blend would be limited by the arsenic concentrations required in the final water. The product water from reverse osmosis or nanofiltration, known as the permeate, would be low in dissolved solids and could require remineralisation by the addition of lime and carbon dioxide or similar treatment.

Microbiological processes

Arsenic could be removed by coprecipitation or be adsorbed on to ferric oxide produced by biological oxidation of ferrous ions in ground waters. Bacteria which could bring about the oxidation are *Gallionella ferruginea, Leptothix sp., Crenothrix polyspora* and *Sphaeratilus natans.* If the bacteria are absent from the groundwater they could be introduced from a suitable source. Rapid gravity or pressure sand filters could be used as biological reactors. The typical pH range for iron oxidation is 6.0 to 7.5 and the dissolved oxygen concentration required is 0.25 to 1.5 mg/l (Mouchet; 1992). Hambsch et al confirmed that biological oxidation of As(III) did not occur at 4°C; at room temperature the reaction commenced after 3 to 7 days with complete removal after 14 days (Hambsch et al; 1995). The water temperature should be greater than about 10°C, which makes the process ideal for tropical countries or for ground waters in temperate climates. Zinc and hydrogen sulphides are considered to be toxic to the bacteria used in the process.

Pilot plant work by Lehimas et al demonstrated that the critical parameter for arsenic removal is the initial iron concentration. For waters containing 8 to 12 mg/l Fe, a 90% As(III) removal was achieved at an initial concentration of 400 Φg/l. In addition iron was totally removed. With low iron concentrations (1 to 2 mg/l Fe) the removal was poor with 36 to 44% removal. The filtration rate was optimised for iron oxidation as it had no effect on the arsenic removal (Lehimas et al; 2000).

Bacteria which could be used to oxidise As(III) to As(V) in the presence of oxygen and alkalinity have been isolated in Australian mine waters by Macy and Dixon. One of the bacteria grows only in the presence of a small concentration of organic carbon. In laboratory tests using fluidised bed reactors over 99% of As(III) with an initial concentration of 3.0mg/l was converted to As(V), which was then removed by adsorption on to ferric hydroxide or ferromagnetic beads coated with ferric hydroxide (Macy and Dixon; 1998).

5 WASTE DISPOSAL

All arsenic removal processes produce either a liquid waste or a sludge (a high concentration of suspended solids in water), or a solid waste, all of which contains arsenic concentrations many times higher than that which was originally present in the raw water. An exception to this rule are the subterranean processes where precipitated arsenic is retained in the ground (Roff et al; 2000).

Waste characteristics

Characteristics of the waste depend on the quality of raw water and the arsenic removal process employed. All wastes would contain As(V) and, additionally, some would contain As(III). In most wastes arsenic would be adsorbed on to aluminium or iron hydroxide. In adsorption processes using media such as activated alumina or ion exchange resin and membrane processes such as reverse osmosis or nanofiltration, waste would contain arsenic in ionic forms As(III) and As(V), which are soluble.

Other constituents of the waste would be representative of the contaminants present in the raw water and removed in the arsenic treatment process. For surface waters subjected to chemical precipitation, contaminants include suspended solids, colour and organic matter and the pH value would be that of the precipitation reaction. It is reported that the use of lime instead of sodium hydroxide for pH adjustment, the stability of the iron-arsenic sludge increased from pH range to 4 to 7 to range 4 to 9 (Khoe et al; 1997). When softening is used for arsenic removal, calcium and magnesium carbonates and magnesium hydroxide form most of the waste. The pH value would be about 9 or 10 to 11, depending on the softening process used.

The wastes from adsorption processes subjected to regeneration contains regenerant or displaced ions, thus activated alumina adsorption process wastes contain some soluble aluminium, sodium hydroxide and either hydrochloric or sulphuric acid. The pH value of resultant mixed waste would be about 6.5. Ion exchange process wastes contain the regenerant, which is sodium chloride and displaced ions such as sulphates, carbonates and nitrates.

Wastes from nanofiltration and reverse osmosis processes are highly saline, i.e. very high total dissolved solids containing ions of different charges, depending on the process. Reverse osmosis process wastes would contain ions of all charges and total dissolved solids concentration could be 15 to 20,000 mg/l; nanofiltration waste would contain primarily monovalent ions and the total dissolved solids concentration would be about 5000 mg/l. These concentrations would be a function of total dissolved solids in the source water and the percentage recovery of treated water.

Waste quantities

Precipitation processes, which utilise either aluminium or iron salts, generate arsenic containing sludge in the solid-liquid separation stages. Sludge solids contain any suspended solids in the water, precipitates due to true colour which is equivalent to about 0.2 times the colour value in °Hazen (Dillon; 1997) and ferric or aluminium hydroxides; each 1 mg of iron (Fe) applied will produce 1.9 mg of ferric hydroxide ($Fe(OH)_3$) or each 1 mg of aluminium (Al) applied will produce 2.9 mg of aluminium hydroxide ($Al(OH)_3$).

The sludge production when enhanced coagulation is practised could be estimated from the following equations depending on the coagulant used (Parsons; 2000):

Aluminium salts : $S = Q\,(0.36\ CD + X + TOC)$
Iron salts : $S = Q\,(0.5\ CD + X + TOC)$

Where S - sludge produced (kg/d), Q - flow (Ml/d), CD - coagulant dose (mg/l as Al or Fe), X - any additional chemical doses (mg/l) and TOC - total organic carbon (mg/l).

In surface water treatment suspended solids, colour and the precipitate from iron or aluminium salt would contribute to the sludge solids, whereas in ground water it would primarily be due to the precipitate from iron or aluminium salts used and from any iron present in the water. Volumetric quantities of waste would also vary with the raw water quality. In surface water treatment solid-liquid separation processes could include both sedimentation and filtration stages. The quantity from the sedimentation stage could vary in the range 1 to 2.5% of the inflow depending on the raw water quality and that from the filtration stage could be in the range 1.5 to 2.5% of the inflow depending on the frequency of backwashing of filters. Total wastewater flow would be in the range 2.5 to 5% of the inflow. Therefore the arsenic concentration in the waste stream could be 20 to 40 times that in the raw water. The dry solids concentration in the sedimentation and filtration waste streams would be up to 2.5 g/l (0.25%$^{w}/_{v}$) and 0.25 g/l (0.025%$^{w}/_{v}$) respectively.

In ground water treatment plants, because of the better raw water quality, the sludge quantity and dry solids concentration would be smaller. Solid-liquid separation treatment may consist of a sand filtration stage or a membrane filtration stage; the quantities and concentrations would be of the order of 1%$^{v}/_{v}$ at about 0.5 g/l (0.05%$^{w}/_{v}$) and 2.5%$^{v}/_{v}$ at about 0.2 g/l (0.02%$^{w}/_{v}$) respectively. Therefore, for example, sludge from a groundwater treatment plant removing 1 mg/l arsenic by precipitation could contain 200g As per kg of dry solids.

Ion exchange plants normally generate liquid wastes, which contain primarily sodium chloride from the regenerant, high concentrations of arsenic and dissolved solids with a high sulphate concentration since it is removed preferentially to arsenic. The regenerant volume is of the order of 5 bed volumes and the displacement water rinse volume varies in the range 2 to 6 bed volumes (Perry et al; 2000). For example, the regenerant from an ion exchange column treating 1000 BV of water with an arsenic concentration of 1 mg/l could contain up to 200 mg/l of arsenic. Clifford et al have reported that both the salt usage and regenerant volume could be minimised by reusing the waste for several regeneration (Clifford et al; 1998). The removal of sulphates in the waste by precipitation with calcium chloride would allow waste to be reused almost indefinitely (Perry et al; 2000).

Regeneration of activated alumina produces a waste high in soluble arsenic and dissolved solids. In addition it could contain some aluminium; up to 2% of alumina could dissolve during the regeneration cycle. The pH value of waste would vary according to the stage of the regeneration cycle. During the caustic soda wash phase its concentration could be of the order of 0.25N and during the acid wash the concentration could be about 0.4N. When mixed the resulting waste would be alkaline. The regenerant volume is of the order of 5 to 10 bed volumes. Acid and water rinse volumes are typically 5 and 2 to 5 BV respectively. The arsenic concentration in the waste would depend on the raw water arsenic concentration and the number of bed volumes treated between successive regenerations. One report suggests an arsenic concentration range of 23 to 41 mg/l and a pH of 12 (Clifford and Lin; 1991). Another study has confirmed these arsenic concentrations with similar values of 20 to 40 mg/l (Simms and Azizian; 1998).

Adsorption media such as granulated ferric hydroxide which are not usually regenerated once exhausted, do not produce a liquid waste or a sludge. The exhausted material could contain an arsenic content in the range 1 to 10 g/kg (Driehaus; 1998).

The quantity of waste from nanofiltration and reverse osmosis processes would depend on the concentration of sparingly soluble inorganic salts such as calcium sulphate, and in turn, water recovery. Typically the recovery could be between 75 to 90%. The reject flow from reverse osmosis and nanofiltration could therefore contain from 5 to 10 times the raw water arsenic concentration and would be very saline because these processes reject most of the ions present in the water. The very high waste volume from these processes would be a concern.

There are several other less commonly used arsenic removal processes. The quantities of waste generated from these processes are not well documented.

Waste treatment and disposal

Not many countries have standards for arsenic in waste sludges returned to the environment. The US requirements are summarised by Chwirka et al, 2000. Under the US Resource Conservation and Recovery Act, sludge from an arsenic removal plant may be defined as a hazardous waste if it contains 5.0 mg/l or more of arsenic. For liquid wastes containing less than 0.5%$^{w}/_{v}$, (5 g/l) solids, the 5.0 mg/l criterion is applied to soluble arsenic in the liquid fraction. For solid wastes and liquid sludge containing more than $0.5\%^{w}/_{v}$ solids, the solids should be subjected to Toxicity Characteristic Leachate Procedure (TCLP). TCLP test consists of rotating a flask containing approximately 125g of sludge in a solution of glacial acetic acid at pH 4.8 for 18 hours. The resulting solution is filtered and the filtrate is analysed for arsenic. For sludge containing less than $0.5\%^{w}/_{v}$ solids, the sample is filtered without any chemical treatment and the filtrate analysed for arsenic.

Chemical precipitation processes would produce sludge derived from solid-liquid separation processes such as sedimentation or filtration. Arsenic would be adsorbed by the chemical precipitate, which would be either aluminium or ferric hydroxide. Water present in the sludge would generally be free of arsenic or at most could contain trace concentrations of arsenic.

Disposal processes would normally consist of separation of water from the sludge by settlement or thickening, followed by dewatering of the concentrated sludge by mechanical methods or by evaporative drying. The recovered water, which could contain small concentrations of arsenic, could be discharged to a watercourse. The dewatered sludge would normally be disposed in a landfill. Concentration of sludge by either settlement or thickening or both would be desirable as these processes help to reduce the volume of sludge for subsequent treatment. They also help to recover water either to recycle back to the treatment plant, reuse such as for irrigation or discharge to a watercourse.

Wastes from filtration processes are generally dilute containing less than about 250 mg/l dry solids. This is normally concentrated about 20-fold by settlement in tanks over a period of several hours. The rate of settlement could be significantly increased by adding a settling agent such as natural settling aids e.g. sodium alginate, starch, activated silica, or synthetic varieties such as polyelectrolytes. Supernatant could be drawn-off by devices fitted with floats, so called floating arm draw-off units, outlets fitted with removable weir boards or by pumps. The supernatant liquor usually contains less than 10 mg/l suspended solids.

Sludge from sedimentation processes contains much higher concentrations of solids (about 2,500 mg/l) and is normally concentrated 10-fold by thickening with the aid of natural settling aids or synthetic polyelectrolytes. When both sedimentation and filtration are used to separate chemical precipitates, the settled sludge from the used filter washwater treatment is usually mixed with the sedimentation process sludge in the thickeners. The supernatant from the thickeners usually contains less than 10 mg/l suspended solids and could be recycled, reused or discharged to a watercourse.

Thickened sludge, which now contains about 10 per cent of the original waste flow, is dewatered. Dewatering could be by low technology methods such as lagoons or drying beds or by high technology mechanical methods.

Lagooning is suitable where land is not at a premium. It is, usually, a simple method of sludge disposal, employing either man-made basins with earth embankments or natural depressions in the ground. The mechanism of dewatering of sludge in a lagoon involves a combination of evaporation and drainage. Lagoons are not usually provided with an underdrainage system and the water separating from the sludge percolates into the soil.

The contribution of drainage to the total loss of water depends on the permeability of the soil and the characteristics of the sludge. The nature of chemical sludge is such that where drainage is not controlled it compacts rapidly to an impermeable mass, blinding the soil underneath. Thus, in a short period the lagoon becomes impermeable and dewatering occurs predominantly through evaporation. The effectiveness of the lagoon, therefore, becomes significantly influenced by those climatic conditions, which affect the evaporation rate, mainly temperature, humidity and wind velocity. If the lagoon floor is largely impervious, performance will be impaired by heavy rainfall; the rainwater collecting in the lagoon increasing the water content of the sludge. Lagooning is in general an inefficient method for dewatering chemical sludge, particularly when climatic conditions are not ideal for drying. Typical average solids concentrations in well designed and operated lagoons range from 10 to $15\%^{w}/_{w}$, the higher concentration being reached after many years of gradual consolidation (Albrecht; 1972), (Chappell and Burley; 1971). The concentration of solids in a lagoon, however, is rarely uniform throughout the depth. It is reported by Hubbs and Pavoni that in several lagoons tested, the concentrations range from $1\%^{w}/_{w}$ at the surface to $14\%^{w}/_{w}$ at the bottom (Hubbs and Pavoni; 1974).

If lagoons are intended to be permanent they may be made very deep - as much as 6m. In most instances these would be existing basins either natural or man-made, such as gravel pits or quarries, and having a variable depth. These lagoons, when full, must be abandoned since the removal of sludge for ultimate disposal is both difficult and uneconomical. Alternatively, shallow reusable lagoons may be used, the sludge being regularly removed after drying; the depth of sludge in such lagoons may range from 0.75 to 1.25 m. The lagoon is usually filled over a period of about 9 to 15 months, and is then rested to permit drying over a period of up to about 6 months, before dried sludge is removed for ultimate disposal. Where this method of operation is practised, at least three lagoons should be provided, one being filled, one rested for drying and one being emptied. It is generally recommended that a minimum of six or seven lagoons should be made available (Burley; 1974). In sizing lagoons, allowance should be made for storage of sludge during wet months when lagoons are unproductive.

The removal of sludge from lagoons may be accomplished by the use of a dragline or front loader. The layout of the lagoons should permit easy access for the removal equipment. When sludge is discharged to lagoons it is initially thin and significant settlement occurs during the first few weeks leaving a supernatant which can be removed to accelerate dewatering by evaporation. The lagoons should therefore be provided with weirs in removable sections for decanting the supernatant, which could be discharged, to a watercourse. The weir arrangement would also permit removal of rainwater collected in lagoons after a storm. Siting of lagoons is critical to their performance. They should be located above the water table and ideally should be in an area unaffected by runoff. The latter is rarely possible, in which case the lagoons should be bunded to protect them from run-off. They should also have maximum access to wind and sun. The poor solids concentration achieved in lagoons precludes the use of abandoned lagoons for any form of development. Furthermore lagoons present a safety problem in view of the possibility that persons or animals may fall into them. They should therefore be fenced off. Where desludging is practised the solids, with an average concentration of $10\%^{w}/_{w}$, but a limited use as fill material and can pose ultimate disposal problems.

Lagooning can be economic where land is inexpensive, is readily available for use with the minimum of preparation, and where there are no plans for ultimate use. Where lagoons are filled and abandoned, the method can prove more expensive than would first appear, if the actual life expectancy proves to be significantly less than the estimated life. The operating costs are expected to be low unless ultimate disposal of sludge poses problems. Drying beds are an improvement on lagoons in terms of dewatering efficiency. They differ from lagoons primarily in that they are provided with a permeable supporting sand base and underdrainage system. Dewatering is therefore accomplished by both evaporation and drainage. The latter is a fast process, and accounts for a significant proportion of the total water lost including almost all the initial water loss. For effective performance therefore, the provision of an adequate underdrainage system is a necessity. After a period of time drainage gradually ceases to be the dominant factor, leaving evaporation as the major process by which further dewatering can be effected. The permeable sand base may become blocked, so that from very early stages evaporation becomes the predominant mechanism of dewatering.

The efficiency of the drainage process is a function of the depth and the size grading of the sand layer. Deep layers of fine sand are known to retard the drainage process. Typically the supporting bed consists of 150 to 250 mm of sand of uniformity coefficient less than 4 and effective size between 0.3 and 0.75 mm supported by about 300 mm of graded gravel laid over an underdrainage system of vitrified clay pipes laid with open joints and covered with coarse gravel. Sludge dewatering by evaporation of water due to convection and radiation is a slower process and the degree of drying is a function of temperature, humidity and the wind velocity. Climatic changes, in particular rainfall, do not affect the rate of drainage. Rain falling during drainage, however, would prolong the drainage period. Rain falling in the later stages of evaporation, once the sludge is well cracked should not retard the dewatering process, but rewetting of drying sludge by rain would affect the performance of the drying beds. The effect of rain on the dewatering processes could be prevented by covering beds during wet months. The gain on drying time for covered beds could be up to 20%. Higher gains are possible if the enclosures are properly ventilated.

The depth of sludge on drying beds affects dewatering by both evaporation and drainage, the shallower the depth the greater being the dewatering efficiency. Chemical sludges are usually applied in a 200 to 300 mm layer, and allowed to dry. When dry, the sludge is removed before the next application. Alternatively, sludge may be spread in say 50 mm layers on several beds to a total depth of about 300 mm. After placing each layer, sludge is allowed to dry before the next layer is placed. The practice of layering, however, leads to deterioration in drying performance and is not likely to give any savings in drying time. The operation of drying beds is similar to that of lagoons and at least three beds should be provided; one each for filling, drying and emptying. A total of six or seven drying beds would be desirable. In drying beds, chemical sludges dewater to about 15 to $25\%^{w}/_{w}$ dry solids. The removal of solids is effected either by manual shovelling into trucks or, for large beds, by scraping using front loaders or travelling bridge scrapers. Drying beds are economical for dewatering small quantities of sludge, when cheap land is readily available and low cost construction methods are used. Operational costs would vary according to the method of sludge removal adopted and the cost of replacing sand lost from the beds.

Next to lagoons, drying beds are the most commonly used sludge dewatering system. The drainage from lagoons and drying beds and any supernatant water decanted from lagoons would normally be free of arsenic. Therefore lagoon drainage could be allowed to percolate into the soil and drainage from drying beds and supernatant from lagoons could be discharged to a watercourse. During sludge removal operations in lagoons and drying beds, manual handling would bring workers into contact with arsenic bearing sludge. Although there is one reported case where a patient developed toxic symptoms after dermal contact (Van den Berg, 1999), such workers should be regularly tested for dermal adsorption. To minimise risk of contamination workers should be encouraged to wear boots and gloves during handling.

Mechanical dewatering devices include plate and frame filter presses with or without the use of membranes inflated by air or water belt presses and centrifuges. All of the processes are dependent on polyelectrolytes for optimum performances. Although other material such as hydrated lime, coal dust or diatomaceous earth are known to improve the performance of presses. Centrifuging and belt pressing are continuous processes and dewater sludges to about 12 to 20% $^{w}/_{w}$. Filter pressing is a batch process and produces a cake of dry solids content in the range 20 to 30% $^{w}/_{w}$. Dewatered sludge would be disposed to landfills.

Liquid wastes containing arsenic such as those originating from ion exchange, activated alumina adsorption processes or ion separation membrane processes i.e. reverse osmosis or nanofiltration would not normally be allowed to be discharged to lagoons or watercourses. These wastes may be accepted in sewers, if available in the proximity of the arsenic removal plant and depending on the sewage treatment employed. They should be treated with ferric or aluminium salts to precipitate arsenic. In practice iron or aluminium salts are required in greater than stoichiometric quantities. It is reported that a wastewater from an ion exchange plant containing 90 mg/l As(V) and total dissolved solids of 50,000 mg/l required about 12 times the stoichiometric quantity of iron with the pH adjusted to 8.5 or aluminium with the pH adjusted to 6.5 to reduce the As(V) concentration to 5 mg/l (Clifford; 1991). A 20-fold stoichiometric dose of either iron or aluminium salts was required to achieve a reduction of As(V) to less than 1.5 mg/l.

The regenerant waste product from the activated alumina process contains a moderate quantity of soluble aluminium. This is considered to be adequate to precipitate As(V) in the waste, subject to lowering the pH of the wastewater to about 6.5. Any As(III) present should be oxidised to As(V) by chlorine prior to pH adjustment. Work has been carried out in the USA to establish the best methods for treating liquid wastes containing arsenic generated from processes such as activated alumina, ion exchange, reverse osmosis and nanofiltration (MacPhee et al; 2000). The methods compared included precipitation using aluminium sulphate or ferric chloride and adsorption processes. The results are given in the Table 1.6 below.

Table 1.6 : Comparison of treatment processes for arsenic removal in wastewater (MacPhee et al; 2000)

Wastewater		Treated water arsenic concentration (mg/l)					
Source	Arsenic Conc (mg/l)	Precipitation		Adsorption			
		$Al_2(SO_4)_3$	$FeCl_3$	Fe-based media	AA	IX	Modified AA
Activated alumina (AA)*	2.63	-	0.154	-	-	-	-
Ion exchange (IX)(A)	10.5	5.98	1.28	3.60*	-	-	-
IX(B)	24.8	22.8	18.7	22.3	24.0		
Reverse osmosis (RO)(A)	0.526	0.526	0.041	0.252*	0.526		
RO(B)	0.663	0.286	0.078	0.018	0.071		
Nanofiltration (NF)(A)	0.523	0.029	0.009	0.021	0.034	0.535	0.376
(NF)(B)	0.486	0.035	0.005	<0.002	0.004	0.438	0.452

Note: Adsorption processes were operated at an empty bed contact time of 3 minutes and samples tested after 120 bed volumes have passed through the column, expect for '*' where an empty bed contact time of 1.5 minutes was used.

These results indicate that ferric chloride out-performed aluminium sulphate and of the adsorption processes activated alumina and iron-based media performed equally well. They also show that ion exchange regenerant wastes were most difficult to treat; nanofiltration and reverse osmosis process wastes generally treated well by most processes. The exceptions being the ion exchange and modified activated alumina processes.

MacPhee et al also concluded that the molar ratio of Fe : As varied in the range 4 : 1 to 143 : 1 and the optimum pH was 5.0 to 6.2. Other findings were that the results from the toxicity characteristic leachate procedure (see later) on adsorption process media were all well below the limit of 5.0 mg/l (the current US standard) and also less than 0.5 mg/l, which could be established as the new US standard. In the case of waste regenerants, after precipitation or adsorption the liquid remaining would have low arsenic concentration but could contain a high concentration of total dissolved solids and it should not be discharged to a watercourse unless sufficient dilution could be achieved in the receiving waters. In sewered areas, discharge of treated liquor to sanitary sewer could be acceptable depending on the treatment applied. For coastal sites it could be discharged to the sea. In arid areas it could be evaporated in ponds and the resulting salt taken to a landfill or disposed in the sea. The evaporation ponds should be lined and receiving landfill sites should also have liners to prevent any drainage from it contaminating the ground water.

Adsorption processes, which do not employ regeneration do not have a liquid waste problem. The media are used for a single application and therefore generate a solid waste. The best disposal route is landfill provided it can be shown by leachate tests that arsenic is fixed to the adsorbent. UK Severn Trent Water has carried out leachate tests with granulated ferric hydroxide media containing 2.3%$^{w}/_{w}$ arsenic, using conditions to simulate leachants from methanogenic landfills. Five separate 24-hour contact periods were used. Each time the media was subjected to a fresh leachant: over the 5-day period 3.5mg arsenic leached out. Further tests showed that when a media containing 0.036%$^{w}/_{w}$ arsenic was subjected to toxicity characteristics leachate procedure (TCLP) (see later), less than 5Φg/g of arsenic leached (Selvin; 2000a).

Arsenic contaminated dewatered sludges or solid wastes should not be disposed on domestic waste landfills because low pH values of liquor resulting from the biological action in the presence of moisture in such landfills could dissolve arsenic adsorbed on to iron or aluminium hydroxides and contaminate ground water. Of the two, aluminium hydroxide is stable over the narrow pH band of about 6.2 to 7.2 whereas ferric hydroxide is stable over the pH range of about 4 to 10. If domestic landfills are to be used, the landfill should be made impermeable by a lining of clay or better with a synthetic material such as polyethylene. To minimise the moisture content in the landfill, sludge should be ideally dewatered to about greater than 20% by weight. The landfill should be fenced in and made 'out of bounds' to scavengers, because of the potential risk of developing toxic symptoms by dermal adsorption.

Alternatively landfills dedicated to arsenic contained sludge could be used. These could also be used for other chemically compatible sludges and inert wastes. These landfills should also be provided with an impermeable lining. Landfills should be sited above the natural ground water and flood levels. They should be located away from ground water sources or aquifers feeding such sources. In the selection of a suitable site a hydrogeologist should be consulted. Landfills should be provided with a drainage collection system. Such drainage, if it contains arsenic, should be treated with a ferric or aluminium salt before disposal.

Since the permanence of the impermeable lining cannot be guaranteed, it is recommended that several observation wells are placed in strategic locations for monitoring the ground water for arsenic and other contaminants such as iron or aluminium. Experiments carried out by the School of Environmental Studies at Jadavapur University, Calcutta have shown that mixing arsenic bearing sludges with cow-dung would convert arsenic to its methylated form by micro-organisms present in cow-dung and release it to air. (Jadavapur University; 2000).

Dewatered sludges and solid waste from non-regenerable processes may find application in several industries depending on the environmental conditions they are subjected to. Sludges and solid wastes containing iron are the most useful. Typical applications may include:

- production of high grade iron and steel containing arsenic and cast iron (Henke; 1989);
- sulphide binding to prevent hydrogen sulphide generation in sewers and sewer lining corrosion;
- ceramic industries (brick, tiles and other products) to supplement iron in clay to between 5 and 7% by weight to give the red coloration;
- to produce ferric chloride by the action of hydrochloric acid for use in sludge dewatering or phosphate removal in wastewater treatment;
- as an additive in the manufacture of aggregate and cement (Cornwell; 1990).

Of these methods, use in the iron and steel industry is not proven and research needs to be carried out to establish its technical and economic feasibility on a large scale. The use in sewers or in sewage treatment (as ferric chloride) where such facilities are locally available is viable provided the arsenic concentration is within the limits acceptable to the sewerage authority. The use of waterworks derived ferric sludges in the ceramic industry as a colourant to add a red colour and as a flux is used in many countries. Experiments have been successfully carried out mixing dry clay with 10% liquid sludge containing 5%$^{w}/_{w}$ solids and 10 to 15% liquid sludge containing 15 to 20%$^{w}/_{w}$ solids. During brick production organic matter in the sludge reduced the firing temperature. The metal hydroxide content helped to produce a low porosity brick (Owen; 2000). In practice a temperature reduction of about 50°C is known to be feasible, thus reducing the energy required during the firing process. Owen has reported that in one specific case the total savings to the brick manufacturer was estimated at £(UK)15,000 per annum. In the UK bricks made from ferric sludges are used in house building (Anon; 1985).

The most likely application of iron sludges containing arsenic is in the manufacture of bricks. The high temperatures (about 900°C) used in the brick kilns are expected to fix arsenic. Work carried out by Harbauer GmbH of Germany (a manufacturer of granulated ferric hydroxide), has demonstrated that heating the adsorbent containing arsenic to 900°C caused no detectable emission of arsenic. It is also reported that the leachable arsenic content of bricks in contact with distilled water for 24 hours was less than 1% by weight (Harbauer; 1999).

Arsenic bearing sludges could be stabilised using ordinary portland cement (OPC). Leachate tests carried out using dried arsenic sludge produced by co-precipitating As(V) with ferric sulphate and mixed with OPC and lime in the ratio, dried precipitate : cement : lime : water of 4 : 0.8 : 0.2 : 3 indicated that dissolved arsenic in the leachate was less than 5 mg/l (US TCLP limit) (Khoe et al; 1997). This stability was considered to be due to the formation of calcium arsenates, which are insoluble. It has also been concluded that iron oxide compounds in the stabilised product would control the release of arsenic due to the absorption of atmospheric carbon dioxide by controlling the resulting pH to about 8.

6. REVIEW OF METHODS AVAILABLE FOR THE ANALYSIS OF ARSENIC IN DRINKING WATER

Introduction

Arsenic may be present in surface derived or ground water sources used for drinking purposes at concentrations up to 2 or 3 mg/l, although more typically it is present at much lower levels e.g. 0.1 to 0.2 mg/l. The World Health Organisation (WHO) has a guideline value of 0.01 mg/l (10 Φg/l) for arsenic in drinking water (WHO; 1993), while the US Environmental Protection Agency (USEPA; 1975) and the European Union (CEC; 1999) have criteria of 0.05 mg/l (50 Φg/l) and 10 Φg/l respectively. The USEPA is currently considering the downward revision of its standard value to 5 Φg/l.

Arsenic may be present in water in particulate, colloidal or soluble form. In the latter state it may be present either as the Arsenite (trivalent) or Arsenate (pentavalent) form. It is found in both organic or inorganic compounds but in water is more typically present in the latter form. In groundwater it is frequently present in association with iron in its lower oxidation state (Fe^{2+}) or less commonly manganese. At the concentrations found in surface and ground water arsenic compounds are colourless, odourless and tasteless and is not easily detectable by simple chemical techniques. However a number of instrumental methods which permit the detection of arsenic at concentrations down to 1 Φg/l or less are available. Such equipment is expensive and only usually available in laboratories run by universities, government organisations or commercial analytical services.

Arsenic (V) may be co-precipitated with iron (Fe^{2+}) when both are present in groundwater which comes into contact with air, for example, when sampled. It is therefore important that the appropriate precautions are taken when samples are collected, particularly if the analysis is not to be carried out within a few hours of sampling. The use of a number of preservatives has been investigated for use with samples intended for the analysis of arsenic in water. These include hydrochloric, nitric, sulphuric and ascorbic acids. Their use is discussed in more detail in the following section dealing with analytical methods, since in some cases they are specific to a particular technique.

A number of other compounds or ions can interfere with the determination of arsenic; these include hydrogen sulphide, chloride, phosphate, nitrate, sulphate or iron. These are also discussed in more detail in the following Section since they are also frequently specific to a particular method.

Laboratory Methods

Electrothermal Atomic Absorption Spectrometry, Method 3113B (APHA, AWWA, WEF; 1998)

Atomic absorption spectrometry (AAS) using flame atomisation is not a suitable method for the determination of low levels of arsenic, but modifications of the technique permit the detection of concentrations of 1 Φg/l or less.

The use of electrothermal (graphite furnace) atomic absorption (GFAA) permits the determination of arsenic with significantly increased sensitivity and detection limits over conventional flame AAS. In addition only very small sample volumes are required. The technique is, however, subject to more interference and requires more time to complete the analysis. It is recommended that the technique of standard addition be used to ensure validity of data. This is the preferred technique in the absence of overwhelming interference. In this technique an electrically heated atomiser (graphite furnace) replaces the standard burner head. A discrete sample volume is dispensed into the graphite sample tube. Typically determinations are made by heating the sample in three or more stages. In the initial stage the sample is dried, in the second organic matter is destroyed and other matrix components are volatilised. Finally a high current heats the tube to incandescence and, in an inert atmosphere, the element is atomised. Electrothermal atomisation determinations may suffer significant interferences from molecular absorption, chemical and matrix effects. Various background correction techniques are commercially available for the former, while chemical modifiers are used to modify relative volatilities of matrix and metal, and are typically used at high concentration. The use of the standard addition technique can compensate for matrix interference which give rise to low recovery rates.

Nitrogen or argon are used as inert purge gases, although the latter provides greater sensitivity. Further increases in sensitivity may be achieved by the use of pyrolytically coated graphite tubes. The Method Detection Limit (MDL) for GFAA may be as low as 1 Φg/l and this can be improved by the use of 'Stabilised Temperature

Platform Graphite Furnace AA' together with the multiple deposition technique which together are capable of providing a detection limit of 0.1 Φg/l.

The apparatus required includes the following:

- Atomic absorption spectrophotometer with background correction
- Source lamp
- Graphite furnace with minimum of three heating steps, argon as purge gas and graphite tubes
- Sample dispensers (5 to 100 Φg/l), cooling water supply, membrane filtration apparatus.

Hydride generation - Atomic Absorption Spectrometry, Method 3114B *(APHA, AWWA, WEF; 1998)*

In this technique arsenic is converted to arsine (arsenic hydride) gas by the addition of sodium borohydride and hydrochloric acid. Hydride generation may be either manual or continuous. The latter technique offers good reproducibility, lower detection limits and high sample volume throughput. It is the preferred method when interferences are present that cannot be overcome by standard electrothermal techniques. The arsine formed is purged by argon or nitrogen into an appropriate atomiser of an AAS and converted to gas phase atoms.

At room temperature and solution pH values of 1 or less any arsenic in the As(V) state is converted slowly by sodium borohydride to As(III) which is almost immediately converted to arsine. The As(V) absorption peaks are decreased by about 25 to 30% when compared to the equivalent concentration of As(III). Determination of total arsenic requires that all inorganic arsenic compounds are in the As(III) state. Organic and inorganic forms of arsenic are first oxidised to As(V) by acid digestion which is then quantitatively reduced to As(III) with potassium iodide before reaction with sodium borohydride.

The apparatus required includes the following:

- Atomic absorption spectrophotometer
- Hydride generation kit with quartz atomisation cell
- Source lamp.

Interferences are minimal since the arsine is removed from the solution containing most of the potential interfering substances. The presence of other hydride forming elements at concentrations greater than 1 mg/l may interfere and may suppress arsine formation. Such elements include Selenium, Bismuth, Antimony, Tin and Terullium. Consistency in borohydride and hydrochloric acid concentrations are important since variation may result in inconsistent results. The recommended concentrations are 4% $NaBH_4$ in 0.1% NaOH, and 4 to 6N HCl. Nitric acid should not be used in the hydride generation method. The MDL is 0.5 Φg/l and the optimum concentration range is 2 to 20 Φg/l.

Plasma Emission Spectroscopy, Methods 3120A & 3125 *(APHA, AWWA, WEF; 1998)*

An Inductively Coupled Plasma (ICP) source consists of a flowing stream of argon gas ionised by an applied ratio frequency field typically oscillating at 27.1 MH_z. This field is inductively coupled to the ionised gas by a water cooled coil surrounding a quartz "torch" that supports and confines the plasma. A sample aerosol is generated in an appropriate nebulizer and spray chamber and is carried into the plasma through an injector tube located within the torch. The sample aerosol is injected directly into the ICP, subjecting the constituent atoms to temperatures of about 6000 to 8000^{o}K. Because this results in almost complete disassociation of molecules, significant reduction in chemical interferences is achieved and low detection limits are attainable for many elements. The light emitted from an ICP is focussed onto the entrance slit of either a mono or polychromator that effects dispersion. These are linked with a computer controlled scanning mechanism to monitor emission wavelengths, either sequentially or simultaneously; the former giving improved sensitivity and the latter greater sample throughput.

The estimated detection limit for ICP is 50 Φg/l with an upper concentration limit of 100 mg/l. The analysis utilises a wavelength of 193.7nm. Interferences may be caused by elements with similar special lines, high dissolved solids content causing 'drift' or chemical interference by molecular compound formation due to the nature of the sample matrix. The sensitivity and detection limits attainable may be improved by changing the type of detector which is linked to the ICP. Typically this will be a mass spectrometer (MS) or atomic emission spectroscopy (AES), which provide detection limits of <1.0 Φg/l and 8 Φg/l respectively for arsenic. The ICP-AES method is widely utilised for As concentrations greater than 50 Φg/l. In the MS technique ions generated in the plasma are extracted through a differential vacuum interface and separated on the basis of their mass-to-charge ratio by the MS. The ions are counted by an electron multiplier detector and the resulting information processed by a computer based data system. A recovery of 97% has been shown for a 1.0 Φg/l As standard using ICP.MS.

In 1994 US EPA approved the use of selective ion monitoring linked with ICP-MS which, together, are capable of achieving an MDL of 0.1 Φg/l for arsenic.

Miscellaneous Instrumental Methods

Ion Selective Electrodes

Arsenate in high concentrations may be measured by titration using a fluoride electrode with a reference electrode as the end point indicator. A solution of sodium fluoride is used as the titrant. The sample is prepared by adding an excess of lanthanum nitrate to precipitate arsenate. The excess lanthanum being determined by back titration (Orion Research; 1982). Trivalent arsenic in high concentrations may be determined by titration using a combination redox electrode as the end-point indicator and a solution of potassium permanganate as the titrant. (Orion Research; 1982).

Anodic Stripping Voltammetry (ASV)

Anodic stripping voltammetry is a USEPA approved (EPA Method 7063) electrochemical method which utilises gold film/fibre electrodes with computerised instrumentation. It is a fairly rapid method, is capable of producing the required sensitivity and also provides speciation of As(III) and As(V) ionic states. The presence of antimony, bismuth or copper may give rise to positive interference, while turbid samples should be filtered through a 0.45 Φm membrane to prevent physical erosion of the gold film. The ASV technique, which is similar to polarography, involves two steps; in the first the metal is plated from solution onto the cathode; in the second step the electrode becomes the anode and the metals are stripped sequentially from it by application of a potential sweep (pulsed). Metals are stripped at potentials which are characteristic of them and the currents which flow are proportional to the concentration of the particular elements of the original solution. As with polarography, interferences due to overlapping of plating potentials and changes of potential due to complexion are not unknown, but can be overcome.

The apparatus may be relatively simple and inexpensive, but analysis time is rather long. More complex and expensive units are available on which more rapid detection and multi-element analysis can be carried out. Work is currently being carried out (Huang and Dasgupta; 2000) into the development of a field instrument utilising this technique.

Polarography

Polarography offers an alternative electrochemical analytical technique, although it is not widely used for the determination of arsenic. The principal of the method is that a solution containing an electroactive species is subjected to a linear potential increase from about +0.1 volts to -1.5 volts between, usually, a dropping mercury cathode and a suitable reference electrode as anode; a graph of the current against the potential being made. The potential at which a sudden increase in current occurs is characteristic of the ionic species discharging at that potential, and the magnitude of this current rise is directly proportional to the concentration of the species. The half wave potential varies with the ion, its oxidation state and the composition of the electrolyte. Analyses are made by comparison of current increase given by the sample at the appropriate potential with that given by standard solutions of the metal of interest at the same potential.

Total Reflection X-ray Fluorescence (TXRF)

This method gives the total arsenic concentration independent of the chemical or ionic state and is highly sophisticated and accurate. It is, however, unsuitable for the routine analysis of a large number of samples.

Instrumental Neutron Activated Analysis (INAA)

This technique utilises 669.1 KeV gamma rays and achieves the necessary detection limits for arsenic. It is currently a technique more applicable to a research laboratory than routine analysis.

Proton Induced X-ray Emission (PIXE)

Multi-element water analysis is possible with this system by the analysis of a water residue. The MDL attainable is also satisfactory, however sample preparation is slow and the necessary equipment is not widely available.

Laboratory Colourimetric Methods (HMSO; 1972)

There are two principal methods, which utilise 'wet' chemical techniques, they are based upon the use of either silver diethyldithiocarbamate (SDDC) or mercuric chloride. These are based upon the Gutzeit procedure in which inorganic arsenic is reduced to arsine by hydrogen generated in-situ by the action of hydrochloric acid on zinc. The purity and particle size of the zinc, and the acid strength are important in the replication of data. An initial oxidising stage for the destruction of organic matter may be required, this involves the use of strong acids such as perchloric or a sulphuric-nitric mixture. Increased sensitivity may be obtained by the use of an initial sample concentration stage under acid conditions.

The recommended 'wet'-chemistry method is based upon the use of silver diethyldithiocarbamate and is used when greater precision and accuracy are required. The mercuric chloride stain method is typically confined to qualitative tests only. In the former technique arsine is generated and passed through a guard tube containing lead acetate wool, then into a bubbler tube containing silver diethyldithiocarbamate dissolved in pyridine in which arsine reacts with the silver salt forming a soluble red complex which is determined photo-electrically. Pyridine, which is carcinogenic, may be replaced by chloroform.

The two main interferences are germanium and antimony, which may be dealt with either by separation or by calibration techniques. In addition, reducible anions such as nitrate and chlorate will require preliminary reduction. The chemical reagents used are, based upon a 50ml sample, 2g potassium iodide, 2ml stennous chloride (40% in 20%HCl) and 10ml concentrated hydrochloric acid. Then 3.0ml of silver diethyldithiocarbamate is added followed by 10g zinc. The reaction time is 30 minutes. A reagent blank should be prepared. The optical densities of the test and blank solutions are then measured either on a spectrophotometer at 540nm or on an absorptiometer with a green filter. The sample concentration is derived from a calibration graph. Without the use of preliminary sample concentration the typical working range for this method is 1 to 10Φg arsenic in a 50ml sample, equivalent to a concentration range of 20 to 200Φg/l As.

In the mercuric chloride stain method arsenic is reduced after destruction of any organic matter by nascent hydrogen to arsine which is passed through mercuric chloride paper; the resulting stain is compared with standard arsenic stains.

Six sets of apparatus (120ml capacity wide-mouth bottles, rubber bung through which pass a 6.5m ID x 200mm glass tube) are usually used for the preparation of the standard stains. Each tube is charged with lead acetate wool and 'capped' between two bungs, with mercuric chloride paper. The maximum sample volume should be 50ml (or 100ml in 250ml bottles) containing about 5Φg As (equivalent to 0.1mg/l As). A blank determination on all reagents should be carried out. If arsenic is present a yellow stain develops on the mercuric chloride paper; this is compared with a series of standard stains as described above. Mercuric bromide may be substituted for mercuric chloride, in which case a more orange colour is produced in the presence of arsine.

Miscellaneous Colorimetric Methods

Methylene blue (Vogel; 1964) Blue book Method (HMSO; 1978)

When arsenic, as arsenate is treated with ammonium molybdate solution and the resulting heteropoly molybdi-arsenate (arseno-molybdate) is reduced with hydrazinc sulphate or with stennous chloride, a soluble blue complex (molybdenum blue) is formed. Phosphate reacts in the same way and with about the same sensitivity as arsenate and should therefore be absent. Both macro and micro quantities of arsenic may be isolated by distillation of arsenious chloride from hydrochloric acid solution in an all-glass apparatus in a stream of carbon dioxide or nitrogen. A reducing agent such as hydrazine sulphate (or potassium iodide with stennous chloride solution) is used to reduce arsenic(V) to arsenic(III).

Arsenic when present at higher concentrations may be determined colourimetrically by the hypophosphite method. This technique is applicable to concentration ranges of 0.4 to 100mg/litre As.

Methods for Arsenic Speciation

Arsenic speciation is important because toxicity studies indicate that the inorganic forms As(III) and As(V) vary considerably in toxicity and are generally much more toxic than the organic forms (Clifford and Ghurye; 2000). In groundwaters only inorganic arsenic forms are significant while surface waters may also contain organic forms derived from pollution.

In well-oxygenated surface and ground waters As(V) is the commonly found form (Ferguson and Gavis; 1972). The monovalent anion $H_2AsO_4^-$ is dominant in the pH range 6 to 7, whereas divalent $HAsO_4^{-2}$ is the dominant form in the pH range 7 to 9. Under weakly reducing conditions the usual form in natural waters is arsenious acid (H_3AsO_3) that is the As(III) form. It has been shown that, in general, arsenite and arsenate account for 85 to 99% of total arsenic found in waters. The organic forms of arsenic (mono and dimethyl arsenates) are found where microbial activity is significant or where herbicide pollution has occurred (Andreae; 1977).

The inorganic forms of arsenic are readily concentrated and separated by ion exchange. Of the many methods available for arsenic speciation, those based on ion-exchange mini-columns or the newer membrane filters offer possibilities for adaptation to field use. A number of workers have followed this avenue of investigation, including Clifford et al (1983) who used the chloride form of commercially available resins including IonacA-104 and

Amberlite IRA458, 410, 900, 400 and 402. Recoveries greater than 99% for both As(III) and (V) were obtained with sample pH values in the range 3.0 to 8.4 and iron was absent. The presence of iron adversely affected recoveries, particularly in the pH range 6.5 to 8.5. When iron is present a pH value of 3.0 is recommended.

Edwards et al (1998) combined the work of Clifford and Ficklin (1983) to develop a field speciation method for As(III) and (V) based on the passage of As(III) through an acetate strong base anion resin that retained As(V). The method also incorporated a membrane pre-filtration stage to quantify particulate arsenic. This method required 10-15 mins to speciate As(III) and (V). Arsenic analysis was achieved by ICP-MS. Iron was again found to interfere by permitting passage of As(V) through the resin.

A speciation method has been developed by the University of Houston that can speciate As(III) and (V) in less than 2 minutes and does away with the need to condition and pack resins, and is unaffected by the common ions found in the source waters. Furthermore it was unaffected by low levels of chlorine, ozone or permanganate.

