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PEOPLE-CENTRED APPROACHES TO WATER AND ENVIRONMENTAL SANITATION

Experiences with domestic defluoridation in India

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During the International Drinking Water Supply and Sanitation Decade 1980-1990 in India, there was a marked preference in rural drinking water supply programmes, to seek community based water treatment solutions, attached to handpumps where such problems existed. This was true for iron removal and defluoridation. However, over the next few years most of these treatments systems became inoperative, primarily attributed to a lack of a sense of ownership by user communities, resulting in an attitude of indifference towards the operation and maintenance of these plants. It is also possible that the complexities of O&M by user communities, in the rural Indian socio-political context, had not been institutionally understood. Since 1990s there has been an increasing trend to seek household based water quality treatment solution within rural drinking water supply programmes in India. This paper summarises the experiences of UNICEF in India in tackling the problem of high fluoride content in rural drinking water supply sources, using household-based defluoridation filter using activated alumina. Since 1991, UNICEF supported the research work for development of the technology by the Department of Chemistry, Indian Institute of Technology (IIT), Kanpur. This resulted in pilot projects on Domestic Defluoridation Units in the states of Andhra Pradesh and Rajasthan during 1996-2002. Gradually a demand for these filters has grown and the private sector is gradually becoming interested. Perhaps this approach, addressing households specifically rather than the nebulous "community" in general, is ensuring the use of safer water to a greater degree.

Introduction

By early 2004, the rural drinking water supply programme in India was estimated to have 3.7 million handpumps that are dependent on groundwater. While this may have resulted in lowering the incidence of water borne diseases, it has led to the emergence of a number of other problems, such as failure (depletion) of drinking water sources due to excessive withdrawal by irrigation wells and environmental degradation, bacteriological contamination of drinking water sources due to poor quality of construction and unsanitary conditions and the excessive presence of chemical constituents like fluoride and arsenic, which have become major geo-environmental issues. As per recent estimates, millions are affected in India by arsenicosis and fluorosis.

Fluoride is a normal constituent of natural waters and its concentration varies depending on the water source. Surface waters seldom have fluoride concentrations beyond 0.3 mg/lit, except in isolated cases. Geological processes, weathering of fluoride bearing minerals and hydro-geological conditions can lead to higher fluoride levels in groundwater in certain areas, which become endemic for fluorosis. Large areas in India show differing degrees of presence of fluorides in groundwater.

The usual remedial measures are:

- Basing supply on distant safe source
- Using surface water after conventional treatment
- Household rainwater harvesting
- Community based treatment unit
- Household treatment.

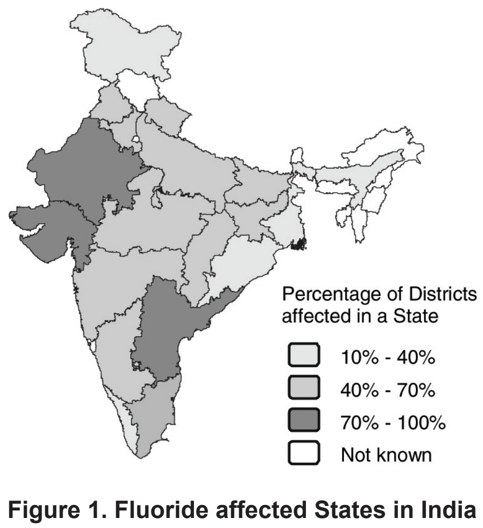

Figure 1. Fluoride affected States in India
Source: UNICEF, New Delhi, 2001

Each of the above solutions has situation-specific applicability. The first two alternatives are cost intensive, have long gestation periods and require a sophisticated level of O&M capability and are generally not the choice for rural water supply solutions in developing countries.

Rainwater harvesting is possible but can only be a seasonal supplementary source during the monsoons in India. Hence the preference has been to seek solutions around small habitation based and household level treatment systems.

Defluoridation methods can be broadly divided into following categories, each with its own merits and limitations:

- Chemical addition/precipitation.
- Adsorption/ion exchange.
- Membrane based technologies.

By mid 1980's, it was evident that excess fluoride was present in groundwaters in many parts of the country. In 1987, Rajiv Gandhi National Drinking Water Mission estimated that about 25 million people in 8700 villages were drinking water with excess fluoride. A Sub-Mission to control fluorosis was set up with a plan to overcome the problem. Testing of all of water sources for fluoride and technology interventions were initiated in many states. The technology option considered was mainly "Nalgonda"[1] technique.