The Ion-exchange membrane filter (IXMF) technique uses a commercially available 47mm ion-exchange filter with micron sized resin particles imbedded in it. Flow rates of up to 60ml/min may be used without adverse effect on recoveries. The method is based on the ion-exchange work of Clifford et al; (2000). At the normal pH values found in drinking water As(III) is an un-ionised species whereas As(V) is a charged ion. As(III) therefore passes through the resin while As(V) is retained. The ion exchange filter is conditioned in two stages prior to use, firstly with acetone and methanol and secondly with hydrochloric acid and salt (NaCl) to convert the ion exchange filter to the chloride form. The filter may be used at least five times so long as it is regenerated with M HCl and MNaCl followed by a 0.005MNaCl rinse. This method requires further development and testing before it can be adopted for the field separation of As(III) from As(V). Analysis of the separated forms of arsenic by a laboratory technique is required; ICP-AES is usually the preferred method.

Field Testing

A range of field test kits for the determination of arsenic have been reviewed (NEERI; 1998). The kits reviewed were manufactured by:

- Asia Arsenic Network (AAN), Japan
- Aqua Consortium, Calcutta, (Aqua)
- National Institute of Preventive and Social Medicine (NIPSOM)
- E.Merck, Germany
- Bangladesh and the All India Institute of Hygiene and Public Health (AIIH&PH)

In addition to these kits the following are also available for monitoring arsenic in water in the field:

- Merckoquant
- Hach

Each of the 5 test kits evaluated by NEERI depend upon the generation of arsine by the Gutzeit method (hydrochloric acid on zinc) and its reaction with mercuric bromide to form a yellow-orange 'stain'. The basic principle of the method is that the arsenic present in water is converted to the trivalent form by the addition of potassium iodide and stannous chloride. The subsequent addition of zinc and hydrochloric acid to the water sample liberates nascent hydrogen, which reacts with trivalent arsenic to form arsine gas. The arsine gas liberated reacts with mercuric bromide paper to form mercury arsenic complexes, which may be yellow, brown or black in colour. The coloration is due to the formation of the compounds $H(HgBr)_2As$ which is yellow, $(HyBr)_3As$ which is brown, and (Hg_3As) which is black. At low arsenic concentration a yellow stain is formed while at high concentration a black spot is produced.

(a)AAN kit

The AAN kit is compact, durable and light in weight (400g). The reagents and other consumables are designed to provide 100 tests. Hydrochloric acid is not provided with the unit, although it is an essential reagent. A single test takes 15 minutes to complete. Arsenic concentration is measured by comparison with a standard colour strip sealed in a glass tube covering the range 0.02 to 0.7mg/l as As. There is no provision for the elimination of sulphide interference with this kit.

(b) E.Merck kit

The E.Merck kit is compact and weighs about 0.5kg including all reagents, which are adequate for 100 tests. The kit includes two reagents and a test takes about 30 minutes to complete. A printed standard colour chart is provided with the kit for the quantification of arsenic. The limit of detection is 0.10mg/l as As. There is no provision for the elimination of sulphide interference if present in the sample.

(c)Aqua kit

The Aqua kit is supplied in a flexible carrying case and weighs approximately 1kg, including all of the reagents. The limit of detection is 0.05mg/l as As, as shown by a yellow stain on mercuric bromide paper. A disadvantage is that the mercuric bromide paper has to be rolled by hand and since the compound is highly toxic this is a health hazard and therefore undesirable.

(d) NIPSOM kit

The NIPSOM kit is a modification of the AAN kit and is made in Bangladesh. The kit including all reagents weighs about 1.2kg. The arsenic detection range is from 0.02 to 0.7mg/l as for the AAN. Similarly there is no provision for the elimination of sulphide in the determination of arsenic. The test time is short at 5 minutes. As at June 1998 the kit was not commercially available.

(e) AIIH&PH kit

The kit is larger and heavier at 2.2kg than those described above and has all glass apparatus with glass joints. The kit is of the Yes/No type with a detection limit of 0.05mg/l as As, as indicated by the development of a yellow stain on the mercuric bromide paper. The kit does have provision for the elimination of interference due to sulphide, if present in the sample. Again the kit was not available commercially as at June 1998.

Test papers

The Camlab and Merck companies both produce test papers for the determination of arsenic based on the reaction with mercuric bromide.

(a) The Camlab test paper (Camlab; 2000) provides a qualitative rather than a quantitative method, but reports a detection limit of 0.5 Φg As.

(b) The Merck oquant test kit (Merck; 2000) is designed for the quantitative detection of As, but the limit of detection is 100 Φg/l and is not therefore suitable for compliance monitoring of well waters for which the acceptable limit is usually 50 Φg/l As. It consists of a reactive test zone bonded to a plastic backing. The test zone is impregnated with the reagents required to detect arsenic. The reaction tube, reagents and a box of 100 test strips are included in a very compact form which can be held in one hand. The range of concentrations which can be determined are 0.1 to 3.0mg/l.

As-Top HE test kit

This kit is produced by ASI (Arsenic Solutions Inc) of the USA. The kit contains reaction vessels, reagents, moistening and reaction solutions and a colour comparison card. The card is calibrated from 0.01 to 0.5 mg/l, with 5 intermediate values. The kit uses a 50ml sample and the result is achieved in 15 minutes.

Hach test kit

Hach also manufacture an arsenic test kit (Hach; 2000) which, at present, appears to only be available in the USA. In this system any hydrogen sulphide is first oxidised to sulphate to prevent interference. Sulphamic acid and zinc (powdered) are then reacted to create strong reducing conditions in which inorganic arsenic is reduced to arsine gas. This gas then reacts with mercuric bromide in a test strip to form arsenic-mercury halogenides that discolour the test strip. The colour ranges from yellow through tan to brown, depending on the concentration. The kit detects inorganic arsenic compounds, organic forms are not measured, although total arsenic may be quantified with a simple modification of the test procedure. The limit of detection for this method is given as 10 ppb (Φg/l). The kit is claimed to be compact and portable. The reagents are in powder or test strip form. Each kit contains sufficient reagents and other consumable items for 100 tests and claims to minimise exposure to arsine gas. The test reaction takes 30 minutes to complete after which the test strip is compared with a colour chart in steps of 0, 10, 30, 50, 70, 300 and 500 ppb (Φg/l). The kit is provided with two reaction vessels so that two tests can be run simultaneously.

Arsenator

This device was developed by Dr Walter Kosmos (Kosmos; 1998). The instrument combines chemical and electronic technology and was developed in two forms. A laboratory instrument capable of accurate (3%) measurements down to 1 Φg/l and a field instrument capable of measurements (10% accuracy) down to 5 Φg/l. The method is based on the generation of arsine and its subsequent detection via the reaction with mercuric bromide (Gutzeit method). The arsine gas passes through a mercuric bromide impregnated paper; the colour developed is quantified by a light absorption measurement, achieved by a diode emitting light in the desired wavelength and a photodiode arranged in transmission mode. A sample volume of 1, 5 or 50ml is chosen depending upon the expected concentration. The reagents used in the Arsenator system are impregnated test papers, hydrochloric acid, sodium thiocyanate in sodium chloride solution to reduce As(V) to As(III), zinc and lead acetate solution. The reaction times are 5 minutes for the initial As reduction and a further 20 minutes for the reduction to arsine. After the reaction is complete the instrument measures the light absorption of the filter and compares the signal with a stored calibration curve giving a result in ppb. The instrument is powered by a 9.6V Ni.Cd battery which is rechargeable; battery life is 10 hours fully charged. Linearity of results over a range of concentrations was as given being within the 95% confidence interval.

A recent review of field kits (3rd International Arsenic Conference in Dhaka; May 2000) reported that in field trials the Arsenator was hard to use; batteries were unconventional and did not last and dust got into the instrument. A recent communication (October; 2000) with the manufacturer (Peterengineering in Austria) indicated that the instrument has been withdrawn from the market. It has, however, been replaced by the PeCo AS75 Field Test kit which has measuring ranges of 5-100 Φg/l and 2-60 Φg/l with an accuracy of ∀2 Φg/l. It is a hand held device and costs US$ 777 and is supplied with reagents for 20 analysis.

Portable Anodic Stripping Voltameter (ASV)

A portable instrument based upon the anodic stripping voltametry principle has been developed by the Dept of Chemistry, Texas Technical University (Huang and Dasgupta 2000). The system automation and operation is accomplished with a personal computer. The principal components of the system are 4 No. PTFE solenoid valves, a flow cell with two 'arms', one being a platinum wire (soldered to a lead), which is coated with a gold film and serves as the working electrode. The second 'arm' is also a wire electrode, this time of silver, and serves as the reference electrode. There is also a current voltage converter for monitoring the stripping current. The sample (about 200ml) pH is adjusted to between 1 and 2 using 4.5M HCl. The sample is divided into two parts, one portion being spiked with a known amount of As(III) standard. The two samples are then connected to the inlet tubing, as are a stripping solution and a gold plating solution. The operating sequence is controlled by software and is as follows: a gold film is deposited on the Pt wire, the electrode is held at +0.96V for 5 seconds, then at -0.1V for 9 seconds to plate Au. This cycle is repeated 5 times. The sample then flows through the cell for 5 seconds, electrodeposition is started at -0.2V. Deposition periods vary according tot he anticipated concentration and may vary from 1 to 20 seconds for waters containing >300 down to <50 Φg/l. The stripping medium then flows through the cell for 30 seconds while the electrode is held at -0.1V. A linear sweep of 5mv steps to 0.55V is then applied, this requires 2.2 seconds. The computer calculates the results from peak-peak height differences.

The process is then repeated using the spiked samples; replicate samples are tested. As(III) is measured by the above procedure. All As is then converted to As(V) by the addition of bromine water. The ASV system is flushed and the procedure repeated to measure total inorganic arsenic. As(V) is calculated by difference. Interference to the ASV technique may occur due to the presence of copper, zinc, mercury and bismuth as they have similar stripping peaks. Interference from organic compounds can be severe. The use of the standard addition technique is recommended to overcome such interferences.

7. TREATMENT TECHNOLOGIES USED IN COUNTRIES AFFECTED BY ARSENIC IN DRINKING WATER

Regional or community treatment plants

Several countries use precipitation by iron or aluminium salts as the primary treatment method for removing arsenic in ground or surface waters. In most of the developing countries this is the sole method currently in use for arsenic removal from drinking water supplies. For example, in Chile the total system for arsenic removal treats 1730 l/s by precipitation method using ferric chloride (Sancha; 2000). In developed countries the precipitation method is usually limited to the removal of arsenic from surface waters in conjunction with turbidity, colour and other natural organic matter.

When As(III) is present it is necessary to oxidise it to As(V) in which form it is readily removed by precipitation. This oxidation is achieved by chlorine or chlorine containing chemicals such as sodium or calcium hypochlorite, or potassium permanganate. The commonly used precipitation chemical is ferric chloride, primarily because it is readily available as a by-product of the steelmaking industry and also usually cheaper than other iron or aluminium salts. Ferric sulphate or aluminium sulphate are also commonly used. The precipitation method is used at all levels of treatment including point-of-use. The complete treatment process usually consists of oxidation and pH adjustment where applicable, mixing of the iron or aluminium salt and flocculation, followed by solid-liquid separation, which usually includes settlement and/or filtration through a sand medium. In the USA a plant is under construction where a microfiltration membrane filter is to be used on a ground water to separate the solids formed by such a precipitation process (Chwirka et al; 2000).

Other methods used include adsorption on to activated alumina, ion-exchange resin or granulated ferric hydroxide. These methods are mainly used in developed countries where the media is readily available and economically viable. Such countries include USA, Japan, Germany and UK. In developing countries such methods are, at least for the time being, limited to point-of-use treatment or for small community supplies.

Point-of-use treatment units

Adsorption processes using activated alumina or granulated ferric hydroxide are more appropriate for point-of-use treatment than chemical precipitation, although the latter still finds wider application in developing countries (Sancha; 2000) has reported that point-of-use treatment adopted in Chilean homes in essence is chemical precipitation using ferric chloride followed by filtration at $6.25m^3/h.m^2$ in a filter containing coarse sand of effective size 0.84 to 1.19 mm (mesh size 16/20) and fine sand of effective size 0.42 to 0.65 mm (mesh size 26/35).

In Argentina an experimental programme has been carried out in a remote region of about 5,000 people. The removal unit consisted of an activated clay support with oxidation using calcium hypochlorite, followed by precipitation using aluminium sulphate or ferric chloride. A selected home was used as an indicator to check product performance. In most cases removal levels in excess of 70% have been reported (Rivero et al; 2000). All the processes require that the pH of the raw water to be in an optimum pH range specific to the process. Most processes except precipitation by aluminium sulphate have a broad operating pH band, which allow operation without pH adjustment. However with some waters pH adjustment with an acid or an alkali would be necessary. The presence of As(III) in the raw water would require an oxidation stage ahead of almost all the processes to convert it to As(V). An exception being some of the modified activated alumina media, which are claimed to remove As(III) as effectively as As(V). Oxidation processes used in point-of-use treatment units include dosing of bleaching powder (calcium hypochlorite) containing $30\%^{w}/_{w}$ or 65 to $70\%^{w}/_{w}$ chlorine in the form of a powder or a tablet. In some adsorption processes this is followed by a filter containing a catalytic media (such as manganese dioxide) to assist in the removal of iron or manganese. The filter also removes any turbidity present in the water.

The optimisation of the aluminium or ferric salt dose is also necessary to maximise removal of arsenic. Overdosing is costly and underdosing would result in incomplete removal. Since these salts are acidic they could be used to adjust the pH of alkaline waters by increasing the optimum dose required for precipitation. The application of the appropriate chemical doses for pH adjustment, oxidation and precipitation is essential to maximise arsenic removal. The doses must therefore be adjusted with changes in water quality, such a case would be surface waters where the quality could change seasonally. With ground waters such changes are less pronounced or non-existent so chemical doses would not normally need to be changed. Therefore point-of-use treatment is more reliable in giving effective and consistent arsenic removal with ground waters rather than with surface waters. Treatment of the latter would require continuous technical support to analyse the raw water and make changes to chemical doses.

However, short-term changes do occur even with ground waters, since experience in West Bengal, India indicates that arsenic concentrations in the morning tend to be higher than that later in the day, due to the water standing in the well overnight. Ideally therefore, chemical treatment should under such conditions be set for water quality conditions experienced in the morning.

Of the point-of-use methods the activated alumina process requires regular regeneration, although there are modified activated alumina media which are used on a throwaway basis. The supplier under a service contract with a public body would carry out regeneration. Granular ferric hydroxide media once exhausted is thrown away. There are other point-of-use methods, which are more appropriate for countries with a good technical support system. They include reverse osmosis and nanofiltration.

Test methods

Regional treatment plants would normally have well equipped laboratories at the plant or located centrally to several plants. These would carry out analysis for arsenic and other selected water quality parameters on a regular basis. The methods would include Graphite Furnace Atomic Absorption and Gaseous Hydride Atomic Absorption. These are discussed in detail earlier.

Community based treatment plants normally use field test kits. The most commonly used are the AAN (Asia Arsenic Network) and the Merck test kits. Considerable work has gone into the development of test kits in recent years to produce an instrument which is light in weight, reliable, safe and capable of attaining a limit of detection of less than 50 Φg/l (0.05 mg/l). Details of test kits are given in Section 6. The test kits are too costly to be given to individual households for use on point-of-use treatment units. In addition in many cases extensive training and back-up maintenance services would be necessary for satisfactory use. It is therefore not practicable to issue test kits to individual households. In most countries where point-of-use units are used, a public body or a person who could be the supplier of the unit could be under contract with the public body to carry out regular testing of the water.

In some countries the performance of point-of-use devices have been tested by measuring colour and turbidity which have been used as indicators of the presence of arsenic since these parameters are known to correlate well with residual arsenic when iron salts are used as the precipitation chemical. The pH of the water after the addition of precipitation chemical is also a good measure of the performance of the process. Since pH, the precipitation chemical dose and arsenic removal efficiency are interdependent, pH is a useful control parameter and as such is proposed for the precipitation/microfiltration plant in Albuquerque, USA (Chwirka; 2000),

Waste disposal

In most countries disposal of liquid sludges from large arsenic removal plants is carried out in lagoons, whilst wastes from point-of-use devices are known to be disposed in an uncontrolled manner on land or even to water courses. Disposal to sewer or mechanical dewatering by membrane plate process with dried cake disposed to landfill are some of the methods proposed in developed countries.

8. TREATMENT TECHNOLOGIES USED IN INDIA AND BANGLADESH

Technologies used in the two countries are similar. There is no central or regional government coordinated programmes for arsenic removal in drinking water supplies in place in either India or Bangladesh. There are some community based programmes in villages, some pilot programmes managed by government or non-governmental agencies, primarily charitable organisations and some demonstration units supplied by manufacturers of arsenic removal units. Technologies used in India (West Bengal) and Bangladesh are very similar and in most cases identical. They include the following:-

(a) Chemical precipitation using ferric or aluminium salts;

(b) Adsorption on to classical activated alumina or modified activated alumina;

(c) Adsorption on to granulated ferric hydroxide.

(d) Activated charcoal/ferric or aluminium salt tablets.

(e) Heamatite filter

(d) Laterite filter

These processes are usually preceded by an oxidation stage to convert As(III) to As(V) and, in the case of a chemical precipitation process, are followed by a solid-liquid separation stage. Some technologies are applied to all types of supplies, whilst some are limited to point-of-use devices. UNIDO representatives visited some villages in West Bengal during August 2000 to inspect some of the devices in use. A brief description of the installation is given below:-

(i) Sardarpara Village

The treatment unit supplies a small community. It treats a well water using bleaching powder for oxidation and aluminium sulphate for precipitation followed by upward flow clarification and filtration. The unit is used intermittently by operating a hand pump as and when necessary by people visiting the unit to collect water. The capacity of the unit was said to be about 12,000 l/d.Chemicals are drip fed into the inlet tank throughout, even when the unit is not being used. This could mean that at times filtered water could contain high concentrations of aluminium. The clarifier is desludged regularly by opening a bottom drain. The filter is backwashed when the filtered water becomes cloudy. Wastes are discharged into a sump where sludge is supposed to settle. A villager has been given the responsibility of overseeing the operation of the unit. There were no raw or treated water quality data available.

(ii) Sherpur Village

The treatment unit is by Pal Trockner (P) Ltd, India and supplies a small community. It treats a well water intermittently on demand by adsorption using granulated ferric hydroxide media. The unit consists of a catalytic manganese dioxide media gravity filter in series with an upflow granulated ferric hydroxide adsorber. The former is used to oxidise iron and filter ferric hydroxide and turbidity. The flow to the catalytic filter can be reversed for backwashing. The unit had been recently installed, but had not been used because of a fault in the foot valve of the hand pump.

(iii) Moyna village

The treatment unit supplies a small community. It treats a well water intermittently on demand. The technology behind the process is not known. It has been supplied by Water Systems International Ltd. It consists of four vessels in series. The first vessel contained a material held in a nylon bag, immersed in water. The material in the other two resembled a resin and the fourth vessel contained a filter media. Raw water arsenic and iron concentrations were measured using a Merck unit and were found to be 0.35 mg/l and 3.75 mg/l respectively. The treated water arsenic concentration was measured at less than 0.0 mg/l (see (iv) below). Some of the vessels are backwashed with water every 10,000 litres. The media in the vessels were said to be suitable for treating about 50,000 litres. It is not known whether media required replacement when it is exhausted, or regenerated.

(iv) Adahada Village

The treatment unit is by Apyron of USA and supplies a small community. It treats a water drawn from a 40m deep tubewell intermittently on demand. The unit is fed by a hand pump and consists of a strainer followed by a gravity fed column made of two beds: one containing a manganese dioxide catalytic media and the other containing the adsorbent activated alumina. The strainer is used to remove any sand in the water. Tablets containing a proprietary chemical believed to be an oxidant are added ahead of the column, presumably to oxidise Fe(II) and As(III). Ferric hydroxide so formed removes some of the As(V) by coprecipitation followed by filtration in the catalytic media bed, which also helps to oxidise ferrous ions in the water. The remaining As(V) is removed by activated alumina. The unit has a daily capacity of 1,000 to 2,000 litres.

On the day of the visit the performance of the unit was tested by using a Merck field test kit, which has the following detection values: 3.0, 1.7, 1.0, 0.5, 0.1 and 0.00 mg/l. Thus 0.0 mg/l could mean any value less than 0.1 mg/l. Raw water contained 6.5 mg/l of iron as Fe and 3.0 mg/l of arsenic as As and had a pH of 7.5 to 8.0. The treated water had arsenic and iron concentrations both recorded at less than 0.01 mg/l and a pH of 7.0. The top section of the bed could be backwashed separately and this is carried out every 10 to 12 days by routing the raw water to the main column. The backwash water volume is about 5 to 10 litres per wash. The unit had been in service for about 10 weeks.

(v) Ashoknagr-Kankpul Village

The treatment unit is manufactured by the All India Institute Hygiene and Public Health and supplies a small community. The unit is similar to that seen in Sardarbara Village (see (i) above). Water is drawn from a tube well about 25m deep by a hand pump and it was said to contain about 1.8 mg/l arsenic. The unit has a treatment capacity of 15,000 l/d.

(vi) Lakpur (Hindu Milan Mandir) Village

The treatment unit is manufactured by the Bengal Engineering College and supplies a small community. A hand pump is used to feed well water to an activated alumina column. The raw water was said to contain 0.09 mg/l arsenic as As with the column removing arsenic concentration down to 0.006 mg/l. The unit was installed in May 2000 and has since treated 88,400 l of water. It is backwashed every 2 to 3 days by reversing the flow.

(vii) Lakpur Village

This was a point-of-use device using precipitation by aluminium sulphate. The treatment process consisted of adding 20 drops of bleaching powder and a thumb-nail equivalent of aluminium sulphate powder, stirring the contents 20 times and leaving it to settle for 3 hours. The supernatant is then decanted off leaving arsenic in the settled sludge. The unit treats about 10 litres per batch. This is based on design provided by AIIH&PH.

(viii) Gobardanga urban area

A large scale plant treating a well water by oxidation using potassium permanganate and precipitation using aluminium sulphate, followed by filtration in pressure filters rated at about $12.5m^3/h.m^2$. The plant has a capacity of about 2.2 million litres a day and provides about 56,000 people via piped supplies to stand pipes. The raw water was said to contain an arsenic concentration of about 0.05 mg/l and the treated water contains concentrations below the detection limit. The plant was commissioned in December 1999. The filters are backwashed regularly; the used washwater is discharged to a local drain.

(iv) Dhab Dhabi Railway Station

The point-of-use device was using granulated ferric hydroxide adsorption media supplied by Pal Trockner (P) Ltd, India. It has been in use only for about six weeks. The user was generally satisfied with the device except for the low flow rate, it was therefore used to treat drinking water only. Water from a local polluted pond is used for cooking.

(x) Chandokhalm Village

Another household in the same locality uses a point-of-use device called the Amal Domestic Super Water Purifier supplied by Oxide (India) Catalysts Pvt. Ltd. This is a design by Bengal Engineering College based on activated alumina media. The device has not been used because of a leaking valve.

Jadavpur University of Calcutta carried out a performance evaluation of a selection of seven units serving small villages in Betai, West Bengal. The units operate on the principles of oxidation by bleaching powder, aluminium sulphate precipitation followed by sedimentation and filtration in units supplied by All India Institute of Hygiene and Public Health, and adsorption on to activated alumina developed by Bengal Engineering College (Anon; 2000c).

Several problems were identified over the 10 month evaluation programme which, in some cases, kept the units off line for several days per month. Some of the problems were:-

(a) Failures in the raw water supply system.

(b) Brown coloration in the treated water from the activated alumina units due to ferric hydroxide precipitate breakthrough caused by inadequate backwashing of the bed.

(c) Leakage from valves, soldered connections and joints.

(d) Activated alumina particles in the finished water due to breakdown of the media.

(e) Blockage of the bleaching powder solution drip feeder orifice which interrupted the chemical feed.

(f) Interruptions to chemical dosing due to failures to refill the chemical tanks used in the precipitation system on a regular basis.

(g) Red worms (probably midge larvae) and brown precipitates in the tanks due to prolonged periods (up to 15 days) between cleaning of the precipitation system.

Only one unit, which was using activated alumina operated without any problem over the 10 month evaluation period. This was attributed to good maintenance and better community participation.

Table 1.7 : Arsenic Removal in Community Treatment Units Installed in Betai, West Bengal (Anon; 2000c)

Site	Technology	Arsenic concentration (Φg/l)

		Raw	Treated						
1	AA	170	<3	131	<3	<3	<3	121	NW
2	AA	122	<3	<3	<3	<3	<3	<3	<3
3	AA	327	56	<3	<3	<3	NW	<3	35
4	AA	235	NW	187	69	12	NW	NW	NW
5	PP	51	45	NW	NW	6	5	<3	NW
6	PP	463	NW	NW	NW	NW	52	92	35
7	PP	149	NW	NW	NW	24	43	88	81

AA - Activated alumina adsorption
PP - Oxidation using bleaching powder and precipitation by aluminium sulphate
NW - Not working on the day of the sampling

These results show that both technologies, when operated and maintained well, are capable of producing a finished water containing arsenic concentrations of less than 50Φg/l. Of the two technologies, activated alumina adsorption offered a more reliable and robust system as it was simple to operate and the maintenance requirements were less. This is demonstrated by the number of times the units were found to be 'not working', when compared to the systems using precipitation. The unit at Site 2 which was well maintained gave the best and most consistent performance.

A UNIDO representative visited a number of developers or suppliers of three arsenic removal technologies currently being tested in India. Bengal Engineering College have developed an activated alumina adsorption design for both point-of-use applications and community use. The technology is marketed by Oxide (India) Catalyst Pvt. Ltd. The point-of-use device is called the 'Amal' arsenic removal unit. The developers have tested several grades of activated alumina and selected AS37, a grade produced locally by Oxide (India) Catalyst Pvt. Ltd. It has an arsenic adsorption capacity of 0.04 to 0.05 mg As per g of activated alumina. The media size has been optimised at 0.6 to 0.9mm to improve flow characteristics.

The empty bed contact time was said to be at least 5 minutes. The flow rate of community based and point-of-use devices is of the order of 600 and 5 l/h respectively. Iron in the form of Fe(II) tends to coat the alumina and precipitate in the bed, therefore the bed should be backwashed when the flow drops. The frequency of regeneration is expected to be once a year and would be by 4% $^{w}/_{w}$ sodium hydroxide followed by 0.5N hydrochloric acid with backwashing and rinsing. Community units would be regenerated in-situ. Media from point-of-use devices, which is contained in an impervious nylon bag with a permeable base would be removed by Oxide (India) Catalyst Pvt. Ltd for off-site regeneration leaving a new bag of media in the device. Recovery of the adsorption capacity of the media after the first regeneration was said to be 80% and subsequent regeneration did not further reduce it. Point-of-use devices performed better after the first regeneration. It was stated that regenerant waste, when mixed with iron removed in the bed forms ferric arsenate and after settlement, the supernatant contains about 5 mg/l arsenic. This is passed through a bed of sand which becomes coated with ferric arsenate leaving arsenic free water as the filtrate. Media loss was said to be about 5% by weight over the year during backwashing and regeneration, resulting from degradation and dissolution.

Arsenic is removed by coprecipitation when iron is present in the raw water and then by adsorption on to activated alumina. The maximum arsenic concentration in the raw waters treated to date is about 0.5 mg/l while the iron concentration has varied from 10 to 13 mg/l. Without an oxidant the process is reported to remove arsenic to less than 0.05 mg/l and iron to 1 to 2.5 mg/l. Arsenic removal efficiency was said to be independent of the raw water arsenic concentration, this would however influence the regeneration frequency of the media.

Pal Trockener Pvt Ltd fabricates treatment devices for granulated ferric hydroxide media imported from GEH Wasserchemic GMBH & Co, Germany. The supplier stated that there are plans to manufacture the media in India if there is sufficient demand. The media has the tradename AdsorpAs and contains 52 to 57% of the active substance, ferric hydroxide as ∃-FeOOH; the remainder is water. The adsorption density for arsenic is 45g AsO/kg dry medium and for phosphorus is 16g P/kg dry medium.

Physical characteristics are:

Grain size : 0.2 to 2.0 mm
Density of grains : 1.59 kg/l
Bulk density : 1.22 to 1.29 kg/l
Porosity of grains : 72 to 77%
Specific surface : 250 to 300 m^2/g
Bulk porosity : 22 to 28%

It is claimed that the Media can remove both arsenite and arsenate with almost equal effectiveness; a pre-oxidation stage ahead of the adsorption process is considered unnecessary. The adsorption capacity for arsenite and arsenate is 25g As/kg of the dry media (Pal; 2000). The Media is said to be capable of removing total arsenic concentrations to less than 0.01 mg/l independent of the inlet arsenic concentration. The supplier does not foresee any problem with the short term high arsenic concentration likely to be present in the first draw of water after it has been standing in the well overnight. He also considers that the intermittent use and the community and point-of-use devices would be subjected to, as beneficial to the performance. The inlet iron concentration should be less than 10 to 15 mg/l as Fe to minimise clogging of the pre-filter. The treated water would have an iron concentration of less than 0.3 mg/l. The optimum pH range for satisfactory operation is 5.5 to 8. Most ground waters in West Bengal were said to fall within this pH band. Phosphates interfere with the process and reduce the arsenic removal capacity at concentrations greater than 0.05 mg/l.

High concentrations of iron in the raw water tend to clog the media resulting in the rapid development of head loss. In this case the media must be backwashed from time to timem otherwise the performance of the media with respect to arsenic removal would be adversely affected. An iron removal filter under such circumstance would be highly beneficial. The iron removal pre-filter, when provided, contains layers of gravel (4mm), sand (1.4mm) and manganese oxide catalyst. Point-of-use devices are not normally provided with an iron removal unit. However, they contain three strainers; one on the inlet pipe to remove any dirt in the feed water, one in the unit to support the media and the other in the outlet to prevent carry over of the media. It was said that in the community units at Barasat and Baruipr in West Bengal an oxidising agent is used. The life of media to exhaustion is proportional to the source water arsenic concentration. Typically at an influent arsenic concentration of 1 mg/l, 20 to 30,000 bed volumes could be treated before breakthrough occurs. The supplier claimed that the plant in Barasat which contains about 60 litres of the media could treat more than 1.6 million litres of water containing 1 mg/l arsenic. This is equivalent to an adsorption capacity of about 21g As/kg of dry media. Once exhausted the media is discarded. The pre-filter when provided is backwashed at approximately two weekly intervals.

There are three full scale plants operating on this principle. The details are given in Table 1.8 below.

Table 1.8 : Arsenic Removal Plants Operating on AdsorpAs Media

Project	Flow rate m^3/h	Arsenic concentration (mg/l)		Inflow pH
		Inflow	Outflow	
Haveleck	40	0.8	<0.01	7.1
Lacufa	50	0.2	<0.01	7.5
Airliquide	35	0.35	<0.01	7.3

The spent adsorbent was said to be non-toxic and non-hazardous. Results of the TCLP tests conducted showed that arsenic does not leak from the spent adsorbent under normal environmental condition below pH 8.5.

Apyron Technologies Inc supply an arsenic removal media operating on the principle of adsorption using modified activated alumina. The Indian agent for the company at present imports the pre-engineered units complete with media from the USA. The media has the trade name Aqua-Bind Arsenic HP. Currently only a community based unit is available in India; introducing a point-of-use device is being studied.

The physical characteristics of the media are:-

Media size	:	US mesh sizes 12 x 32 (1.7 to 0.50mm) 28 x 48 (0.59 to 0.30mm) or 80 x 325 (0.18 to 0.047mm)
Bulk density	:	0.64 kg/litre
BET surface area	:	150 to $225m^2$/gram

The Media can reportedly remove both arsenite and arsenate without the use of a pre-oxidation stage. At the plant in Adahata a 'white tablet' is added to the water ahead of the alumina column. The supplier has declined to identify the chemical added and disclose its function. The manufacture has not been forthcoming with the information regarding the adsorption capacity of the media either. The media was said to remove total arsenic to concentrations of less than 0.01 mg/l irrespective of the influent arsenic concentration. Typical arsenic removal efficiency is considered to be greater than 90%. To date an upper limit for source water arsenic concentration has not been identified. The maximum arsenic concentration in the source water treated to date has been 3.0 mg/l. The suppliers consider that the high arsenic concentrations likely to be in the first draw of water in the morning after it has been standing overnight is treatable and also that the intermittent operation that the unit would be subjected to leaving the media dry is not likely to be a problem. For best performance the following limiting water quality into the adsorption column is recommended:-

pH range	:	5.5 to 8.5
Hardness as $CaCO_3$	:	500 mg/l

Iron as Fe : 0.5 mg/l
Manganese as Mn : 0.2 mg/l
Turbidity : 5 NTU
Suspended solids : 5 mg/l
Sulphates as SO_4 : 300 mg/l
Silica as SiO_2 : 30 mg/l
Sulphur as S : 3 mg/l

When iron and suspended solids concentrations exceed the stated limits pre-filtration stage is recommended to minimise clogging of the bed and hence the rapid development of head loss. The device, with a pre-filtration stage, could accept up to 15mg/l of iron. This usually takes the form of a manganese dioxide catalytic filter. This bed must be backwashed regularly. The activated alumina bed could also be backwashed if necessary. For an iron concentration of approximately 3.0 mg/l, the backwash frequency is expected to be about once a week using approximately 130 litres of water.

The media currently used at the plant in Adahata requires regeneration and this would be carried out by the supplier in India. The new media is proposed for 'single use' operation with no regeneration, thus once exhausted, the media would be discarded. The typical life of the media to exhaustion is about 180,000 litres assuming an average influent arsenic concentration of 0.5 mg/l. The community based units supplied in India typically consist of a single column of 250mm diameter containing 5 to 6 kg (bed depth: 225mm) of manganese dioxide catalytic media and 8kg (bed depth: 355mm) of activated alumina. The empty bed contact time is typically in the range 2 to 3 minutes. The feed flow is downwards and varies from 900 to 1200 l/h. Larger or smaller units could also be provided to suit other applications such as the capacity of a handpump which varies in the range of 500 to 750 l/h. Since the media is used on a 'throw away' basis after exhaustion, there is no regenerant waste for disposal. The exhausted media were said to be stable. The degree of leaching of arsenic into the environment was said to meet the US TCLP requirements.

9. TREATMENT TECHNOLOGIES SUITABLE FOR INDIA

There are three types of applications in India. They are:-

(a) Urban
(b) Rural
(c) Point-of-use

Urban application

Urban areas where the population density is high would be best served by centralised treatment facilities with water piped directly to houses and standpipes. Depending on the size of the conurbation, the treatment capacity could be several million litres per day. The most appropriate technology for such an application would be precipitation followed by solid-liquid separation, irrespective of whether the source is surface or ground water. The typical treatment process would comprise:-

(a) Oxidation to convert any arsenite to arsenate by chlorine, bleaching powder, sodium hypochlorite or potassium permanganate. The use of chlorine or chemicals with free available chlorine should only be considered if trihalomethane precursor concentrations in the source water are low.

(b) pH adjustment where necessary with hydrated lime or sulphuric acid.

(c) Precipitation by aluminium sulphate, ferric chloride or ferric sulphate. These chemicals being acidic could also be used in place of sulphuric acid for pH adjustment.

(d) Sedimentation, primarily for surface water treatment or ground waters containing iron concentrations in excess of about 5 mg/l or high turbidity.

(e) Filtration in sand media filters of the gravity or pressure type.

(f) Disinfection by chlorine or compounds containing free available chlorine.

(g) Contact to ensure a 'ct' value (c - free residual chlorine concentration in mg/l after an effective contact time of t minutes) greater than 15 mg minute/litre.

(h) pH adjustment to ensure water is not aggressive.

Waste streams from sedimentation tanks and filters would ideally be settled and sludge disposed to lagoons. Water recovered from settling tanks could be returned to the treatment process at the inlet or discharged to a water course. Such a treatment facility should be backed up by trained operators and maintenance staff and either a local or a regional laboratory. The latter is important to ensure chemical doses are optimised to maximise total arsenic removal and to minimise residual iron or aluminium concentrations in the final water. The advantages of this technology are that it is proven in conventional treatment for colour or turbidity removal, is suitable for treating small or large flow rates, relies on locally available chemicals, can be constructed from locally available materials and the process is robust.

Adsorption methods using activated alumina or granular ferric hydroxide are also suitable for urban applications treating ground waters. However the volume of water which could be treated by these methods would be limited by the number of adsorber vessels that could be physically accommodated on the site. Typically each adsorber vessel would be able to treat up to 2.5 million litres of water a day. In addition vessels, each with a treatment capacity of up to 1. million litres a day, would be required for pre-filtration if the turbidity or iron concentration in the water is high. Activated alumina is locally available and is of the regenerable type. Regeneration would be carried out in-situ using hydrochloric acid and caustic soda; both of these chemicals are hazardous. In addition an oxidant will be required for converting As(III) to As(V) and an iron or aluminium salt will be required as a coagulant for precipitation of arsenic in the waste. There are other regenerable type media, which are more efficient than the local material and are claimed to remove both As(III) and As(V) with equal efficiency. These would have to be imported in to India and would be costly.

Media types, which do not require regeneration, include granulated ferric hydroxide and some modified activated aluminas. Both types would have to be imported in to India and would be costly. An advantage with the use of a media on a 'throwaway' basis is that there would be a saving on regeneration and waste disposal costs. This saving could, however, be offset by the media replacement costs.

The technology is not new to India as there are iron and manganese removal plants operating on the adsorption principle. However, such a treatment facility would require trained operators and maintenance staff and also a laboratory. The issues to consider when selecting a technology should include the availability of the media, including delivery period, and the whole life costs of the options.

Rural application

These include villages with population of up to 5000, which are served by public tube wells. The criteria for selecting the most appropriate technology for the application should be:

- Simple to operate and maintain;
- Minimum use of chemicals;
- Suitable for intermittent use;
- Effluent quality complies with arsenic standard irrespective of influent arsenic concentration;
- Ease of waste disposal without treatment;
- Robust process.

An adsorption media, which removes both As(III) and As(V) and is used on a 'throwaway' basis would meet most of the above criteria. Such media include granulated ferric hydroxide and some of the modified activated aluminas. Activated alumina, which requires regeneration, also meets the criteria provided it is regenerated off-site by the supplier. The media would be ideal for ground waters containing low concentrations of As(III), as otherwise an oxidation step involving a chemical would be required and the removal efficiency would depend on the continuous availability of the chemical and maintenance of the chemical dosing arrangement.

When iron or turbidity is present in the water, an adsorption process would be preceded by a filtration stage with a manganese dioxide catalyst. The filter should be backwashed when the outlet flow rate visibly falls. A flow meter should be provided on the inlet. Most ground waters in West Bengal are neutral with respect to pH, therefore the two adsorption media discussed above could be used without pH adjustment, although activated alumina would be performing at somewhat reduced efficiency. Maintenance would be limited to that required for the hand pump and regular backwashing of the pre-filter, if installed. The latter would normally be carried out by manipulation of designated valves, routing of flow into the filter in the opposite direction and discharge of the effluent to waste. This waste could contain some arsenic coprecipitated with iron and should be safely disposed.

The supplier should check treated water for residual arsenic at least once a month. Ideally samples should be taken to a laboratory and analysed by a method, which has a detection limit lower than the compliance value. Analysis by the Merck Test Kit, which has a minimum detection limit of 0.1 mg/l as arsenic, is of limited use. Local government should carry out spot checks to monitor the performance of the supplier in this respect. Adsorption Media should not be used on waters containing unacceptable concentrations of interfering ions as the arsenic removal efficiency would be reduced. Once exhausted the supplier should remove the media for off-site regeneration or disposal leaving fresh media in the adsorber. Safe disposal of waste should be the responsibility of the supplier. The washwater from the filter should be discharged to a small settlement tank in the ground with the overflow discharged to a local drain. The sludge collected in the tank should be regularly removed for disposal to a landfill.

The local government should award a maintenance contract for the hand pump and arsenic removal unit, renewable on a regular basis, to the supplier. The duties should include:

- remove/regenerate/replace media when exhausted;
- Analysis of raw and treated waters for arsenic and iron at least on a monthly basis;
- Analysis of raw water for pH, arsenic, iron and any interfering ions at six month intervals;
- Removal of filter washwater sludge for off-site disposal;
- Maintenance of the unit including supply of spare parts;
- Training of two operators on filter backwashing and routine maintenance.

The precipitation method is not an appropriate technique for rural treatment units because of the following disadvantages:

- Requires up to three chemicals, an oxidant, acid or alkali for pH adjustment and either an aluminium or iron salt for precipitation;
- Availability of chemicals could be interrupted;
- Maintenance of chemical dosing unit to ensure continuous dosing;
- Control of chemical dosing could be poor resulting in unacceptable concentrations of aluminium or iron residuals or arsenic in the treated water;
- Not suitable for intermittent use unless chemical dosing could be limited to the in service period only;
- Potential for overdosing of chemicals;
- Requires regular backwashing of the filter unit and desludging of the sedimentation unit;
- Mosquitoes could breed in the sedimentation unit;
- Requires adjustments to chemical treatment in line with variations in arsenic concentration in the raw water such as may be seen in the mornings;
- Frequent testing of treated water for arsenic as a measure of performance efficiency.

If the precipitation method is to be successful, a robust chemical dosing arrangement with dosing initiated by flow and supported by good operation and maintenance is required.

Point-of-use devices

Several point-of-use devices are available, but only a few have been proven in use or are likely to perform satisfactorily. The criteria for selection should be similar to those for rural units:

- Simple to operate and maintain;
- Absence of, or simplified, chemical addition;
- Suitable for intermittent use;
- Effluent quality complies with arsenic standard irrespective of influent arsenic concentration;
- Ease of waste disposal;
- Sufficient flow rate (15 to 30 l/h);
- Low cost.

Here again adsorption methods with 'throw-away' media or media regenerated off-site are the most appropriate. Any chemicals to be used for oxidation or pH correction should be provided in tablet form. Media, which remove both As(III) and As(V) without pre-oxidation and have a broader operating pH band would be preferable for point-of-use devices as they would eliminate the need for chemical use. The precipitation method point-of-use device is not suitable for sources of varying raw water quality as the householder would be unable to adjust the chemical dose to suit. With ground water however, raw water quality is reasonably consistent over a period of time, except possibly during the first draw-off in the morning. This problem could be overcome by having two levels of dosing provided that the variations in quality could be clearly identified and quantified. It would also be necessary to sample the sources on a regular basis (say every three to six months) to monitor long term variations in the raw water quality. The chemicals to be added include an oxidising agent (normally calcium hypochlorite), an alkali for raising the pH (if necessary) and aluminium or iron salts which could also be used to lower the pH. The use of optimum doses of these chemicals is important for efficient performance. No great harm is done by dosing excess of the oxidising agent or the precipitation chemical, however, dosing of the pH correction chemical should be properly regulated.

Chemicals are best applied in tablet form as in the case of the device developed by Jadavpur University. Alternatively, if chemicals are used in powder form the householder should be given a standard measure such as a spoon constructed of a durable material. Calcium hypochlorite powder loses its strength with time and therefore kept in sealed containers. Chemicals (in solution form) should not be used.

The primary disadvantage with the precipitation method is that it develops a wet sludge, which would be difficult to dispose of in a controlled manner. Disposal locally would be unacceptable as it could re-contaminate the ground water. It is best disposed in centrally located lagoons, which should be managed by the local government. However, it is unlikely that householders would be sufficiently disciplined to carry out this task regularly. Training, education and supervision may overcome this. Ideally the devices should be provided by the supplier on a rental basis to the householder as part of a term contract (lasting say 5 years) with the local government, which should also include a maintenance contract to carry out monthly analysis for arsenic in treated water, six monthly analysis of raw water for pH, iron, arsenic and any interfering ions, maintenance of the units and removal of regeneration/replacement of media once exhausted.

There are several other methods, which may be suitable for point-of-use applications, but are not adequately proven for immediate consideration.

One of the key advantages of the adsorption methods using classical or modified activated alumina or granulated ferric hydroxide for rural and point-of-use applications is that they could reduce arsenic concentrations to values significantly less than 0.05 mg/l, irrespective of the influent concentration, albeit at the expense of life to exhaustion. Therefore should the Indian Standard for arsenic be lowered, the equipment could still be used, but at a higher operating cost. The main disadvantage of the adsorption method is that there is only one local supplier of the media, which is of the regenerable type. Other media are imported and therefore the reliability of supplies cannot be guaranteed and media would be costly. The manufacturers of these media should be encouraged to produce them locally using locally available raw materials, which would also reduce the cost.

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Report on Evaluation of Performance of Various Arsenic Removal Equipments

Prepared under the Project

Concerted Action on Elimination/Reduction of Arsenic In Ground Water, West Bengal, India

Prepared by: Central Ground Water Board Eastern Region Kolkata

Executed by: United Nations Industrial Development Organization

New Delhi
July, 2001

EVALUATION OF PERFORMANCE OF VARIOUS ARSENIC REMOVAL EQUIPMETNTS INSTALLED IN ARSENIC INFESTED AREA OF WEST BENGAL

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I.INTRODUCTION

Collaborative Work Program

Arsenic contamination in ground water has rendered parts of West Bengal, face serious quality problem and health hazard. Many national and international institutions and organizations are involved in finding various solutions to this problem. One such solution has emerged in the form of providing community based arsenic removal.treatment plants and domestic filters to the suffering people. However, the extent to which these arsenic removal equipments are effective poses a proposition, which requires serious consideration. At this backdrop, an agreement to have a collaborative project for the evaluation of performance of arsenic removal equipments installed by various firms in the arsenic affected parts of West Bengal, was reached between Central Ground Water Board and the United Nations Industrial Development Organization.

Terms of Reference of Collaboration

The terms of reference includes test of water quality of 16 community-based units comprising six technologies and 40 domestic units comprising four technologies (10 of each technology). The test of water quality as envisaged was in terms of determination of arsenic, iron and heavy metals along with other parameters of general chemistry for the water samples before and after it has undergone treatment process. The terms of reference also includes comparison of different technologies. All the water samples were to be analysed in the chemical laboratory of Eastern Region office of Central Ground Water Board, as per the terms of reference. Apart from the water samples, the study of the effect of arsenic rich ground based irrigation on the food chain, forms another item of the terms of reference. In addition, hydrogeological data already available with Central Ground Water Board, was to be examined to get an inside idea of overall hydrogeological situation in which high incidence of arsenic has taken place. The term of reference also includes the visits of two senior level officers of CGWB from Delhi and three scientists from the Kolkata office to International Consortium of repute, located in Stockholm in Sweden and Berlin in Germany to get an exposure to the level of expertise and aptitude available and research work being carried out there.

The project was to be completed by December 2000, but due to unprecedented flood in West Bengal during the post-monsoon period of 2000, the work could be completed only by March 2001.

Personnel

The present study to ascertain the efficacy of various arsenic removal plants and filters in West Bengal, was undertaken by the following Officers of Central Ground Water Board, Eastern Region, under the guidance of Regional Director, Central Ground Water Board, ER:

Abhijit Ray, Scientist 'D', Dr. B. C. Mehta, Scientist 'C', A. K. Ghosh, Scientist 'B', Dr. P. K. Roy, Scientist 'B', T. Talukdar, Asst. Hydrogeologist., K. K. Srivastava, Asst. Chemist., A. K. Chatterjee, Asst. Hydrogeologist.

The entire work was coordinated by Dr. S. P. Sinha Ray, Member (SM&L), Central Ground Water Board.

The collaborative work was benefited by the valuable suggestions and guidelines offered by Dr. D. K. Chadha, Chairman, Central Ground Water Board.

Study Tour

A study tour was undertaken by the Chairman, Central Ground Water Board, Dr. D. K. Chadha and Mr. Mukul Joshi, Joint Secretary, Ministry of Water Resources, in the month of November 2000. This tour was followed by a team of 3 scientists (Mr. A. Ray, Scientist 'D'; Dr. B. C. Mehta, Scientist 'C' & Mr. A. K. Ghosh, Scientist 'B') from the Eastern Region office of Central Ground Water Board, in the month of February 2001. Both the visits to selected laboratories/ Research Centres of Sweden, Germany and England, were identified by CGWB & UNIDO and sponsored by UNIDO. The objective of the study tour was to comprehend the latest research work being undertaken in the institutes and laboratories in Europe.

In Sweden, the Royal Institute of Technology (KTH) was visited and useful discussion and interaction took place with Prof. Gunar Jack, Professor of Hydrochemistry and Mr. P. Bhattacharya, Research Coordinator, Arsenic Research Group and a possible long term collaboration between KTH & CGWB, was also discussed at length. A presentation was made by CGWB officers to appraise them the status of arsenic study being undertaken in West Bengal.

In analytical work related to arsenic determination, the use of I. C. P. - MS and hydride generation using Atomic Absorption Spectrometer (AAS) is being used as emerged from the discussions. The other instruments, which are being used for specific purpose, are Ion Chromatograph and Total Organic Carbon.

In documentation methods, the MS-Excel is used for recording chemical analysis results and other software related to hydrochemistry.

In mapping of test results, the Global Positioning System (GPS) is used. The other software used for mapping are GIS, ARCVIEW and SURFER-Ver.7-VI.

In Germany, Harbauer Gmbh & Co. KG, Berlin was visited to comprehend the technology developed for removal of arsenic. Treatment plants located at different places in and around Berlin were also visited. In Germany, The Technical University of Berlin was also visited, where a research project is under progress using resins, which can be used for removal of arsenic, heavy metals etc. The national Laboratory was also visited, where detailed chemical analyses are being undertaken on water samples, effluents, treated waste etc.

In United Kingdom, discussions were held by Dr. D. K. Chadha, Chairman, Central Ground Water Board & Mr. M. Joshi, Joint Secretary, with Dr. D. G. Kinniburgh and Dr. P. L. Smedley of British Geological Suevey, London, showed keen interest on the study of geometry of deeper arsenic free aquifer of West Bengal, which has continuation in Bangladesh.

Mr. A. Ray, Dr. B. C. Mehta & Mr. A. K. Ghosh, also discussed with Dr. D. Ratnayake, at length on the interim report prepared by Central Ground Water Board on the evaluation of arsenic removal equipments.

ACKNOWLEDGEMENT

Critical suggestions and invaluable guidance offered by Dr. D. K. Chadha, Chairman, Central Ground Water Board, and Central Ground Water Authority, in the accomplishment of the project objectives are gratefully acknowledged. The sincere efforts and the total involvement of Dr. S. P. Sinha Ray, Member (SM&L). CGWB, in coordinating the work programme were found to be of immense value. Cordial thanks are also due to Mr. A. K. Sengupta, National Expert on Water Sanitation, UNIDO, for providing technically useful suggestions and arranging study tour to selected international laboratories and treatment plants of repute. Field level assistance provided by Mrs. Susmita Roy, Mr. Kajol De and Mr. Ashish Chatterjee of Development Consultant Group was found to be extremely helpful. Technical expertise and guidance offered by Professor Saroj Kumar Sanyal of Bidhan Chandra Krishi Viswa Vidyalaya, Kalyani, during chemical analysis of food chain samples, are sincerely acknowledged. Analytical expertise rendered by Mr. M. M. Gaumat, Scientist 'D' and the assistance by the staff of the chemical wing of Northern Region, Lucknow, are heartily acknowledged.

Gratitude is expressed for the active support of the village people, where the arsenic removal equipments have been installed and without their spontaneous cooperation, the project would not have been completed.

II. BACKGROUND INFORMATION - History of Arsenic Menace

In the early years of the eighth decade of the last century, a few cases of arsenic poisoning were detected through epidemiological study by the School of Tropical Medical (S.T.M.) and All India Institute of Hygiene and Public Health (AIIH & PH). It was observed that the people suffering from arsenical dermatosis, were all consuming ground water and when the samples of ground water of the respected area were chemically analysed, they were found to contain arsenic beyond the permissible limit of 0.05 mg / l.

In order to combat arsenic menace in the State of West Bengal, various measures and steps were recommended and put into practice by the experts and organizations, associated with arsenic investigation work. An expert committee constituted by the Government of West Bengal under the Chairmanship of Dr. S. P. Sinha Ray, the then Director, C.G.W.B., E.R. (at present Member, SM&L) had recommended in 1992 several measures. One of the measures was to tap deep arsenic free aquifers at various depths in the affected parts of the State. Another important recommendation was the use of arsenic removal filters for domestic use and arsenic removal treatment plants for large scale supply of arsenic free water from arsenic contaminated ground water, and to study the impact of arsenic rich ground water on the food chain of the affected area.

Since the submission of expert committee report in 1992, some national and international agencies got into the work of providing arsenic elimination equipments. These equipments can be categorized into two classes. The one is community based arsenic removal plant, which is designed to cater to the need of several households. The other one is a domestic filter, which is meant for individual family. These arsenic removal equipments are in operation for quite some time now. But only periodic monitoring of these equipments in terms of arsenic concentration of both source water and the treated water would have established their efficacy and make them a viable alternative for the mitigation of arsenic menace. With this in view, an agreement was reached between C.G.W.B. and UNIDO to determine the efficacy of various arsenic removal plants and filters, installed at various places of arsenic infested area of West Bengal.

III. GENERAL HYDROGEOLOGICAL CONDITIONS

(i) *Geomorphology of the affected area:*

The area is characterized by a series of meander belts of which an older composite belt has been recognized occupying the central part and trending NNE – SSW coinciding with the trend of the neck of the alluvial valley at the head of the delta. The sediments of the upper delta plain rest directly over the extensive clay beds of the tertiary period in the sub-surface at a depth of about 150 m with a pronounced unconformity and there is no evidence for the preservation of older quaternary deposits at depth. The migration of meander belts with components of channel lag-front bar, levee-back swamp gives rise to festoons of fining upwards sequence in a vertical section. Each of the meander streams will have sand, silt and clay sequences arranged laterally across the composite upper delta plain. This change may take place within a few meters to several hundred meters laterally depending upon the density of channel network. The apparent discontinuity of the arseniferous aquifer is explained by complete sealing off of arseniferous aquifer from a non-arseniferous one due to cross over from one meander belt to the other with consequent possible juxtaposition of contrasting lithology at the same horizontal plane.

(ii) *Occurrence & Distribution:*

At present 67 blocks in 8 districts of the State of West Bengal are in the grip of arsenic menace. Over 5 million people stay in the zone of risk. The distribution of arseniferous aquifers in the arsenic infested districts falling in the study area of West Bengal, is discussed as under:

1. Malda district:

Arsenic in ground water is found to occur in 5 blocks as English Bazar, Manikchak & Kaliachak (I, II, III) and generally is restricted to the depth span of 20-95 m below ground level with concentration ranging between 0.05 - 1.43 mg/l.

2. Murshidabad district:

Arsenic in ground water occurs in 15 blocks as Raninagar (I, II), Domkol, Nawada, Jalangi, Hariharpara, Beldanga (I), Suti (I, II), Bhagwangola (I & II), Berhampore, Raghunathganj (II), Murjiaganj and Farakka blocks. In general the maximum concentration is found within the depth range of 50m and low concentration occurs even at greater depth. Arsenic concentration varies between 0.05-1.85 mg/l.

3. Nadia district:

In Nadia district, arsenic occurs in 15 blocks as Karimpur (I, II), Tehatta (I, II), Kaliganj, Nakashipara, Nabadwip, Hanskhali, Krishnaganj, Haringhata, Chakdaha, Santipur, Ranaghat (I&II) and Chapra blocks, within 80m. Arsenic concentration ranges between 0.05-0.77mg/l.

4. North 24 Parganas district:

Arsenic in ground water occurs in 18 blocks as Habra (I, II), Barasat (I, II), Deganga, Basirhat (I, II), Swarupnagar, Sandeshkhali (II), Baduria, gaighata, Rajarhat, Amdanga, Bagdah, Bongaon, Haroa, Hansnabad and Barrackpur (II) within the depth of 80m. Arsenic concentration in ground water ranges between 0.05-1.18mg/l.

5. South 24 Parganas district:

Arsenic occur in 9 blocks as Baruipur, Sonarpur, Bhangar (I, II), Budge Budge (II), Bishnupur (I, II), Joynagar (I) and Mograhat (II) blocks and is restricted in depth generally to 30m in southern part and 100m in northern part. Arsenic concentration in ground water varies from 0.05-3.20 (Baruipur block) mg/l.

(iii) Sub surface disposition of aquifers:

To understand the distribution of arsenic content both vertically and laterally within sediments and ground water, study of sub-surface lithological character is essential. District wise sub-surface lithological character where arsenic elimination equipments have been introduced is discussed below:

1. Malda District:

Eastern part of the area is more argillaceous in nature. The top clay layer in the western part is about 6m where as it is 14 m in thickness in the eastern part (Habibpur). The upper clay horizon at Mathurapur, Milki, Kaliachak, Mathabari and EnglishBazar is underlain by fine sand horizon of huge thickness. Medium to coarse sand occurs within fine sand horizon at 40m, 52m, 24 m, 80m and 70m b.g.l. Thickness of medium to coarse sand horizon varies between 10-40 m (Plate 3 a). Arsenic in Ground water is found in Manikchak, Maliachak –Kaliachak-II and English Bazar Blocks and English Bazar Blocks and generally is restricted within the depth span of 20-95 b.g.l.

2. Mushidabad District :

From the lithological correlation of the area, it is seen that clay horizons are predominant in the western part than the eastern part of the area. Fine to medium sand occurs from Kadamtala to Jalangi down to the depth 120m b.g.l. within lenses of gravel. At Jalangi , clay horizon occurs at the depth range of 68-83 m b.g.l. and 120 m b.g.l. At Domkal clay horizon occurs at the depth range of 0 – 14 m, 128-142m, 228-260m b.g.l. generally find to medium sand occurs at the depth range between 15-76 m b.g.l. (Plate 3 b). Concentration of arsenic is higher in shallower depth. It is generally found that the maximum concentration of arsenic is found within the depth range 31-35 b.g.l. and low concentration occurs even at greater depth.

3. **Nadia District :**

From the lithological correlation of the above blocks, it is clear that 6-10 m clay horizon occurs at the top of the formation below which fine to medium sand zone occurs. Coarse sand mixed with gravel occurs below 60m depth (Plate 3c). Arsenic concentration is generally high in all the sand horizons.

4. **North-24 Parganas District :**

From the sub-surface correlation of the aquifer it is seen that 24-30m clay horizon occurs at Dogachi to Kochua area and this clay thins to 6m towards Habra. Fine to medium sand occurs below this clay horizon and it is 12m thick at Dogachi, 26m at Kochua and 8m at Habra. A thick clay zone occurs below the sand horizon in all the places. Sand horizon again occurs below 105m b.g.l at Kochua and 60m b.g.l at Habra (Plate 3d). Generally arsenic occurs within fine sand zone at the depth range of 20-100m b.g.l.

5. **South 24 Parganas District :**

From the lithological correlation it is observed that 18-26m thick clay horizon occurs here. The sand horizon is 18-90 m thick. Below the sand horizon thick clay zone occurs. Another sand zone occurs at the depth range of 170-216m (Plate 3e). Arsenic occurs in the upper sand horizon.

IV. DETAILS OF WORK PROGRAMME

1. It was agreed upon to collect 3 sets of samples from the affected tube-well (source water) in three different period along with the corresponding samples from arsenic removal equipments (treated water) and to chemically analyze them. All the available 16 (sixteen) community based plants installed in the districts of Malda, Murshidabad, Nadia, North 24 Parganas and South 24 Parganas were considered as target group for monitoring. The agencies, whose community based plants were monitored are APIRON, WSI, AMAL, AIIH & PH, PHED, Pal Trockner, & ION EXCHANGE, who use different technology for removal of arsenic. It may be mentioned here that all the samples pertaining to three sets of monitoring of the above mentioned plants could not be analysed, either due to non-availability of source water, or treated water or both. In case of domestic filters, four firms namely AIIH & PH, AMAL, Pol Trockner and CSIR (Jadavpur University) were the target group. Initially 15 filters of each firm (who use different technology for arsenic removal) were selected for ascertaining their efficacy which had to be brought down to 10 each considering the low concentration (below detection limit) of arsenic in source water and also due to non availability of samples for successive collection. Even then there has been occasions, when samples were not available for collection. It is worth mentioning here that the list of the plants and filters that were monitored was provided by the UNIDO.

As per the programme, apart from arsenic, other relevant chemical constituents like iron, pH, turbidity, total hardness, calcium, magnesium, alkalinity, chloride, sulphate, nitrate, sulphide, silica, fluoride and dissolved oxygen were also analysed for each set of samples. In addition, heavy metals like aluminum, chromium, copper, lead, zinc, cadmium, manganese, were also analysed for only one set of samples of source or raw water. The results of the chemical analysis have been presented in appendices.

Apart from analysing the raw water and the water after treatment for each equipment, samples were also collected during washing the filter media with raw water for analysing arsenic content in it. The objective behind this test, is to estimate whether washing of filter media at the spot, forms a secondary source of arsenic contamination and also whether arsenic totally gets adsorbed in the media or it leaches back into the aqueous form. Only one set of backwash samples was chemically analysed for each of the equipment. which had provision for this test.

2. A test was conducted at Dhapdhapi village of Baruipur block of South 24 Parganas district, to compare the efficacy of domestic filters using different technology against the same source of arsenic contaminated water. The samples were collected at three different rate of flow of water into the filters and fresh media of each technology was utilised for this test. The objective was not only to compare the efficacy of different technology, but also to judge whether the media of different technology is effective over different rates of water inflow, involving different contact period with the media.

3. Ground water samples from arsenic contaminated aquifer of Dhapdhapi village of Baruipur block of South 24 Parganas district was collected at two different phases of ground water withdrawal. The sample was first collected in the morning, when the aquifer is least disturbed in terms of water withdrawal. The other sample was collected in the evening, when the maximum abstraction from the aquifer had been completed. The aim in this experiment is to decipher any appreciable change in the concentration of arsenic due to the normal rate of ground water withdrawal.

4. A hydrological pumping test was conducted at Moyna in Barasat I block in North 24 Parganas district. The idea was to notice the change in arsenic concentration at various stages of pumping with a constant rate of ground water withdrawal from the aquifer.

5. A wide range of food chain samples which includes cereals, vegetables and fruits were collected from the arsenic infested parts of Nadia, North 24 Parganas and South 24 Parganas district. They were subjected to weighing, drying and digestion, before determining arsenic content in them.

6. Food chain samples were also collected from Dhapdhapi area of South 24 Parganas district and were boiled with highly arsenic contaminated water. This experiment helps to know whether arseniferous water as boiling medium, would introduce arsenic in otherwise arsenic free food chain samples.

V. DESCRIPTION OF ARSENIC REMOVAL EQUIPMENTS

During the course of present study 16 numbers of community based arsenic treatment plant of different types and 4 different types of domestic filters were examined. The details of treatment plants / filter are given below.

1. AIIH & PH (Community & Domestic)

As the effective removal of arsenic from water requires complete oxidation of As (III), the bleaching powder is used for As III to AS (V) in this method with controlled dosing to keep the residual chlorine at the level of 0.2 mg/l. in the treated water. The next step is of co-precipitation process i.e. coagulation – flocculation. The ferric salts or alum is used as coagulant as both metal salts undergo hydrolysis and can be reduced to a very low residual if soluble hydroxides are formed at the proper pH and can be filtered off completely. The alum salts (30-60 mg/l) or ferric salts (20 – 40 mg/l) are added followed by rapid mixing for 60 seconds followed by very slow mixing for couple of minutes. The supernatant water is filtered through selected filtering media. The filter media used is domestic candle gravel and sand.

The domestic filters have been developed by AIIH & PH with candle filter as well as sand gravel filter. Domestic filter fitted with two candle filters can produce 30 lit. per day Arsenic free water.

AIIH & PH have also developed Arsenic removal plant with piped water supply scheme and also hand pump attached Arsenic removal plant with maximum treated rate of 1000 lit / hour.

The simplest domestic filter contains two pitchers with candle.

The plant uses oxidation coagulation flocculation – Sedimentation technology

2. **PAL TROCKNER : (Domestic & Community)**

The method uses adsorption technique for arsenic removal. Granular Ferric Hydroxide reactors are fixed bed absorbers operating like conventional filters with a downward water flaw. The granular ferric hydroxide is prepared from a ferric chloride solution by neutralization and precipitation with sodium hydroxide. It is poorly crystallized β FeOOH with a specific surface of 250-300 m^2 /g and porosity of 75 to 80%, the grain size ranges from 0.2 to 2.0 mm. As no drying procedure is included in its preparation all the pores are completely filled with water leading to high density of available adsorption sites and thus to a high adsorption capacity. The arsenate adsorption density on granular ferric hydroxide is almost similar to that on freshly prepared ferric hydroxide. Granulation does not lead to considerable decrease in adsorption capacity. The method can be applied in the pH range of 5.5. to 9.0, however the arsenic adsorption decreases slightly with pH, which is typical of anion absorption .

The typical domestic filter is a cylinder filled will granular ferric hydroxide with a inlet and outlet which can be easily fitted. The community-based plants are having two chambers one for iron removal and another for Arsenic removal filled with granulated ferric hydroxide. The facility for collecting back wash is available. The technique uses absorption method.

3. **AMAL (Domestic & Community)**

The technique used in this treatment plant is based on adsorption. The Amal domestic arsenic removal units consist of two chambers upper one houses the media (which contains pretreated activated alumina, i.e. protanation where the media is treated with either HCl or H_2SO_4, the Activated alumina used is AS-37 (Oxide India Ltd. Durgapur, India) and the treated water is collected in the bottom chamber. It is constructed using the conventional domestic candle filter from which the ceramic candles were removed and were replaced by an arrangement to produce a suitable rate of flow. The media is enclosed in the impervious nylon bags with pervious bottom for easier handling during regeneration and restoration. One such domestic unit is expected to operate for about 6 to 8 months. For regeneration of media two methods are available (I) treatment with only caustic soda. (NaOH) or with hydro chloric acid or first with NaOH and then HCl, for this the bed is dipped in 4% NaOH for two hours (regeneration) following by rinsing with water (till PH of rinsing water (7.0 –8.0) and subsequently dipped the media for 2 hours in 0.5 N HCl (restoration) filled by similar rinsing.

The AMAL arsenic removal units (hand pump attached) for community use, uses the same activated alumina based media. The medium is housed within a stainless steel column and operated in the down flow mode. The each units is capable of serving 200 families. The frequency of regeneration-restoration depends on the raw water arsenic concentration and rate of consumption of water. After exhaustion the media is regenerated and restored by using caustic soda and hydrochloric acid in situ. The units are provided with a back washing arrangement if needed in view of the high iron content in raw water and subsequent iron fouling and clogging of the bed.

4. **PHED (Community)**

The oxidation –coagulation-flocculation-sedimentation is used in this method. In this process chlorine is used an oxidant for converting as (III) to (V), the bed material is activated carbon siliceous material and activated alumina. Uses Ferric chloride as co-precipitator for coagulation followed by multi media in the sand.

5. WSI (Community)

There are four cylinders one for filtration followed by two-iron removal and one for Arsenic removal. The media of resin requires to be changed periodically.

6. **APIRON (Community)**

Uses activated alumina an as adsorbent. There is one box connected to hand pump which contains media fall owed by another box containing free water Vertical type of APIRON Arsenic removal plant is also available. The boxes are locked and media can be changed only by firms' representative.

5. **CSIR (JU) (Domestic)**

The fly ash is the main ingredient. A tablet has been developed containing chemicals for water treatment. The water is to be treated with tablet for 2 hours and then decantation- filtration by usual filter candle.

VI. HYDROCHEMICAL STUDIES

COLLECTION OF WATER SAMPLES

To evaluate the performance of the different types of filters / treatment plant water samples were collected 3 times during the present investigation from 16 (community based plant) and from 10 location using 4 different types of domestic filters. The samples were collected as per the details (appendix – 1)

(1) Samples for general Chemical Analysis :

Water sample were collected in a 1 litre cleaned polythene bottle from the direct hand pump after purging sufficiently to ensure the representative water from the aquifer, and also from the filter using the same water.

(2) For determination of Arsenic and Iron :

The samples for determination of Arsenic and Iron were collected from hand pump and also the treated water from the same raw water simultaneously. The samples were treated with 2 ml of A.R. conc. Hydrochloric acid per litre, the conc. nitric acid was not used as the presence of nitric acid interfere with the determination of Arsenic both spectrophotometeric method using silver diethyl dithio carbonate (GEM 87) and also by HVG atomic absorption method (Former 93). The hydrochloric acid was preferred on sulfuric acid as the methodology for determination of Arsenic uses hydrochloric acid.

(3) Collection of water samples for determination of Heavy Metals. :

The water surplus from the hand pump and also from the filter / plant using the same source water was collected in the cleaned 1 litre polythene bottle and acidified with 2 ml/l of A.R. Conc Nitric Acid to ensure pH. below 2.

(4) Collection of Back wash sample :

During the course of investigation back wash samples mere collected in 1 lit / 2 lit. cleaned polythene bottle to determine the concentration of Arsenic iron, and Aluminum (Where ever alumina has been used) where ever it was possible to collect in all 27 number of back water samples were collected.

Special care was taken to ensure that the source water and treated water are from the same hand pump and at times it was difficult to collect the water samples either because of non use of filter or the source water for filter was from the near by deep tubewells.

(5) **Collection of water samples for Arsenic and Iron** concentration with time

The water sample from the hand pump at Paschim Mallickpur, Baruipur block, S-24 Parganas was collected and acidified in the morning and evening to ascertain the change in Arsenic and Iron concentration with time.

(6) Collection of water samples Arsenic and Iron consequent to pumping.

The water samples were collected from Moyna, Village, Barasat-I, N-24 Parganas from shallow tubewell (depth 40 m) during pumping (at discharge of 28 m3/hr) at half an hour interval to ascertain the change of Arsenic and Iron concentration.

(7) Collection of water samples for Arsenic and Iron for comparison of selected adsorption media under controlled condition.

An attempt was made to compare the different adsorption media under controlled condition. The well site at Baruipur Block, (Paschim Mallickpur, S-24 Parganas) having high Arsenic content was selected for the study. The arrangement was made to supply ground water with Arsenic at same pressure head. The samples were collected from three different adsorbent (Amal, Paltrockner & RPM) at 3 different flow rate at half an interval in each case.

METHODOLOGY

(I) IN FIELD

The following parameter were determined in the field

1. Temperature : Mercury bulb thermometer was used.
2. pH : pH of water sample was determined at the well head using pen type pre standardised Henna pH meter. The instrument was standardised frequently.
3. Electrical Conductivity : EC was determined by pre calibrated hand held type EC meter of Henna make.
4. Dissolved Oxygen : The dissolved oxygen determination of the water sample from the hand pump was done after sufficient purging at the well head (discharge point) to avoid exposure to air using diffusion type DO meter.

(ii) IN CHEMICAL LABORATORY.

1. Alkalinity : Alkalinity was determined trimetrically using 0.02 m H_2SO_4 and mixed indicator at Bromo creasol green and methyl red.
2. Chloride : Chloride was determined argentometric using silver nitrate and potassium chromate.
3. Sulphate : Sulphate was determined by using turbidimetric – $BaCl_2$ method.
4. Nitrate : Nirtrate was determined spectrophotometrically using ultra violet range.
5. Fluoride : Spectrophotometrically using Eriochrome cyanine R method.
6. Sulphide : Iodometrically

7. Phosphate : Phosphate was determined by ammonium moloybdate spectrophotometric method.

8. Sitica : Spectrophotometrically using molybdenum blue method.

9. Total Hardness : Total hardness was determined by using complexornetric method using EDTA and Eriochrome black T. Ammonium chloride-ammonium hydroxide buffer was used.

10. Calcium : Calcium was determined by using EDTA and Pattan and Reeders reagent, the pH was maintained by using 2 M NaoH.

11. Magnesium : Magnesium was determined by using values of Total hardness and Calcium.

12. Heavy Metals : The pre concentrated raw water samples were subjected to SHIMADZU atomic absorption spectrophotometer for heavy metals determination.

13. Arsenic : Arsenic was determined by silver diethyl dithio carbamate-pyridine method.

14. Iron : Spectrophotometrically using Bipyridine.

ANALYSIS AND RESULTS

The water samples (both raw & treated / filtered) thus collected from different sites where community based plants and domestic filters have been introduced were analysed mainly in the chemical laboratory of central Ground Water Board, Eastern Region, Calcutta and from the Central Laboratory of Northern Region, Lucknow (for heavy metals except aluminum). The general chemistry of raw water collected from all the source that were tested fall within the normal range excepting the concentration of arsenic and iron and in some cases Manganese. In general, the raw water is mainly of calcium bicarbonate and calcium-magnesium bicarbonate type with appreciable hardness. The pH of ground water has been found nearly neutral and the electrical conductivity is within 1000 µs / cm at 25^0C. Which may be considered as fresh in most of the cases. These ground water are also characterized by very low turbidity, low dissolved oxygen and also low sulphate, chloride, nitrate, fluoride and sulphide. The trace metals content of ground water are within the acceptable limit, except the manganese content in few cases which is normally the case when iron concentration is ground water is also high. Therefore, it is suitable for drinking purposes leaving mainly arsenic and iron contamination.

Different Arsenic removal plants and filters thus introduced in arsenic infested study areas of West Bengal whose efficacy have been examined by analysing treated / filtered water. It may be mentioned that efficacy has been computed irrespective of the arsenic concentration in raw /source water as it as was basis.

The chemical analysis data of raw and treated water of individual make of plants / filters have presented in appendix 4,5,6,7,8.

A. Arsenic removal plants and filters :

The gist of the results of all the plants and filters that have been tested -

Community

Type of Plant	Removal of Arsenic upto (mg/L)	Removal of Fe upto (mg/L)
AIIH & PH	0.31	10.74
Amal	0.96	12.42
Pal Trockner	1.12	12.00
APIRON	2.34	11.17
WSI	0.24	8.00
PHED	0.30	19.60

Domestic

Type of Filter	Removal of Arsenic upto (mg/L)	Removal of Fe upto (mg/L)
AIIH & PH	0.38	14.26
Amal	0.41	22.00
Pal Trockner	2.95	13.92
J.U. (C.S.I.R)	0.28	8.95

B) Heavy metals in raw / source water :

Raw / source water used for 14 community based plants and 43 domestic filters were collected once from Malda, Murshidabad, Nadia, North 24 Parganas and South 24 Parganas district of West Bengal and analysed for heavy metals (Al, Cd, Cr, Cu, Mn, Pb & Zn). The details of the chemical analysis results are presented in appendix 11 & 12.

The range of the heavy metals in ground water used for community plants and domestic filters is presented in the table 1.

Table –1 Range of Chemical Parameters of heavy metals in raw water

Raw water used	Al	Cd	Cr	Cu	Mn	Pb	Zn
←			micrograms per				→
Community Plants	19 to 172	ND to 1.0	ND to 11	ND to 6.0	ND to 1421	ND to 40	ND to 416
Domestic filters	5 to 280	ND to 2.0	1.0 to 11	ND to 25	ND to 1756	ND to 12	ND to 562

ND: Not Detectable

The heavy metals content of ground water used in both cases are within the acceptable limit, except the Mn. Content in a few cases.

C) Analysis of backwash samples:

Back wash samples from 9 locations of 6 different community plants and 18 locations of 4 different domestic filters have been collected and analysed for arsenic, iron and aluminium. (vide appendix 13). The gist of the results is as follows:

Table 2 Analysis of backwash samples:

Type of plants / filters		**As mg/l**	**Fe mg/l**	**Al mg /l**
Community based plant	WSI	0.184	0.56	0.21
	APIRON	1.36	28.02	0.22
	PHED	0.78	0.18	0.10
	AMAL	0.02 – 1.89	0.18 – 0.38	0.03 – 0.121
	AIIH & PH	0.01 – 2.52	1.8 – 2.52	0.056 – 0.095
	PAL TROCKNER	1.11	32.54	___
Domestic filter	AMAL	0.005 – 2.04	0.2 – 0.62	0.024 – 0.072
	J.U. (CSIR)	0.01 – 2.23	0.44 – 4.98	0.082 –0.088
	AIIH & PH	0.005	0.14	0.198
	PAL TROCKNER	0.005-0.15	0.2 – 33.28	___

It has been observed that in all the arsenic removed plants / filters, backwash contains arsenic and iron and in some cases arsenic content is alarmingly high (2.52 for community plant and 2.23 for domestic filter) which may cause environmental hazards in future.

D. Arsenic and Iron concentration consequence to pumping.

An experiment was conducted to examine the arsenic and iron concentration consequent to pumping of arsenic water from a shallow irrigational tube well at Moyna, Barasat I block, North –24 Parganas district. The detailed results are presented in appendix – 14. The summary of results is given below:

Location	**Type of well**	**Depth of well mbgl**	**Discharge m^3/hr**	**Time of collection of water sample since pumping started (min)**	**Ec µs / cm at 25^{0}c**	**Ph**	**Cl mg/l**	**Fe mg/l**	**As mg/l**	**Remarks**
Mayna	PW	40	28	0	772	7.42	21	10.28	0.214	
				30	-	-	-	10.36	0.21	
				60	773	7.41	19	10.14	0.21	
				90	-	-	-	10.26	0.21	
				120	775	7.43	19	10.18	0.214	
				150	-	-	-	10.0	0.21	
				180	776	7.43	21	10.04	0.22	
				210	776	7.44	21	10.02	0.20	
Mayna	OW	40		0	883	7.62	21	15.4	0.655	Observation well is at 17.2m from pump well
				210	866	7.6	21	23.4	0.87	

Consequence to pumping arsenic & iron concentration does not change much though slightly decreases where as in observation (Same depth located at a distance of 17.2m) shows increase in arsenic concentration.

E. Study the effect of arsenic concentration in ground water in different time at a particular day.

Water samples from a particular well located at Pachim Maallikpur, Baruipur block, South 24 Parganas district were collected in morning and evening on a particular day. The samples were analysed for arsenic concentration and it was found that concentration is more or less same in the morning sample (2.93 mg / l) and evening sample (2.99 mg/l)

F. Comparison of selected arsenic adsorption media under controlled condition

An attempt has been made at Dhabdhabi, Paschim Mallickpur village, Baruipur block, South 24 Parganas district to study the efficiency of different arsenic adsorption media from a known high source of arsenic under controlled condition. The study has made maintaining constant head of raw water and allowing it to pass through different arsenic adsorption media. The result of arsenic and iron of treated water after passing through different arsenic adsorption media is presented in appendix – 15

VII. ARSENIC CONTENT OF SOME SELECTED FOOD CHAIN SAMPLES

As a part of the study the effect of arsenic containing water in the cooked food was undertaken.

Collection of samples: Four different types (Rice, papaya, potato and Guava) of food material was collected from arsenic infested area and a portion of the same was kept separate for initial Arsenic content. The portion of the food material was boiled in Arsenic containing water in field for 15 minutes and the water decanted and the boiled samples carried to the laboratory.

Digestion of cooked food: The raw food items and boiled portion was dried in an oven at 600C and 1g. of dried material was subjected to digestion first with nitric acid followed by nitric acid/sulphurric acid mixture at 180 to 2000C.

The arsenic content of raw food material and boiled one was done by GBC atomic absorption spectro-photometer.

A. RESULTS OF ARSENIC CONTENT OF SOME RAW FOOD CHAIN SAMPLES FROM NORTH, SOUTH 24 PARGANAS AND NADIA DISTRICTS.

(Irrigated by Ground Water varying in Arsenic concentration from 0.06 to 0.40 mg/l)

Sl. No.	Location	Food Chain Samples	Results mg / kg
1.	Madanpur, Nadia	Coriander	0.3
2.	Joypur, N 24 Parganas	Spinach	0.9
3.	"	Bean (F)	0.5
4.	"	Tomato	2.0
5.	"	Cabbage	1.65
6.	"	Potato	1.8
7.	"	Chilli	1.3
8.	"	Brinjal	0.5
9.	"	Pumpkin	1.3
10.	"	Papaya	1.45
11.	"	Banana	1.50
12.	Madanpur, Nadia	Tomato	0.55
13.	"	Cabbage	1.1
14.	"	Bitter Gupri	0.9
15.	"	Papaya	Nd
16.	"	Pumpkin	1.3
17.	"	Brinjal	1.6
18.	"	Potato	1.85
19.	"	Chilli	1.25
20.	"	Banana	0.35
21.	"	Mustard	4.90
22.	"	Masur Dal	Nd
23.	"	Wheat	1.25
24.	"	Rice	Nd
25.	Joypur, N 24 Parganas	Corianoen (seed)	Nd
26.	"	Wheat	0.4
27.	"	Mustard	0.65
28.	Kamdevpur	Tomato	1.65
29.	"	Spinach	0.8
30.	"	Cabbage	3.35
31.	"	Banana	Nd
32.	"	Lal sag	Nd

Sl. No.	Location	Food Chain Samples	Results mg / kg
33.	Kamdevpur	Cauliflower	1.85
34.	"	Pumpkin	0.30
35.	"	Flat Beans	1.25
36.	"	Chilli	0.30
37.	"	Papaya	Nd
38.	Ramnagar, S 24 Parganas	Jamrul	0.2255
39.	"	Tomato	1.729
40.	"	Pea	2.534
41.	"	Potato	3.969
42.	"	Pea	2.018
43.	"	French Beans	1.473
44.	"	Guava	7.088
45.	"	Flat Beans	2.393
46.	"	Papaya	3.747
47.	"	Banana	2.3095
48.	"	Leman	3.532
49.	"	Safeda	4.658
50.	"	Lalbag	4.7705
51.	"	Flat Beans	1.941
52.	"	Flat Beans	2.3525
53.	"	Jamrul	5.7075
54.	"	Papaya	2.5075
55.	"	Tomato	2.622
56.	"	Drumstick	2.038
57.	"	Leman	2.916
58.	"	Chilli	2.4115
59.	"	Bitter Gourd	3.4605
60.	"	Brinjal	2.191

B. ARSENIC CONTENT OF RAW & COOKED FOOD IN DHABDHABI S-24 PARGANAS.

Serial No.	Items (dried)	Arsenic (mg / kg)
1.	RICE (RAW)	0.3
2.	RICE (BOILED)	0.8
3.	POTATO (RAW)	1.15
4.	POTATO (BOILED)	1.05
5.	PAPAYA (RAW)	0.90

6.	PAPAYA (BOILED)	1.10
7.	GUAVA (RAW)	1.10
8.	GUAVA (BOILED)	1.00

VIII. MAJOR FINDINGS

In order to ascertain the effectiveness of arsenic removal equipments, using different technologies, water quality test were carried out in the chemical laboratory of Eastern Regional office of Central Ground Water Board. Some other experiments associated with arsenic contamination in ground water were also conducted. The major findings of the experiments and tests conducted are: -

1. The arsenic & iron removal capacity of different filters are reflected through the values indicated below (in mg/l)

DOMESTIC FILTERS

	AIIH & PH	AMAL	PAL TROCKNER	CSIR (J.U.)
As	0.38	0.41	2.95	0.284
Fe	14.26	22	13.92	8.95

TREATMENT PLANTS

	AIIH & PH	AMAL	PALTROCKNER	APIRON	WSI	PHED
As	0.31	0.96	1.12	2.34	0.238	0.30
Fe	10.74	12.42	12.0	11.17	8.0	19.6

The values presented above, have been arrived at, considering the maximum arsenic concentration, each technology has been able to remove at the available input water concentration. It is worth mentioning that, while in the case of domestic filters, the target sample number is the same for all the technologies tested, in the case of community based plants, the sample number is different for different technology and is very small for any statistical analysis.

2. The concentration of both arsenic and iron is high in the backwash samples that were analysed. Arsenic concentration which goes up to 2.52 mg/l , is mainly high in the samples of community based plants. Iron concentration is also high and is of the order of 33 mg/l in some of the samples. It is therefore recommended that Research and Development 'study is required for their safe disposal otherwise backwashing may form a secondary source of contamination.

3. The samples collected from the same source at different period of the day reveals that there is no noticeable change in the concentration of arsenic between the samples collected in the morning and the one that was collected in the evening. This definitely indicates that arsenic concentration in groundwater does not change as a result of ground water abstraction at a normal rate.

4. Parameters of general chemistry of both input and output fall with the normal prescribed limits. Even the alluminium content of output water of equipments using, activated alumina as adsorbent material is found to be within the normal limits. Heavy metals concentration of input water (except manganese in a few cases) is within the range of drinking water standard.

5. Experiment conducted by passing arsenic rich water at three different controlled rates of flow through three different types of media i.e. granulated ferric hydroxide of Pal Trockner, activated alumina of AMAL and Alkon supplied by UNIDO, reveals an interesting feature.

   The rate of reduction of arsenic concentration in the output water enhances with slower rate of flow through the media, indicating the influence of longer contact time of water with media in the removal process.

6. Hydrological test conducted, reveals that the arsenic concentration does not change appreciably (it reduces slightly) due to pumping of from the aquifer at rate of $28m^3$ /hr for a period of 210 minutes.

7. On perusal of the results of Arsenic content in food chain it is observed that Arsenic content in food chain (dried) is normally more than 1 mg/L and the highest value (7.09 mg/L) has been found in case in Gauva at South 24 Parganas.

8. The food items were cooked with ground water containing 2.93 mg/L arsenic. In cooked food item the appreciable difference has been found in case of Rice, the Raw Rice (dried) contained 0.3 mg / kg where as the arsenic content of cooked Rice (dried) has been found to be 0.8 mg / kg.

   There is not much difference in the arsenic content of raw food items (Potato, Guava and Papaya) as compared to the cooked one.

IX. CONCLUDING REMARKS

Constraints faced

Since the nature of the study involving various tests and experiments, was unique and first of its kind, the team of scientists engaged in the study had to overcome some constraints, while carrying out the job. Some of the major constraints are discussed below:

1. State of the media: Effectiveness of a removal media is governed by the total quantity of water that has passed through it, reducing thereby its removal capacity. Since the collection of water samples was a time bound programme, it was not feasible to collect sample with fresh media every time. In addition, backwashing of the media may also influence the removal capacity, which is done off and on.

2. Sometimes in the case of domestic filters, it had to be ensured that the same raw water is used in the filters that were tested. Users have the tendency to put water from different tubewells especially from the deep tubewells.

3. It was hard to collect samples due to discontinuous use of domestic filters. Discontinuous use was influenced either by the non-availability of filter material or due to proximity of deep tubewells.

4. Flow rate could be compared, only for the technologies using adsorbent material.

5. Arsenic removal equipments were subjected to input water of arsenic concentration that range between wide limits. As a result, it is difficult to judge their efficacy in terms of bringing down input water concentration to less than 0.05 mg/l in the output water.

6. Unprecedented flood of West Bengal in the year 2000, delayed the field level work programme as chalked out earlier.

7. In case of domestic filters of AIIH&PH, the container being earthen, some people refuse to use them in winter.

Overall observation

The present study has been able to throw some light on the performance of various arsenic removal plants and filters, that are in operation for quite some time now in the arsenic infested parts of West Bengal.

Although, by and large the arsenic removal equipments are effective in bringing down the concentration of input water to less than 0.05 mg/l, there are instances, when the output water does contain noticeable arsenic concentration. In the case of community based plants, output water of the plants contain arsenic (in mg/l) from:

a) AIIH&PH at Sardarpara, Baruipur 0.122 to 0.352.
b) WSI at Joypur, Barasat I, 0.16.
c) Pol Trockner at Serpur 0.136.
d) PHED at Gobardanga, 0.072. and at Bakerpur, Kaliachak I 0.54.

Another feature that draws attention is that while other technologies negotiated comparatively less input water concentration, APIRON and Pol Trockner technology worked with higher input water concentration.

In the case of domestic filters, also there are cases where treated water is not free from arsenic. Treated water from domestic filters contain arsenic (in mg/l) from:

a) C.S.I.R. Jadavpur at Amkhola, Gaighata 0.112 to 0.15 and Uttar Kolsur, Deganga 0.14 to 0.2.
b) Amal at Sangrampur, Basirhat 0.07 to 0.102.
c) Pol Trockner at Chandokhal, Baruipur 0.14.
d) AIIH&PH at Laxmipur, Habra 0.064 to 0.078.

The concentration of arsenic in the treated water above the permissible limit can mainly be attributed to poor maintenance and monitoring than any inherent weakness in the technology itself. It is recommended that periodic monitoring over a considerable period of any arsenic removal equipment should be made mandatory, otherwise it is an act of sheer injustice to provide **arsenic rich water** to the affected people in the name of **arsenic free water.**

It was observed that social acceptance of arsenic removal equipment, especially the domestic filters are yet to gather momentum, and requires awareness programmes for their promotion.

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LOCATION OF ARSENIC FILTER INSTALLED AND SAMPLE COLLECTED

Sr. No	Location	Type of filter	Manufacturer	Location	Block	District	Date	Access/ Owner	Remarks
1	1	**Community**	Pal Trockner	Mayna	Barasat 1	N24 Pgns	03/08/2k	At Nimai Biswas House	N W
		Community	Pal Trockner	Mayna	Barasat 1	N24 Pgns	11/08/2k	At Nimai Biswas House	Sample no 26
2	2	**Community**	WSI	Joypur	Barasat 1	N24 Pgns	03/08/2k	Near Mahadav Senapati'house	Sample No 1
3	3	**Community**	APIRON	Sibalaya	Barasat 1	N24 Pgns	03/08/2k	Kaborkhola, In Rabin Paul's House	Sample No 2
4	4	**Community**	APIRON	Adhata	Amdanga	N24 Pgns	03/08/2k	Beltola at Nanigopal Das' house	Sample No 3
5	5	**Community**	AIIHPH	Amkhola	Gaighata	N24 Pgns	04/08/2k	Amkhola on road side	N W/R W 4
6	6	Domestic	CSIR (J.U.)	Amkhola	Gaighata	N24 Pgns	04/08/2k	At Sunil Debnath's House	Sample No 5
7	7	Domestic	CSIR (J.U.)	Amkhola	Gaighata	N24 Pgns	04/08/2k	At Amar Samanta's house	Sample No 6
8	8	**Community**	PHED	Gobardanga	Gaighata	N24 Pgns	04/08/2k	At water supply scheme 1	Sample No 7
9	9	Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	04/08/2k	In Swamiji Sewa Sangha	N W
		Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	08/08/2k	In Swamiji Sewa Sangha	Sample no 15
10	10	**Community**	AMAL	Laxmipur	Habra 1	N24 Pgns	04/08/2k	Near Hindu Milan Mandir	Sample No 8
11	11	Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	04/08/2k	At Sarat ch mondal's house	Sample No 9
12	12	**Community**	Pal Trockner	Serpur	Baruipur	S24 Pgns	05/08/2k	Near Serpur(Dhobdhobi) more	Sample No 10
13	13	**Community**	AIIHPH	Sardarpara	Baruipur	S24 Pgns	05/08/2k	Near Surat Ali Sardar's house	Sample No 11
14	14	Domestic	Pal Trockner	Chandokhali	Baruipur	S24 Pgns	05/08/2k	Mandalpara in Jharna Halder's house	Sample No 12
15	15	Domestic	Pal Trockner	Sakhari pukur	Baruipur	S24 Pgns	05/08/2k	At Nirmal Biswas's house	Sample No 13
16	16	Domestic	Pal Trockner	Beliaghata	Baruipur	S24 Pgns	05/08/2k	Biswaspara in Susanta Mondal's house	Not in use
17	17	Domestic	Pal Trockner	Sakhari pukur	Baruipur	S24 Pgns	05/08/2k	In Kamal Biswas's house	Sample No 14
18	18	Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	08/08/2k	In Nandodulal Chakraborty's House	Sample No 16
19	19	Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	08/08/2k	In Anil Bapari's House	Sample No 17
20	20	Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	08/08/2k	Bramhinpara, Madav Banerjee	Sample No 18
21	21	Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	08/08/2k	Bramhinpara, Bijoy Banerjee	Sample No 19
22	22	Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	08/08/2k	Bramhinpara, Tapash Chakraborty	Using deep TW water
23	23	Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	08/08/2k	Bramhinpara, Basudev Mukherjee	Sample No 20
24	24	Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	08/08/2k	Amal Roy	N W
25	25	Domestic	CSIR (J.U)	Simulpur	Habra 1	N24 Pgns	08/08/2k	Nibash Roy	Sample No 21
26	26	Domestic	CSIR (J.U)	Simulpur	Habra 1	N24 Pgns	08/08/2k	Dilip Biswas	N W
27	27	**Community**	AMAL	Sadpur	Habra 1	N24 Pgns	08/08/2k	Near Machlandapur 1no Panchyat office	Sample No 22
28	28	**Community**	AMAL	Sangrampur	Basirhat 1	N24 Pgns	09/08/2k	Near Sangrampur primary school	Sample No 23
29	29	Domestic	AMAL	Sangrampur	Basirhat 1	N24 Pgns	09/08/2k	Paschimpara, Gita Mondal	Sample No 24
30	30	**Community**	Pal Trockner	Sibhati	Basirhat 1	N24 Pgns	09/08/2k	In Sibhati block primary health centre	Sample No 25
31	31	**Community**	Ion Exchange	Dasdia	Haringhata	Nadia	11/08/2k	PHED,near house of Qutubuddin Mondal	N W
32	32	Domestic	Pal Trockner	Baruipur	Baruipur	S24 Pgns	17/08/2k	Chakrabortypara, Ranjit Dutta	Sample NO 27
33	33	Domestic	Pal Trockner	Baruipur	Baruipur	S24 Pgns	17/08/2k	Chakrabortypara, Jiban Krishna Bhattacharjee	Sample No 28
34	34	Domestic	Pal Trockner	Baruipur	Baruipur	S24 Pgns	17/08/2k	Chakrabortypara, Ranjan Guha Thakurada	Not in use
35	35	Domestic	Pal Trockner	Baruipur	Baruipur	S24 Pgns	17/08/2k	Chakrabortypara, Ashoke kr Tiwary	Sample No 29
36	36	Domestic	Pal Trockner	Baruipur	Baruipur	S24 Pgns	17/08/2k	Fultala,Dudhnoi, Rosan Ali Sapui	Sample No 30
37	37	Domestic	Pal Trockner	P. Mallickpur	Baruipur	S24 Pgns	17/08/2k	Khanpara, Dhobdhobi 2no, Eyakub Mollah	Sample No 31

Sr. No	Location	Type of filter	Manufacturer	Location	Block	District	Date	Access/ Owner	Remarks
38	38	Domestic	Pal Trockner	Serpur	Baruipur	S24 Pgns	17/08/2k	Sardarpara, Prafulla Sardar	Using deep TW water
39	39	Domestic	Pal Trockner	Baruipur	Baruipur	S24 Pgns	17/08/2k	Banerjeepara, Nirmal Kr Banerjee	Sample No 32
40	40	**Community**	AIIHPH	Batai	Tehatta-1	Nadia	25/08/2k	Jitpurpara(North),Near Gauranga Poddar's house	Sample No 33
41	41	**Community**	AMAL	Betai	Tehatta-1	Nadia	25/08/2k	Itkholapara,Near Khitish ch Adhikari's house	Sample No 34
42	42	**community**	PHED	Jaudia(Jalangi)	Jalangi	Murshidabad	25/08/2k	Chandbila para,Near Munsar Mondal's house	Sample No 35
43	43	Domestic	AMAL	Kaliachak	Kaliachak 1	Malda	26/08/2k	Puratan hat,Mukulesh Rahman Chowdhury,near NH-34,Allahabad bank Chandpur Branch	Sample no 36
44	44	Domestic	AMAL	Kaliachak	Kaliachak 1	Malda	26/08/2k	Puratan hat, Layakat Ali Biswas	Sample No 37
45	45	Domestic	AMAL	Kaliachak	Kaliachak 1	Malda	26/08/2k	Rishipara, Rumi Machinary Works, Sekh Jafulla	Sample No 38
46	46	Domestic	AMAL	Uttar Dariapur	Kaliachak 1	Malda	26/08/2k	Nayabasti,Md Anowar Ali, 2.5km from Kaliachak	Sample No 39
47	47	Domestic	AMAL	Uttar Dariapur	Kaliachak 1	Malda	26/08/2k	Nayabasti, Murshed Ali, adj to location 46	Sample No 40
48	48	Domestic	AMAL	Dakshin Laxmipur	Kaliachak 1	Malda	26/08/2k	Mozampur,Kashimnagar, Ajoy Kr Ghosh	Sample No 41
49	49	Domestic	AMAL	Dakshin Laxmipur	Kaliachak 1	Malda	26/08/2k	Mozampur,Kashimnagar, Bivuti Bhusan Ghosh	Sample No 42
50	50	Domestic	AMAL	Dakshin Laxmipur	Kaliachak 1	Malda	26/08/2k	Anchal Alipur 2, Mukulesh Rohman Khan	Sample No 43
51	51	Domestic	AMAL	Kaliachak	Kaliachak 1	Malda	26/08/2k	Master para, Maniruddin Biswas opposite to Kaliachak Police Station	Sample No 44
52	52	Domestic	AMAL	Kaliachak	Kaliachak 1	Malda	26/08/2k	Baliadanga, Binoy Krishna Karmakar, approach near from Kaliachak Police Station	Sample No 45
53	53	Domestic	AMAL	Malda	Englishbazar	Malda	27/08/2k	Mokdumpur,on Gour road,Hitanksu Chowdhury	Using deep TW water
54	54	Domestic	AMAL	Malda	Englishbazar	Malda	27/08/2k	Krishnapalli,Owner Ratan Kr Saha, from main road,cross Rly line on bandh road near tulsi more	Sample No 46
55	55	**Community**	PHED	Bakherpur	Kaliachak 1	Malda	27/08/2k	Sujapur water supply scheme PHED	Sample No 47
56	56	Domestic	AMAL	Jalalpur	Kaliachak 1	Malda	27/08/2k	Nurnagar,Md Murshed Mahammad	Sample No 48
57	57	Domestic	AMAL	Khagra	Berhampur 1	Murshidabad	27/08/2k	42/18B Dayamoipara,Nimai Ch Biswas	Sample No 49
58	58	Domestic	AMAL	Khagra	Berhampur 1	Murshidabad	27/08/2k	Saydabad,near PS, 191 Maharaja Nandokumar road,.Owner Dulal Paul	Sample No 50
59	59	Domestic	AMAL	Kharga	Berhampur 1	Murshidabad	27/08/2k	68A Biswaswar Chowdhury Lane, Maturapara, Owner Apurba Biswas	Sample NO 51
60	60	Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	28/08/2k	Near Ashram, Samurendranath Hazra	Sample no 52
61	61	Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	28/08/2k	Near to High School, Mrs. Helen Dutta	Sample no 53
62	62	Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	28/08/2k	Approach from High School, Owner Amal Roy	Sample no 54
63	63	Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	28/08/2k	Near to Amal Roy's house, Owner Sunil Kr. Jana	Sample no 55
64	64	Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	28/08/2k	Bishnupada Bhowmick, Near to Vidya Sager Smriti Sangha	Sample no 56
65	65	Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	28/08/2k	Near location 64, owner Arindam Chatterjee	Sample no 57
66	66	Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	28/08/2k	Opposite to Milan Mandir, Smt. Barnali Bhattacharya	Sample no 58
67	67	Domestic	AIIHPH	Laxmipur	Habra 1	N24 Pgns	28/08/2k	Owner Sri Pankaj Das	Sample no 59
68	68	Domestic	Pal Trockner	Dhobdhobi	Baruipur	S 24 Pgns	29/08/2k	Sarkar Para, Owner Rajiya Bibi	Sample no 60
69	69	Domestic	Pal Trockner	Dhobdhobi	Baruipur	S 24 Pgns	29/08/2k	Gabtala, Owner Sri Gopal Mandal	Sample no 61
70	70	Domestic	Pal Trockner	Dhobdhobi	Baruipur	S 24 Pgns	29/08/2k	Owner Kachimuddin Sardar	Sample no 62
71	71	Domestic	Pal Trockner	Dhobdhobi	Baruipur	S 24 Pgns	29/08/2k	Owner Ajit Ali Sarkar	Sample no 63
72	72	Domestic	Pal Trockner	Dhobdhobi	Baruipur	S 24 Pgns	29/08/2k	Owner Rajiya Bibi, Raw water from location 13.	Sample no 64
73	73	Domestic	J. U. (CSIR)	Berachampa	Deganga	N24 Pgns	07/09/2k	Dr. Paresh Nath Kayal, near Primary School & near Pragati Club	Sample no 65

Sr. No	Location	Type of filter	Manufacturer	Location	Block	District	Date	Access/ Owner	Remarks
74	74	Domestic	J. U. (CSIR)	Berachampa	Deganga	N24 Pgns	07/09/2k	Owner Madan Mohan Kayal, adjacent to location 73	Sample no 66
75	75	Domestic	J. U. (CSIR)	Uttar Kaisur	Deganga	N24 Pgns	12/09/2k	Fakir Para, owner Saiddul Islam	NW
76	76	Domestic	J. U. (CSIR)	Uttar Kaisur	Deganga	N24 Pgns	12/09/2k	Fakir Para, owner Abddul Hameed Biswas	Sample no 67
77	77	Domestic	J. U. (CSIR)	Uttar Kaisur	Deganga	N24 Pgns	12/09/2k	Fakir Para, owner Hyder Ali Mullah	Sample no 68
78	78	Domestic	J. U. (CSIR)	Uttar Kaisur	Deganga	N24 Pgns	12/09/2k	Fakir Para, owner Alijul Mullah	Sample no 69
79	79	Domestic	J. U. (CSIR)	Uttar Kaisur	Deganga	N24 Pgns	12/09/2k	Fakir Para, owner Abdul Khallack Mullah	Sample no 70
80	80	Domestic	J. U. (CSIR)	Uttar Kaisur	Deganga	N24 Pgns	12/09/2k	Fakir Para, owner Abdul Latif Mandal	Sample no 71
81	81	Domestic	J. U. (CSIR)	Uttar Kaisur	Deganga	N24 Pgns	12/09/2k	Fakir Para, owner Abdul Rashid Mandal	Sample no 72

ARSENIC REMOVAL PLANTS
(Community Based)

Results of Performance for three set of samples

Sr. No.	Technology / Manufacture	Location / Sample No.	Block	District	Arsenic (mg/L)		Iron (mg/L)	
					Raw	Treated	Raw	Treated
1.	Pal Trockner	Mayna (26)	Barasat I	N-24 Pgs.	0.82	BDL	12.0	0.02
					1.07	BDL	7.74	<.01
					1.12	BDL	10.28	1.26
2.		Serpur (10)	Baruipur	S-24 Pgs.	0.33	BDL	5.62	2.12
					0.34	BDL	6.20	<.01
					0.38	0.136	10.20	3.16
3.		Sibhatu (25)	Basirhat	N-24 Pgs.	0.165	BDL	4.73	0.41
					0.189	BDL	5.71	3.52
					0.28	BDL	7.76	1.76
4.	AIIH & PH	Amkhola(4)	Gaighata	N-24 Pgs.	0.377	N.A.	6.37	N.A.
					0.252	N.A.	6.95	N.A
					0.382	N.A.	8.56	N.A.
5.		Sardarpara (11)	Baruipur	S-24 Pgs.	0.78	0.352	11.12	4.34
					0.52	0.310	11.59	5.37
					0.63	0.122	17.5	1.48
6.		Batai (33)	Tehatta-I	Nadia	BDL	BDL	5.59	<.01
					BDL	BDL	19	3.9
					0.31	BDL	10.74	0.66
7.		Joypur (1)	Barasat-I	N-24 Pgs.	0.238	BDL	5.45	0.31
					0.310	0.16	5.55	0.07
					0.126	BDL	8.0	0.96
8.	APIRON	Sibalaya (2)	Barasat-I	N-24 Pgs.	1.035	BDL	10.76	0.60
					0.290	BDL	11.17	0.01
					0.360	BDL	15.98	1.12
9.		Adahata (3)	Amdanga	N-24 Pgs.	1.42	0.045	4.64	0.21
					2.34	0.025	5.00	<0.01
					1.145	0.030	6.96	0.92
10.	PHED	Gobardanga(7)	Gaighata	N-24 Pgs.	N.A.	0.072	5.00	<.01
					0.087	BDL	2.50	0.64
					0.05	BDL	2.64	1.0

Sr. No.	Technology / Manufacture	Location / Sample No.	Block	District	Arsenic (mg/L)		Iron (mg/L)	
					Raw	Treated	Raw	Treated
11.		Jaudia (35)	Jalangi	Murshidabad	0.3	BDL	10.22	<.01
					0.29	BDL	19	0.60
					0.266	BDL	19.6	0.64
12.		Bakerpur (47)	Kaliachak-I	Malda	N.A.	0.03	N.A.	0.67
					0.61	0.054	6.68	4.30
					0.172	0.054	3.46	1.38
13.	AMAL	Sadpur (22)	Habra –I	N-24 Pgs.	0.107	.01	1.38	<.01
					0.098	0.010	1.96	0.06
14.		Sangrampur (23)	Basirhat – I	N-24 Pgs.	0.34	BDL	10.0	0.02
					0.28	0.020	11.17	0.06
					0.36	0.25	13.8	1.54
15.		Betai (34)	Tehatta-I	Nadia	0.082	BDL	9.66	<.01
					0.72	BDL	12.5	1.06
					0.96	BDL	0.88	0.60
16.		Laxmipur (8)	Habra-I	N-24 Pgs.	0.14	BDL	9.17	0.82
					0.13	0.03	12.0	0.82
					0.112	0.035	12.42	0.98

BDL: Below detection limit i.e. (0.005 mg / L)

ARSENIC REMOVAL FILTER
AIIH & PH (Domestic)

Results of Performance for three set of samples

Sr. No.	Location / Sample No.	Block	District	Arsenic (mg/L)		Iron (mg/L)	
				Raw	Treated	Raw	Treated
1.	Laxmipur(15)	Habra -I	N-24 Pgs.	0.122	BDL	7.32	0.52
				0.117	BDL	7.54	<.01
				0.101	N.A.	10.86	N.A.
2.	Laxmipur (9)	Habra –I	N-24 Pgs.	0.122	0.072	7.75	0.52
				0.160	0.078	8.40	<.01
				0.15	0.070	10.8	0.78
3.	Laxmipur(16)	Habra-I	N-24 Pgs.	0.122	BDL	6.76	0.39
				0.091	0.02	7.32	<.01
				0.085	0.011	10.16	0.6
4.	Laxmipur(17)	Habra-I	N-24 Pgs.	0.102	0.102	6.78	5.89
				0.091	0.020	7.57	<.01
				0.101	N.A.	10.36	N.A.
5.	Laxmipur(20)	Habra-I	N-24 Pgs.	0.065	0.064	3.49	2.32
				0.035	0.032	4.45	1.05
				0.03	BDL	5.8	0.32
6.	Laxmipur(52)	Habra-I	N-24 Pgs.	0.055	BDL	6.38	<.01
				0.078	0.016	4.96	<.01
				0.066	N.A	13.54	N.A.
7.	Laxmipur(56)	Habra-I	N-24 Pgs.	0.184	BDL	4.72	0.2
				0.064	BDL	3.95	<.01
				0.015	N.A.	6.76	N.A.
8.	Laxmipur(57)	Habra-I	N-24 Pgs.	0.039	BDL	2.86	<.01
				0.025	BDL	3.05	0.26
				0.03	0.015	5.14	0.31
9.	Laxmipur(58)	Habra-I	N-24 Pgs.	0.136	BDL	9.28	<.01
				0.082	0.045	5.09	0.23
				0.107	0.035	14.26	0.35
10.	Laxmipur(59)	Habra-I	N-24 Pgs.	0.050	BDL	2.53	0.92
				0.082	0.010	3.09	0.98
				0.073	BDL	5.96	0.24

BDL : Below detection limit i.e. (0.005 mg / L)

ARSENIC REMOVAL FILTER
Pal Trockner (Domestic)

Results of Performance for three set of samples

Sr. No.	Location / Sample No.	Block	District	Arsenic (mg/L)		Iron (mg/L)	
				Raw	Treated	Raw	Treated
1.	Chandokhal (12)	Baruipur	S-24 Pgs.	0.136	BDL	5.12	0.52
				0.140	BDL	5.71	0.10
				0.665	0.140	22.60	5.38
2.	Sakharipur (13)	Baruipur	S-24 Pgs.	0.056	BDL	7.32	1.05
				0.01	BDL	8.68	0.66
				0.064	BDL	16.12	1.78
3.	Sakharipur (14)	Baruipur	S-24 Pgs.	0.126	BDL	3.40	3.85
				0.068	BDL	3.50	0.88
				0.136	BDL	4.32	1.24
4.	Baruipur (29)	Baruipur	S-24 Pgs.	0.102	BDL	0.35	<.01
				0.087	BDL	0.217	<.01
				0.064	BDL	1.68	0.28
5.	P.Mallickpur (31)	Baruipur	S-24 Pgs.	2.95	0.02	8.14	0.43
				2.38	BDL	8.19	0.46
				2.29	BDL	10.66	1.38
6.	Baruipur (32)	Baruipur	S-24 Pgs.	0.035	BDL	2.47	0.98
				0.030	BDL	3.28	0.20
				0.039	BDL	4.20	1.80
7.	Dhabdhabi (60)	Baruipur	S-24 Pgs.	0.091	BDL	0.10	<.01
				0.136	BDL	1.05	0.37
				N.A.	N.A.	N.A.	N.A.
8.	Dhabdhabi (61)	Baruipur	S-24 Pgs.	0.435	BDL	5.06	0.2
				0.410	BDL	1.08	0.37
				0.41	BDL	8.02	1.08
9.	Dhabdhabi (62)	Baruipur	S-24 Pgs.	0.725	BDL	12.9	0.64
				0.800	BDL	13.49	1.58
				0.585	BDL	14.64	2.52
10.	Dhabdhabi (63)	Baruipur	S-24 Pgs.	0.78	BDL	11.12	1.52
				0.275	BDL	13.92	0.72
				0.41	BDL	21.48	4.86

BDL : Below detection limit i.e. (0.005 mg / L)

ARSENIC REMOVAL FILTER
AMAL (Domestic)

Results of Performance for three set of samples

Sr. No.	Location / Sample No.	Block	District	Arsenic (mg/L)		Iron (mg/L)	
				Raw	Treated	Raw	Treated
1.	Sangrampur (24)	Basirhat	N-24 Pgs.	0.142	0.102	0.62	0.02
				0.180	0.035	1.75	<.01
				0.214	0.070	2.04	0.3
2.	Kaliachak (36)	Kaliachak-I	Malda	0.34	BDL	7.08	<.01
				0.30	BDL	22	0.6
				0.21	BDL	14.16	0.28
3.	Kaliachak (37)	Kaliachak-I	Malda	0.34	BDL	0.1	<.01
				0.3	BDL	0.85	0.3
				N.A.	N.A.	N.A.	N.A.
4.	Uttar Dariapur (39)	Kaliachak – I	Malda	0.016	BDL	1.52	<.01
				0.110	BDL	4.3	0.72
				0.018	BDL	2.68	0.42
5.	D. Laxmipur (41)	Kaliachak – I	Malda	0.145	BDL	4.77	<.01
				0.131	BDL	4.30	0.72
				0.146	BDL	9.02	0.16
6.	D. Laxmipur (42)	Kaliachak-I	Malda	0.244	BDL	0.97	<.01
				0.204	BDL	4.32	0.76
				0.41	BDL	3.6	0.44
7.	D. Laxmipur (43)	Kaliachak – I	Malda	0.378	BDL	0.10	<.01
				0.388	BDL	20.0	0.26
				0.41	BDL	14.64	0.66
8.	Kaliachak (44)	Kaliachak – I	Malda	0.107	BDL	1.92	<.01
				0.102	BDL	5.52	0.52
				0.109	BDL	4.14	0.48
9.	Kaliachak (45)	Kaliachak – I	Malda	0.194	BDL	1.43	<.01
				0.156	BDL	3.0	1.4
				0.133	BDL	5.58	0.56
10.	Jalalpur (46)	Kaliachak – I	Malda	0.107	BDL	2.76	<.01
				0.098	BDL	8.04	0.19
				0.078	BDL	7.46	0.38

BDL : Below detection limit i.e. (0.005 mg / L)

ARSENIC REMOVAL FILTER
CSIR (J.U.) Domestic

Results of Performance for three set of samples

Sr. No.	Location / Sample No.	Block	District	Arsenic (mg/L)		Iron (mg/L)	
				Raw	Treated	Raw	Treated
1.	Amkhola (5)	Gaighata	N-24 Pgs.	0.284	BDL	8.44	1.16
				0.234	0.03	0.23	0.01
				0.131	BDL	11.58	1.38
2.	Amkhola (6)	Gaighata	N-24 Pgs.	0.476	0.112	6.38	0.65
				0.150	0.150	6.95	1.47
				0.14	0.13	8.48	0.74
3.	Simulpur (21)	Habra – I	N-24 Pgs.	0.122	BDL	1.57	0.05
				0.055	BDL	2.22	<.01
				0.06	BDL	3.08	0.45
4.	Berachampa (65)	Deganga	N-24 Pgs.	0.120	BDL	6.04	<.01
				0.117	BDL	10.82	1.16
				0.107	BDL	3.2	<.01
5.	Uttarkalsur (66)	Deganga	N-24 Pgs.	0.05	BDL	2.60	<.01
				0.045	BDL	5.12	0.90
				0.052	BDL	1.7	0.03
6.	Uttarkalsur (67)	Deganga	N-24 Pgs.	0.145	BDL	3.63	<.01
				0.176	BDL	6.73	0.80
				N.A.	N.A.	N.A.	N.A.
7.	Uttarkalsur (68)	Deganga	N-24 Pgs.	0.945	0.140	2.24	<.01
				1.05	0.20	4 40	1.06
				N.A.	N.A.	N.A.	N.A
8.	Uttarkalsur (69)	Deganga	N-24 Pgs.	0.234	BDL	.234	0.1
				0.220	BDL	0.452	0.2
				0.198	BDL	0.37	0.11
9.	Uttarkalsur (70)	Deganga	N-24 Pgs.	0.223	0.195	8.95	0.06
				0.189	0.082	7.02	0.14
				0.144	0.04	7.3	0.08
10.	Uttarkalsur (72)	Deganga	N-24 Pgs.	0.165	BDL	4.44	0.10
				0.194	BDL	8.58	1.20
				0.555	N.A	3.7	N.A

BDL : Below detection limit i.e. (0.005 mg / L)

CHEMICAL ANALYSIS RESULTS OF WATER SAMPLES FROM COMMUN1TY BASED ARSENIC TREATMENT PLANT BOTH RAW AND TREATED WATER

Results in milligrams per litre

AIIH & PH

Sl. No.	Lab. No. Sample No.	Well No. District	Block	Location	Type of water	Temp. °C	DO	Turbibid (NTU)	SiO_2	Ca	Mg	Alkalinity	Cl	SO_4	NO_3	F	PO_4	S	T.H. as $CaCO_3$	Sp.Cond. µS/cm at 25°C	pH	Al
1	4	24-Parganas (N)	Gaighata	Amkhola	1R	28	0.9	0	26	94	33	405	21	1.2	1.0	0.3	0.38	<.05	370	825	7.3	
					1T									NA								
					2R	28.2	0.4	0	31	100	26	410	25	1.4	7.0	0.51	0.25	<.05	355	765	7.29	
					2T									NA								
					3R	27.9	0.6	0	30	104	28	430	14	1.2	1.5	0.09	.21	<.05	375	889	7.24	
					3T									NA								
2	11	-Do-	-Do-	-Do-	1R	28	0.7	1	20	130	18	415	32	1.0	3.5	0.87	0.57	<.05	400	873	7.32	
					1T			0	11	140	24	260	35	175	9.4	0.75	0.18		450	927	7.07	0.090
					2R	28.2	0.4	0	26	120	27	405	39	2.0	1.7	0.46	0.25	<.05	410	812	7.22	
					2T									NA								
					3R	28.4	0.5	1	23	114	32	405	39	1.2	1.8	0.25	0.01	<.05	415	929	7.33	
					3T			0	19	112	33	375	39	47	11	0.52	0.01		415	986	7.65	0.088
3	33	Nadia	Tehatta	Betai	1R	27	0.9	0	23	150	16	380	50	0.35	2.7	.01	.01	<.05	440	771	727	
					1T			0	19	136	17	245	46	70	14	.01	.01		380	840	7.13	0.050
					2R	26.6	0.7	1	22	134	21	405	43	5	12	0.34	0.49	<.05	420	7.46	7.18	
					2T			0	21	120	17	325	43	1.3	28	BDL	0.37		370	759	7.63	0.052
					3R	26.8	1.0	2	25	108	28	380	35	1.7	1.6	0.30	0.25	<.05	385	815	7.30	
					3T			0	15	142	26	490	18	1.2	7.1	0.28	0.28		460	1150	699	0.056

BDL= Below detection limit F = 0.01 mg /L
PO_4= 0.01 mg/L

CHEMICAL ANALYSIS RESULTS OF WATER SAMPLES FROM COMMUNITY BASED ARSENIC TREATMENT PLANT BOTH RAW AND TREATED WATER

Results in milligrams per litre

PAL TROCKNER

Sl. No.	Lab. No. Sample No.	Well No. District	Block	Location	Type of water	Temp. °C	DO	Turbibidy (NTU)	SiO_2	Ca	Mg	Alkalinity	Cl	SO_4	NO_3	F	PO_4	T.H. as $CaCO_3$	Sp.Cond. µS/cm at 25°C	pH
1	10	24-Parganas (S)	Baruipur	Serpur	1R	28.5	0.6	1	18	114	24	370	152	2.0	11	0.87	0.45	385	1130	7.36
					1T			0	14	104	30	370	152	2.0	0.28	0.81	0.05	385	1150	7.44
					2R	28	0.4	0	24	100	32	355	149	1.8	2.5	0.57	0.36	380	1100	7.2
					2T			0	23	98	30	350	145	1.6	1.0	0.41	0.05	370	1120	7.26
					3R	28.2	0.3	1	29	86	18	2.75	14	1.3	6.4	0.14	BDL	290	589	7.44
					3T			0	25	86	13	270	16	1.4	4.0	0.37	BDL	270	560	7.40
2	25	24Pargamas (N)	Basirhat	Shibahati	1R	28.5	0.9	0	27	106	2.92	320	106	1.3	1.2	0.31	6.53	4.10	841	7.02
					1T			0	5	102	2.1	330	67	1.0	1.2	0.11	0.38	360	845	703
					2R	28	0.7	0	31	104	28	345	99	1.2	0.98	0.77	0.40	375	855	7.29
					2T			0	26	86	39	345	96	1.0	0.50	0.73	0.14	375	860	7.32
					3R	28	0.7	1	30	66	50	350	71	2.0	0.9	0.77	0.21	370	896	7.34
					3T			0	31	86	41	360	71	1.0	0.7	0.72	0.15	385	896	7.21
3	26	-Do-	Barasat	Mayna	1R	28	0.8	0	23	40	36	210	64	1.2	1.0	0.31	0.16	250	603	8.2
					1T			0	6.0	66	33	270	67	1.4	3.0	0.21	BDL	300	714	7.99
					2R	28.2	0.6	0	29	120	41	430	57	1.2	1.4	0.5	0.19	470	940	7.16
					2T			0	5.0	118	39	435	67	1.6	5.6	0.41	BDL	455	969	7.26
					3R	27.8	0.6	1	30	116	44	450	64	1.3	1.3	0.01	0.46	474	1080	7.3
					3T			0	7.0	104	50	445	64	1.4	2.0	BDL	0.21	465	1075	7.34

BDL= Below detection limit F = 0.01 mg /L
PO_4= 0.01 mg/L

CHEMICAL ANALYSIS RESULTS OF WATER SAMPLES FROM COMMUNITY BASED ARSENIC TREATMENT PLANT BOTH RAW AND TREATED WATER

Results in milligrams per litre

AMAL

Sl. No.	Lab. No. Sample No.	Well No. District	Block	Location	Type of water	Temp. °C	DO	Turbibid (NTU)	SiO_2	Ca	Mg	Alkalinity	Cl	SO_4	NO_3	F	PO_4	S	T.H. as $CaCO_3$	Sp.Cond. µS/cm at 25°C	pH	Al
1	22	24-Parganas (N)	Habra	Sadpur	1R	29	0.5	0	34	114	30	465	16	1.2	3.0	0.07	0.37	<.05	410	879	7.13	
					1T			0	30	128	26	455	43	2.1	1.74	0.02	0.53		425	886	7.19	0.072
					2R	29.1	0.3	1	37	118	34	455	25	2.1	19	0.77	0.25	<.05	435	830	7.42	
					2T			0	36	156	39	395	344	2.4	2.2	0.74	0.25		550	1580	7.06	0.068
					3R	28.9	0.5							NA								
					3T			0	37	112	29	450	80	1.3	0.69	0.09	0.19		400	967	7.36	0.075
2	23	-Do-	Barasat	Sangrampur	1R	28.5	0.6	0	27	176	38	390	362	2.1	0.91	0.03	0.45	<.05	595	1830	683	
					1T			0	25	176	41	330	351	1.8	25	0.01	0.46		575	1715	6.79	0.072
					2R	28	0.4	1	32	140	43	360	21	2.1	0.60	0.79	0.18	<.05	385	810	7.31	
					2T			0	29	76	47	395	21	2.9	2.50	0.77	0.32		395	735	7.85	0.070
					3R	27.8	0.3	1	31	141	40	400	284	2.6	1.75	0.07	0.16	<.05	515	1560	7.20	
					3T			0	26	22	54	375	277	3.3	39	0.01	0.19		525	1630	7.00	0.068
3	34	Nadia	Tehatta	Betai	1R	27.5	0.6	0	25	158	39	475	74	35	1.16	.01	.04	<.05	555	1110	7.22	
					1T			0	15	158	39	465	78	35	1.34	.19	.04		555	1120	7.33	0.030
					2R	27	0.4	0	23	172	30	470	71	41	14	.015	.42	<.05	555	1080	7.26	
					2T			0	20	186	18	475	71	41	21	.010	.49		540	1090	7.41	0.038
					3R	27	0.4	0	26	160	38	480	71	34	1.2	0.08	.37	<.05	555	1180	7.35	
					3T			0	22	158	38	460	71	35	1.3	0.05	.31		555	1230	7.50	0.041

AMAL

Sl. No.	Lab. No. Sample No.	Well No. District	Block	Location	Type of water	Temp. °C	DO	Turbibid (NTU)	SiO_2	Ca	Mg	Alkalinity	Cl	SO_4	NO_3	F	PO_4	S	T.H. as $CaCO_3$	Sp.Cond. µS/cm at 25°C	pH	Al
4	8	24-Parganas (N)	Habra-I	Laxmipur	1R	28	0.5	1	30	112	29	425	21	1.2	4.47	0.51	0.31	<.05	400	824	7.09	
					1T			0	13	122	22	410	21	1.0	3.20	0.44	0.13		395	800	7.2	0.090
					2R	28	0.3	1	36	112	28	450	25	1.84	1.73	0.58	0.19	<.05	395	820	7.2	
					2T			0	24	112	23	420	25	1.26	3.47	0.61	0.25		375	793	7.09	0.100
					3R	28.1	0.4	0	35	110	30	450	18	1.13	2.61	0.25	0.15	<.05	400	985	7.19	
					3T			0	33	96	36	440	18	1.10	3.98	0.21	0.16		390	880	7.16	0.110

CHEMICAL ANALYSIS RESULTS OF WATER SAMPLES FROM COMMUNITY BASED ARSENIC TREATMENT PLANT BOTH RAW AND TREATED WATER

Results in milligrams per litre

WSI

Sl. No.	Lab. No. Sample No.	Well No. District	Block	Location	Type of water	Temp. °C	DO	Turbidity (NTU)	SiO_2	Ca	Mg	Alkalinity	Co_3	Cl	SO_4	NO_3	F	PO_4	T.H. as $CaCO_3$	Sp.Cond. µS/cm at 25°C	pH	Al
1	1	24-Parganas (N)	Barasat -I	Jaypur	1R	28	0.9	1	27	100	35	465		18	0.19	2.2	0.06	0.38	395	914	7.18	
					1T			0	07	6.0	113	435	66	25	0.59	0.10	0.14	0.07	480	813	10.06	0.019
					2R	28	0.7	0	33	110	24	470		14	2.0	2.2	0.23	0.25	375	829	7.14	
					2T			0	18	64	61	490		14	3.1	0.72	0.17	0.20	410	888	7.94	0.026
					3R	28.1	0.5	1	35	108	31	475		18	1.0	4.7	0.01	0.43	395	1036	7.40	
					3T			0	7	12	23	500		18	1.0	0.63	0.01	0.15	535	1300	8.3	0.028

CHEMICAL ANALYSIS RESULTS OF WATER SAMPLES FROM COMMUN1TY BASED ARSENIC TREATMENT PLANT BOTH RAW AND TREATED WATER

Results in milligrams per litre

AP1RON

Sl. No.	Lab. No. Sample No.	Well No. District	Block	Location	Type of water	Temp. °C	DO	Turbibidy (NTU)	SiO_2	Ca	Mg	Alkalinity	Cl	SO_4	NO_3	F	PO_4	T.H. as $CaCO_3$	Sp.Cond. µS/cm at 25°C	pH	Al
1	2	24-Parganas (N)	Barasat –I	Shibalaya	1R	28.5	0.9	0	23	106	57	450	96	3.6	6.4	0.38	0.18	500	1110	7.6	
					1T			0	10	70	81	450	113	2.0	0.6	0.29	0.02	510	1200	7.34	0.037
					2R	28	0.5	1	28	130	46	470	85	0.40	0.92	0.42	0.36	515	1030	7.20	
					2T			0	16	128	35	405	96	2.1	0.48	0.41	0.04	465	1040	7.28	0.032
					3R	28	0.3	1	25	136	38	475	92	2.2	1.9	0.08	0.26	475	1120	7.31	
					3T			0	11	142	35	485	96	2.1	1.0	0.05	0.14	485	1130	7.24	0.041
2	3	-Do-	Amdanga	Adahata	1R	28.5	0.8	1	35	122	44	510	18	7.0	1.9	0.51	0.51	485	982	7.35	
					1T			0	19	88	58	490	21	2.1	3.57	0.45	0.26	460	955	7.29	0.058
					2R	28	0.6	0	39	140	26	460	11	1.0	2.3	0.62	1.81	455	895	7.23	
					2T			0	17	138	28	435	21	0.9	5.2	0.41	0.2	460	888	7.29	0.067
					3R	28.3	0.8	0	31	136	24	475	11	2.0	5.5	0.23	1.61	440	930	7.4	
					3T			0	15	142	26	540	18	3.2	7.1	0.28	0.28	460	1150	6.99	0.071

CHEMICAL ANALYSIS RESULTS OF WATER SAMPLES FROM COMMUN1TY BASED ARSENIC TREATMENT PLANT BOTH RAW AND TREATED WATER

Results in milligrams per litre

PHED

Sl. No.	Lab. No. Sample No.	Well No. District	Block	Location	Type of water	Temp. ^{0}C	DO	Turbibidy (NTU)	SiO_2	Ca	Mg	Alkalinity	Cl	SO_4	NO_3	F	PO_4	S	T.H. as $CaCO_3$	Sp.Cond. μS/cm at 25^{0}C	pH	Al
1	7	24-Parganas (N)	Gaighata	Gobardanga	1R							NA										
					1T			0	29	90	44	425	82	7.16	7.15	0.37	0.18		405	1030	7.62	0.072
					2R	27	0.3	0	36	106	38	480	78	2.0	1.7	0.61	0.18		420	981	7.37	
					2T			0	32	98	44	435	85	27	12	0.61	0.31		425	1000	7.37	0.068
					3R	27.2	0.2	0	37	110	35	490	82	2.3	3.4	0.13	0.16		420	1190	7.33	
					3T			0	36	106	44	485	78	9.3	8.0	0.10	0.13		445	1220	7.78	0.080
2	35	Murshidabad	Jalangi	Jandia	1R	27.5	0.7	0	26	66	16	230	14	0.51	0.20	0.5	0.09	<.05	230	684	7.22	
					1T			0	18	86	7.3	250	25	0.10	3.38	0.84	0.02		245	564	7.80	0.20
					2R	27	0.5	1	25	104	15	315	21	1.0	29	0.06	0.70	<.05	320	724	7.06	
					2T			0	23	96	18	285	28	1.0	26	0.05	0.23		315	667	7.63	0.018
					3R	27.1	0.6	0	26	96	23	340	21	1.2	0.83	0.06	0.29	<.05	335	745	7.16	
					3T			0	24	86	18	280	21	1.4	1.0	.03	0.18		290	648	7.79	0.027
3	47	Malda	Kaliachak	Bakerpur	1R								NA									
					1T			0	29	56	47	310	53	9.55	3.47	0.18	0.42		335	665	7.79	0.031
					2R	28	0.8	0	27	102	19	350	28	7.0	2.4	0.02	0.41	<.05	335	792	7.45	
					2T			0	26	100	1.2	310	43	5.0	11	0.01	0.27		345	785	7.74	0.038
					3R	28.1	0.6	0	32	98	19	315	25	2.2	2.1	0.07	0.13	<.05	325	714	7.50	
					3T			0	30	102	20	340	25	2.0	1.8	0.04	0.10		335	764	7.94	0.048

Sl. No.	Lab. No. Sample No.	Well No. District	Block	Location	Type of water	Temp. °C	DO	Turbibid (NTU)	SiO_2	Ca	Mg	Alkalinity	Cl	SO_4	NO_3	F	PO_4	S	T.H. as $CaCO_3$	Sp.Cond. µS/cm at 25°C	pH
4.	29	24 Parganas (S)	Baruipur	Baruipur	1R	27	0.5	1	25	126	28	465	113	0.9	1.30	0.86	0.26	<.05	430	1220	7.32
					1T			0	21	114	38	460	110	0.7	1.90	0.74	0.19		440	1220	7.41
					2R	27.5	0.3	0	29	104	43	485	103	32	1.92	0.57	BDL	<.05	435	1180	7.30
					2T			0	26	102	43	475	99	37	2.43	0.46	BDL		430	1180	7.32
					3R	27.2	0.2	1	31	104	40	480	99	74	2.80	BDL	0.39	<.05	435	1290	7.44
					3T			0	32	104	51	490	96	75	2.50	BDL	0.25		480	1300	7.49
5	31	-DO-	-DO-	P.Mallickpur	1R	27.5	0.5	0	19	122	23	440	18	1.1	4.5	0.81	0.79	<.05	400	892	7.35
					1T			0	4.0	60	24	310	43	0.8	3.66	0.69	0.32		250	799	7.45
					2R	27.3	0.4	1	28	100	39	465	28	0.6	1.47	0.57	1.05	<.05	410	905	7.38
					2T			0	8.0	60	24	310	43	21	2.16	0.34	0.02		250	787	7.48
					3R	27.0	0.5	1	22	112	35	475	21	1.7	1.10	0.14	1.13	<.05	425	950	7.28
					3T			0	7.0	22	40	255	60	27	1.80	BDL	BDL		220	750	7.30
6	32	-Do-	Baruipur	Baruipur	1R	28	0.5	0	21	136	11	470	160	0.7	2.80	0.96	0.26	<.05	370	1530	7.25
					1T			0	15	134	7.3	510	163	0.5	0.8	0.86	0.20		365	1480	7.34
					2R	27.8	0.5	1	22	110	53	495	170	46	0.9	0.41	0.24	<.05	495	1480	7.27
					2T			0	29	92	69	490	174	56	1.9	0.52	0.21		515	1510	7.42
					3R	28.1	0.4	0	29	96	66	480	145	135	1.3	BDL	0.23	<.05	510	1580	7.26
					3T			0	26	96	72	480	170	70	237	BDL	0.23		535	1560	7.46

Sl. No.	Lab. No. Sample No.	Well No. District	Block	Location	Type of water	Temp. °C	DO	Turbibid (NTU)	SiO_2	Ca	Mg	Alkalinity	Cl	SO_4	NO_3	F	PO_4	S	T.H. as $CaCO_3$	Sp.Cond. µS/cm at 25°C	pH
7	60	-DO-	-DO_	DHABBHABI	1R	27.5	0.5	0	20	165	22	290	18	0.7	4.9	.02	BDL	<.05	255	959	7.18
					1T			1	5	170	22	285	21	0.9	4.4	BDL	BDL		260	874	7.75
					2R	27.5	0.3	0	32	90	58	280	18	86	1.9	.16	BDL	<.05	465	954	7.37
					2T			0	32	100	50	2.75	57	86	1.3	.08	BDL		4.55	765	7.29
					3R								NA								
					3T								NA								
8	61	-DO-	-DO-	-DO-	1R	28	0.5	0	20	92	27	375	18	1.2	1.4	BDL. 010	BDL	<.05	340	800	7.20
					1T			0	37	56	38	305	21	34	1.2	BDL	BDL		295	736	7.44
					2R	28.2	0.3	1	28	100	23	395	18	0.7	1.0	.008	BDL	<.05	345	760	7.30
					2T			0	26	94	23	445	18	25	2.2	BDL	BDL		330	748	7.54
					3R	28	0.5	0	19	104	26	410	21	0.8	1.2	.005	BDL	<.05	365	890	7.56
					3T			0	8	56	27	310	46	40	6.6	BDL	BDL		250	885	7.53
9	62	-DO-	-DO-	-DO-	1R	27.5	0.6	0	25	108	36	430	35	0.7	2.9	0.02	BDL	<.05	420	917	7.2
					1T			0	1.6	76	18	190	99	23	1.7	BDL	BDL		265	755	6.97
					2R	27.2	0.5	0	32	110	6	345	18	1.2	1.9	BDL	BDL	<.05	300	867	7.20
					2T			0	8.0	78	27	250	57	24	2.5	BDL	BDL		305	720	7.02
					3R	27.0	0.5	1	31	136	24	475	11	2.0	5.5	0.23	BDL	<.05	440	930	7.40
					3T			0	4.0	76	30	280	46	16	4.4	BDL	BDL		315	749	7.05
10	63	-DO-	-DO-	DO-	1R	28	0.6	0	22	102	32	365	50	1.7	5.6	0.01	BDL	<.05	385	774	7.02
					1T			0	3.0	74	30	275	43	25	1.2	BDL	BDL		310	749	6.97
					2R	28	0.5	0	26	116	28	445	28	1.8	2.5	BDL	BDL	<.05	405	893	7.2
					2T			0	8	82	23	295	43	6.9	1.5	BDL	BDL		300	802	7.02
					3R	28.2	0.6	0	21	104	36	445	35	2.0	2.4	0.16	BDL	<.05	410	970	7.21
					3T			0	8	84	28	230	92	13	4.3	BDL	BDL		325	855	7.16

CHEMICAL ANALYSIS RESULTS OF WATER SAMPLES USING AMAL (DOMESTIC) FILTERS FOR BOTH RAW AND TREATED WATER

Results in milligrams per litre

Sl. No.	Lab. No. Sample No.	Well No. District	Block	Location	Type of water	Temp. °C	DO	Turbibidy (NTU)	SiO_2	Ca	Mg	Alkalinity	Cl	SO_4	NO_3	F	PO_4	S	T.H. as $CaCO_3$	Sp.Cond. µS/cm at 25°C	pH	Al
1.	24	24-Parganas (N)	Bas1Rhat	Sangrampur	1R	27	0.9	3	28	116	27	370	53	1.0	6.0	0.38	0.45	<.05	400	742	7.03	
					1T			1	28	98	27	335	18	1.6	6.2	0.38	0.53		355	690	7.52	0.005
					2R	27.2	0.5	2	31	90	91	395	21	2.9	2.5	0.77	0.32	<.05	395	735	7.85	
					2T			1	30	104	28	395	99	1.0	1.0	0.77	0.40		375	855	7.29	0.002
					3R	27.0	0.6	3	31	78	47	395	7.1	4.4	0.74	0.19	0.21	<.05	390	775	7.23	
					3T			1	30	68	51	395	7.1	2.6	2.9	0.07	0.18		380	735	7.94	0.005
2.	36	Malda	Kaliachak	Kaliachak	1R	28	0.7	2	26	152	28	520	14	1.2	2.9	0.10	0.02	<.05	495	942	7.18	
					1T			1	14	42	38	295	40	4.8	5.8	0.01	BDL		260	634	7.94	0.026
					2R	28.2	0.5	1	22	132	43	560	14	1.0	25	0.01	0.16	<.05	505	960	7.25	
					2T			1	10	122	18	430	21	2.0	30	.01	0.11		380	806	7.61	.024
					3R	28.1	0.3	0	25	134	28	480	14	1.2	1.1	0.12	0.27	<.05	450	999	7.27	
					3T			0	14	124	20	430	18	1.4	1.4	0.10	0.17		390	910	7.77	0.030
3	37	-Do-	-Do-	-Do-	1R	28	0.7	2	26	152	28	520	14	1.2	2.9	0.10	0.02	<.05	495	942	7.15	
					1T			0	23	80	17	295	18	22	6.0	0.09	BDL		270	607	7.77	0.090
					2R	28.2	0.5	1	22	132	43	560	14	1.0	25	0.01	0.16	<.05	380	806	7.61	
					2T			0	2.8	68	36	340	14	14	26	.01	0.11		320	682	7.72	0.10
					3R	28.1	0.3	0	25	134	28	480	14	1.2	1.1	0.12	0.27	.05	450	909	7.27	
					3T								NA									
4	39	-Do-	-Do-	Uttar Dariapur	1R	27	0.6	2	26	92	26	285	64	10	0.8	0.01	0.09	<.05	335	755	7.39	
					1T			1	9	92	22	280	64	10	2.0	0.01	0.06		320	712	7.86	0.085
					2R	27.3	0.4	1	24	98	21	295	60	7.0	17	0.01	0.11	<.05	330	729	7.32	
					2T			0	13	96	23	290	67	7.0	21	0.01	0.43		335	714	7.72	0.10
					3R	27.4	0.3	1	28	84	27	290	57	1.7	3.1	0.03	0.10	<.05	320	774	7.42	
					3T			0	15	80	24	280	61	8.0	13	.02	0.10		300	786	7.85	0.09

BDL= Below detection limit F = 0.01 mg /L
PO_4= 0.01 mg/L

Sl. No.	Lab. No. Sample No.	Well No. District	Block	Location	Type of water	Temp. °C	DO	Turbibid (NTU)	SiO_2	Ca	Mg	Alkalinity	Cl	SO_4	NO_3	F	PO_4	S	T.H. as $CaCO_3$	Sp.Cond. µS/cm at 25°C	pH	Al
5	41	-Do-	-Do-	Dakshin Laxmipur	1R	28	0.6	1.0	26	88	24	330	7.1	0.3	1.9	0.27	0.05	<.05	320	634	7.36	
					1T			0	5.0	62	23	295	7.1	0.22	5.34	BDL	0.01		250	586	7.81	0.072
					2R	28.2	0.3	0	23	90	29	325	7.1	0.31	22	0.21	0.43	<.05	345	612	7.32	
					2T			0	5.2	86	17	295	7.1	0.18	34	BDL	0.27		285	548	7.59	0.080
					3R	28.4	0.7	1	25	108	6.1	310	7.1	0.45	0.50	0.15	0.26	<.05	354	638	7.41	
					3T			0	6.5	100	3.6	275	7.1	0.62	0.50	0.10	0.17		265	565	7.86	0.076
6	42	-Do-	-Do-	-Do-	1R	27.0	0.9	3	26	72	27	330	7.1	1.0	1.0	0.18	0.37	<.05	290	631	7.49	
					1T			1	6.0	80	11	290	7.1	1.2	11	0.64	BDL		245	584	7.96	0.038
					2R	27.2	0.5	2	24	92	24	330	7.1	1.6	22	0.23	1.17	<.05	330	613	7.20	
					2T			0	9.6	94	21	335	7.1	1.4	34	0.1	0.43		320	613	7.61	0.042
					3R	27.4	0.6	1	25	88	21	320	7.1	2.0	2.8	0.13	0.85	<.05	315	685	7.26	
					3T			0	10	84	18	300	7.1	2.2	1.2	0.08	0.43		285	625	7.72	0.050
7	43	-Do-	-Do-	-Do-	1R	27	0.5	0	25	118	27	390	32	1.0	3.97	0.18	BDL	<.05	405	835	7.187	
					1T			0	3.5	52	28	245	32	1.4	15	0.08	BDL		245	591	7.91	0.045
					2R	28	0.3	1	24	132	33	410	57	7.0	8.0	0.17	0.41	<.05	465	973	7.26	
					2T			1	5.2	86	33	330	53	5.0	21	0.12	0.27		350	804	7.84	0.048
					3R	27.2	0.3	1	24	134	21	380	42	7.6	2.8	0.10	0.35	<.05	420	887	725	
					3T			0	6.0	98	24	305	43	6.0	4.0	BDL	0.27		345	770	7.78	0.052
8	44	-Do-	-Do-	Kaliachak	1R	28	0.7	2	31	22	44	490	25	2.1	1.3	0.08	BDL	<.05	485	923	7.30	
					1T			1	30	89	55	450	25	1.0	2.64	0.09	BDL		435	880	7.61	0.020
					2R	28.1	0.5	1	28	144	24	495	14	1.1	3.3	0.08	.34	<.05	460	975	7.3	
					2T			0	17	118	30	450	11	1.2	12	0.05	0.2		420	882	7.59	0.026
					3R	28.0	0.3	2	30	154	19	460	14	1.1	0.5	0.03	0.26	<.05	465	976	7.22	
					3T			0	22	128	16	410	11	1.0	0.3	BDL	0.18		385	865	7.72	0.032

Sl. No.	Lab. No. Sample No.	Well No. District	Block	Location	Type of water	Temp. °C	DO	Turbibid (NTU)	SiO_2	Ca	Mg	Alkalinity	Cl	SO_4	NO_3	F	PO_4	S	T.H. as $CaCO_3$	Sp.Cond. µS/cm at 25°C	pH	Al
9	58	-Do-	-Do-	-Do-	1R	27.0	0.6	0	32	125	21	425	11	1.2	2.1	0.02	BDL	<.05	390	908	7.09	
					1T			0	23	40	16	270	11	1.0	13	BDL	BDL		215	608	8.03	0.045
					2R	27.2	0.3	1	31	96	46	445	43	2.0	2.1	0.90	0.13	<.05	430	982	7.07	
					2T			0	29	36	28	260	35	1.0	16	0.85	0.15		205	675	8.20	0.038
					3R	27.2	0.2	0	32	126	28	430	35	1.2	4.3	0.25	0.33	<.05	430	958	7.22	
					3T									NA								
10	59	-Do-	-Do-	-Do-	1R	27	0.6	0	31	92	19	265	50	2.1	1.21	0.12	BDL	<.05	310	683	7.32	
					1T			0	29	84	28	270	50	1.2	7.1	BDL	BDL		325	670	7.89	0.050
					2R	27.2	0.4	0	28	82	17	300	18	1.8	1.7	0.16	BDL	<.05	275	565	7.26	
					2T			1	31	82	17	280	18	8.2	6.8	0.16	BDL		270	545	8.20	0.070
					3R	27.4	0.3	0	30	94	11	275	18	1.7	0.9	0.08	0.38	<.05	280	590	7.58	
					3T			2	37	114	16	455	28	1.8	3.8	BDL	0.27		350	950	8.06	0.062

CHEMICAL ANALYSIS RESULTS OF WATER SAMPLES USING PAL TROCKNER (DOMESTIC)
FILTERS FOR BOTH RAW AND TREATED WATER
Results in milligrams per litre

Sl. No.	Lab. No. Sample No.	Well No. District	Block	Location	Type of water	Temp. C^0	DO	Turbibidy (NTU)	SiO_2	Ca	Mg	Alkalinity	Cl	SO_4	NO_3	F	PO_4	S	T.H. as $CaCO_3$	Sp.Cond. µS/cm at 25^0C	pH
1	12	24 Parganas (S)	Baruipur	Chandokhali	1R	28	0.7	1	25	88	80	300	25	1.8	4.3	0.56	0.44	<.05	295	590	7.30
					1T			0	15	92	16	285	18	0.7	2.1	0.56	0.19		295	578	7.50
					2R	28.2	0.5	2	31	84	15	2.70	14	0.9	1.2	0.36	0.08	<.05	270	569	7.33
					2T			0	25	84	15	270	14	1.0	3.6	0.36	BDL		270	557	7.40
					3R	27.8	0.4	1	29	86	18	275	14	1.2	6.4	.14	BDL	<.05	290	589	7.44
					3T			0	25	86	13	270	16	0.8	4.0	.17	BDL		270	580	7.40
2	13	-Do_	-Do-	SHAKHARIPUKUR	1R	27.5	0.6	2	21	140	3.6	350	39	0.7	3.2	0.7	0.58	<.05	365	754	7.27
					1T			0	18	126	13	355	35	0.8	3.3	0.62	0.30		370	762	7.47
					2R	27.6	0.5	1	28	30	24	350	35	1.2	1.2	0.36	BDL	<.05	360	740	7.19
					2T			0	22	128	9.7	350	39	1.3	2.7	0.29	BDL		360	768	7.34
					3R	27.4	0.3	2	25	118	18	365	35	2.1	2.0	0.03	0.13	<.05	370	850	7.26
					3T			0	18	58	27	375	39	18	3.98	BDL	0.12		255	920	7.54
3	14	-Do-	-Do-	-Do-	1R	27.5	0.7	1	23	118	16	350	32	1.7	1.5	0.70	0.31	<.05	360	738	7.40
					1T			0	16	116	15	350	35	1.2	2.0	0.70	0.20		350	754	7.45
					2R	27.8	0.5	1	30	106	21	335	32	1.0	1.0	0.41	0.05	<.05	350	707	7.38
					2T			0	9	112	16	330	35	0.8	0.8	0.41	BDL		345	711	7.31
					3R	27.4	0.3	1	27	100	29	345	28	2.5	3.5	0.02	0.18	<.05	345	785	7.35
					3T			0	14	82	35	370	32	1.4	1.2	BDL	0.12		350	786	7.45

BDL= Below detection limit F = 0.01 mg /L
PO_4= 0.01 mg/L

CHEMICAL ANALYSIS RESULTS OF WATER SAMPLES USING AIIH & PH (DOMESTIC) FILTERS FOR BOTH RAW AND TREATED WATER

Results in milligrams per litre

Sl. No.	Lab. No. Sample Nc.	Well No. District	Block	Location	Type of water	Temp. °C	DO	Turbidid (NTU)	SiO_2	Ca	Mg	Alkalinity	Cl	SO_4	NO_3	F	PO_4	S	T.H. as $CaCO_3$	Sp.Cond. µS/cm at 25°C	pH	Al
1	9	24 Parganas (N)	Habra	Laxmipur	1R	27.5	0.5	0	28	136	2.4	425	21	2.1	1.4	0.58	0.58	<.05	350	908	7.26	
					1T			0	25	110	24	415	21	6.6	10	0.64	0.12		375	845	7.68	0.195
					2R	27.0	0.5	1	32	112	38	510	18	2.0	2.2	0.68	0.25	<.05	435	893	7.58	
					2T			0	29	70	41	375	18	11	12	0.74	0.25		345	720	7.78	0.180
					3R	27.0	0.4	0	34	120	30	500	14	4.0	2.4	0.35	0.15	<.05	425	967	7.1	
					3T			0	29	84	40	420	14	20	11	BDL	0.14		375	895	7.61	0.195
2	15	-Do-	-Do-	-Do-	1R	28	0.8	2	27	102	17	350	30	1.7	0.97	BDL	0.86	<.05	325	640	6.91	
					1T			0	34	98	33	475	85	1.2	4.3	BDL	0.45		380	965	8.15	0.052
					2R	28.2	0.7	1	37	96	22	355	18	1.7	1.2	0.62	0.38 BDL	<.05	330	650	7.13	
					2T			0	37	94	16	455	57	2.0	5.4	0.54	0.21		300	992	8.05	0.042
					3R	28	0.7	1	36	100	19	350	18	1.2	4.8	0.20	0.4	<.05	330	774	7.05	
					3T									NA								
3	16	-Do-	-Do-	-Do-	1R	27.5	0.6	1	30	102	21	355	35	1.8	0.97	0.20	0.69	<.05	340	721	6.94	
					1T			0	27	94	29	325	50	24	8.9	.20	0.45		355	679	7.93	0.047
					2R	28	0.5	1	33	90	27	365	21	1.2	1.8	0.8	0.24	<.05	335	685	7.12	
					2T			1	32	82	28	320	25	28	12	0.77	0.25		320	666	7.90	0.048
					3R	27	0.3	1	34	98	26	375	18	6.0	1.4	0.18	0.33	<.05	350	820	7.10	
					3T			2	31	98	23	350	21	41	14	0.19	0.21		340	810	7.95	0.050
4	17	-Do-	-Do-	-Do-	1R	27.5	0.6	1	29	110	30	370	58	1.3	1.1	0.73	0.67	<.05	400	760	6.9	
					1T			0	27	108	26	355	21	16	4.43	0.67	0.53		375	751	7.1	0.040
					2R	27	0.4	0	33	104	22	380	25	0.8	1.5	0.83	0.2	<.05	350	696	7.43	
					2T			0	29	64	29	310	25	8.9	8.66	0.85	0.13		305	616	8.08	0.052
					3R	27.8	0.6	0	34	106	23	385	21	2.5	2.51	0.35	0.25	<.05	360	856	7.14	
					3T									NA								

BDL= Below detection limit F = 0.01 mg /L
PO_4= 0.01 mg/L

Sl. No.	Lab. No. Sample No.	Well No. District	Block	Location	Type of water	Temp. ^{0}C	DO	Turbidid (NTU)	SiO$_2$	Ca	Mg	Alkalinity	Cl	SO$_4$	NO$_3$	F	PO$_4$	S	T.H. as CaCO$_3$	Sp.Cond. µS/cm at 25^{0}C	pH	Al
5	20	-Do-	-Do-	-Do-	1R	28.5	0.8	1	25	54	39	265	14	1.2	1.2	0.33	0.38	<.05	285	525	7.1	
					1T			0	26	84	18	260	43	0.8	5.0	0.18	0.53		285	540	7.38	0.065
					2R	28	0.6	0	29	84	12	255	14	1.1	1.5	0.52	BDL	<.05	260	520	7.3	
					2T			0	42	114	45	485	21	0.9	0.26	0.46	BDL		470	872	7.31	0.068
					3R	28.3	0.5	1	29	78	16	255	11	2.0	0.9	0.16	0.26	<.05	260	538	7.34	
					3T			0	37	88	38	480	28	1.2	4.1	0.23	0.22		375	985	8.18	0.078
6	52	-Do-	-Do-	-Do-	1R	28	0.6	1	30	100	19	370	11	1.8	1.2	0.25	BDL	<.05	330	786	7.12	
					1T			0	31	95	18	340	18	1.3	8.2	0.25	BDL		320	766	7.63	0.038
					2R	28.2	0.4	1	31	90	26	370	21	1.2	1.08	0.46	BDL	<.05	330	747	7.08	
					2T			3	23	74	35	350	25	1.3	6.8	0.41	BDL		330	707	7.62	0.048
					3R	27.8	0.3	0	30	80	32	370	21	4.0	1.0	0.03	0.26	<.05	330	780	7.26	
					3T									NA								
7	56	-Do-	-Do-	-Do-	1R	27	0.7	0	24	100	12	320	11	2.0	3.5	0.28	BDL	<.05	300	7.56	7.16	
					1T			0	29	100	13	305	7.1	2.6	2.4	1.4	BDL		305	766	7.15	0.044
					2R	27.5	0.5	1	23	88	28	350	35	0.7	2.4	0.30	BDL	<.05	345	733	7.16	
					2T			0	30	86	17	310	32	0.8	1.3	0.41	BDL		285	648	7.56	0.050
					3R	27.3	0.4	0	25	98	19	310	25	1.0	5.0	0.1	0.41	<.05	325	670	7.01	
					3T									NA								
8	57	-Do-	-Do-	-Do-	1R	27.0	0.6	0	28	98	17	280	32	1.2	1.2	0.21	BDL	<.05	315	618	7.37	
					1T			0	27	94	16	295	25	2	2.9	0.30	BDL		300	600	8.01	0.065
					2R	27.2	0.2	1	26	92	16	305	11	2.2	1.7	0.34	BDL	<.05	295	586	7.3	
					2T			0	27	84	21	310	32	1.1	5.0	0.30	BDL		315	658	7.94	0.068
					3R	27.0	0.3	0	27	102	15	305	18	1.9	1.8	0.09	0.44	<.05	315	646	7.25	
					3T			2	27	92	21	305	18	1.2	2.7	BDL	0.55		315	596	8.04	0.072

Sl. No.	Lab. No. Sample No.	Well No. District	Block	Location	Type of water	Temp. ^{0}C	DO	Turbibid (NTU)	SiO_2	Ca	Mg	Alkalinity	Cl	SO_4	NO_3	F	PO_4	S	T.H. as $CaCO_3$	Sp.Cond. μS/cm at 25^{0}C	pH	Al
9	45	-Do-	-Do-	-Do-	1R	28	0.6	1	28	134	57	535	60	0.3	1.8	0.27	BDL	<.05	570	1120	7.22	
					1T			0	4.3	60	66	360	138	46	35	0.09	BDL		420	1240	7.81	0.032
					2R	28.2	0.6	0	25	178	33	600	64	1.1	6.16	.03	0.27	<.05	580	1200	7.16	
					2T			0	6.1	92	50	410	113	62	38	BDL	0.19		435	1320	7.72	0.028
					3R	28	0.4	1	29	142	23	490	3.6	1.1	1.6	0.02	0.28	<.05	450	1044	7.17	
					3T			0	7.2	78	80	575	1.8	1.1	32	BDL	0.16		270	1270	7.82	0.03
10	48	-Do-	Kalia chak	Jalalpur	1R	28	0.9	1	27	68	52	365	60	4.3	0.4	BDL	BDL	<.05	385	782	7.33	
					1T			0	7.6	44	50	310	53	3.5	2.5	BDL	BDL		315	691	7.59	0.040
					2R	28	0.7	1	26	124	18	380	28	6.0	0.34	0.08	0.27	<.05	385	828	7.36	
					2T			0	8.3	86	24	320	28	1.0	5.9	0.06	0.18		315	714	7.81	0.046
					3R	28.2	0.5	0	28	88	33	360	28	5.0	0.58	0.06	0.23	<.05	355	788	7.36	
					3T			0	9.2	82	36	325	35	6.0	0.2	0.04	0.21		355	782	7.82	0.048
11	49	Murshidabad	Berhampur	Khagra	1R	28.5	0.8	0	36	68	22	330	60	1.06	1.0	0.42	BDL	<.05	260	708	7.39	
					1T			1	6.8	30	34	265	60	3.5	1.2	0.18	BDL		215	650	7.92	0.030
					2R	28.2	0.9	2	32	78	16	350	60	1.0	14	0.41	0.2	<.05	260	750	7.35	
					2T			0	7.29	68	12	270	62	13	2.6	BDL	0.2		220	645	7.65	0.028
					3R	28.3	0.5	2	38	60	29	360	28	4.8	12	0.042	0.16	<.05	270	734	7.48	
					3T			0	8.1	68	26	370	32	9.0	3.4	0.01	0.12		275	878	7.65	0.03

CHEMICAL ANALYSIS RESULTS OF WATER SAMPLES USING C.S.I.R (J.U.) (DOMESTIC) FILTERS FOR BOTH RAW AND TREATED WATER

Results in milligrams per litre

Sl. No.	Lab. No. Sample No.	Well No. District	Block	Location	Type of water	Temp. ^0C	DO	Turbibid (NTU)	SiO_2	Ca	Mg	Alkalinity	Cl	SO_4	NO_3	F	PO_4	S	T.H. as $CaCO_3$	Sp.Cond. µS/cm at 25^0C	pH	Al
1.	5	24-Parganas (N)	Gaighata	Amkhola	1R	30	1.0	1	29	100	38	440	18	1.0	1.0	0.3	0.44	<.05	405	880	7.24	
					1T			0	22	106	34	400	46	1.4	12	0.3	0.18		405	884	7.68	0.085
					2R	29.5	0.8	1	32	112	30	450	25	1.2	1.2	0.47	0.18	<.05	405	824	7.22	
					2T			1	29	108	34	395	64	1.3	5.1	0.29	0.14		410	851	7.49	0.087
					3R	29.8	0.7	1	33	118	30	470	18	1.2	1.7	0.1	0.19	<.05	420	956	7.17	
					3T			2	33	110	30	390	35	1.3	16	0.1	0.16		400	883	7.71	0.078
2	6	-Do-	-Do-	-Do-	1R	29	0.9	0	25	94	28	395	14	1.4	8.5	0.30	0.37	<.05	350	799	7.24	
					1T			1	25	60	27	280	21	1.6	18	0.3	0.18		260	583	7.99	0.097
					2R	29.2	0.7	0	32	98	26	405	14	1.2	1.3	0.47	0.25	<.05	350	738	7.34	
					2T			2	31	84	16	355	18	1.2	15	0.47	0.18		325	670	7.72	0.090
					3R	29	0.3	0	30	100	29	420	14	1.2	1.6	BDL	0.21	<.05	370	892	7.31	
					3T			2	30	100	24	390	100	1.2	19	BDL	0.16		350	854	7.95	0.105
3	21	-Do-	Habra-I	Simulpur	1R	29	0.4	0	36	130	21	490	16	1.1	1.2	0.38	0.38	<.05	410	913	7.12	
					1T			1	35	102	29	430	21	1.2	3.5	0.21	0.52		375	805	7.88	0.065
					2R	29.2	0.3	0	37	114	28	315	21	1.3	1.4	0.8	0.19	<.05	400	824	7.26	
					2T			0	37	118	34	455	25	1.4	19	0.77	0.25		435	830	7.42	0.041
					3R	29	0.2	0	38	92	50	475	18	1.2	1.4	0.36	0.18	<.05	435	995	7.30	
					3T			1	31	104	24	385	21	1.8	4.7	0.21	0.25		360	830	7.64	0.060
4	65	-Do-	De-ganga	Berachampa	1R	29.4	0.5	1	31	100	26	350	35	1.2	1.17	0.04	0.01	<.05	355	776	7.76	
					1T			1	27	105	23	270	106	1.0	7.9	0.04	0.01		350	874	7.90	0.078
					2R	29.2	0.4	1	35	100	21	300	35	1.6	5.2	0.05	1.66	<.05	335	705	7.12	
					2T			0	32	108	19	280	99	1.3	7.8	0.05	0.97		350	860	7.44	0.075
					3R	29.0	0.5	0	30	98	19	300	35	1.8	1.2	0.09	0.27	<.05	325	632	7.13	
					3T			1	28	114	15	275	99	1.0	1.0	0.03	0.15		345	832	7.71	0.082

BDL= Below detection limit F = 0.01 mg /L
PO_4= 0.01 mg/L

Sl. No.	Lab. No. Sample No.	Well No. District	Block	Location	Type of water	Temp. ^{0}C	DO	Turbibid (NTU)	SiO_2	Ca	Mg	Alkalinity	Cl	SO_4	NO_3	F	PO_4	S	T.H. as $CaCO_3$	Sp.Cond. µS/cm at 25^{0}C	pH	Al
5.	66	-Do-	-Do-	Uttar Kalsur	1R	29	0.7	1.1	31	72	18	185	71	1.2	2.5	0.05	BDL	<.05	255	634	7.5	
					1T			0	28	64	19	235	14	1.5	0.32	0.02	BDL		240	520	7.36	0.078
					2R	29.1	0.5	1	32	72	16	260	14	1.7	2.8	0.16	0.97	<.05	245	564	7.44	
					2T			1	27	78	12	185	71	1.1	3.6	0.06	0.44		245	647	7.33	0.085
					3R	29.0	.4	1	26	86	60	270	18	1.3	1.5	0.07	0.12	<.05	280	589	7.4	
					3T			1	23	92	13	145	135	1.2	1.0	0.01	0.06		285	714	7.56	0.075
6	67	-Do-	-Do-	-Do-	1R	29	0.7	1	29	106	21	360	18	1.0	1.1	0.01	BDL	<.05	350	792	7.35	
					1T			0	32	96	28	320	71	1.0	4.0	0.01	BDL		355	864	8.00	0.010
					2R	29	0.5	1	27	104	24	390	28	1.3	2.1	0.05	1.34	<.05	360	808	7.3	
					2T			0	29	96	32	390	39	1.2	4.9	0.05	1.14		370	792	7.99	0.010
					3R								NA									
					3T								NA									
7	68	-Do-	-Do-	-Do-	1R	28	0.7	0	31	128	35	410	92	1.7	1.2	0.02	BDL	<.05	465	1070	7.0	
					1T			0	26	114	24	320	131	1.2	1.1	0.01	BDL		385	1020	7.85	0.026
					2R	27.7	0.5	0	31	142	33	420	92	1.2	2.2	0.05	1.24	<.05	490	1070	7.22	
					2T			1	31	110	38	335	110	1.7	1.2	0.02	1.05		430	1010	7.74	0.030
					3R								NA									
					3T								NA									
8	69	-Do-	-Do-	-Do-	1R	29	0.7	1	22	102	32	365	50	1.3	5.6	0.07	BDL	<.05	385	774	7.32	
					1T			0	28	126	26	140	277	1.0	9.6	0.01	BDL		420	1220	7.62	0.040
					2R	28.5	0.5	1	26	92	36	370	46	1.8	3.3	0.07	0.52	<.05	380	684	7.21	
					2T			0	24	96	36	295	128	1.0	8.1	0.01	0.30		390	975	7.5	0.045
					3R								NA									
					3T								NA									
9	70	-Do-	-Do-	-Do-	1R	29	0.6	1	29	98	19	300	28	1.9	1.3	0.13	BDL	<.05	325	686	7.46	
					1T			0	37	86	24	375	43	1.1	5.4	0.34	BDL		315	874	7.18	0.061
					2R	28.5	0.5	1	28	84	22	295	21	1.7	2.5	0.05	0.39	<.05	300	650	7.37	
					2T			0	35	90	22	375	39	1.1	5.6	0.05	0.52		315	846	8.08	0.065
					3R								NA									
					3T								NA									
10	71	-Do-	-Do-	-Do-	1R	27.5	0.5	0	28	96	22	305	32	1.4	2.13	0.01	BDL	<.05	330	693	7.3	
					1T			0	25	108	18	240	106	1.0	3.0	0.01	BDL		345	828	7.9	0.052
					2R								NA									
					2T								NA									
					3R								NA									
					3T								NA									

SALIENT FEATURES OF COMMUNITY BASED ARSENIC REMOVAL PLANTS
(IRON POINT OF VIEW)

		No. of samples collected		Iron Content in mg/l					
Arsenic Removal Plants	No. of locations where introduced	Raw/Tubewell water (Having >1.00 mg/l of Fe)	Treated water (after treatment of raw water having > 1.00 mg/l of Fe)	Raw Water		Treated Water		No. of Treated samples Having >1.00 mg/l of Fe	‹ Max. Iron content in Raw Water removed by plants below 1.00 mg/l of Fe.
				Max.	Min.	Max	Min.		
AIIH & PH	3	9	6	19	5.59	5.37	<.01	4	10.74
PALTROCKNER	3	9	9	12	4.73	3.52	<.01	5	12.00
AMAL	4	11	11	13.80	0.88	1.54	<.01	2	12.42
WSI	1	3	3	8.00	5.45	0.96	0.07	NIL	8.00
APIRON	2	6	6	15.98	4.64	1.12	<.01	1	11.17
PHED	3	8	8	19.6	2.50	4.30	<.01	1	19.6

SALIENT FEATURES OF COMMUNITY BASED ARSENIC REMOVAL PLANTS
(ARSENIC POINT OF VIEW)

		No. of samples collected		Arsenic Content in mg/l					
Arsenic Removal Plants	**No. of location**	**Raw/Tubewell water (Having >0.05 mg/l of As)**	**Treated water (after treatment of raw water having > 0.05 mg/l of As)**	**Raw Water**		Treated Water		**No. of Treated samples Having >0.05 mg/l of As**	**Max. arsenic content in Raw Water removed by plants below 0.05 mg/l of As**
				Max.	**Min.**	**Max**	**Min.**		
AIIH & PH	3	7	4	0.78	0.25	0.352	BDL	3	0.31
PALTROCKNER	3	9	9	1.12	0.28	0.136	BDL	1	1.12
AMAL	4	11	11	0.96	0.082	0.035	BDL	0	0.96
WSI	1	3	3	0.31	0.126	0.16	BDL	1	0.238
APIRON	2	6	6	2.34	0.29	0.045	BDL	0	2.34
PHED	3	7	7	0.61	0.05	0.07	BDL	3	0.3

SALIENT FEATURES OF ARSENIC REMOVAL FILTERS (DOMESTIC)
(ARSENIC POINT OF VIEW)

		No. of samples collected		Arsenic Content in mg/l					
Arsenic Removal filters	**No. of location**	**Raw/Tubewell water (Having >0.05 mg/l of As)**	**Treated water (after treatment of raw water having > 0.05 mg/l of As)**	**Raw Water**		Treated Water		**No. of Treated samples Having >0.05 mg/l of As**	**Max. arsenic content in Raw Water removed by filters below 0.05 mg/l of As.**
				Max.	**Min.**	**Max**	**Min.**		
AMAL	10	27	27	0.388	0.078	0.102	BDL	2	0.41
AIIH & PH	10	24	20	0.184	0.05	0.102	BDL	5	0.184
PAL TROCKNER	10	26	26	2.95	0.056	0.14	BDL	1	2.95
J.U (CSIR)	10	27	26	1.05	0.05	0.20	BDL	7	0.284

SALIENT FEATURES OF ARSENIC REMOVAL FILTERS (DOMESTIC)
(IRON POINT OF VIEW)

		No. of samples collected		Iron Content in mg/l					
Arsenic Removal filters	No. of locations where introduced	Raw/Tubewell water (Having iron content >1.00 mg/l)	Treated water (after treatment of raw water having > 1.00 mg/l of Fe)	Raw Water		Treated Water		No. of Treated samples Having >1.00 mg/l of Fe	Max. Iron content in Raw Water removed by filters below 1.00 mg/l of Fe.
				Max.	Min.	Max	Min.		
AIIH & PH	10	30	29	14.26	2.53	5.89	<.01	3	14.26
PALTROCKNER	10	26	26	22.60	0.10	5.38	<.01	12	13.92
AMAL	10	25	25	22.00	0.10	1.4	<.01	01	22.00
J.U (CSIR)	10	24	24	11.58	0.23	1.47	<.01	05	8.95

CHEMICAL ANALYSIS RESULTS OF HEAVY METALS
(SOURCE WATER FOR COMMUN1TY BASED PLANTS)
Results in micrograms per litre

Sl. No.	Sample No.	District	Block	Location	Name of the Plant	Al	Cd.	Cr.	Cu	Mn	Pb	Zn
1.	1	N.24 Parganas	Barasat-I	Joypur	WSI	19	1	3	2	817	Nd	416
2.	2	-Do-	-Do-	Sibalaya	AP1RON	34	1	5	Nd	1339	Nd	3
3.	3	-Do-	Amdanga	Adahata	AP1RON	59	1	5	Nd	1421	Nd	Nd
4.	4	-Do-	Gaighata	Amkhola	AIIH & PH	64	Nd	5	Nd	94	Nd	5
5.	11	S. 24 Parganas	Baruipur	Sardarpara	-Do-	88	Nd	10	1	924	40	125
6.	33	Nadia	Tehatta-I	Betai	-Do-	52	Nd	Nd	Nd	870	Nd	8
7.	26	N. 24 Parganas	Barasat-I	Mayna	Pal Trocknar	52	Nd	11	Nd	65	8	9
8.	25	-Do-	Bas1Rhat	Shibhari	-Do-	1721	Nd	11	Nd	36	Nd	9
9.	10	S-24 Parganas	Baruipur	Serpur	-Do-	75	Nd	8	6	204	4	43
10.	35	Murshidabad	Jalangi	Jaudia	PHED	19	Nd	1	Nd	760	2	35
11.	22	N-24 Parganas	Habra-I	Sabpur	Amal	67	Nd	7	Nd	74	Nd	7
12.	34	Nadia	Tehatta-I	Betai	Amal	29	Nd	1	Nd	385	4	27
13.	23	N-24 Parganms	Bas1Rhat-I	Sangrampur	-Do-	64	Nd	9	Nd	162	10	10
14.	8	N-24 parganas	Habra-I	Laxmipur	-Do-	91	Nd	8	Nd	Nd	Nd	5

Nd = not detected

CHEMICAL ANALYSIS RESULTS OF HEAVY METALS
(SOURCE WATER FOR DOMESTIC FILTERS)
Results in micrograms per litre

Sl. No.	Sample No.	District	Block	Location	Name of filter	Al	Cd.	Cr.	Cu	Mn	Pb	Zn
1.	5	N-24 Parganas	Gaighata	Amkhola	CS1R (ju)	76	Nd	7	Nd	141	Nd	5
2.	6	-Do-	-Do-	-Do-	-Do-	127	Nd	6	Nd	82	Nd	132
3.	21	-Do-	Habra-I	Shimulpur	-Do-	51	Nd	7	Nd	167	Nd	212
4.	65	-Do-	Deganga	Berachanpa	-Do-	75	Nd	5	Nd	1267	1	21
5.	66	-Do-	-Do-	-Do-	-Do-	78	Nd	5	Nd	446	Nd	363
6.	67	-Do-	-Do-	Uttar Kolsur	-Do-	9	Nd	6	Nd	258	Nd	3
7.	68	-Do-	-Do-	-Do-	-Do-	25	Nd	5	Nd	70	Nd	56
8.	69	-Do-	-Do-	-Do-	-Do-	41	Nd	7	Nd	1756	Nd	2
9.	70	-Do	-Do-	-Do-	-Do-	63	Nd	7	Nd	81	1	30
10.	71	-Do	-Do-	-Do-	-Do-	51	Nd	7	Nd	736	Nd	10
11.	72	-Do	-Do-	-Do-	-Do-	145	Nd	6	Nd	357	Nd	1
12.	24	-Do-	Bas1Rhat	Sangrampur	Amal	5	Nd	11	Nd	Nd	Nd	Nd
13.	36	Malda	Kaliachak –I	Kaliachak	-do-	24	Nd	2	6	894	5	562
14.	37	-Do	-Do-	-Do-	-Do-	24	Nd	2	6	894	5	562
15.	39	-Do-	-Do-	Uttar Dinajpur	-Do-	82	Nd	3	Nd	461	1	30
16.	41	-Do-	-Do-	Dakshin Laxmipur	-Do-	68	Nd	3	2	1427	6	197
17.	42	-Do	-Do-	-Do-	-Do-	37	Nd	3	Nd	978	8	75
18.	43	-Do	-Do-	-Do-	-Do-	40	Nd	4	3	1248	7	96
19.	44	-Do-	-Do-	Kaliachak	-Do-	18	Nd	4	3	840	10	192
20.	45	-Do	-Do-	-Do-	-Do-	28	Nd	6	Nd	1032	10	7
21.	48	-Do-	-Do-	Jalalpur	-Do-	38	Nd	8	Nd	110	9	91
Sl. No.	**Sample No.**	**District**	**Block**	**Location**	**Name of filter**	**Al**	**Cd.**	**Cr.**	**Cu**	**Mn**	**Pb**	**Zn**
22.	49	Murshidabad	Barhampur	Khagra	-Do-	26	Nd	8	Nd	113	5	567
23.	12	S-24 Parganas	Baruipur	Chandrakhali	Pal Trockner	67	Nd	9	2	706	8	34
24.	13	-Do-	-Do-	Shakharipukur	-Do-	34	Nd	10	1	665	7	65
25.	14	-Do	-Do-	-Do-	-Do-	13	Nd	11	Nd	364	Nd	198
26.	29	-Do-	-Do-	Baruipur	-Do-	43	Nd	1	2	1002	Nd	94
27.	31	-Do-	-Do-	P.Mallickpur	-Do-	34	Nd	1	Nd	1156	Nd	150
28.	38	-Do-	Do-	Baruipur	-Do-	25	Nd	1	25	247	Nd	201
29.	60	-Do-	-Do-	Dhabbhabi	-Do-	47	Nd	2	Nd	276	2	117
30.	61	-Do	-Do-	-Do-	-Do-	73	Nd	3	Nd	786	4	134
31.	62	-Do	-Do-	-Do-	-Do-	280	Nd	3	Nd	678	3	146
32.	63	-Do	-Do-	-Do-	-Do-	280	Nd	3	Nd	678	3	141
33.	64	-Do	-Do-	-Do-	-Do-	85	Nd	4	Nd	725	1	13
34.	15	N-24 Parganas	Habra-I	Laxmipur	All & PH	40	Nd	10	Nd	41	7	41
35.	9	-Do	-Do-	-Do-	-Do-	180	Nd	9	Nd	5	Nd	Nd
36.	16	-Do	-Do-	-Do-	-Do-	46	Nd	11	1	56	2	25
37.	17	-Do	-Do-	-Do-	-Do-	40	Nd	11	Nd	59	5	91
38.	20	-Do	-Do-	-Do-	-Do-	64	Nd	10	Nd	129	1	24
39.	52	-Do	-Do-	-Do-	-Do-	38	Nd	10	Nd	150	9	128
40.	56	-Do	-Do-	-Do-	Do-	44	2	1	12	140	3	40
41.	57	-Do	-Do-	-Do-	-Do-	54	Nd	2	Nd	283	12	25
42.	58	-Do	-Do-	-Do-	-Do-	38	Nd	2	3	254	8	323
43.	59	-Do	-Do-	-Do-	-Do-	52	Nd	3	Nd	110	3	18

Manganese content of treated water incase of Pal Trockener treatment plant and Domestic Filter

.Sr. No.	Sample No.	Location	Type of Plant/Filter	Manganese content (micro gram/ L)
1.	10 T	Serpur	Community	407
2.	25 T	Sibhati	do	602
3.	26 T	Moyana	do	nd
4.	12 T	Chandokholi	Domestic	8
5.	13 T	Sakharipukur	do	34
6.	14 T	Sakharipukur	do	9
7.	29 T	Baruipur	do	66
8.	31 T	P. Mallickpur	do	766
9.	32 T	Baruipur	do	nd
10.	60 T	Dhabdhabi	do	4
11.	61 T	do	do	28
12.	62 T	do	do	1110
13.	63 T	do	do	30

Appendix-13

RESULTS OF BACK WASH SAMPLES

COMMUNITY BASED

Sl.No.	Lab.No. Almg/L	Type	Location	Dist	Fe mg/L	Asmg/L	
1	1B 0.21	WSI-C	JOYPUR	N24pgs.	0.56	0.184	
2	3B 0.22	APIRON-C	ACHATA	N24pgs.	28.02	1.36	
3	7B	PHED-C	GOBARDANGA	N24pgs.	0.18	0.78	0.1
4	8B 0.121	AMAL-C	LAXMIPUR	N24pgs	0.18	0.02	
5	10B	PT-C	SERPUR	S24pgs.	32.54	1.11	
6	11B 0.095	AIIHPH-C	SARDARPARA	S24pgs.	1.8	2.52	
7	23B 0.065	AMAL-C	SANGRAMPARA	S24pgs.	4.18	0.035	
8	33B 0.056	AIIHPH-C	BETAI	NADIA	2.52	0.01	
9	34B 0.03	AMAL-C	BETAI	NADIA	0.38	1.89	

DOMESTIC BASED

Sl.No.	Lab.No. Almg/L	Type	Location	Dist	Femg/L	Asmg/L
1	9B 0.198	AIIHPH-D	LAXMIPUR	N24pgs.	0.14	0.005
2	12B	PT-D	CHANDOKHALI	S24pgs.	32.54	0.15
3	13B	PT-D	CHANDOKHALI	S24pgs.	21.9	0.03
4	14B	PT-D	SAKHARIPUKUR	S24pgs.	22.04	0.025
5	26B	PT-D	MOYNA	S24pgs.	9.02	0.16
6	28B	PT-D	BARUIPUR	S24pgs.	2.06	0.005
7	29B	PT-D	BARUIPUR	S24pgs.	33.28	0.005
8	30B	PT-D	BARUIPUR	S24pgs.	3.48	0.005
9	60B	PT-D	BARUIPUR	S24pgs.	21.6	0.03
10	61B	PT-D	DHABDHABI	S24pgs	29.5	0.131
11	62B	PT-D	DHABDHABI	S24pgs	14.22	0.016
12	63B	PT-D	DHABDHABI	S24pgs	22.04	0.005
13	64B	PT-D	DHABDHABI	S24pgs	4.98	0.005
14	36B 0.024	AMAL-D	KALIACHAK	MALDA	0.2	0.005
15	41B 0.072	AMAL-D	D.LAXMIPUR	MALDA	0.174	1.4
16	42B 0.038	AMAL-D	D.LAXMIPUR	MALDA	0.62	2.04
17	65B 0.082	CSIR(JU)D	BEHRACHAMPA	N-24pgs.	4.98	0.01
18	66b 0.088	CSIR(JU)D	BEHRACHAMPA	N-24pgs.	0.44	2.23

PT: PAL TROCKNER C= Community basic plants
D= Domestic filter.

Appendix-14

CHANGES IN CHEMICAL PARAMETERS CON SEQUENT TO PUMPING AT MOYNA, NORTH 24 PARGANAS

Pumping well:

Sl.No.	Hours As mg/	Date	Location	E.C.	pH	Cl mg/L	Fe mg/L
1	12.30 0.214	19-03-2001	MOYNA	772	7.42	21	10.28
2	1300 0.21	19-03-2001	MOYNA				10.36
3	1330 0.21	19-03-2001	MOYNA	773	7.41	19	10.14
4	1400 0.21	19-03-2001	MOYNA				10.26
5	1430 0.214	19-03-2001	MOYNA	775	7.43	19	1018
6	1500 0.21	19-03-2001	MOYNA				10
7	1530 0.22	19-03-2001	MOYNA	776	7.43	21	10.04
8	1600 0.2	19-03-2001	MOYNA	776	7.44	21	10.02

MAIN WELL:

Location	Moyana
Block	Barasat-I
District	North 24 Parganas
Pumping Well	Irrigation Well
Owner	Mr. Dewan sarif
Pump	5HP Centrifugal Pump
SWL	5.6 mbgl
Duration of Pumping	210min.
Discharge	6.71ps=24m3/hr=405.3lpm.
Draw Down	0.87m
Recuperation	0.752 in 30min.

OBSERVATION WELL:

	Domestic
Owner	Mr. Gopal ch. Biswas
Depth	130 ft
SWL	5.79 mbgl
DD	0.235 mafter 210 min.
Distance of MW&OW	17.2m
Recuperation	0.12in 30 min.

Appendix-15

VALUES OF IRON AND ARSENIC OBTAINED DURING COMPARISON OF SELECTED ADSORPTION MEDIA UNDER CONTROLLED CONDITION

FLOW RATE 43 L/H(APPROX)

SL.NO.	TIME	DISCRIPTION	LOCATION	Fe mg/L	As mg/L
3	1230PT		DHABDHABI	0.89	0.258
4	1230	AMAL	DHABDHABI	0.75	1.32
5	1230	ALCON	DHABDHABI	0.23	0.373
6	1300PT		DHABDHABI	0.78	0.248
7	1300	AMAL	DHABDHABI	1.52	1.47
8	1300	ALCON	DHABDHABI	0.36	0.476
9	1330PT		DHABDHABI	0.62	0.229
10	1330	AMAL	DHABDHABI	2.25	1.27
11	1330	ALCON	DHABDHABI	0.89	0.476
FLOW RATE 36 L/H (APPROX)					
12	1430PT		DHABDHABI	0.63	0.165
13	1430	AMAL	DHABDHABI	0.5	1.6
14	1430	ALCON	DHABDHABI	0.18	0.245
15	1500PT		DHABDHABI	0.74	0.176
16	1500	AMAL	DHABDHABI	0.55	1.465
17	1500	ALCON	DHABDHABI	0.31	0.293
18	1530PT		DHABDHABI	0.56	0.189
19	1530	AMAL	DHABDHABI	0.39	1.4
20	1530	ALCON	DHABDHABI	0.22	0.304
FLOW RATE 14 L/H (APPROX)					
21	1630PT		DHABDHABI	0.5	0.14
22	1630	AMAL	DHABDHABI	2.06	1.2
23	1630	ALCON	DHABDHABI	0.44	0.474
24	1700PT		DHABDHABI	0.51	0.176
25	1700	AMAL	DHABDHABI	2.39	1.18
26	1700	ALCON	DHABDHABI	0.47	0.462
27	1730PT		DHABDHABI	2.03	0.204
28	1730	AMAL	DHABDHABI	1.99	1.16
29	1730	ALCON	DHABDHABI	10.37	0.372

PT. Pal Trockner (granulated ferric hydroxide)
Amal: Oxide India limited (activated alumina)
Alcon: Activated Alum

Report on Socio-economic, Marketing & Training Issues

Prepared under the Project

Concerted Action on Elimination/Reduction of Arsenic in Ground Water, West Bengal, India

Prepared by: Development Consultant Group, Calcutta

Executed by: United Nations Industrial Development Organization

New Delhi
July, 2001

KEY FINDINGS

COMPARATIVE ASSESSMENT

MARKETING ISSUES

TRAINING ISSUES

CONTROL VILLAGES

BACKGROUND

Introduction

In the early eighties, a few cases of arsenical dermatitis were reported from some districts of West Bengal. It was gathered through analysis of water samples that the ground water was contaminated by arsenic in these districts.

As ground water serves more than 80% of the drinking water requirements in the state, **the Government of West Bengal formed an Experts' Committee in order to ascertain the cause, extent and magnitude of the problem, as well as to suggest remedial measures for the same.**

The Cause

The present crisis in West Bengal has been found to be precipitated by **geogenic** factors. As such, the control of the problem is more complicated than had it been due to **anthropogenic** factors.

Extent and Magnitude

According to studies carried out by various agencies, it has been noted that **1312 mouzas** and **15 non-municipal / outer growths in 68 blocks** and **9 municipalities within 8 districts** are prone to arsenic contamination. The 8 districts include Malda, Murshidabad, Nadia, North 24-Parganas, South 24-Parganas, Burdwan, Howrah and Hooghly. At present, some parts of Calcutta have also been identified as arsenic affected areas. A CGWB report of 1999 says that around 5.3 million people, i.e., 8% of the total population of West Bengal are reliant on arsenic contaminated ground water. Due to continuous movement of ground water and certain peculiarities in the geochemical conditions, the extent of the problem may increase over time.

ARSENIC IN GROUND WATER IN WEST BENGAL

- Around 5.3 million people (8% of the total population) under threat.
- 1,00,000 tube wells (approx.) contains arsenic above the permissible limit of 0.05 mg / lit (SOES,1999)
- 3,00,000 people estimated to have arsenical skin lesions (Chowdhury et.al,2000)

Mitigation Measures

As there is hardly any clinical treatment of arsenicosis, provision of arsenic-free water is considered to be of prime importance in tackling the problem. Towards this end, some work has already been initiated in West Bengal. The Government of West Bengal, with financial support from the Government of India, has undertaken a number of measures, both long term and short term in nature. Moreover, various institutes like the All India Institute of Hygiene and Public Health, Bengal Engineering College and Jadavpur University, as well as some private organizations, have developed technologies for arsenic removal.

A Joint Plan of Action to address Arsenic Contamination of Drinking Water has been launched in a collaborative manner by the Public Health Engineering Department (PHED), Government of West Bengal and UNICEF.

Apart from awareness generation and water quality surveillance, this project is also evaluating the performance of the various arsenic removal technologies mentioned earlier.

Population Status of Arsenic-Risk Districts and Blocks

SL	Districts (At-risk / tot blocks)	Total Population of the District (1991 census)			Total Population of the Blocks at Arsenic-Risk		
No	District	Total	Rural	Urban	Total	Rural	Urban
1.	Malta (5/15)	2637032	2450495	186537	980385	980385	-
2.	Murshidabad (15/26)	4740149	4245802	494347	2546303	2435710	110593
3.	Nadia(13/17)	3852097	2980279	871818	2431494	2289091	142403
4.	N-24Pgs (19/22)	7281881	3551581	3730300	3643683	3183296	460387
5.	S-24Pgs (10/29)	5715030	4954653	760377	2061146	1889191	171955
6.	Howrah (3/14)	3729644	1880530	1849114	439998	295935	144063
7.	Hooghly (1/18)	4355230	2996979	1358251	186056	171390	12866
8.	Burdwan (2/31)	6050605	3927613	2122992	310208	310208	-
	8 Districts (68/172)	38361668	26987932	11373736	12599273	11557006	1042267

Explanation of the Table

1. Total population of 8 districts (1991): 38.36 million

2. Total population of 68 arsenic-risk block (1991) : 12.6 million (33% of districts)

3 Any village, any non-municipal or municipal urban area having a tubewell with water of 0.05 ppm or more of arsenic concentration, is designated as arsenic-risk.

1. Estimated population of arsenic-risk villages and urban areas : 6 million

2. Figure 6 million constitutes 48% of block population and 16% of district population.

SOURCE: JOINT PLAN OF ACTION FOR ARSENIC MITIGATION IN WEST BENGAL (PHED & UNICEF)

STUDY RATIONALE AND SCOPE

Arsenic contamination of ground water has assumed menacing proportions in West Bengal. Several studies have established the presence of arsenic in about 68 blocks of 8 districts of West Bengal - Malda, Murshidabad, Nadia, North 24 parganas, Burdwan, Howrah and Hoogly.

Initiatives are being taken for the mitigation of arsenic related problems – e.g., the Government of West Bengal, with support form the Government of India, has launched a number of large River Water Based Piped Water Supply Scheme Projects in the affected areas. Simultaneously, a number of institutes / companies have been developing units, based on various technologies, for providing relief to the affected people.

However, most of these technologies are still at the **Research & Development level** – substantial effort is required, before they can be utilized for **large –scale, commercial purposes.**

Certain studies have been undertaken by different institutes to carry out comparative assessments of these arsenic removal technologies. However, while they have focussed on the **technical aspects** (efficacy of removal of arsenic, etc.), **the socio – economic and marketing aspects have largely been left out.** The aspect of long-term sustainability of these various technologies has also not been covered properly. Moreover, since these studies have primarily been conducted by the very agencies who have developed the arsenic removal units, there is, understandably, an inherent **bias in these studies.**
In this backdrop, the scope of the present study encompassed the following:

1. To synthesize knowledge and perception and take an integrated view of the arsenic problem by better understanding socio-economic issues and potential solutions.
2. To assess capacities and identify training needs at different levels and suggest broad mechanisms for capacity building.

3. To assess the opportunities and constraints in privatization of adopted technologies and suggest ways and means of ensuring acceptability at the grass roots level.

STUDY OBJECTIVES

1. AWARENESS

Assessment of the extent and depth of awareness amongst the community On problem of arsenic and related social, environmental and health issues;

2. Health Implication

Assessment of the health implications of arsenic contamination

- the number of people affected
- the source of contaminated water
- the manifestation of the health problem and its severity
- the number of death caused by arsenic contamination
- mechanisms to address the health problem caused
- extent of awareness on the arsenic-health linkage

3. Technology

Identification and socio-economic assessment of the mechanisms being used (in terms of technology introduction) to address the arsenic problem

- the specific technology being used
- the decision makers for technology selection
- the basis for selection (such as cost, maintenance aspects, available information etc.)
- the extent of information available with the community on different technologies available and specifically on the one selected
- the extent of acceptance of the technologies and its reasons
- the extent to which technology is community based
- Environmental implications of technology being used, such as sludge/waste water disposal etc.

4. Location of Treatment Units

Analysis of the community's choice regarding location of the technology

- the implication of choice of location
- identification of the decision makers regarding location
- Problems relating to location

5. Operation and maintenance

Identification of existing mechanism for maintenance of treatment units

- extent of community involvement and their specific role in operation and maintenance
- in absence of community involvement, who carried out O&M and the bottlenecks, if any

- In case of community plants, the existence of a committee (community based organization) for maintenance. If so, the constitution of such a committee and mechanism for its constitution
- Source of funds for O&M
- Training needs for O&M
- Availability of raw material and any other input for O&M

6. Existing Capacity and Training Needs

Assessment of capacity and identification of training needs of local stakeholders, institutions, based on existing capacities and community needs. This will include training for planning, implementation and O&M.

7. Privatization and Marketing

Analysis of issues relating to privatization and marketing of adopted technologies, keeping in mind community needs and their paying capacity. The possibility of involving local entrepreneurs to manufactures and market ARP units would be explored.

- Opportunities for privatization of treatment units;
- Constraints relating to privatization and marketing;
- Paying capacity of community - for community and households units.

STUDY METHODOLOGY

Approach

The approach of the present study has been both **investigative** as well as **exploratory** in nature In the investigative part, the precise nature of the situation or circumstances in which the arsenic affected patients as also the community at large are living and look upon the arsenic menace, have been studied.

In the exploratory part, the main task was to explore the nature and extent of various essential services that have been rendered by governmental and non-governmental agencies to ward off the menace of arsenic contamination of ground water, as also those who have been affected by arsenicosis. The exploratory part also dealt with the **motivation of the various private agencies** that have started to produce ARPs, with regard to their marketing activities and how far they have tried to make it popular among the population residing in the arsenic-risk areas.

Target Segments

a) Users of Arsenic Removal Plants (ARP) – both community, as well as domestic units

b) Non-users-residents of Control Villages, falling under the Arsenic zone, but with no intervention yet.

c) Panchayat members

d) Company/ institution personnel, involved in developing / marketing Arsenic Removal Plants.

e) Dealer personnel, marketing ARPs

f) Maintenance personnel of community – based ARPs

g) Community opinion leaders

h) Training Institutions

i) NGOs involved in the arsenic mitigation process

Survey Technique:

a) Users of Community – based ARP – treated Water and non-users of Control Villages: Focus Group Discussion.

b) All others – Depth Interviews

Instruments:

a) For the FGDs, two sets of Group Guides were developed one for users, one for non-users of Control Villages.
b) For the Depth Interviews, separate sets of Depth Guides were developed, catering to specific target groups of respondents. These instruments were finalized in consultation with Mr. A.K.Sengupta.

SAMPLING ISSUES

The approach here was techno-centric, i.e., in the first place, all the leading institutes / companies who have put various technologies to use, in order to remove arsenic, were chosen in consultation with Mr. A.K.Sengupta. Thereafter, a sample of the plants installed by them was selected and the social survey conducted at these sites.

Here, the aim was to have an **unbiased and accurate representation** of the universe, both in terms of the technologies in vogue, as well as the arsenic – affected population. The effort was made to have **adequate representation** across all the affected districts and even the blocks.

The actual choice of samples, however, was influenced by **certain extraneous factors,** which did not always allow us to strictly adhere to our sampling objective. For example, in the case of community –based ARPs, we had to encounter the following constraints:

(a) Limited number of plants of each technology has been installed (mostly on an experimental basis), thus restricting choice – e.g., only two Pal Trockner ARPs and one each of W.S.I. and Ion Exchange had been installed at the time of survey – therefore, unit selection was sometimes a foregone conclusion.
(b) Concentration of ARPs of most of the technologies in one district, i.e., North 24 Parganas, injected a certain degree of bias towards this particular district in our sample. However, notwithstanding these constraints, we have tried to ensure dispersed representation, to the extent possible. For example, AIIH & PH, having units in three districts (North 24 Parganas, South 24 Parganas and Nadia) were represented in all three. Similarly, for Amal (two districts) and PHED (three districts.)

In the case of Household units, lists of filter users were collected, either from the NGOs which have collaborated in their installation (e.g., AIIH & Pal Trockner) or from published reports of the institute concerned (e.g., Jadavpur University). In Amal's case, since it has been privatized with Oxide India marketing the filters at present, its dealers were contacted in the two districts where it is currently operating, viz, Malda and Murshidabad, and the necessary lists collected from them. (The only filter to be installed in North 24 Parganas was also included). These lists served as Sampling Frames, from where the respondents were chosen at random, ensuring representation across blocks, to the extent feasible.
The following table illustrates our Sampling Approach:

SAMPLE SELECTTION

COMMUNITY – BASED

TECHNOLOGY	TOT.NO. INSTALLED	DISTRICT	SELECTED	DISTRICT	LOCATION	SAMPLE SIZE
AIIH & PH	14	S-24 PGS: 8 N-24 PGS: 2 NADIA : 4	3	S-24 PGS: N-24 PGS: NADIA :	SARDAR PARA (BARUIPUR) GAIGHATA BETAI (TEHATTA-I)	42

PAL TROCKNER	2	S-24 PGS: 1 N-24 PGS: 1	2	S-24 PGS : SHERPUR (BARUIPUR) N-24 PGS : MOYNA (BARASAT)	16
B.E. COLLEGE (AMAL)	10	N-24 PGS : 6 NADIA : 4	3	N-24 PGS : SADPUR (HABRA – 1)/ SANGRAMPUR (BASIRHAT) NADIA : BETAJ (TEHATTA)	46
APYRON	2	N-24 PGS : 2	2	N-24 PGS: – SHIBALAY,ADAHATA (BARASAT)	18
PHED	3	N-24 PGS : 1 MALDA : 1 MURSHI DABAD : 1	3	N-24 PGS : G OBARDAN- G.A .M.C. (HABRA) MALDA : BAKHARPUR (SUJAPUR) MURSHIDABAD : JHAUDIA (JALANGI)	51
W.S.I	1	N-24 PGS:	1	N-24 PGS: JOYPUR (BARASAT)	9
ION EXCHANGE	1	NADIA	1	NADIA : NONAGHATA (HARINGHATA)	12

CONTROL VILLAGE : THREE IN TWO BLOCKS OF SOUTH 24 PARGANAS ; SAMPLE SIZE : 40

DOMESTIC			**SAMPLE SELECTION**		
TECHNO-LOGY	TOT.NO. INSTALLED	DISTRICT	SELEC-TED (SAMPLE SIZE)	DISTRICT	LOCATION
PAL TROCKNER	25	S-24 PGS	15	S-24 PGS	DHAPDHOPI, RAMNAGA (BARUIPUR)
AIIH & PH	150	N-24 PGS	15	N-24 PGS	LAKSHMIPUR & ADJ.VILLGS (HABRA– 1)
JADAVPUR UNIVER SITY	150	N-24 PGS	15	N-24 PGS	SHIMULPUR & ADJ.VILLGS
B.E. COLLEGE (AMAL)	200	MALDA/ MURSID-ABAD / N-24 PGS	16	MALDA :12 MURSI-DABAD : 3 N-24 PGS 1	

Total number of respondents (community + domestic + control) = Two hundred and Ninety five only.

<u>Other segments covered</u>

1. Technology Provider

- Institute / Organisation
- Company

2. Training Institute : 6

3. Dealer : 2
4. Maintenance Personnel : 5
5. Panchayat : 5

Data Collection

A number of investigators, who were conversant in administering such instruments were recruited. However, researchers also visited a fair number of sites of each technology in all the districts covered. The fieldwork was conducted during July – Nov, 2000.

Data Analysis

The data collected from the Field Survey were subsequently analyzed and the report written on the basis of the computed information.

KEY FINDINGS

PERCEPTIONS ABOUT ARSENIC

Awareness

Level of awareness varied from site to site, ranging from low in some areas to very high in others. The awareness level was generally positively co-related to the following:

i) Incidence of arsenicosis in the village and/or adjoining areas

ii) Arsenic-related activities, e.g., water quality tests, mitigation measures, etc. undertaken by various governmental and non-governmental organizations. Understandably, the level of concern regarding the arsenic issue was also higher in these areas.

Thus, we found people more aware in Baruipur (South 24 Parganas), Betai (Nadia) and Nonaghata (Nadia), where NGOs are active in spreading awareness about it and urging people to avail of arsenic-free water of the various ARPs.

On the other hand, villagers, especially the women, in some parts of North 24 Parganas (e.g., Joypur) seemed to have a very poor understanding of the term arsenic, since they had hardly seen any arsenic-affected patients, and moreover, NGOs were hardly active in these regions.

Arsenic is commonly referred to as 'poison' which is present in 'tubewell' water. Some educated persons mentioned that arsenic is a metal, which remains dissolved in water. Several illiterate people thought arsenic was the name of a disease. Even if knowledge about arsenic is poor in most places, it is nevertheless perceived as an extremely 'harmful' substance, which enters the human body via consumption of contaminated water.

Health Concern

Awareness of the physical consequences of arsenic contamination was again directly co-related with the prevalence of arsenicosis in a particular village.
Thus, people in Baruipur (South 24 Parganas) and Nonaghata Uttarpara (Nadia) were quite well aware of the consequences, while those in Sadpur (North 24 Parganas - very few reported cases of arsenicosis) were not.

The most commonly mentioned symptoms of arsenicosis were:
Skin Diseases: black spots on hands/feet/body, roughness of skin warts.

Other symptoms mentioned were:
- Acidity
- General weakness (sometimes affecting one's capacity to work)
- Respiratory trouble

Patients and members of patients' families pointed out that these symptoms usually require 3-5 years to set in.

Medical cases

Villagers were aware of arsenic afflicted patients in almost all the sites we visited. However, more number of these cases were reported from:
(i) Baruipur area of South 24 Parganas
(ii) Betai area of Nadia
(iii) Nonaghata Uttarpara and Sangrampur of North 24 Parganas

While several deaths have been reported in the Baruipur region, villagers were aware of fewer deaths in Nonaghata and Sangrampur.
The reported cases of arsenicosis were least in the villages visited in Malda and Murshidabad.
Interestingly, villagers were not aware of any arsenic - induced death in Adahata (North 24 Parganas), where the concentration of arsenic appeared to be the highest.

Effects on Agriculture / Livestock

People in general are not aware of any adverse effects of arsenic contamination on agriculture or livestock. In fact, to most, it appeared to be too remote a concept, with which they were not at all familiar.
However, one respondent each in Nonaghata and Sangrampur remarked that arsenic present below ground level affects crops (fruits and vegetables), and in turn affects the human system. They have come to know of this either from PhD students of Kalyani University who had visited their village to collect samples (Nonaghata), or heard it in a seminar which they had attended (Sangrampur). The person who mentioned this phenomenon in Nonaghata also said that arsenic is so highly poisonous that plants die in the vicinity of arsenic-contaminated tubewells and it can affect fishes, too, if this water is allowed to drain into ponds.

Social Implications

By and large, incidence of social ostracization was not noticed anywhere. People generally do not perceive arsenicosis to be a contagious disease.

However, patients are concerned that it gives them a 'dirty' or 'ugly' look. They point out that people visiting their houses hesitate to accept water from them, asking them as to why they are looking so dirty? (Dark spots / warts on their bodies).

A doctor we spoke to in Nadia said that many of his arsenic-affected patients, especially the women, expressed concern about the fact that it made them appear dark and ugly.

Since it is thought to mar one's looks, some people feel that it could cause problem in getting a girl married off.

TECHNOLOGY OPTIONS

PAL TROCKNER

Community based

FGDs were conducted at two Pal Trockner community - based sites:

i. Moyna village of North 24 Parganas.
ii. Sherpur village of South 24 Parganas.

While the former unit is on its trial run, having been set up by the PHED, the latter was set up on the initiative of the NGO, Ram Krishna Mission Lokashisksha Parishad (RKLMSP). When we visited the first site, it was out of order. Moreover, since it is located within the prmises of an individual's house, it is being used only by the family members of that particular household. The other villagers preferred fetching water from a nearby deep tubewell. Water quality tests are being conducted by PHED from time to time, as part of its monitoring execise of various Arsenic removal technologies. The costs of installation and maintenance are being borne by the company itself.

The second ARP has been set up in a highly arsenic affected area (Sherpur) of South 24 Parganas. RKMLSP played the key role. They involved the community and the Panchayat in the project, especially in taking key decisions like choice of location of unit, etc. The choice of technology was made by RKMLSP, while the cost of installation was borne by the company.

Day-to-day maintenance is done by a caretaker at Sherpur – he has been suitably trained by the Company to carry out backwashing ,etc. In case of any problem , he gets in touch with the Company personnel.The Company personnel visit it as and when required.

There have been teething problems with the plant - e.g, there was no provision for iron removal, which happens to be a sevre problem of the area. On being notified, the company introduced an iron removal filter in the unit.

Unit Efficacy

While the Pal Trockner model seems to remove arsenic effectively (as revealed by water quality tests conducted by RKLMSP for the second unit), the issue of waste water / sludge management still remains.

According to the Company personnel, the sludge will ultimately be removed during replacement of the media after three - four years and disposed through cement based stabilization to be used in bricks, etc. However, the waste water was being drained off into the adjacent pond. On being notified, the company has set up a sand bed, through which the waste water is being passed at present - this helps in retaining arsenic, while the water slowly drains off.

Initially, the community members were quite satisfied with the plant (after installation of the iron filter). However, on our subsequesnt visit, we found they had several complaints, i.e.

- An oily layer forms on the water, if stored
- The water turns reddish on storing
- Rice does not cook well in it ("looks blackish--")

Some community members felt that the water of a nearby 1000 ft. tubewell tastes better. At present the ARP Unit has been modified and is working satisfactorily.

About 100 families are drawing water from the plant, which is mostly used for drinking and cooking purposes.

Daily water output : 2000 litre (approx)

Monthly O&M costs : Rs.300 /-, which is borne by the Company itself.

Although the community does not at present contribute towards plant maintenance, they are not completely averse to the idea, provided they get uninterrupted supply of clean and safe water.

DOMESTIC ARP

We interviewed 15 respondents who had installed the Pal Trockner domestic ARP model in their houses. These were all in the highly arsenic affected block of Baruipur in South 24 Parganas. These households were quite well-off, where the main earner was employed in Banks, ONGC or engaged in business.

The general level of awareness and concern about arsenic was quite high here, especially because there are quite a few affected patients in this zone.

A local club, Antodaya Surya Sangha, has held several arsenic awareness camps in this area. This club, with the active cooperation of RKMLSP, and the local Panchayat, has been instrumental in promoting domestic ARPs here. These Pal Trockner ARPs have been supplied at a price of Rs. 1000/- (50% subsidy borne by RKLMSP). Two patients have been supplied free of cost as a goodwill gesture by the company. Most of the respondents were of the opinion that if the filter is to be accepted by the masses, it should be priced around Rs.500/-.

The particular model was chosen by RKLMSP. The filter is a compact unit with in-built media,which pre-empts the necessity for chemical dosing. The system is an "on line" one - this is possible only in households with taps - in other houses, the pipe of the ARP is immersed in a bucketful of water, from which, water is drawn when required.

In most households, the filter has been installed close to the kitchen. The housewife is primarily responsible for looking afetr the filter, although in some houses, male members also share these responsibilities,. Respondents pointed out that there is no need for any daily maintenance job - the filter only has to be backwashed, usually once a week, to clean the system of various deposits, i.e. iron. The waste water thus generated is thrown into open drains. This process has been explained to them either by the company personnel, or members of Antodaya Surya Sangha.

Again it has been brought to the notice of the company by RKMLSP that arsenic is being recycled into underground water by this method of waste water disposal. The company has looked into the matter and has suggested plastic buckets to the users, where the waste water can be stored. Afetr a certain period of time, this can be removed by the company personnel. However, this proposal is yet to be finalised.

Most respondents said, they used the filtered water for drinking and cooking purposes. The users appeared to be satisfied with the qulaity of the treated water, especially since it has helped to get rid of various common stomach ailments, i.e. acidity, indigestion, constipation, etc.

Of the two patient users, one felt the black spots on his hands had reduced somewhat, while the other could not discern any apparent improvement.

Role of Panchayat

The panchayat has taken steps to make the community aware about arsenic and its ill effects. It has sunk deep tubewells in the locality and has fully cooperated with RKMLSP and the Rotary Club to install ARPs. It is also trying to procure vitamin tablets and distribute them among arsenic affected patients.

The panchayat reported that it has scanty information regarding domestic ARPs – it came to know about these from a seminar which was organised in the area. The panchayat pradhan felt that domestic ARP was a good proposition, but at its prevailing price, hardly 10% of the households can afford it.

When asked whether the panchayat could possibly subsidise these domestic filters, the Panchayat Pradhan pointed out that it would require budgetary allocation, which, apparently,.is a cumbersome process.

Conclusion:

1. As far as the community based ARP is concerned, there seems to be a certain lack of coordination between beneficiaries, the implementing agency and the company. One way to get over this problem is - encouraging community participation at the grass roots level, e.g., a local club could be involved in plant O & M and could serve as a link between the beneficiaries and the company,keeping RKMLSP informed about developments, instead of depending on it for every requirement. Moreover, if community contribution is initiated by the club, minor maintenance jobs can be handled by the community itself, instead of waiting for company personnel to come and do it.

2. As far as domestic ARPs are concerned, we have the following observations

- the cost of Rs.2000 per filter can be afforded only by the well - off; the company should also look into the possibility of developing a low cost option in order to gain mass acceptance

- there is a strong felt need to gain assurance that the treated water is actually arsenic – free – thus, periodic water quality tests need to be carried out here, again, if a link organisation can be trained in conducting water quality tests, etc., by the company, they could conduct regular tests to the satisfaction of the users.

3. For both the models, the issue of sludge / waste water disposal is of utmost concern. We hope that the various proposals mooted by the company in this regard translate into effective implementation.

4. Clear instructions in the form of a guide book /manual,in simple language, for operation and maintenance is required for the beneficiaries.

B.E. COLLEGE – AMAL

Community-based

We conducted FGDs at three community-based sites of AMAL filter of BE college:
(i) Sadpur of North 24 Parganas
(ii) Sangrampur of North 24 Parganas
(iii) Itkhola (Betai region) of Nadia.
Although all three are arsenic-affected areas, the last two are more severely affected than the first.
In all the above sites, local NGOs played a key role in ARP installation-e.g. , Breakthrough Science Society in Sangrampur and Chandranath Basu Seva Sangha (CBSS) in Betai took the initiative in providing a solution to the arsenic menace in their respective zones. Whereas in the first two, the NGOs got in touch with B.E. College directly, CBSS was introduced to it via Jadavpur University - here, Dr. Dipankar Chakrabarty of the University took the initiative.

In all the above sites, B.E. College personnel held meetings with the local people and helped in forming committees to look after its O&M. The Panchayat seemed to have been involved only in Sangrampur.

Whereas in Sadpur and Sangrampur, the installation costs were borne by B.E. College, in case of Itkhola, CBSS paid Rs. 60,000/- for it, out of funds received from a Japan Government grant (the total grant was for Rs.15 lakhs, which was spent on installation of seven ARPs in Betai).

Community Participation was clearly evident in Sadpur and Itkhola, whereas in Sangrampur, it was somewhat missing because of intra-committee bickering. Maintenance Committees have been constituted in Sadpur, comprising seven members. Whereas in Sadpur, two caretakers have been appointed (who work in shifts), in Itkhola, several community members take turns in plant maintenance. These caretakers have been trained in backwash procedure (which is usually done twice a week) and handling of minor repair jobs. The two caretakers together receive Rs.1700/- p.m. in Sadpur, whereas they do it free of cost in Itkhola. In Sangrampur, also, two caretakers had been appointed, but due to charges of favouritism, etc., may be replaced soon.

Community contributes towards O & M in both Sadpur and Itkhola. In the former, a Water Committee has been formed of nine members, including a President and a Secretary. About 300 households contribute towards plant upkeep - Rs.25/- when it becomes a member for the first time and Rs. 15/- thereafter in every subsequent month. In the latter, seventy families pay 50 paise per bucket of water drawn from the unit, while another thirty-four pay a monthly subscription. The money thus collected is deposited in a UCO bank account in Sadpur, whereas it is kept in the cashier's custody at Itkhola. In Sangrampur, although contribution had been initiated, at present it is on hold due to differences among committee members themselves. Their O & M fund meets caretakers' salaries in Sadpur, minor repair jobs in both the sites and the balance is being accumulated for plant re-charging, when it becomes due. The re-charging is done by Kar Enterprises, a service agency of B.E.College.

Water quality tests are carried out regularly by B.E. College - however, whereas they are conducted every week in Sadpur, it is done only once in three months in Itkhola. The test results are shared with the Committee members in Sadpur.

The community members of Sadpur and Itkhola appeared to be quite satisfied with the plant. They mentioned having been cured of stomach disorders, e.g., acidity, indigestion, lack of appetite etc. and pointed out that they had come to depend totally on it for drinking purpose. However, most people in all the three sites prefer either pond water or water from their private tube wells for cooking purpose. This is either because they feel that food, especially rice, does not cook well in it, or because they are unwilling to pay for it (Itkhola). ARP treated water is perceived to be 'light', but not as tasty as water drawn from a deep tube well. In Sadpur, some beneficiaries pointed out that it smelt of 'chemicals' after every backwash.

All three units were centrally located and thus there was no cause for complaint with regard to ARP location.

The ARP at Sangrampur appeared to be a little neglected and ill maintained, although perhaps, it was heavily used.

None of the beneficiaries in any site were aware of any other ARP model.

Daily ARP treated water consumed: about 5000 liters on an average in Sadpur (according to the Committee President) and about 1400 liters in Itkhola.

Sludge Disposal

The wastewater generated during plant backwash and regeneration flows into a sand filter adjacent to the plant and gets stored there. Once it is full, B.E. College will remove it for final disposal

The sludge that gets adsorbed within the media will be removed, once the media is replaced on exhaustion. In both the cases, the arsenic will be subjected to cement-based stabilization.

However, in none of the plants has the need arisen to remove the sludge, as yet.

Domestic

Sixteen beneficiaries who have installed 'AMAL', the domestic arsenic removal filter developed by B.E. College and manufactured and marketed by Oxide India Pvt. Ltd, were interviewed. Of the 16 beneficiaries, 12 beneficiaries were from Malda district, 3 from Murshidabad district, whereas one from North 24 Parganas. 8 of the beneficiaries happened to be Muslim, while another 8 belonged to the Hindu Community; of the 8 who belonged to the Hindu Community, 5 belonged to Scheduled Caste, while 3 hailed from General Caste. Some were traders, others engaged in the silk export-import business, while others included teachers and government employees.

Of the 16 beneficiaries, 6 had first hand experience of arsenic poisoning. Two of the beneficiaries were afflicted with arsenicosis, while 4 of the beneficiaries had come across arsenic poisoning of their near and dear ones, mostly relatives and other family members. The rest 10 beneficiaries had gathered information about arsenic from media sources, like television / newspaper and even from awareness camps organized by Panchayat and the Indian Medical Association.

All the respondents pointed out that they were very much concerned about arsenic and to counter the problem of arsenic contamination of water, they have installed domestic filters, which can remove arsenic from water. All the respondents reported that they have been using the ARP (domestic) for the last 6-12 months. None of them were aware of any other model of ARP.

They could learn about the present ARP from various sources, like relatives, the dealer directly approached the respondent, demonstration at exhibitions organized by Panchayat / Indian Medical Association and NGOs.

All of them reported that the 'AMAL' variety of ARP costs about Rs.2400.00. The respondents further stated that arsenic free water derived from the ARP, has been found to be very helpful to reduce indigestion / acidity / general weakness and so on. Moreover, one of the respondents reported that the black warts on his father's body were gradually disappearing and there had been no fresh emergence of black warts / spots, on drinking the filtered water.

The filtered water is chiefly used for drinking purpose – several families use it for cooking, as well.

All of them admitted that since the installation of the filters, there had been no effort to test the quality of the filtered water. Although they were not having any problem, all of them expressed the opinion that such tests need to be carried out, as it would make them feel more reassured.

The respondents reported that the maintenance of the ARP was not much of a problem. The water has to be poured into the upper container. The water percolates through the media, which is placed in a cloth bag in the upper container and the filtered water settles into the lower container, from where it is collected. All the respondents reported that once in a month, the media is washed with water and that water was thrown away down the drain.

Conclusion

While the plant is being well maintained by the community at some sites, the Committee needs to be strengthened at the others. Also, the Committees require to be trained in financial matters – e.g., system of collecting community contributions, depositing the same into bank accounts and handling the same, etc.

As far as the domestic filters are concerned, the following points are worth considering:

Regular water quality tests are a legitimate demand of the users – this should be considered for providing assurance to the users

The filter worth Rs. 2, 400/- cannot be afforded by the majority of the people at risk – the Company needs to look into the possibility of developing a low cost option, as well.

Water System International Ltd (W.S.I)

Community – based

So far, only one community - based unit of W.S.I. has come up at Joypur in North 24 Parganas - we conducted an FGD next to the plant itself.

This particular ARP is a trial one, set up by the company in collaboration with PHED. As such, its efficacy is being monitored by PHED by conducting periodic water quality checks.

The community members are aware that it is primarily a government project, in which the Panchayat was also involved in matters of site selection, etc.

The community members were apprised of the project, but not involved in the decision - making process. They were not aware of any other technology options.

Earlier, very few people were drawing water from this unit- however, at present, about a hundred families are drawing water from it – 2000 liters daily output (approx.).

The community seemed to be quite satisfied with the working of the ARP, as also its location - a busy roadside spot, accessible to all. They felt that the ARP- treated water is 'clean' and believe it is arsenic - free. They also mentioned that they use this water primarily for drinking purpose - for other purposes, including cooking, they are continuing to use water from private tubewells (which are very common here). It was somewhat alarming to note that they are extensively using water of tubewells whose water they think is arsenic - contaminated (via tests carried out by NGOs mostly). This is mainly because there are very few patients in this particular locality, and as such the level of concern is also low. The general consensus was - " we have been using water from these private tubewells for so long, nothing has gone wrong so far...... so, why change now?"

There is a brewing notion that plant maintenance be handed over to the beneficiaries. In a place where the majority of the villagers live under the poverty line, this is viewed as a possible source of income generation.

The community members had no idea about waste water or sludge management and were not concerned about it, either.

Regarding O &M contribution, there was a general apathy; however, some felt that "if others contribute, we can also do the same".

They were aware that the company has borne the costs of installation, and is also responsible for maintaining the ARP. One particular company personnel, Mr. Raju Sharma, have been designated as plant caretaker - it is his job to visit the plant regularly (six days a week), to ensure its smooth functioning. He has been trained by the company in matters of plant backwash, which he carries out once a fortnight. The wastewater is drained off in the adjoining land itself.

Mr. Sharma further pointed out that the media of the ARP has to be recharged after approximately 2,00,000 liters water is discharged - however, the need has not arisen as yet for it.
Monthly maintenance cost of the plant works out to about Rs. 4, 000/-, inclusive of the caretaker's salary, travel, etc., which forms the major component.

ION EXCHANGE

Community - based

FGD was conducted at the lone site of ARP installed by the company at Nonaghata Uttarpara in Haringhata block of Nadia district. The maintenance staff deputed by the company, Mr. Gautam Kumar Dey, was also present and we spoke to him, too.
This particular ARP has also been set up as part of PHED's trial run of various arsenic removal technologies.
This area is a severely affected one, where, according to local estimates, there are more than two hundred arsenic affected patients. Of them, a group of young boys had met the Block Development Officer, the Block Medical Officer and other functionaries, some time back. Subsequently, PHED people had come over and conducted water quality tests of the tube wells in the vicinity. Of these, one tube well was found to have a high concentration of arsenic, which was chosen for installation of the ARP. This was followed by visits of the Company personnel, who spoke to the local educated people (including a Doctor) about the benefits of having such an ARP in the village. Ultimately, the Company set up the plant in August 2000, which has borne all the costs of installation.

The beneficiaries have not been exposed to any other technology.

Of a total of about two hundred families in the village, about fifty-sixty families are drawing water from this ARP, the others draw water from the three deep tube wells installed by the Panchayat in and around the village. Several women we spoke to mentioned that they fetch water both from the ARP, as well as the deep tube wells. The flow of water of the ARP being less, they go to the tube well to fetch water when they are in a hurry. However, they are quite satisfied with the ARP treated water because of the following reasons:

-Food cooks well in it ('rice looks white')
-No iron/yellow sedimentation as in case of tube well water
-Stomach problems have reduced
One young, educated girl felt that it has also helped her to overcome 'physical weakness'.

A couple of patients present said that they had started getting spots on their body after drinking shallow tube well water for several years. A doctor who had visited them advised them to eat vegetables like carrot, tomatoes etc, and had given them some ointment, which was of no use. However, on using the ARP treated water, they feel that the outbreak of spots on their body has been checked, although they have not faded. They wanted to know how long it would take for the spots to disappear.
The ARP treated water is used for drinking and cooking purposes. However, pond water is also used for drinking (by some) and cooking purposes, as well.

Plant O&M

Mr. Goutam Dey is in charge of plant O&M. He visits the plant everyday. He has trained a local person as caretaker (whose house is situated next to the ARP) to carry out the following activities:

(a) Plant backwash- this is done every day, early in the morning, to remove iron deposits, etc-this takes about fifteen minutes to complete. The wastewater is disposed in the nearby land, itself.

(b) Drain out the water present inside the plant
- This is done every evening, so that fresh water may be pumped into the system the following morning.

The caretaker is paid Rs. 1,700 per month to discharge his duties. Certain small parts and tools required for plant maintenance are also stored in his house.

Mr. Dey, who also ensures that people who come to fetch water do not have to face any problem, supervises these activities. Water quality tests are carried out both by PHED (bi-weekly), as well as by Mr.Dey or any other company personnel visiting the site (weekly). For this purpose, the company uses Field Test Kits.
The entire O&M costs are borne by the company itself.

The media (resin in this case) has not yet been re-charged - it is expected to run continuously for at least five-six years. Thereafter, the exhausted resin will be removed, treated at the company's Central Regeneration Facility to leach out arsenic, the sludge neutralized by adding iron salts and ultimately used for land filling and industrial purposes – e.g., as raw material for production of certain goods, mirror polishing, etc.

Although the community does not contribute towards O&M, they reacted positively to the idea of doing so. They mentioned that they collect money to carry out repair work on the Panchayat tube well; moreover, people chip in to pay for the transport costs for patients to go to Calcutta (School of Tropical Medicine) for treatment

The Panchayat has played no role in the installation of the unit, or its operations.

Note:
This village is predominantly a Muslim one, where most inhabitants depend on agriculture. The general economic condition of this village is quite poor. Concentration of arsenic affected patients observed was also among the highest among all the villages visited by us.
One redeeming feature noticed was the initiative taken by local young boys, both in influencing the administration to take steps against arsenic, as well as promote usage of safe water by persuading the people to avail of these arsenic-free, safe water sources. These boys spread awareness regarding arsenic and its effects by carrying out door-to-door visits; they try to convince people to use the ARP water instead of shallow tube well water. Responses have been mixed, so far.

Conclusion

(1) Although community participation has been initiated, it can be further strengthened by:

(a) Training the caretaker in minor repair works

(b) Involving the local youth (who are high enthusiasm) to carry out water quality tests-results of these tests can thus be known to all, through these youth-which will further espouse the cause of using the ARP treated water

(2) Being the first unit to be set up by the company, several parameters have still not been defined/determined e.g, when to carry out regeneration exercise? at what cost,etc? These need to be worked upon

(3) Waste water disposal

APYRON

Community - based

FGDs were conducted at the following sites:

(I) Shibalay (North 24 Parganas)

(ii) Adahata (North 24 Parganas)

Both the above-mentioned ARPs have been set up as part of PHEDs trial run of various arsenic-removal technologies.

Water Quality tests conducted by PHED revealed presence of arsenic in these tube wells-subsequently, the company personnel came over to install the ARPs. The Panchayat was informed about installation plans, but did not play any role here in project implementation.

In Shibalay, the ARP is located within the premises of an arsenic-affected family's household (of whom one lady has expired due to arsenicosis)- the male members of this family were taken into confidence during ARP installation.
The community members have no idea about any other technology options.

Plant Location

While the ARP at Adalata is centrally located, the one at Shibalay (as pointed out earlier) has been located in private premises. As such, although there was no complaint about plant location in the former, beneficiaries were understandably dissatisfied with the latter.

About sixty families draw water from the former (1200L. approximately), while only two families (those adjacent to the ARP) draw water from the latter. Even those who had started drawing water earlier shifted to piped water supply, when it was introduced at the latter site.
The beneficiaries use the treated water primarily for drinking purpose in Adahata, while it is used both for drinking and cooking purposes in Shibalay. In Adahata, pond water is preferred for cooking because:

(a) Food tastes/looks better if cooked in pond water
(b) In order to minimize the 'load' on the ARP
(c) ARP treated water is perceived to be 'expensive' and thus, needs to be sparingly used

The level of satisfaction with ARP treated water was higher in Adahata, where people mentioned that it was 'clean' and 'white' water; moreover, it is perceived to stimulate appetite and ensure peace of mind.

In Shibalay, the beneficiaries mentioned that sometimes, the unit is not cleaned regularly- at such times, the water turns red and gives off a foul odor.

Some beneficiaries at Adahata remarked that the treated water smells of chlorine each time 'medicine' is added to it.

In neither site was the community responsible for plant O&M, nor did they contribute towards it.
Both the capital costs, as well as the O&M costs, are being borne by the company itself.

Plant O&M

The ARPs set up by Apyron do not require any chemical dosing. It needs to be backwashed regularly-usually, twice a week- to remove iron deposits, etc. This is done by company personnel, Mr. Rabi Ojha. The beneficiaries also mentioned that he adds some 'medicine' to the unit.
Mr.Ojha clarified that this medicine was actually chlorine tablets, which are replaced usually once a month. He said that the media at Shibalay has been changed five times; however, that at Adalata has not been done so.
Periodic water quality tests are conducted by Mr.Ojha, who has been provided with a Field Test Kit for this purpose, as also by PHED personnel, from time to time.
Mr. Ojha has received training from Apyron regarding aspects of plant maintenance, e.g., backwash process, minor repairs, as also conducting water quality tests.

Waste water / Sludge disposal

The wastewater generated due to plant backwash is thrown into the adjoining soil. The sludge that gets trapped in the media will ultimately be used up in manufacturing construction material (once the media is replaced).
There is no provision for media regeneration in this case.

Accordingly to company personnel, around Rs.3000. is spent on plant O&M per month, of which around 90% is travel/food costs of the maintenance staff.

Conclusion

- Choice of site needs to be more carefully done in order to facilitate trial and ensure wider acceptance
- For long term sustainability, community participation is mandatory – mobilization needs to be initiated now itself; also, training aspects need to be looked into
- Explore possibility of introducing domestic filters
- Consider regeneration/ recharging options, if feasible.

AIIH & PH

Community - based

FGDs were conducted at the following sites where community- based arsenic removal plants have been set up by AIIH & PH:

(i) Sardarpara (South 24 Parganas)
(ii) Gaighata (North 24 Parganas)
(iii) Jitpur (Nadia)
All the three units have been set up with NGOs playing a key role in installation:
Ramakrishna Mission Lokashiksha Parishad (RKMLSP), Vigyan Mancha and Chandranath Basu Seva Sangha respectively.

While RKMLSP installed it as part of its Programme to provide safe drinking water to arsenic affected areas of West Bengal and was assisted by a local NGO, Antoday Surya Sangha, CBSS was guided by Jadavpur University in its project installation. Vigyan Mancha interacted directly with AIIH&PH.

The local Panchayat was apprised of the project and involved in certain decision-making processes by RKMLSP in Baruipur- they did not seem to have been included in the other two sites. In fact, in the case of Gaighata, the Panchayat members were either totally unaware or only vaguely aware of the ARP, although it is situated at a stone's throw distance from their office building.

The costs of installation were shared in Sardarpara (70% by Rajiv Gandhi National Drinking Water Mission, Government of India and 30% by the community), provided by the Japanese Government in Jitpur and borne by AIIH&PH in Gaighata. In the case of CBSS, Jadavpur University assisted them in developing Project Proposal, interact with the Japanese Consulate etc.

Costs- Rs.25,000/- in Sardarpara, Rs. 35,000/- in Jitpur (free technical support was provided in the latter)

Choice of technology was made by the respective NGOs-in the case of Jitpur, it was influenced by Jadavpur University.
The beneficiaries were unaware of any alternate technologies in any site.

Choice of location was usually a joint decision between the implementing organisation and the community members. All three units are conveniently located at central spots of the respective villages.

Present status

The unit at Gaighata is defunct-it was in operation for just two months after installation.
About forty-five families were earlier using the ARP at Sardarpara however; the number has come down to only eighteen now (reasons given later).

The ARP at Jitpur is being mostly used by twenty-four families, situated close to the plant. Besides, villagers working in nearby fields also avail of its water.

The ARP treated water is primarily used for drinking purpose in both Sardarpara and Jitpur. Respondents mentioned that they generally prefer using pond water for cooking purpose. However, some women in Jitpur remarked that they prefer using ARP - treated water for cooking, as well, since 'Rice looks white' and 'Dal cooks well' in it.

The general consensus was that the ARP - treated water is 'light' compared to ordinary tube well water. Respondents in Jitpur were pleased that it had helped them to get rid of stomach ailments, e.g., diarrhoea, acidity, etc.

However, in Sardarpara, the beneficiaries were dissatisfied on the following counts:

(i) the plant is not properly protected against the elements - as a result, they often come across dirt and worms in the water discharged by it

(ii) the galvanized iron sheet cover becomes very hot in summer - as a result, the temperature of the water shoots up, as well, and therefore, 'does not quench thirst'

Moreover, various organizations conducting water quality tests with varying results of arsenic in treated water, has understandably resulted in confusion and frustration among the beneficiaries. RKMLSP has been apprised of all these problems and have taken them up with AIIH&PH. However, no visible improvement has occurred, as yet.

Plant O&M

Caretakers have been assigned from the community itself in Sardarpara and Jitpur. While the former, Rizia Bibi, was trained by AIIH&PH, Gobinda Poddar (Jitpur) was trained by CBSS in matters of plant operation and maintenance.

Both of them stay very close to the respective ARPs.

Their duties include:

(i) daily chemical dosing (alum and bleaching powder). Mr.Poddar mentioned that he adds 2.5 gram alum and 25 gram bleaching powder to the raw water every day.

(ii) backwash-done at an interval of one month or maybe even more at times.

Sludge Disposal – the wastewater is kept stored in a tank for the time being – arrangement for its proper disposal will be made once it is full.

In Jitpur, bleaching powder is procured by a local person, free of cost from the hospital in Baharampore, where she is an employee, while alum is bought from the local market. In Sardarpara, although bleaching powder is purchased locally, alum is being supplied by RKMISP, since the local variety was found to be of suspect quality.

O&M Costs

In Sardarpara, the eighteen families drawing water from the ARP contribute towards its O&M costs. In Jitpur, contributions come in irregularly from the families using the ARP-most of the time, the responsibility falls on the caretaker, Mr.Poddar, to provide the necessary funds.

Average monthly O&M costs works out to around Rs.600/- at the SardarPara plant. Water quality samples are collected from time to time - once every two months by Jadavpur University in Jitpur. However, respondents were not aware of AIIH&PH personnel carrying out any such tests.

Common problems noticed with the AIIH&PH model:

(a) Daily dosing of chemicals - not user-friendly, open to risk of miscalculated doses

(b) The handpump (with which the ARP is attached) is located on a raised platform - so, most users avoid climbing up and pumping it as they are supposed to do (in Jitpur, there are no steps to climb - women, therefore, do not perform this duty at all)

(c) No standardization of the chemicals used is possible – thus, their quality varies from place to place

DOMESTIC

15 respondents who have been using domestic based ARP developed by AIIH &PH have been interviewed. All the respondents were Hindus belonging to General caste and hailed from Lakshmipur and surrounding villages under Habra No. 1 Block, Dist – South 24 Parganas. 5 of the respondents were engaged in small business, 9 of the respondents were service holders while on happened to be daily wage labour.

All the respondents reported that the term 'Arsenic' was not foreign to them and even that arsenic was found in water below the surface and consumption of arsenic contaminated water led to serious physical complications and prolonged drinking of arsenic contaminated water might even lead to death. The respondents reported that they came to know about 'arsenic' from T.V./ Newspaper, awareness camp organised by NGO/ Panchayat and through first hand experience. They conveyed that consumption of arsenic contaminated water generally entailed arsenical skin lesions and the most visible signs were black spots on palm/ feet/ all over the body, blisters on hand / feet and black warts. The respondents further pointed out that consumption of arsenic contaminated water was likely to cause various other complication, loss of appetite, stomach disorders, acute indigestion, hair loss and fading eyesight. The respondents submitted that arsenic affected patients have not suffered from any kind of social ostracization.

Rather the patients themselves felt bit shy, because of the blisters and black spots. The people at large in the beginning felt helpless, because they were not familiar with such type of skin eruptions. But now this uncertain situation has subsided because the presence of arsenic and arsenic skin lesions could be diagnosed.

The respondents reported that to overcome arsenic contamination, have installed domestic filters capable of removing arsenic from water. AIIH in collaboration with the local NGO has installed the domestic filters. The households using the aforesaid domestic ARPs did not have the option to decide between other technologies, because the local NGO has made arrangements with AIIH to install the same. Infact they reported that they were not in the know about the availability of domestic ARPs, other than that installed by AIIH. The respondents had to pay Rs. 100/- towards the installation of arsenic removal filter. The respondents reported that the treated water was primarily used for drinking. For cooking and drinking. Respondents pointed out that daily maintenance related to the adding of chemicals to the water for treatment otherwise there is not much to it. The process of treatment is as follows: un-treated water is stored in a bucket and the minimum quality ought to be 10 ltrs. In 10 ltrs. of water 20 drops of liquid bleaching and ½ teaspoon full of alum are added and stirred briskly, so that it gets dissolved completely. The water is kept in this state for three hours. After that 3/4th of the aforesaid water is poured in the upper chamber of two-chambered filter, which is made up of clay. The upper chamber has candles and the water therein percolates through the candle to the lower chamber and that water is arsenic free. 1/4th of the water is disposed of as that contains arsenic and which is termed as sludge. The sludge is thrown in the pan as per the instruction of AIIH &PH. Monthly maintenance cost worked out to Rs. 10/-. The respondents reported that initially water quality tests used to be carried out but of late such water quality test have been discontinued. The respondents insisted that such water quality test need to be organised periodically. All the respondents reported that there was no problem to handle the domestic ARP, except that **one has to be cautious about dosing** and the availability of chemicals. At present the chemicals were being supplied by the local NGO, but if at anytime the said NGO stopped selling the chemicals, the respondents would in a fix. The respondents opined that using of treated water has had the following effects: stomach problems had been greatly reduced, the treated water tasted good, acidity had also come under control and there was no eruption of arsenic related skin lesions.

The panchayat reported that the main problem was arsenic contamination of ground water. The main casualty of this menace has been the poor people. The Panchayat Pradhan reported that it has taken the initiative to make the people conscious about 'arsenic' and how it entered the human body and the impact thereof. The tubewells, which had been found to disgorge arsenic contaminated water, had been identified but they were yet to be sealed. Ten deep tube wells had been sunk. The Pradhan reported that water quality test of existing tubewells and of deep tubewells were carried out by Public Health Engineering. He also submitted that four arsenic affected patients have been identified. The people of the area did not have any reservation against them. The Pradhan further stated that Shibpur B.E. college has installed a community based ARP, while AIIH &PH has taken the initiative to install domestic ARP. The Pradhan expressed ignorance about the modus operandi of community based as also of domestic based ARP. He reported that panchayat had no role in the selection of site where B.E. College has installed community based ARP. Similarly panchayat had no role in the selection of beneficiaries where domestic ARPs had been installed. He reported that he had no knowledge if at all any training was organised on O&M aspects. The Pradhan reported that he had heard that a committee has been constituted to look after the maintenance of the community based ARP. There was no panchayat member on the committee. The beneficiaries were supposed to pay Rs.15/- every month to meet the maintenance cost of the ARP. Pradhan was of the opinion that domestic ARP was quite helpful because that would ensure arsenic free water to the household and they would not have to depend on external sources. Pradhan pointed out that G.P. had very little fund to organise the installation of community based ARP. He was of the opinion that the panchayat samity should come forward to install community based ARP. He further mentioned that community contribution could be mobilized if there was intensive persuasion and counselling. The pradhan expressed that to ensure proper maintenance of ARPs, easy availability of chemicals and proper disposed of sludge need to be given due attention.

Conclusion

- Address inherent weaknesses in an effort to make the system user-friendly
- AIIH&PH should take initiative in plant performance monitoring and provide re-assurance to users about the safety of the water it provides
- Closer co-ordination and better liaisoning between AIIH&PH and the implementation NGOs is essential for smooth functioning of the units.

At present, the organization is playing the role of only 'technology-provider'; for commercial success, a far more professional and marketing-driven approach is required, especially in terms of suitable product modification to make it more user- friendly and strengthen after sales and other back-up services.

Jadavpur University

Fifteen beneficiaries who are using domestic arsenic removal filter developed by the School of Environmental Studies, Jadavpur University have been interviewed. Of the fifteen beneficiaries, eleven beneficiaries hailed from village Kolsur under North 24 Parganas district two from Amkhola and two from Deoganga under the same district. Thirteen of the respondents happened to be Muslims, while two were Hindus who again belonged to scheduled caste community. The occupation of seven of the beneficiaries happened to be business, while seven respondents were daily wage laborers and one was a bidi worker.

Of the 15 respondents, 10 respondents have been affected by arsenic, while the family members of the two have been affected by arsenic, and remaining three respondents did not have any such arsenic patient. 12 of the respondents reported that a team from Jadavpur University came to the village, examined them as also the water and from them, the respondents could come to know about the presence of arsenic in ground water. The other three respondents approached the doctors at the hospitals to find out the reason for the appearance of warts on their skin and from those doctors they could learn about arsenic.

It transpired from the discussion with the respondents that earlier they were using the tubewells which have been found to disgorge arsenic contaminated water, because those tubewells were yet to be sealed and no alternative handpump have been installed. The respondents have installed domestic ARP, and the ARP was helping them to get arsenic free water.

The respondents reported that domestic ARP has been made available to them by Jadavpur University free of cost. They have been using the filter for the last three to four years. The filter consists of two chambers made of plastic. In the upper chamber, there is a candle. The water is poured into the upper chamber and it then percolates down to the lower chamber. At first the unfiltered water is collected in a bucket. One black tablet, which is also supplied by Jadavpur University free of cost, is put into water and stirred vigorously to ensure that the tablet gets dissolved completely. After that the water is poured into the filter. The water that comes out of the filter is arsenic free.

All the respondents replied that since they have started to take arsenic free water, they have experienced certain very positive results, like, black spots have started to fade away, there has been no fresh spots on the body, indigestion and other stomach problems have been reduced.

It could be garnered from the respondents that previously twice in a month water quality test used to be carried out but this has been discontinued for quite sometime, though all of them were very much in favour of testing the water periodically.

They reported that domestic ARP was easy to maintain. Ten of the respondents reported that they disposed the sludge at the end of every month. While five of them reported that they disposed the sludge every fortnight. The sludge was disposed in a dug out hole, especially made for the disposal of the sludge.

All the respondents reported that sometimes the candle broke or became loose, the tablet got exhausted in that case they had to secure the tablets or mend the candle with the help of the designated person authorized by Jadavpur University. He was not always available, and so the replacement of tablets or candle was bit of a problem.

The Panchayat reported that the community has become well aware about arsenic, but it has yet to grasp the depth and gravity of the problem. The Panchayat has taken the initiative to make the people aware about the menace of arsenic. The Panchayat has identified the affected tube-wells, but they have not been sealed; though the beneficiaries had been asked to refrain from using those tube-well. The Panchayat was aware of the fact that a number of persons had died due to arsenic poisoning and quite a good number of people have been suffering from arsenic poisoning. The Panchayat was trying to solicit the support of Government and non-government agencies to counter the menace of arsenic. AIIH & PH have taken the initiative to install community based ARP in their locality but the selection of site for the setting-up of community based ARP and the identification of beneficiaries for the supply of domestic ARP have been done at the behest or AIIAH & J.U. The panchayat did not know much about the operation of community and domestic based ARP. But it has come to know that the units were performing well. The Panchayat was of the opinion that domestic based ARP was quite a feasible proposition, but how far the common people would be able to buy it would depend on the cost of the filter, as most of them depend on agriculture. The Panchayat felt that alternative source of drinking water needs to be arranged, but it hardly has the means to do so. The Gram Panchayat felt that the Panchayat Samity ought to come forward in this regard.

Conclusion

On the whole it can be said that, due to the intervention of Jadavpur University, the menace of arsenic has become quite well known in the community. The community at large, is very much concerned about the arsenic contamination of ground water. But owing to the lack of alternative arrangements, the community was forced to take arsenic contaminated water. Jadavpur University has taken the initiative to supply domestic ARP free of charge to some of the families, but that hardly has helped to meet the demand for such filters.

Periodic testing of water quality needs to be conducted, which of late has been discontinued. Moreover, the replacement of the media (tablet) or candle depends on the designated person authorized by J.U. and which has posed a problem to get these things in time. Thus, the supply chain needs to be strengthened. In the long term, it would have been better, if the domestic ARPs could have been manufactured locally and the tablet also sold through a local outlet. Moreover, the beneficiaries need to get exposure regarding the other Technologies for arsenic removal

PHED

FGDs were conducted at the following sites:

1.	Bakharpur	(Malda) –	15 Female participents
2.	Masimpur	(Malda) –	20 do
3.	Jhaudia	(Murshidabad) -	12 do
4.	Gobardanga	(North 24 pgs.) -	20 do

The treatment plants were located in Bakharpur and Gobardanga , from where the treated water is supplied through pipes to adjoining villages and Jhaudia, where it is attached to a hand pump. Masimpur was chosen as a tail-end village of the Piped Water Scheme of Bakharpur.

The first three villages were Muslim dominated, while the last was predominantly a Hindu one. While Bakharpur was a poor Muslim village, villagers of Masimpur were relatively prosperous. Occupation of the Malda villagers was mostly silk worm rearing, whereas that in Murshidabad was primarily agriculture.

In Gobardanga, which is a municipal area, there are comparatively more affluent-class people, mix of service men and businessmen, with higher standards of education, as well.

The PHED played the key role in plant design and implementation at all the above sites. While in Gobardanga, the Gobardanga Municipality was apprised of its plants, in Bakharpur, the local panchayat was informed of the same. The respondents of Jhaudia were not sure whether the panchayat was involved at any stage of the installation process in their village or not.

Choice of location

This was a joint decision in Gobardanga (PHED & the Municipal authorities) and Jhaudia (PHED and some influential villagers, e.g., schoolteacher). However it was solely the decision of PHED in Bakharpur.

Treated water usage – in Bakharpur, there are three standpoints supplying the treated water from the plant, while in Jhaudia, there is only one. In Gobardanga, where about 60 – 70,000 litre of water is supplied per day, most of the respondents we spoke to, said they availed of this water. They used this water both for drinking, as well as cooking purpose.

Usage is limited in both Malda and Murshidabad for the following reasons:

(i) Irregular water supply

(ii) Inadequate flow of water

(iii) Presence of impurities, e.g., worms etc.(Jhaudia)

Moreover, since this water is available only during certain fixed hours (usually, 10 – 11.30 A.M. and 4 – 5 P.M.); this results in long queues, which act as a disincentive to drawing water from it.

Thus, we found only seven – eight families regularly using water from one tap in Bakharpur and around fifteen from the lone tap in Jhaudia. In the tail – end village of Masimpur, the water is available for only two hours a day – this creates a lot of pressure on the four taps supplying it. Thus, majority of the respondents avoids it, preferring to avail water from their own tubwell for drinking and cooking purposes. The few, who do avail it, use it only for drinking purpose. In most places, pond water was used for cleaning and washing purposes

Perceptions about treated water:

- Light water
- White water
- Not as tasty as regular tube well water

However, respondents were aware that tap water is free from arsenic. Moreover, the users pointed out that it has helped them get rid of common stomach problems (e.g. gas acidity etc.)

Plant O & M

These community plants require chemical closing, of which the respondents were unaware. However, we came to know of the following chemical dosing from the plant caretakers two of the sites:

i) Gobardanga – Potassium permanganate, bleaching powder and alum – daily basis.
ii) Bakharpur - Ferric chloride, bleaching powder

Caretakers have been appointed by PHED to take care of the respective plants. Apart from chemical dosing, they carry out plant back wash, usually once a week. Moreover, the Bakharpur caretaker claimed to collect water samples for periodic (usually, once a month) quality checks at the PHED lab in Malda. Chemicals required are supplied by PHED itself.

Waste water / Sludge disposal

The sludge is being stored in confined containers. It is proposed to be disposed by absorption through common aquatic plants, or cement based stabilization process.

Costs:

The entire installation, as well as maintenance costs, are borne by PHED. When we asked the respondents whether they would be willing to contribute towards its maintenance, several replied what they wouldn't mind pay Rs.1/- per month towards this end. However, they were categorical that for this to materialize, the following conditions will have to be fulfilled:

i) The water supplied must be 'clean'and free of impurities
ii) Regularity of supply should be ensured and quantum should be increase
iii) More number of taps should be set up, even deep into villages and spread out, so as to reduce the pressure per tap.

CONCLUSION

While PHED's forays into developing long-term solutions for the arsenic menace are commendable, the following needs to be noted:

i) Side by side with the Piped Water Supply Schemes, smaller and low cost projects, e.g., ARP attached to hand pump need to be further popularized, to provide immediate relief to the suffering population.

ii) Community involvement is absent at all the sites – for their success, PHED has to involve the community members at all the relevant stages- planning, implementation and maintenance. This will help to portray a friendly, human face of the Department, which is sadly missing at present. Towards this end, it would make sense to make the units more user-friendly, so that the O & M aspects can easily be taken care of by the local caretakers.

COMPARATIVE ASSESSMENT OF VARIOUS ARSENIC REMOVAL TECHNOLOGIES

COMMUNITY

AGENCY / DESIGNER		SITE	STATUS	NO.OF FAMILIES USING	LEVEL OF ACCEPTANCE / SATISFACTION	COMMUNITY PARTICIPATION	CONTRI-BUTION		REMARKS
						COMMITE	O & M		
1.	AIIH & pH	SANDRA PAR	WORKING	18	LOW & DECLINING	EXISTS	FEMALE CARETA-KER LOOKS AFTER O & M	18 FAMILIS	NIL
2.	DO	GAIGH-ATA	NOT WORKING						COMMUNITY PARTICIPATION WAS NEVER INITIATED
3.	DO	BETAI	WORKING	24	MODERATE	EXISTS	1 LOCAL YOUTH APPOIN-TED AS CARE TAKER LOOKS AFTER O & M	24 FAMILIES CONTRIBU-TE, BUT IRREGULARLY	
4.	PAL TROCKNER	SHER PUR	WORKING	100	HIGH	ON PROCESS			

AGENCY / DESIGNER		SITE	STATUS	NO. OF FAMILIES USING	LEVEL OF ACCEPTANCE / SATISFACTION	COMMU-NITY PARTICIPATION	CONTRI-BUTION		REMARKS
						COMMITTE	O & M		
5	PAL TROCKNER	MOYNA	NOT WORKING	2	DIFFICULT TO ASSESS				COMMUNITY PARTICIPATION NEVER INITIATED.
6	B.E . COLLEGE	SADPUR	WORKING	300 +	HIGH	COMMITTE EXISTS & FUNCTIO-NING SMOOTHLY	2 CARE TAKERS WORK IN SHIFTS TO DISCHARGE O & M DUTIES	300 FAMILIES CONTRIBUTE MEMBERSHIP FEE: RS.25/- MONTHLY SUBSCRIPTION : RS. 15/-	
7	DO	SANG RAMPUR	WORKING	200 +	MODERATE	FORMED, BUT NOT FUNCTIONING PROPERLY	2 CARE TAKERE APPOINTED		ILL-MAINTAINED UNIT LEADING TO USER DISSATISFACTION
8	DO	BETAI	WORKING	120	HIGH	EXISTS	LOCAL SHOPKEEPER ACTS AS CARE TAKER	REGULAR USERS PAY MONTHLY SUBSCRIPTION @ RS.5/- 75 CASUAL USERS:50 P/ BUCKET	

AGENCY / DESIGNER		SITE	STATUS	NO. OF FAMILIES USING	LEVEL OF ACCEPTANCE / SATISFACTION	COMMUNITY PARTICIPATION	CONTRIBUTION		REMARKS
						COMMITTEE	O & M		
9.	APYRON	SHIBALAY	WORKING	2	LOW				DUE TO LOCATION ALL DISADVANTAGE (PVT. PREMISE), POOR ACCEPTANCE
10	DO	ADAHATA	WORKING	60	HIGH				
11	PHED	GOBAR DANGA	WORKING	WATER SUPPLIED TO 8	MODERATE				ACTUAL NO DIFFICULT TO ASSESS, SINCE ITS PIPED WATER SUPPLY

				WARDS					SCHEME
12	DO	SUJAPUR	WORKING	NOT KNOWN	MODE RATE				SAME ABOVE
13	DO	JHAUDIA	WORKING	15 – 20	MODE RATE				
14	W.S.I	JOYPUR	WORKING	100	MODE RATE, PICKING UP				
15	ION EXCHANGE	NONA GHATA	WORKING	50 – 60	MODE RATE		LOCAL VILLAGER APPOINTED AS CARETAKER,O & M DUTIES SUPERVISED BY COMP-ANY PERSONNEL		

NOTE: FOR 10, 11,12,13 & 15 - O & M TAKEN CARE OF BY THE iMPLEMENTING AGENCY.

COMPARATIVE ASSESSMENT OF VARIOUS ARSENIC REMOVAL TECHNOLOIES

DOMESTIC

Sr. No.	Agency/ Dealer	No. of units Installed	District	Level of acceptance	Remarks
1.	Paul Trockner	15	S-24 Pgs	Initially High, Gradually Decreasing	Leakage in the body and facing problem for back washing
2.	B.ECollege(Amal)	15	Malda, Murshida-bad and N-24 Pgs	High	Easy to operate compact and light
3.	AIIH & PH	15	N-24 Pgs	Initially High Gradually decreasing	Daily dosing is a major problem
4.	Jadavpur University	16	N-24 Pgs	Do	Weak supply chain for ,Filter reagent, Chemical etc.

MARKETING ISSUES

All the major companies manufacturing ARPs are primarily banking on the government, specifically, the PHED, for bulk orders for their community plants. At present, four of them, viz, Pal Trockner, Apyron, WSI and Amal (B.E. College) have procured trial orders as part of the Arsenic Mitigation Joint Action Programme of PHED and UNICEF. Besides, they expect to participate in the India-Canada Environment Facility - AIIH&PH sponsored Arsenic Mitigation Programme launched recently.

Moreover, Pal Trockner and Apyron claim to be successful in marketing their ARPs in Bangladesh, which, according to both, offers better potential, primarily due to its government's accordance of priority to the arsenic menace.

Pal Trockner seems to be the only aggressive player as far as the community-based ARPs are concerned. They have tied up with West Bengal Agro Industries Corporation (W.B. Government Undertaking) to market their community-based ARPs. In collaboration with the Zilla Parishad, the latter are in the process of installing 95 ARPs in Murshidabad, all of which are being supplied by Pal Trockner. One such test unit has already been set up in Beldanga, the water quality test results of which have so far been satisfactory. Pal Trockner will provide training facilities to the Corporation's personnel, as well as local beneficiaries. Once a certain number of units are installed, the Corporation plans to appoint a supervisor to provide the necessary services. Since the Corporation has offices and personnel (e.g., mechanics) in every district, this network can be effectively utilized to provide servicing support to the ARPs set up. Pal Trockner also plans to contact individual PHE Departments at the district level, which may be interested to install ARPs in their arsenic-affected blocks.

As part of their promotional exercise, Pal Trockner demonstrates their units (both community and domestic filters) at important fairs, exhibitions and seminars. E.g., it had taken up a stall to demonstrate their units at the Krishi Mela organized by Ramakrishna Mission, Narendrapur. It plans to take up mass media advertising - T.V. / Newspaper / Outdoor / Cinema slides, etc. to spread awareness about its products.

On the domestic filter front, marketing activities are evident for AMAL, the filter developed by B.E. College and whose patent has been handed over to Oxide India (Durgapur), which is solely responsible for its manufacture and marketing. Oxide India has appointed dealers in Malda and Bahrampore (Murshidabad) for selling these domestic filters. These filters are sold at Rs.2, 400/-, of which the dealer gets a commission of Rs.600/- (25%). Dealers' Meets are organised at Durgapur every two months. According to Mr. Gautam Biswas of Oxide India, the Malda dealer has displayed good performance so far.

When contacted, the Malda dealer claimed to have sold around 200 units so far. He is confident of selling 100 units per month, provided he gets adequate support from the company (no supply bottleneck, suitable credit facility, etc.)
He further claimed to get good response from demonstrations given by him at various fairs and workshops, e.g., those of Indian Medical Association and Vigyan Manch. His customers include businessmen (e.g., silk exporters), school teachers and government staff, mostly semi-urban and predominantly of Muslim origin.

At the time of installation, he trains his customers how to backwash the unit, which he advises them to do once a month and dispose the waste water in a sanitary pit. Customers are advised to check the treated water for arsenic after two years and if required, the media is replaced at Rs.350/-. Apart from this, the media is sent for regeneration to Durgapur after every eight months, when a loan media is provided to the customer.

The dealer seemed to share a good rapport with his customers, to whom he provides free service for a period of two years. He provides installment facilities to certain customers at his own risk and discretion. As part of his sales activities, he pays visits to schools, banks, shops, doctors' chambers and homes, gives demos, explains benefits of the filter and then closes the deal.

However, there are no leaflets provided to potential or actual customers.

Promotional Activities

Advertisements in Cable T.V.(urban areas) and participation in fairs and sponsorship of Sports events (rural areas). Oxide India and its dealers share these costs. According to its Malda dealer, awareness about arsenic and its ill-effects are on the rise, people solicit information / make telephonic inquiries.

Marketing opportunities

- Widespread arsenic contamination in eight districts of West Bengal , fuelling greater awareness about the menace

- Media attention that the arsenic issue is receiving leading to heightened awareness and concern about the issue

- Absence of any worthwhile medical treatment –therefore, drinking arsenic - free water is the only alternative to prevent/check its contamination

- Both governmental agencies, as well as several NGOs, active in this field – hence, need for mitigation all the more felt now

- Pockets of high arsenic contamination, with presence of sizeable number of patients, are demanding mitigation measures with immediate effect

Marketing Constraints

- Awareness of the various ARP options itself is low and confined to pockets where they have been set up, mostly on an experimental basis

- Costs of the ARPs act as a deterrent, particularly of the community – based ones; even in the case of the household filters, its mostly the well – off who can afford them

- Lack of marketing network of the companies in operation - most banking on PHED or Unicef to place orders, hence displaying little initiative to explore alternate options

- Lack of experience in rural marketing often acts as a hindrance

- The technologies being still new, several loose ends need to be addressed -primary among them being the issue of safe sludge disposal, so as not to create any environmental pollution

- Lack of service back-up evident – it's a classic case of chicken and egg, where the companies seem to be waiting for the orders to come in, before they set up their service network in place

However, for long-term sustainability, **the need for community participation,** especially in matters of plant O & M cannot be over – emphasized. Hence, thought needs to be devoted in terms of:

(a) Community mobilization for making them positively disposed towards the ARP options.

(b) Plant selection/installation with the active participation of the community based on their informed choice

(c) Entrusting responsibility for plant O & M to the community, both in terms of carrying out maintenance work, as well as mobilizing them to generate resources for the same.
A comprehensive Training Module needs to be worked out for community members, who can subsequently take on the task of plant maintenance. An Operation Manual is a must for these caretakers, to help them in their day – to – day discharge of duties.

A committee would also have to be formed at each site with full financial responsibilities - it would be its task to mobilize resources for plant O & M keep an account of it and spending on necessary repairs, etc.

Only if the marketing agency is able to instill a sense of ownership among the community members who are benefiting from the installation of an ARP, will it prove to be self – sustaining in the long run.

The companies can also explore the following:

- Establish linkages with key stakeholders, e.g., the Panchayat representatives and various NGOs, who could be potential customers

- Sales promotional activities – e.g., participation in fairs, exhibitions, seminars etc., here they could set up demonstration–cum-sales counters; IEC materials (leaflets, handbills, etc)could also be distributed from these outlets

- Product advertising – mass media options like radio, cable T.V. (where feasible) and outdoor (banner, hoarding etc.) can be thought of to spread product awareness and generate interest in the same; moreover, folk media can also be effectively utilized forwards the same end

- In the case of domestic filters, **the Sanitary Marts** present at the block level can also be roped in to act as 'Retail Outlets'; they can take care of not only sales, but also the service aspect – e.g., they may enter into an **Annual Maintenance Contract** for a year or so with the customer, against a token charge. This charge can not only take care of repairs, etc., but also the cost of conducting periodic water quality tests, which is a strong felt need for the household filter users. They will also have to offer **the facility of media replacement,** once it gets exhausted.

- Tap the corporate sector to sponsor ARP costs- several companies, keen to project a socially positive image, may be interested to fund filters (community or domestic) in arsenic – prone areas and thereby, draw mileage from it as doing their bit for society.

- Innovative marketing schemes tailor made for the rural sector – e.g., easy EMI facility, shared – filter concept (where several adjacent households share water from a particular filter, the costs of which get distributed) and may be, even supplying treated water from community ARPs to remote areas on van, etc. and charge an amount for the same.

Along with all these, one also needs to mention that the companies must engage in continuous R & D in order to make their products:

a) **more user – friendly**
b) **more cost – effective**
c) **more environment-friendly**

TRAINING ISSUES

a) Training Institute

The following institutes were contacted which are either already involved in the Arsenic Mitigation Process, or could play a role in it:

- All India Institute of Hygiene and Public Health, Kolkata is an institute of repute. It has both the manpower and the infrastructure to impart training and provide technical assistance. At present, it is collaborating with UNICEF to impart training (technical aspects) on arsenic related aspects. It is also collaborating with India-Canadian Environmental Fund (ICEF) to implement an arsenic mitigation project in West-Bengal.

- The Technical Teachers' Training Institute has been set up by the Ministry of Human Resource Development. It has a network of polytechnics spread across West-Bengal. It conducts various training programs for people working at the grass-root level. At present, the institute is responsible for executing the training aspects of PHED's arsenic Project. As a part of it, it is collecting water samples and sending them for testing at PHED labs.

- Ramakrishna Mission Lokasiksha Parishad, Narendrapur, is a renowned organisation. It has the human resource and infrastructure to conduct training on arsenic related issues. Ramakrishna Mission has also implemented an arsenic mitigation project funded by the World Bank in North and South 24 Parganas. It is also in the process of developing a low-cost domestic arsenic removal filter. It has a wide network of village clubs, who is actively involve in social and cultural activities, throughout the state. At present, one of its branches in Murshidabad is engaged in identifying the handpumps which are delivering arsenic contaminated water.

- Society for Equitable Voluntary Action is an NGO mainly working in North 24 Parganas and Birbhum. It has qualified personnel and infrastructure to organize training on the arsenic issue. It has set up a laboratory at Atghara, North 24 Parganas to conduct water quality test. At present, it has launched an awareness programme on arsenic contamination.

- Mass Education is an NGO, which is correctly working in about five districts. It is also collaborating with Calcutta Municipal Corporation in the disposal of clinical waste from hospitals and garbage clearance. It has the infrastructure to organize training on arsenic related issues. The strength of the organization is that it has a wide network of Self Help Group, which can be harnessed to spread the awareness about arsenic related issues.

- Economic Rural Development Societies is an NGO, working in three districts of West-Bengal - South 24 Parganas, South Dinajpur and Malda. In Malda, it has a very good infrastructure to organize training. It has also set up Sanitary Marts in three blocks in Malda with the support of UNICEF. It has also organized an awareness campaign on arsenic contamination in Malda with the support from WATERAID. It is also implementing other developmental activities.

b) Training **For Sustainable ARP Management**

ARPS have been installed in many villages in West Bengal. **The Consulting Team during its field visits felt that hardly anything has been done to motivate and educate the communities on sustainable management of the ARPs**. With this as the issue, the training objective would be to:

Ensure long term sustainability in use of ARPs

The proponent of the Plants will have to appoint an experienced and qualified Training Consultant to take on the task of training on their behalf, specifically for the non-technical aspects.

The first step for the proponents would be to constitute a committee of users, which would be handed over the management of the plants. Persons with the following qualities need to be involved in the committee:

- Enthusiasm and motivation
- Leadership
- Demonstrated capabilities and commitment towards community organization
- Willingness to devote time for the project
- Basic literacy

Steps in Training

It is felt that, the following steps would be necessary for a successful training program aiming at sustainability:

1. **Process oriented participatory training** : The committee that would be formed will be trained in this, so as to involve people, specifically the users, again rapport, act as advocates for use of arsenic free water, overall operational aspects of the plants, contribution for operation and maintenance (payment for caretaker will also form a part of this), monitoring of smooth operation of the plant, etc.

2. **Training for overall IEC:** The committee will be responsible for generating awareness among the people that would included issues such as:

   i. dangers of drinking arsenic contaminated water
   ii. benefits of drinking ARP treated water
   iii. proper use of plant to ensure longevity
   iv. need for maintenance & contribution for the same

3. **Technical training:** This will be meant for the caretakers specifically and will include the following:

   i. all processes involved in the functioning of the plant
   ii. parts of the plants, wear & tear of the same, availability of spare parts, costs involved
   iii. operational methods regarding day to day effective running of the plant, for instance chemical dosing where required
   iv. proper maintenance of plant - backwash method, safe disposal of waste water & sludge, minor repairs (e.g. changing washer), networking for major and other repairs for which local support not available
   v. Water quality surveillance - testing of water samples for relevant quality tests with field kits

4. **Financial Management:** Maintain accounts of contributions collected, expenditure on maintenance, banking transactions, etc.

Training Manual and Operational Manual will be prepared in simple language with pictorial representation of the processes.

Overall monitoring the training program and its effectiveness, an external monitoring agency may be appointed. Initially, quarterly reports (first year) and later biannual reports (2nd & 3rd year) and annually (4th , 5th and 6th year). This is in consideration of the fact that a plant needs replacement of the media, after a stipulated period of time, which would involve resource mobilization.

CONTROL VILLAGES

The following villages, known to be in the arsenic –risk zone, but with no mitigation intervention, were chosen for the purpose of the study:

1. Gharamipara (Baruipur block of South 24 Parganas)
2. Mollapara, Surjapur (do)
3. Baikanthapur (Rajpur - Sonarpur Municipality)

While the first and third were predominantly Hindu, the second one had a Muslim majority population. The occupation profile of most of the respondents in the first two villages was small and marginal farmers, daily labour and petty traders, that of the third was mostly a mix of servicemen, business men and traders.

Most of the respondents were aware of arsenic, mainly due to initiatives taken by Jadavpur University and Vigyan Manch to carry out water quality tests in their area. These tests have established the presence of arsenic in several tubewells at the first sites, and some tubewells in the third. Moreover, some educated people of the suburban area of Baikanthapur had actually carried water quality samples of their private tubewells to RKMLSP for arsenic testing (they had come to know of this facility from a staff of the organization residing in their area).

The level of concern was generally high in the first two villages, while it was largely restricted to the educated people in the third. This was mainly because Jadavpur University has carried out extensive water quality tests in the first two, whereas those of Vigyan Manch were not so. Moreover, people are aware of arsenic induced deaths in Gharamipara – they mentioned that about sixteen patients had died in and around their village. At present, they believe there are about a dozen patients in their village, of whom two male patients were present in the FGD. Similarly, in Mollapara, three male patients were present in the FGD.No patients were present at Baikanthapur FGD.

These patients, as well as the other respondents, were quite concerned about their state of health. In Gharamipara, they avail drinking water from a deep tube well, which has been identified as arsenic – free by J.U, as also from the taps of the Piped Water Supply Scheme of the region. Similarly, in Mollapara, they try to avail water from a deep tubewell situated in their market place. However, some women pointed out that it becomes a bit difficult to collect water from this particular tubewell, since it is situated at a distance from their homes. Moreover being in the midst of a market place, women feel uncomfortable to fetch water from here. In Baikanthapur, respondents mainly depend on the Piped Water Supply Scheme for drinking water.

However, most of the respondents at all three sites indicated preference for their private tubewell water for cooking purpose. This was chiefly due to:

(a) "it is difficult to fetch such a large quantity of water from the deep tubewells".
(b) Some respondents are of the opinion that since the water gets boiled during cooking, it gets rid of arsenic, as well.

Some of the patients at both the sites mentioned that they visit SSKM Hospital in Calcutta for treatment purpose. Hair and nail samples were collected to detect arsenicosis. The doctors, thereafter, advised them to drink arsenic – free water. On doing so, they feel that the spots on their bodies have reduced. Besides, a local NGO, Antoday Surya Sangha has been distributing some protein –rich food to these patients, for which they are grateful to it.

Community Based
Arsenic Removal Plant
(Hand pump attached model)
Marketed by :
PAL Trochner

Amal Domestic Arsenic Removal Filter
Developed by B.E. College, Shibpur, Howrah


COMMUNITY TYPE
Arsenic Removal Plant
Handpump attached model
Developed by :
AIIH&PH, Calcutta

Report on Financial Appraisal of Action Programmes on Alternate Technologies

Prepared under the Project

Concerted Action on Elimination/Reduction of Arsenic in Ground Water, West Bengal, India

Prepared by: K S R N Sarma

Executed by: United Nations Industrial Development Organization

New Delhi
AUGUST, 2001

Concerted Action on Elimination/ Reduction of Arsenic in Ground Water, West Bengal, India (Volume II)

Contributions:

Don Ratanayaka- Water treatment and Technology.

CGWB (Easter Region) – Water Quality Analytical work.

Development Consultant Group – Socio-economic, Training & Privatization issues.

K S R N Sarma – Financial Appraisal

Financial Appraisal of Action Programmes based on Alternative Technologies

Introduction

The quality aspects of community water supply schemes in India have of late received considerable attention of the policy planners at the National as well as at State levels. Urgency is felt for major initiatives in the matter, particularly for maintaining the desired quality standards in rural water supply schemes as recent investigations revealed increasing contamination of their principal source viz. ground water in many parts of the country. The levels of toxics in ground water such as arsenic, fluoride, salinity and iron are observed to be going up at alarming rates. Search is on to find appropriate technologies to control and minimize their adverse impacts. A case in point is the efforts initiated in recent years by the Government of West Bengal to combat the problems posed by the high levels of arsenic found in ground water in wide tracts spread over as many as eight districts viz. Malda, Murshidabad, Nadia, North 24 Paraganas, South 24 Paraganas, Hugli, Haora, and Bardhaman. Action programmes were initiated for provision of arsenic free water for domestic use on three planks (i) Digging deep tube wells to tap arsenic free aquifers at depths and pump that water to reach the domestic clients (mostly through public stand posts). (ii) Installing Arsenic Removal Plants (ARPs) at community hand pumps (iii) Encouraging the households to purchase and use Domestic Arsenic Removal Filters (DARFs) Under strategy planks (ii) and(iii), a number of arsenic removal technologies are being tried at selected locations on experimental basis. Need is generally felt for having an objective assessment of the approaches and technologies to help the choices in their regard for formulation of perspective plan for future development. Hence the genesis of the UNIDO aided project on 'Concerted Action on Elimination/Reduction of Arsenic in Ground Water – West Bengal, India'. The terms of reference of the project required, inter alia evaluation of present action programmes from a number of techno-engineering and other angles. Present study is part of those evaluations. It is focused mainly on aspects relating to finance. The first part of study attempted to determine the costs of provision of arsenic free water using different technologies under different strategy planks and in the second the scope for cost-recovery under alternative action programmes is discussed.

The setting

The Experts Committee Constituted by the Government of West Bengal in 1992 (Chairman : Dr S.P. Sinha Ray) to investigate into the problem of arsenic contamination of ground water, found that the tracts affected in the above mentioned eight districts covered in all 3113 rural habitations (1312 Mouzas), 15 non-municipal areas and 9 municipalities. The population living in these areas, according to the 1991 Census, is 12.6 million and of whom 92 percent are from the rural habitations. Further it is observed that and out of the above population, 5.32 million are highly exposed to health risks such as arsenicosis. It may be pertinent to mention here that from the First Five-Year Plan on wards, extension of safe water facilities in the rural areas has been one of the priority thrusts of development efforts in the country. Towards that end two major schemes have been in operation in the state quite for some time now. These are; State sector's Minimum Needs Programme and Central Government-sponsored, Accelerated Rural Water Supply Scheme. Emphasis under these schemes all along has been on physical extension of coverage. Quality aspects till recently, however, do not seem to have received due attention. Ground water is generally assumed to be a safe and hand pump, because of its low capital investment requirement, has been adopted as the principal vehicle. Even so, the progress of rural water schemes is generally found to be very slow. Till the end of November 2000, only 74 percent of the rural habitations in West Bengal could be fully covered under community water supply facilities and rest 26 percent were only partially covered. The accomplishments compare poorly even with All India Averages. The observed positions with regard to the latter are 84.5percent fully covered villages; 13.7percent partially covered; and 1.7 percent non-covered under community water schemes. Efforts, therefore, need to be considerably stepped up. Now a double urgency in the matter has arisen with the investigations revealing contamination of ground water. In shaping the future plans two factors may, however, be given due cognisance. First is that huge investments have already been made in setting up hand pumps/ tube wells in the affected areas, they may not be discarded without exploring fully all the alternatives for their continued usage. Second is the predominance of small size rural habitations in West-Bengal. According to the 1991 Census, 35,54% of rural habitations in the state have population less than 500; 24.34% have population in the range of 500-999; and 21.22% have population in the range of 1000-1999. (vide Table 1 in Appendix A)An inference that could be drawn from this position is that at least some time to come, the hand pumps may still have to be relied upon for extension of water supply facilities to the rural habitants. While still on the subject of role of hand pumps, some interesting observations in their regard from the recent report of National Sample Survey may be stated. First is that 78.42 percent of rural households in the state of West Bengal depend upon hand pump/tube well, as the principal source for meeting their drinking water requirements (column 13 of Table 2 in Appendix A). Out of these households 72 percent draw their daily water from the hand pump/tube well located outside their residential premises (community facility). The second observation is that 70.5 percent of households that relied on hand pump/tube well for meeting their drinking water requirements draw water from that source for cooking as well. However, for bathing and washing utensils, majority of rural households in the state are observed to prefer local tank and pond water. (Table 3 in Appendix A). A third observation is that a very few households are found to filter, chemically treat or boil their drinking water. (Table 4 in Appendix A). An inference that could be drawn from these findings is that, since ground water drawn through hand pump is used by the households primarily for purposes of drinking and cooking only, the state government is advised to go about in establishing the facilities for arsenic removal from ground water in phased manner. .In the initial phase the treatment facilities may be installed on a limited scale. to supply 40 litres of arsenic free water to household per day. This should suffice to meet its requirement for drinking and cooking.

Deep Tube Wells:

Digging deep tube wells is one of the options that could be pursued for provision of arsenic free water to the domestic users. Some strongly recommend the proposition on two counts. First is that it would facilitate the provision of water to large number of clients from a single location and this in turn, helps inter alia, to keep a close tab on the quality of service provided Second is that since water is supplied with some pressure, the clients need not have to wait for long duration in a queue to collect their daily requirements. As against these advantages claimed, there are many arguments advanced against the proposition. Foremost is that it would involves huge capital investments. From the data given in col 8 of table in Appendix B, it may be seen that the installation of a deep tube well calls for an initial investment of about Rs1.1 million. A unit can serve about 10-12 thousand population. The capital investments work out to Rs.9000-10000 per capita. In case all the hand pumps in the arsenic affected areas are to be replaced by the piped water supply from deep wells, the capital investments required would be of the order of Rs12600 million. It is highly doubtful whether the state government would be in a position to mobilize funds of this order to a sectoral programme and that too, to the one intended to benefit 7.8 percent of State's population. Even one were to assume that funds of such high order would some how be mobilized, it might take years to execute piped water schemes and commission them. A major hurdle here is locating the aquifers of adequate size at central locations. It may be seen from Col.7 of the table under reference, that out of the eight deep tube wells covered in the sample study, only in the case of three the water supplied is observed to meet the per capita norm of 40 litres per day. In the case of three viz, Kantanagar, Mithipur and Chhaygham, the per capita daily supplies are observed to be as low as 6.7 litres, 14.00 litres and 16.38 litres respectively. Progress in the execution of deep wells could be tardy also on account of the lengthy procedures that are to be usually to be followed in the execution of large civil works, non -cooperation from contractors etc. Here it may be mentioned, that against an allocation of Rs.700 million proposed for the rural water supply under the State's MNP for the year 2000-2001, the amounts released were only Rs 379.987 million and expenditure actually incurred was Rs.304.056 million (i.e. 35% of the allocation). Similarly under the Accelerated Rural Water Supply Scheme of the State, as against an allocation of Rs.789.5 million up to the end of 2000, expenditure incurred was just Rs 260.162 million (32.95% of allocation)*

A frequent complaint against the piped water supply schemes of the rural areas is that the villages at the tail end of the systems hardly get any water. Electricity/ Diesel, required to run the motors to pump the water are items that are often in short supply. Whenever there is a disruption in their availability, water supply gets affected. Irregular supply is another frequent complaint against several piped water supply schemes.

Now the examination may be turned to compare the costs under each of the 8 deep tube wells covered in the sample study. The expenditure (costs) presently incurred for providing 100 litres of water are given in column 15 of the table. It may be seen that the amounts vary from 0.86 in the case of Natra unit to Rs 7.27 in the case Kanta nagar unit. The monthly charges that a household has full cost recovery are given in column 18 of the table. The lowest amount is Rs74.75 in the case of Natna Unit and the highest is Rs245.01 in the case of Iswarachandrapur.

A proposal under the Central government sponsored Accelerated Rural Water Scheme, is that water charges may be so fixed as to recover from the direct beneficiaries only 10% of the capital costs and full amount of the O & M expenditures. The charges that households have to pay as per this proposal are given in Col. 19 of the table. These again are found to vary considerably across the units. The lowest is Rs 10.91 in the case of Natna unit and the highest is Rs.48.41in the case of Iswarachandrapur unit.

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*Annual Administrative Report, Min of Rural Development, Govt. of India. 2000.

Community Arsenic Removal Plants (ARP)

The strategy of installing ARP at the community hand pump for provision of arsenic free water is strongly advocated on the ground that it involves relatively very low initial (capital) investment (say in comparison to the amount required for digging a deep tube well). As already explained in the earlier paragraph, considerable investments have already been made in setting up community hand pumps, and most rural households in the State are observed to be drawing water from them for meeting their drinking and cooking requirements. Additional investments that are required are only for the acquisition of ARPs and their installations. Another advantage of the proposition is that the installation and commissioning of ARPs do not take much time and so the benefit-flows from the investments are almost immediate. The operation of community ARP does not require high technical skills and the community volunteers could be trained to perform the tasks of a caretaker. This incidentally would save a lot of botheration to the government in appointing personnel, paying their salaries supervising their work etc. The beneficiary communities could be easily persuaded to take over the responsibilities of eventual operation and maintenance. As against these advantages, one major problem anticipated is the conducting of periodic quality control inspections. Then there is the need for arrangements to attend to the repairs etc. Thus even in the event of concerned community agreeing to take over the routine operation responsibilities of their of ARP, government would still be duty bound to maintain a well equipped water testing laboratories, appoint Inspectors to conduct the regular quality control checks and Mechanics to attend to the repairs.

Now we may proceed to the estimation of costs of provision of arsenic free water from ARP plants employing different technologies. The technologies that are being put on test at present are (i) Amal (Bengal Engineering College), (ii) Paltrockner (iii) WSI (iv) Apyron (v) Ion Exchange (vi) AIIH&PH and (vii) PHED. With a view to facilitate the comparisons two uniform norms have been adopted. First is cost per 100 litres of supply and the second is the costs of provision of a minimum of 40 litres of arsenic free water per day to a family. As already explained earlier, a supply of 40 litres per day should be adequate to meet a family's need for water for drinking and cooking. It is assumed that an ARP plant would be installed to serve 50 families only, so that they are ensured of above mentioned quantity of supply and also could easily be organized into water committees to look after their ARP. The details of estimation of costs** under different scenarios are given in the Tables 1-7 in Appendix C. Table8 of the Appendix C gives a comparative picture of unit-costs and also the monthly charges that a client household has to pay for availing 40 litres per day of arsenic free water. From column14 of that table it may be seen that lowest cost per 100 litres of supply is Rs 3.75 in case of Amal unit and the highest is Rs29.10 in the case of Apyron unit. The monthly charges that a household has to pay for availing daily 40 litres of arsenic free water are given in col 11 . Here again the lowest is Rs45.05 in the case of Amal unit and the highest is Rs 350.94 in the case of Apyron unit. When the expenditures on account of capital component and replenihment are born by government the monthly charges are observed to come down significantly as could be seen from col 12. Here the lowest is Rs23.35 in case of Amal unit and the highest is Rs 144.68 in the case of Apyron unit. The charges that households have to pay in the event of their community organisations taking over the responsibilities for routine operations are given in col13. The lowest charge Rs8.34 is in the case of Amal unit and the highest Rs39.95 in case of Ion Exchange unit.

Domestic Arsenic Removal Filters (DARF)

The strategy that emphasize the use of domestic filters by the households for obtaining arsenic free water is quite different from the earlier discussed deep tube well and ARP strategies. It is 'household' centered, where as the other two are based on the `community' approach. It expects the market-forces to play a major role in the realization of the objective set, whereas in the earlier mentioned strategy planks, the responsibility for effectuation of the objective is assumed to be entirely that of the government. Under the domestic filters strategy the role envisaged to government is largely that of a facilitator. It of course, is expected shoulder

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**The assumptions made with regard to the `discounting' in cost calculations are as under.

i) In the case of capital expenditures the discount rate is 12 percent per annum.
ii) In the case of O&M expenditures the replenishment expenditure is incurred at the beginning of the year/period and in the case of other items of O & M the expenditures are incurred in the middle of the year. The discount rate applicable in their case is one percent per month /part of it.
iii) Costs of stoppage of service due to break downs, annual maintenance, sludge removal etc, are not taken into reckoning. Only a mention about them is made.

major responsibilities in regard to extension work among the potential purchasers of domestic filters-educating them about the advantages that could accrue to them from a domestic filter, helping them in conducting assessments about the technical efficiency, informing them about the prices of different models etc. The government is also expected to mobilize efforts on two other fronts. First is to encourage the entrepreneurs to set up manufacturing facilities for domestic filters and market them in large numbers. For, competition is the sure way to ensure the best value for money to the clients. The second is that the government may have to establish suitable regulatory mechanisms for conducting periodic tests and ensure the quality of water produced by domestic filters and that vendors of filters do fulfil all the obligations promises that they made as part after sales service..

Major advantage of the domestic filter is that a householder need not have to wait in a queue for long hours at a public stand post of deep tube well or community ARP unit to collect his/her daily requirement of water. The required arsenic free water could be collected from the filter whenever needed. The water from the household's own source i.e. hand pump/dug well could used as the input.

The biggest roadblock to the strategy, however, is making households to mobilize 3 to 4 thousand rupees for the purchase of a filter. Not that many of them do not have the required economic capacity, but the matter is more to do with their mind set -. willingness to spend that much of money on a water filter. Published data on household expenditures of `Below Poverty Line' families indicate that many among them purchase durable assets such as bicycle, colour T.V. wrist watch, radios and electric fan (Table 6 in Appendix D). It is true that all along rural households are accustomed to get free water supply from government facilities and it would not be easy for them to come out of that mind set. It would require considerable amount of extension work by government; voluntary agencies to convince them about the advantages that could accrue to them from `domestic filters'. The vendors may also have to adopt considerable amount of ingenuity in their marketing approaches. To help the poorest among the rural poor, government may consider giving them some price subsides or introduce loan schemes on easy terms. The past experience, however, indicates that in all such schemes, the best results are obtained when community based approach' is adopted rather than the ones that try to reach the subsidies/loans directly to the individuals. These approaches may preferably be further modified to meet location specific conditions.

At present domestic filters employing four different technologies are under experiment. These are filters developed by Bengal Engineering College (Amal), Paltrocknor, AIIH&PH and Jadavpur University. The total costs that a consumer has to bear during the economic life (5years) of a filter are worked out and given in Table 1 of Appendix D. The unit developed by the AIIH&PH is observed to be the cheapest.. But then one also has to take into consideration the cumbersome processes that its use involves. Many consumers may not like to use iton that count. This leaves the choice to other three. Here Amal filers seems to have gone in for aggressive marketing. It is reported that its agent viz Exide India has already sold a couple of hundreds of them. Most of its clients belong to the educated and economically better off sections of the society. The socio-economic profiles of the users of domestic filters of all the four makes based on sample surveys are given in tables 2 to 5 of Appendix D. It is observed that their average household size is 6.1; in the case of Hindu households it is 5.4 and in the case of Muslim households it is 6.8. Nearly 60 percent of the clients are high school and above educated. The average monthly income clients of Amal filters isRs10466.67; Paltroknor's clients is Rs7566.67; AIIH&PH's users is Rs4166.67 and that of the users of Jadavpur University filter is Rs2010. While Amal and AIIH & PH filters were sold to clients with no subsidy, the buyers of Paltrockner received a 50 percent subsidy and Jadavpur filters were supplied free of cost.

Cost comparisons over the three Strategy Planks

Two benchmarks have been adopted for purposes of inter strategy/plank cost comparisons. First is the capital investment required per client served and second is the cost per 100 litres of supply. As regards per client capital investments they are observed to be around Rs 1000 in the case deep tube wells. In the case of community ARP the per capita investments are observed to differ significantly over the technologies employed. The lowest figure Rs48 is in the case of AIIH&PH unit and the highest Rs 1312 is in the case of Apyron Unit (vide col 15 of table 8 of appendix C). The per capita investments in the case of domestic filters are also observed to differ significantly. In case of Amal it is around Rs 330; in the other cases they are -Paltrockner Rs 700 (10 litres)and Rs 900 (30 Litres); AIIH&PH Rs 10 and Jadavpur Rs 120. Turning to the cost per 100 litres of supply they are observed to range between Rs 0.86 to Rs 7.27 in the case of deep tube wells (average around Rs 2.63) The per 100 litres cost in the case of community ARP vary from Rs 3.75 in the case of Amal to Rs 29.25 in the case of Apyron. In the case of domestic filters the cost per 100litres is Amal Rs 5.80; Paltrockner Rs 9,26; AIIH&PH Rs 3.17 and Jadavpur University Rs 3.50.

Cost Recovery

It is held by many that for ensuring speedy and sustained development of a public service it is essential that full cost recovery is effected from its direct clients. An incidental advantage of the proposition is that it would help to improve efficiency and accountability in service delivery. In the case of a basic service such as water supply, it is generally agreed that tariff fixation has to take into cognizance not only revenue and efficiency objectives but also the equity aspects as well.. It is to be noted that the paramount consideration in provision of water supply under public auspices is to ensure that all sections of the population have a fair access to this essential service. Certain minimum quality and quantity of water are reached to all sections to help them to maintain good health and well being. No citizen is priced out from availing the socially desirable minimum level of service. All these would no doubt make the water supply tariff fixation an exacting exercise to accomplish. Delicate balancing may have to be arrived at to steer clear conflicting considerations. Once the level of tariffs to be recovered from the clients is estimated, then the next step is identify the right vehicle/s for revenue raising. These vehicles need chosen carefully to suit to the administrative convenience. A multi part differential tariff structure is therefore, generally suggested to be adopted. Such tariffs are relatively easy to adopt in an urban setting because the clients there comprise besides domestic users, industrial, commercial and institutional users with good paying capacities. Differential pricing and cross subsidization are not difficult to adopt in a rural setting because the clients of rural water supply schemes are all domestic users. The charges, have to be uniform and preferably in the from of periodic payment say monthly payment per family (irrespective of its economic status and the amount of water drawn). This being the framework, the moot point for consideration is how one could go about fixing the rural water supply tariffs.

The exercises here has to take into reckoning not only the costs of service provision, but also two other factors viz. `affordability' and `willingness to pay' of the clients. `Affordability' is the term associated with the clients' paying capacity and it is usually expressed as a certain percentage of the monthly income. It gives an idea of the amount that a client can easily spare for availing the service, without adversely affecting the consumption levels of other essential items. There are two major data sources that one could rely upon to for estimation of affordability' of clients. First is the data about poverty brought out by the Planning Commission. According to the recent estimations the poverty level applicable to the rural population of West Bengal is Rs 350.17 per capita per month in 1999-2000. The population below the poverty line in the state is 18.011 million and they constitute 31.85%of the total. Assuming that the average size of family to be 5,then all families with monthly income of Rs 1750.85 and below could be taken as poor. If one adopts this household income level as standard and assume 1.5 percent of it as the `affordability' level towards water supply service availed, then nearly 70 percent of rural households should be in a position to pay easily about Rs 26.per month towards that service.

The second data source that could be utilized for determining the affordability levels is the household expenditure data from the National Sample Survey. The data about per thousand distribution of rural households in the state of West Bengal according to their per-capita monthly expenditure classifications (compiled in 54th Round of NSS Jan-June 1998) are given in Table 1 in Appendix E. The tables2 &3 indicate the amounts that families in different expenditure classifications spend on such non-essential and health injuring items such as `pan', tobacco and intoxicants. Table2 gives the All India position and Table 3 gives the position in the case of rural household of West Bengal. From the data given in these tables one could take the families in per capita expenditure classification of Rs 265-300 as the representative ones (there are only 38% of the households which have per-capita expenditure levels below that level). The amounts that the families are observed to be spending on above mentioned non-essential items is Rs 10.62 per capita per month i.e. a family is spending about Rs 53 per month on these items. Even if we take half of it as the affordability level for the water supply service availed, then it again works out to Rs 26 per month. The families in the lowest per capita expenditure classification i.e. Rs 0-120 per month are observed to be spending on pan, tobacco and intoxicants about Rs 3.2 per capita per month i.e. Rs 16 per the family per month. From the above accounts one could safely assume, that `affordability' to pay for water supply even in the case of lower income classes of rural households in West Bengal is about Rs 16 per month.

Willingness to Pay:

The term 'Willingness to Pay' in the present context refers to the amounts that clients would be paying on their own voluntarily and not under any external pressure/ compulsion. Since water is basic human need, the demand for it for domestic use is highly price inelastic in certain quantity ranges. People would be readily paying very high prices for water when it has to be purchased from a private vendor, when there is apprehension about its short supply or discontinuation. But once the public authority ensures adequate level of service, then one often notices sea change in peoples' attitudes.. They demand the service as a matter of right and assume that government is duty bound to provide the service free of cost. It is these perceptions that have to be first changed for any cost recovery scheme to be successful. Fore most to be done is extensive education among water supply clients. Make people aware of the benefits that could accrue to them by consuming safe water and following hygienic waste disposal, the long-term consequences of subsidized provision of the service, low level of investments in the sector etc. Involving non-governmental agencies could be very effective in educating the clients. In addition there is a need to organize the local communities and get them involved in various stages of decision making, in planning execution and operation of water facilities in their respective localities. Informal associations and per functionary consultations might not be of much help. The committees of the clients should be formal bodies and they have to be bestowed suitable powers to take decisions about ways they would like to operate in maintaining their community water facility, finance its operations etc. One may emulate the example set-by Kerala with regard to the rural water supply schemes. The social surveys conducted in some of villages where the ARPs are installed throw valuable clues as how community organisations could be made to more effective. We cite the case of Nonaghata village (Nadia district) here to explain as how informal community organisations operate. This village is located in an area that is severely affected by the arsenic contamination of ground water. It is reported that there were more than 200 cases of arsenic affected people in that village. The local youth took initiative, made several representations to the higher authorities and finally got a community ARP of Ion Exchange technology located in their village. But once that unit is installed their enthusiasm seems to have waned. The company installed the Plant free of cost and is also presently meeting its O&M expenditure. It cannot be expected to do so in perpetuity. No thought seems been given at the time of Plant's installation as to who would take over the responsibility for its eventual operation and where from the finances required for it would be mobilized. This position may be compared with one obtaining in the three villages where the Amal plants are located. In these villages the NGOs who played major role in getting the ARP units installed, took care to involve the client communities right from the inception, in deciding about the location of the plant, who would look after the operation and maintenance and most importantly about the ways to finance the operations. The decisions with regard to financing and the charges to be collected from members were taken much before the plant's installation. The arrangements agreed to were on formal basis. In Sadhupur as many as 300 households are contributing to water collections from ARP at the rate of Rs 15 per month (to fully meet the O&M. Expenses of the plant). In Khaddar about 70 families are paying at the rate of Rs 0.50 per bucket and 34 families are paying monthly contributions to their Water Committee. The Water committees formed to run these plants take decisions not only in respect of water charges but also on matters such as appointment of care- takers and the salary to be paid to them. The arrangements are reported to be working fairly satisfactorily in the above mentioned places. The point for consideration, therefore, is when community organizations could be effective in above two villages, why not they made to be so in other villages.

Matching costs and water charges:

Working out affordability positions and putting institutional arrangements for collecting the revenues is only one part of the exercise, the second and equally important task is to match the costs with the charges that the clients could afford/willing to pay. This may entail some major policy decisions and exploring the ways by which the expenditures to be recovered from clients are brought down. Though one would not like the government to heavily subsidize the service, but since it has been providing the service all along almost free, the withdrawal of subsidies may be effected in a phased manner. This is necessary to control and minimize the political backlash. A major O&M expenditure in the case of community based ARPs is the one on periodic replenishment of the media. In the initial phase government may agree to bear capital as well as the replenishment expenditures. Staff salaries is another major item of O&M expenditure. Community volunteers could be trained to operate the systems and this would help to bring down the expenditure to be recovered through the charges still further. Another suggestion is that the dealers who get substantial margins from the manufacturers of the equipment for vending their wares may be persuaded to take care of some responsibilities with regard preventive maintenance for certain period after the sale. This also helps to lower the water charges.

Conclusion:

In conclusion some of the points emerging from the examinations in the foregoing may be briefly recapitulated. The estimations of costs of provision of arsenic free water indicate that they differ significantly not-only across the strategy planks, but also within the strategy planks according to the technology employed for the purpose of arsenic removal. Though cost is an important consideration, the perspective plans for extension of facilities for provision arsenic free water to the households in the affected areas cannot be guided by financial considerations alone. Equally important are the considerations with regard to reliability of the service technology, clients' convenience, and their willingness to pay. If one were to go by the funds needed for initial capital investments, the strategy of deep tube wells does not appear to be a proposition that can be pursued extensively. Apart from the difficulties in mobilizing the needed capital funds, it is not easy to locate the arsenic free aquifers of sufficient size to meet the requirements. Similarly the strategy of Domestic Filters may have to over come the major obstacle of clients' unwillingness to spend a large sum of Rs 3-5 thousand for the purchase of those units. It is learnt efforts are presently on to bring down the prices of the filters to less than Rs 1000. In that event, the strategy of domestic filters may prove to be the best among the alternatives. Till that time the reliance has to be placed mainly on community ARPs for provision of arsenic free water. In order to effect cost recoveries, a pre requisite is the setting up formal community organizations and entrusting them with the responsibilities of routine operation of the systems. In places where the community water committees are formally established and given the authority to operate the plant and effect the cost recoveries the arrangements are reported to be working satisfactorily. To encourage the committees to come forward to take up the responsibility, government may agree to bear in the initial years not-only the capital investments but also expenditures on account of replenishment of the media. The withdrawal of subsidies should done in phased manner. In the case ARP strategy, an average rural household in the state of West Bengal should in a position pay about Rs 26 per month for drawing its daily requirements of arsenic free water for drinking and cooking purposes.

APPENDIX – A

TABLE – 1 : Size classification of rural habitations in West Bengal – 1991 Census.

Size of the habitation	Number	Percentage
1	2	3
Below 500	13,474	35.54
500-999	9,227	24.34
1000-1999	-.8,065	21.27
2000-4999	-5,819	15.35
5,000-9,999	-1,117	2.95
10,000-19,999	-190	0.80
20,000-49,999	-17	0.05
50,000-99,999	-1	0
1,00,000 & above	0	100.0

TABLE – 2 : Per 1000 distribution of households having Principal sources of drinking water by distance from source

S. No	Principal source of drinking water	Within the dwelling	Outside dwelling but within the premises	Outside the premises at a distance of in K.m.						All households	Sample of households
				<0.2	0.2-0.5	0.5-1.0	1.0-1.6	>1.6	Non response		
1	2	3	4	5	6	7	8	9	10	11	12
1	Tap	181	97	654	62	5	-	-	-	1000	219 (4.12)
2	Tubewell/ hand pump	82	186	637	77	12	2	2	1	1000	4014 (75.76)
	Well	-	195	747	0	1	1	48	-	1000	965 (18.17)
4.	Tank/Pond reserved for drinking	-	43	620	-	-	-	336	-	1000	46 (0.86)
5	Other tank/Pond	-	107	196	-	-	-	697	-	1000	13 (0.24)
6	River/Canal/ lake	-	-	829	-	-	-	171	-	1000	10 (0.19)
7	Spring	-	-	822	178	-	-	-	-	1000	12 (0.13)
8	Tanker/other	-	-	831	169	-	-	-	-	1000	-
9	Other	-	709	291	-	-	-	-	-	1000	3 (0.06)
10	Non Response	-	61	891	-	-	-	-	-	-	30 (0.56)
11	All sources	70	181	659	63	9	2	15	1	1000	5312 (100.00)

Source: Sarvekshana, Vol.XXIII, No.3, 82nd Issue (Special) Jan.-March 2000, National Sample Survey Organisation, Ministry of Statistics & Programme implementation, Government of India, page S-119.

APPENDIX – A

TABLE – 3: Per 1000 distribution of households by principal and supplementary sources of water for cooking, bathing and washing utencils

S. No	Source of water	Number of Households using the source of water for					
		Cooking		Bathing		Washing Utencils	
		Principal Source	Supplementary source	Principal source	Supplementary source	Principal Source	Supplementary Source
1	Tap	39	88	13	18	13	40
2	Tubewell / handpumps	705	451	280	534	321	548
3	Well	109	123	60	68	72	55
4.	Tank/Pond reserved for drinking	3	5	9	13	8	17
5	Tank/Pond	139	255	595	262	573	267
6	River/canal	1	30	38	84	8	50
7	Spring	2	28	2	13	2	14
8	Tanker	-	-	-	-	-	-
9	Other	1	21	1	10	2	9
10	All sources	1000	1000	1000	1000	1000	1000
	Estimated No. of household	1,10,552	16,421	1,10,552	32,422	11,552	30,814
	Sample of households	5312	789	5312	1580	5312	1491

APPENDIX – A

TABLE – 4 : Number of Rural households per 1000 filtering/chemically treating/boiling their drinking water in different states.

State	Number of households in 1000 treating water					
	Filtering		Chemically treating	Boiling	No. of households	
	With plain cloth	By other process			Estimated	Sample
1	2	3	4	5	6	7
Andhra Pradesh	218	36	7	26	119333	5721
Assam	117	193	67	216	35114	3243
Bihar	32	18	5	7	150028	7464
Gujarat	745	64	5	4	54468	2939
Haryana	26	8	1	4	25388	1222
Karnataka	90	13	14	28	69692	3152
Kerala	84	33	50	493	45411	2911
Madhya Pradesh	243	31	13	4	107483	5802
Mahrashtra	415	26	19	12	111247	5359
Orissa	85	16	7	18	63451	3401
Punjab	1	11	4	3	27971	2533
Rajasthan	397	18	4	2	62377	3501
Tamil Nadu	76	16	15	81	96319	5324
Uttar Pradesh	3	11	7	2	230008	10003
West Bengal	46	17	8	13	110552	5312
North Eastern	81	200	28	340	15630	6273
North Western	43	24	14	86	21164	3816
Southern	173	77	9	366	3059	1014
India	152	29	12	43	1348695	78990

Ibid S-248

APPENDIX – B

TABLE : Operation of Deep Tubewells – sample study.

S. No	Name of the village/s (Number)	Population 1991	Estimated population 2001	No. of families (2001)	Volume of daily supply 000e	Per capita daily supply `T'	Investment in Tubewell (Rs.000)	O&M Expenditure Rs.000
1	2	3	4	5	6	7	8	9
1	Iswara Chandrapur(1)	2,463	2,956	591	490.10	165.80	7696	200
2	Natna (4)	10,512	12,614	2,523	727.36	57.70	10805	120
3	Dhoradaha (2)	10,180	12,216	2, 443	395.50	32.40	10700	200
4	Narayanpur(2)	10,054	12,065	2,413	500.06	41.40	10530	300
5	Baria (3)	11,207	13,448	2,689	363.68	27.00	10791	230
6	Mithipur (1)	9,722	11,666	2,333	163.66	14.00	10009	180
7	Kantanagar(1)	11,208	13,450	2,690	90.92	6.76	11145	180
8	Chhayghan(1)	8,326	9,991	1,998	163.66	16.38	9506	200

Annual Expenditure Rs.`000			Expenditure per 100 litres of supply (Rs.)	Monthly charges to be paid by the existing clients of the facility towards covering the full cost of the service (Rs.)			Montly charges to be paid by the existing clients towards covering full costs of O&M component and 10% of capital component (Rs.)
Capital	O&M	Total		Capital component	O&M component	Total	
10	11	12	13	14	15	16	17
1549.20	188.40	1737.60	0.97	218.44	26.57	254.01	48.41
2175.05	113.04	2288.09	0.86	71.84	3.73	75.57	10.91
2153.91	188.40	2342.31	1.62	73.47	6.43	79.90	13.78
2119.69	282.60	2402.29	1.32	73.20	9.76	82.96	17.08
2172.23	216.66	2388.89	1.80	67.32	8.76	76.08	15.49
2014.81	169.56	2184.34	3.66	71.98	6.06	78.04	13.26
2243.49	169.56	2413.05	7.27	69.50	5.25	74.75	12.20
1913.56	188.40	2101.96	3.52	79.81	7.86	87.67	15.84

Source: Sample surveys carried out as part of the project

Assumptions :

1. **Average life of Tubewell and associated pump hand etc. 8 years**
2. **Discount rate is 12%.**

APPENDIX – C
Community ARPs Using different technologies.
Table 1 - AMAL

	EXPENDITURE	AMOUNT (RS.)	LIFE/PERIOD (years)	ANNUAL EXPENDITURE (Rs.)
1	2	3	4	5
A	Capital Expenditure			
1	Civil works	5,000	8	1006.50
2	Plant	45,000	8	9058.00
	Total of capital			10064.50
B	O&M Expenditures			
3	Replenishment	5,000	2	2958.50
4	Maintenance of civil Works	500.00	1	471.00
5	Recharging	-	-	-
6	Quality Control Inspection	250	1/12	2813.78
7	Preventive Maintenance	700	1	659.40
8	Salary and Wages of Staff	800	1/12	9004.08
9	Waste Disposal	1000	2	591.70
10	Chemicals & Consumables	500	1	471.00
11	Costs Stoppage of Supply		2/3 days in a year	-
	Total of O & M			16969.46
	Total			27,033.96

A. Annual expenditure — Rs.

	Rs.
Towards Capital component	10,064.50
Towards O&M component	16,969.46
Total:	27,033.96

B. Monthly charges a family has to pay towards covering full costs of drawing @ 40 litres per day when a Unit is allotted to serve 50 families only

Towards Capital Expenditure	16.77
Towards O&M Expenditure	28.28
	45.05

C. Monthly charges a family has to pay to meet O & M Expenditure, when capital and replenishment expenditure is Borne by the government = Rs.23.35

D. Monthly charges a family has to pay to meet O & M Expenses when capital and replenishment to expenditures are borne by Govt. and community volunteers take care of routine maintenance = Rs.8.34

E. Cost per 100 litres of supply = Rs.3.75

F. Capital Investment per head = Rs.200

TABLE – 2 : PAL TROCKNER

	EXPENDITURE	AMOUNT (RS.)	LIFE/PERIOD (years)	ANNUAL EXPENDITURE (Rs.)
1	2	3	4	5
A	Capital Expenditure			
1	Civil works	2000.00	8	402.60
2	Plant	84,000.00	10	15,270.60
B	O&M Expenditures			
3	Replenishment & Chemicals (MnO2)	15,000.00	1	15,000
4	Maintenance of Platform	500.00	1	471.00
5	Price of Recharging	-	-	-
6	Quality Control Inspection	250.00	1/12	2813.78
7	Preventive Maintenance	1000.00	1	942.00
8	Salary and Wages of Staff	800.00	1/12	9004.00
9	Waste Disposal	1250.00	1	1250.00
10	Chemicals & Consumables	-	-	-
11	Costs Stoppage of Supply	-	2/3 days in a year	-
12	Total			29,480.78
				44,751.38

Annual expenditure	Rs.
Towards Capital component	15,270.60
Towards O&M component	29,480.78
Total:	44,751.38

A. Monthly charges a family has to pay towards covering full costs of drawing @ 40 litres per day when a Unit is allotted to serve 50 families only

Towards Capital Expenditure	25.45
Towards O&M Expenditure	51.31
	76.76

B. Monthly charges a family has to pay to meet O & M Expenditure, when the capital replenishment expenditure is borne by the government = Rs.24.13

C. Monthly charges a family has to pay to meet O & M Expenses when capital and replenishment expenditures are borne by Govt. and community volunteers take care of routine maintenance = Rs.9.13

E. Cost per 100 litres of supply = Rs.6.22

F. Capital Investment per head = Rs.344

TABLE - 3 : WSI

	EXPENDITURE	AMOUNT (RS.)	LIFE/PERIOD (years0	ANNUAL EXPENDITURE (Rs.)
1	2	3	4	5
A	Capital Expenditure			
1	Civil works	4000.00	8	805.20
2	Plant	83,000.00	10	14,691.00
B	O&M Expenditures			
3	Replenishment	20,000.00	½	38,840.00
4	Maintenance of civil Works	1200.00	1	1130.40
5	Recharging	-	-	
6	Quality Control Inspection	250.00	1/24	5310.85
7	Preventive Maintenance	1000.00	1	942.00
8	Salary and Wages of Staff	1000.00	1/12	11,255.10
9	Waste Disposal	1000.00	½	1970.40
10	Chemicals & Consumables	-	-	-
11	Costs Stoppage of Supply	-	2/3 DAYS IN A YEAR	
12	O & M Exp.			59448.75
	Total			74,944.95

A. Annual expenditure

	Rs.
Towards Capital component	15,496.20
Towards O&M component	59,448.75
Total:	74,944.95

B. Monthly charges a family has to pay towards covering Full costs of drawing @ 40 litres per day when a Unit is allotted to serve 50 families only

Towards Capital Expenditure	25.83
Towards O&M Expenditure	99.08
	124.91

C. Monthly charges a family has to pay to meet O & M Expenditure, when capital and replenishment expenditure is Borne by the government = Rs.34.35

D. Monthly charges a family has to pay to meet O & M Expenses when capital and replenishment expenditure are borne by Govt. and community volunteers take care routine maintenance = Rs.15.59

E. Cost per 100 litres of supply = Rs.10.41

F. Capital Investment per head = Rs.348

TABLE – 4 : APYRON

	EXPENDITURE	AMOUNT (RS.)	LIFE/PERIOD (years)	ANNUAL EXPENDITURE (Rs.)
1	2	3	4	5
A	Capital Expenditure			
1	Civil works	3000.00	8	603.90
2	Plant	79,000.00	5	21,914.60
B	O&M Expenditures			
3	Replenishment	20,000.00	½	38,840.00
4	Maintenance of civil Works	500.00	1	471.00
5	Recharging	-	-	-
6	Quality Control Inspection	250.00	1/24	5310.85
7	Preventive Maintenance	2000.00	1	1884.00
8	Salary and Wages of Staff	3000.00	1/12	33,765.30
9	Waste Disposal	1000.00	½	1970.40
10	Chemicals & Consumables	-	-	-
11	Costs Stoppage of Supply		2/3 days in a year	
12	O & M Expenditure			82,241.55
	Total			1,04,760.05

A. Annual expenditure

	Rs.
Towards Capital component	22,518.50
Towards O&M component	82,241.55
Total:	1,04,760.05

B. Monthly charges a family has to pay towards covering Full costs of drawing @ 40 litres per day when a Family of 50 is being served.

	Rs.
Towards Capital Expenditure	75.06
Towards O&M Expenditure	275.88
Total:	350.94

C. Monthly charges a family has to pay to meet O & M Expenditure, when capital and replenishment expenditure is Borne by the government = Rs.72.34

D. Monthly charges a family has to pay to meet O & M Expenses when capital replenishment expenditures are borne by Govt. and community volunteers take care routine maintenance = Rs.16.06

E. Cost per 100 litres of supply = Rs.14,55

F. Capital Investment per head = Rs.324

TABLE – 5 : ION EXCHANGE

	EXPENDITURE	AMOUNT (RS.)	LIFE/PERIOD (years)	ANNUAL EXPENDITURE (Rs.)
1	2	3	4	5
A	Capital Expenditure			
1	Civil works	5000.00	8	1006.50
2	Plant	67,000.00	8	13,487.10
B	O&M Expenditures			
3	Replenishment	10,000.00	3	4,164.00
4	Maintenance of civil Works	500.00	1	471.00
5	Recharging	500.00	1/12	5,627.55
6	Quality Control Inspection	250.00	1/12	2813.78
7	Preventive Maintenance	1000.00	1/12	11,255.10
8	Salary and Wages of Staff	1500.00	1/12	16,882.65
9	Waste Disposal	3000.00	3	1,249.20
10	Chemicals & Consumables	200.00	1/12	2251.02
11	Costs Stoppage of Supply	-	2/3 days in a year	-
12	O & M Exp.			44,714.30
	Total			59,207.90

A. Annual expenditure

		Rs.
Towards Capital component		14,493.60
Towards O&M component		44,714.30
	Total:	59,207.90

B. Monthly charges a family has to pay towards covering Full costs of drawing @ 40 litres per day when a Unit is allotted to serve 50 families only

Towards Capital Expenditure	24.16
Towards O&M Expenditure	74.52
	98.68

C. Monthly charges a family has to pay to meet O & M Expenditure, when capital and replenishment expenditure is Borne by the government = Rs.67.58

D. Monthly charges a family has to pay to meet O & M Expenses when capital and replenishment expenditure are borne by Govt. and community volunteers take care routine maintenance = Rs.39.45

E. Cost per 100 litres of supply = Rs.8.22

F. Capital Investment per head = Rs.288

TABLE – 6 : AIIH&PH

	EXPENDITURE	AMOUNT (RS.)	LIFE/PERIOD (years)	ANNUAL EXPENDITURE (Rs.)
1	2	3	4	5
A	Capital Expenditure			
1	Civil works	3000.00	8	603.90
2	Plant	27,000.00	8	5435.10
B	O&M Expenditures			
3	Replenishment	-	-	-
4	Maintenance of civil Works	2000.00	1	1,884.00
5	Recharging	-	-	-
6	Quality Control Inspection	250.00	1/12	2813.78
7	Preventive Maintenance	1000.00	1	942.00
8	Salary and Wages of Staff	500.00	1/12	7878.57
9	Waste Disposal	1000.00	1	942.00
10	Chemicals & Consumables	30.00	1/24	637.30
11	Costs Stoppage of Supply	-	2/3 days in a year	-
12	O & M Expen.			15,097.65
	Total			

A. Annual expenditure

	Rs.
Towards Capital component	6039.00
Towards O&M component	15097.65
Total:	21,136.65

B. Monthly charges a family has to pay towards covering Full costs of drawing @ 40 litres per day when a Unit is allotted to serve 25 families only (becayse the Daily capacity of Plant is only 1000 litres

Towards Capital Expenditure	20.13
Towards O&M Expenditure	50.33
Total:	70.46

C. Monthly expenditure a family has to pay when capital Expenditure is borne by Government Rs. 25.41

D. Monthly charges a family has to pay to meet O & M Expenditure, when capital expenditure is Borne by the government and community volunteers Take care of routine operations = Rs.24.06

E. Cost per 100 litres of supply = Rs.5.87

F. Capital Investment per head = Rs.120

TABLE – 7 : PHED

	EXPENDITURE	AMOUNT (RS.)	LIFE/PERIOD (years)	ANNUAL EXPENDITURE (Rs.)
1	2	3	4	5
A	Capital Expenditure			
1	Civil works	6750.00	8	1,358.78
2	Plant	29,375.00	5	10,922.63
	Total capital			12,281.41
B	O&M Expenditures			
3	Replenishment	7,312.50	1	7,312.50
4	Maintenance of civil Works	500.00	1	471.00
5	Recharging	-	-	-
6	Quality Control Inspection	250.00	1/12	2813.78
7	Preventive Maintenance	1000.00	1	942.00
8	Salary and Wages of Staff	4000.00	1/12	45,020.40
9	Waste Disposal	1000.00	1	942.00
10	Chemicals & Consumables	350.00	1/52	13,718.64
11	Costs Stoppage of Supply	-	2/3 days in a year	-
12	Total			71,220.32
				83,501.73

A. Annual expenditure

	Rs.
Towards Capital component	12,281.41
Towards O&M component	71,220.32
Total:	83,501.73

B. Monthly charges a family has to pay towards covering Full costs of drawing @ 40 litres per day when a Unit is allotted to serve 50 families only

	Rs.
Towards Capital Expenditure	20.45
Towards O&M Expenditure	118.70
	139.15

C. Monthly charges a family has to pay to meet O & M Expenditure, when capital and replenishment expenditure is Borne by the government = Rs.106.51

D. Monthly charges a family has to pay to meet O & M Expenses when capital and replenishment expenditure are borne by Govt. and community volunteers take care routine maintenance = Rs.31.48

E. Cost per 100 litres of supply = Rs.11.60

F. Capital Investment per head = Rs.144.50

APPENDIX – C

TABLE – 8 : Comparative Analysis of Costs of Water Supply under different ARP technologies

S. No.	Technology	Daily capacity	Daily withdrawals	No. of families drawing water	Monthly charges paid (Rs.)	Assumed effective withdrawal from the Plant	Assumed No. of households served
1	2	3	4	5	6	7	8
1	Amal	5000	2500	300	15.00	2000	50
2	Paltrocknor	3000	2000	100	Nil	2000	50
3	WSI	2000	1500	100	Nil	2000	50
4	Apyron	1200	1200	60	Nil	1000	25
5	Ion Exchange	2000	2000	60	Nil	2000	50
6	AIIH & PH	1000	500	24	Nil	1000	25
7	PHD	2000	500	20	Nil	2000	50

Monthly charges a household has to pay to draw water @ 40L per day (Rs.)					Cost for 100 litres of supply (Rs.)	Capital Investment per client (Rs.)
Capital	O&M	Total	To cover O&M Expenditure minus Replenishment	To cover O&M Expenditure Minus replnishment & salaries		
9	10	11	12	13	14	15
16.77	28.28	45.05	23.35	8.34	3.75	200
25.45	51.31	76.76	24.13	9.13	6.22	344
25.83	99.08	124.91	34.35	15.59	10.41	348
37.53	137.94	175.47	72.34	16.06	14.55	324
24.16	74.52	98.68	67.58	39.45	8.22	288
10.06	25.17	35.23	25.41	24.06	5.87	120
20.45	118.70	139.15	106.51	31.48	11.60	144.50

APPENDIX – D

TABLE – 1 : DOMESTIC ARSENIC FILTERS

A. **AMAL**	**CAPACITY 24 Litres**	**AMOUNT**
		Rs.
1. Initial price		1650.00
2. Annual Replenishment for five years @ Rs.150 p.a.		540.72
3. Replacement at the end of 5 years Rs.600		340.44
		2541.16

B. **PATROCKNER**	**10 Litres**	**30 Litres**
	Rs.	Rs.
1. Initial Price	3,500	4,500
2. Replacement at the end of the fifth year Rs.1000	567.40	567.40
	4,067.40	5,067.40

C. **AIIPH&H** 10 litres	
	Rs.
1. Initial Price	.200
2. Cost of chemicals @ Rs.10 p.m. for 5 years i.e For 60 months	377.70
	Rs.577.70

D. **Jadavpur University (20litres)#**	
	Rs.
1. Initial Price	600.00
2. Cost of chemicals @ Rs0 .75 per day i.e. 68.25 for 91 days (Unit's life is3years)	679.36
	1279.36

#Note: The filter is reported to be still in the development stage. Costs taken in the exercise, therefore, are tentative. A small number of filters were produced and supplied free of cost to a sample of households. Those households are also given regularly free supplies of the chemical (tablet) for daily use. Information is not readily forth coming from the project team as to when these filters are going to be produced on large scale and at what price they are going to be made available in the market and how the distribution network for the supply of chemicals will be established.

APPENDIX - D

TABLE – 2: Comparative Analysis of Water Supply under different DARF technologies.

Sl.No.	Technology	Per capita Investment (Rs.)	Cost per 100 litres of water drawn (Rs.)
1	2	3	4
1	Amal	330	5,80
2	Palrockner (30 litres)	900	9.26
3	AIIH & PH	40	3.17
4	Jadavpur	120	3.50

TABLE – 3: Socio-Economic Profile of the users of Domestic Arsenic Filters

Sl.No.	Technology	Number with high school and above education	Number in Non Agri./Labour occupation	Religion and Average Family size				Average monthly Income (Rs.)	Total
				Hindu	Family size	Muslim	Family size		
1	2	3	4	5	6	7	8	9	10
1	Amal	16	16	8(5)	4.3	8	7.7	1046.7	16
2	Paltrockner	12	9	12(6)	6.2	3	7.7	7566.7	15
3	AIIH & PH	15	14	15	5.5	-	-	4166.7	15
4	Jadavpur	3	10	4 (2)	5.5	11	6.1	1046.7	15

Source: Socio-Economic sample surveys conducted as part of the Present Project (Figures in the bracket in Col.5 are scheduled caste families).

APPENDIX – D

TABLE – 4 : Ownership of Deurables by population below Poverty line as estimated from MISH 1997-98 (per `000 hhs)

Durables	Number of households in 1000 owning the item		
	Urban	Rural	Total
1	2	3	4
Tansistor Radio	423	309	319
Casette Recorders	202	150	156
Pressure Cooker/Pan	260	76	92
Bicycle	419	410	411
Electric Iron	153	47	56
Electric Fans	582	220	252
Wrist Watches	1024	706	734
TV-B&W	312	79	100
Sewing Machine	98	54	58
Colour T.V.	43	7	10
Two Wheelers (motorized)	49	14	17
Washing Machine	12	0	1
Refrigerator	35	4	7

Source: Deepak Lal Et.al, Economic Reforms and Poverty Alleviation – A Tale of two Surveys, Economic and Political Weekly March 24, 2001, page 1027.

APPENDIX – E

TABLE – 1 :Per thousand distribution of households according to the per capita monthly expenditure classifications, in rural West Bengal and in rural India.

Sl.No.	State/India (Rural)	Number of households in the Percapita expenditure classification of (Rs.) in 1000													
		000 120	120 140	140 165	165 190	190 210	210 235	235 265	265 300	000 300	300 355	355 455	455 560	560 & above	All classes
1	West Bengal	6	6	27	27	27	78	93	119	383	196	209	111	100	1000
2	All India	5	12	27	44	48	71	84	106	397	154	182	108	159	1000

Source: Sarvekshana, Volume XXIII No.2, 81st Oct.-Dec.1999, National Sample Survey Organisation,
Ministry Statistics & Programme Implementation, Government of India (NSS 54th Round January 1998 – June 1998) page

APPENDIX – E

TABLE – 2: Value (Rs.) of Consumption of broad groups of food and non-food items per person for a period of 30 days for each monthly expenditure classes/All India Rural

S.No.	Item of consumption	Value of (Rs.) Per capita monthly consumption according to the per capita monthly expenditure classificatin of the households													
		000 120	120 140	140 165	165 190	190 210	210 235	235 265	265 300	300 355	355 455	455 560	560 & above	All Exp. categories	% in the total Exp.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	All Food items	78.33	96.10	113.10	130.08	143.72	158.70	176.77	197.06	220.36	257.48	302.25	404.26	232.40	60.48
	Non-Food items														
	i)Pan	0.46	0.37	0.45	0.61	0.64	0.87	1.03	1.46	1.41	1.92	2.28	2.96	1.58	0.41
	ii)tabacco	2.32	2.17	3.10	3.42	3.96	4.62	4.70	5.84	6.06	7.05	7.51	10.85	6.31	1.65
	iii)Intoxicants	0.76	0.61	1.05	1.14	1.77	1.62	1.82	2.30	2.35	3.32	3.87	7.57	3.07	0.80
	iv)Durables	0.05	0.75	0.68	0.96	1.33	1.82	2.04	2.96	3.49	6.68	10.49	75.80	13.46	3.52
	All Non-food items	30.27	35.09	41.12	48.60	57.02	64.27	73.40	85.92	105.65	142.69	197.13	459.76	149.67	39.17
	Total Exp.	108.61	131.1131.19	154.23	178.67	200.74	222.97	250.17	282.97	326.01	400.17	499.38	864.02	382.07	100.00

Ibid page

APPENDIX – E

TABLE – 3: Average monthly Per capita expenditure (Rs.) Rural West Bengal

	Rural	Percentage	All India	Percentage
1	2	3	4	5
Total food items Non-food items	238.80	66.80	232.40	60.83
Pan	1.26	0.35	1.58	0.41
Tobacco	6.26	1.75	6.31	1.65
Intoxicants	1.35	0.38	3.07	0.80
Fuel & Light	26.19	7.33	30.02	7.86
Clothing	19.44	5.44	22.34	5.85
Food Wear	1.74	0.49	3.97	1.04
Misc.consumer goods	14.73	4.12	18.80	4.92
Misc. consumer Services	8.85	2.47	17.95	4.70
Rent	0.09	0.02	1.29	0.34
Taxes & Cesses	0.10	0.03	0.47	0.12
Education	12.58	3.52	9.57	2.50
Medical Institutional	4.65	1.30	6.10	1.60
Medical (Non-Institutional)	13.19	3.69	14.74	3.86
Durable goods	8.29	2.32	13.46	3.52
Total non-food	118.69	33.20	149.67	39.17
Total consumption Exp.	357.50	100.00	382.07	100.00
Sample hhs.	668.00		9986	

Source: Sarveskshana, Volume XXIII, No.2, 81st Issue, Oct.-December 1999, National Sample Survey Organisation, Ministry of Statistics & Programme Implementation, Government of India, (NSS 54th Round January 1998 – June 1998).

APPENDIX – E

TABLE – 4 : Number of households per 1000 willing to contribute money/Labour towards improvement of sanitation in their neighbourhood and in their village/town

	Number of households per 1000 willing to contribute towards improvement of sanitation in our village/town						No. of households (Estd) 000	Sample of households
	Money & labour	Money only	Labour only	Neither	Non Response	All		
Rural West Bengal	106	54	537	277	27	1000	110552	5312
Rural India	153	58	454	323	12	1000	1348695	78990

Source: Sarvekshana, Vol.XXVII, No.3, 82nd Issue (Special) January-March, 2000, page S-281.

APPENDIX – E

TABLE – 5: Number of households per 1000 willing to contribute money/Labour towards improvement of sanitation in their neighbourhood and in their village/town

	Number of households per 1000 willing to contribute towards improvement of sanitation in their neighbourhood					
	Money and labour	Money only	Labour only	Neither	Non Response	All
Rural West Bengal	96	56	570	230	47	1000
Rural India	162	66	523	241	8	1000

Source: Ibid p.281.