The National Environmental Engineering Research Institute, Nagpur had developed the "Nalgonda" Technique for the defluoridation of drinking water. It involved the addition of alum and lime to water, followed by settling and filtration. The first report on this method was published in 1975 (Nawlakahe, et al.). However, it did not achieve a great degree of success in field application both as handpump based units and smaller domestic units, primarily because of its need for constant attention.

Defluoridation using Activated Alumina (AA) has been one of the widely used adsorption/ ion exchange methods for water and many reports are available on large-scale installations for townships, requiring supervision and skilled personnel. The quality of treated water from such facilities was assured. However, this approach was not immediately feasible in developing countries, especially in rural areas. Initially it was thought that treatment may only be possible at a community level, i.e. treatment systems attached with handpump installations or at the 'point of use', i.e., domestic level. Reports on the adaptation of AA technology with handpump or home units were scarce till 1990's as this technology was rarely used in developing countries.

Laboratory studies on the use of indigenously manufactured activated alumina for defluoridation of drinking water carried out by Bulusu and Nawalakhe (1990), Rao and Mahajan (1988), Sharma (1997) reported the development and evaluation of domestic and handpump units where activated alumina was used as the defluoridation medium. Karthikeyan et al. (1994) screened three different grades of activated alumina (particle size, < 0.4 mm) for fluoride uptake capacity as well as designed and evaluated domestic defluoridation unit. A handpump defluoridation unit designed by a company in New Delhi, with a special grade of activated alumina, developed by Alcal Chemicals, England, was reported to have been installed in Madhya Pradesh. This grade of AA was said to have a much higher fluoride removal capacity and was supposed to be better suited for application at natural water with pH of 7.5. Due to these factors, exhausted AA was not required to be regenerated and could be land-filled after using once. Recently (2001-03) Department of Science & Technology, Govt. of India, have supported the Public Health Engineering Department of the State Govt. of Rajasthan in the development of two handpump attached defluoridation units.

This paper confines itself to relating some experiences with defluoridation based on the use of Activated Alumina. It is based on the research work done at the Department of Chemistry, Indian Institute of Technology (IIT), Kanpur since 1991 supported by the Water, Environment and Sanitation Section (WESS), UNICEF, India and the pilot projects based on this research, on Domestic Defluoridation Units supported by WESS, UNICEF, India in the states of Andhra Pradesh and Rajasthan.

Major areas of Study at IIT Kanpur

The initial intention of the research project in 1991 was to develop and field test a handpump based defluoridation unit that could be maintained by local communities. Around 1996, the focus of the research changed to finding solutions for domestic defluoridation. At the same time, the discontinuation of the grade of AA used during 1991-96, led to the screening of other grades indigenously manufactured of activated alumina for defluoridation application. Hence, the major areas of studies were:

- Development of handpump attached defluoridation unit.
- Screening of indigenous activated alumina grades in domestic defluoridation units.
- Development of Domestic Defluoridation Units.
- Development of Regeneration procedure for exhausted AA and the reuse potential of AA.
- Safe disposal of spent regenerants.

1. Development of handpump attached defluoridation units

A cylindrical defluoridation unit was fabricated and field-tested in Makkur, Unnao district, UP in 1993. It was a drum, 0.5 m in diameter and 1.5 m in height, fabricated from mild steel sheet. The unit was designed to operate in the up-flow mode. It used 110 Kg of AA of grade G-87, having a particle size range of 0.3-0.9mm, which gave a bed depth around 55 cm.

The installation required the raising of handpump discharge level with an addition to its normal pedestal and construction of an elevated platform. Users had to go up few steps to operate the handpump. A by-pass line was provided to draw the water directly from the handpump for washing and bathing.

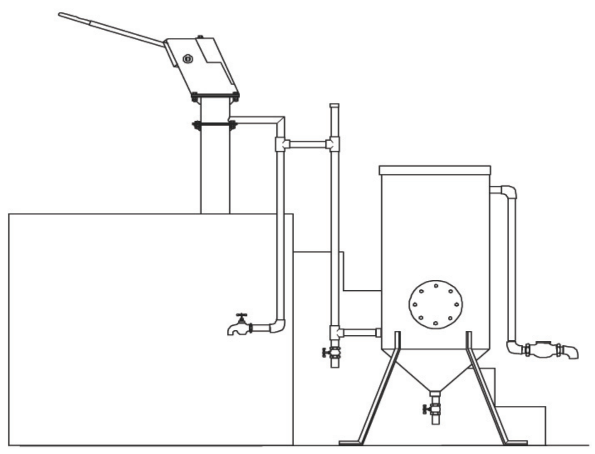

Figure 2. Handpump attached Defluoridation Unit

The unit was maintained by IIT Kanpur. Raw water fluoride concentration was in the range of 6-7 mg/l. Regeneration of exhausted activated alumina was carried out *'in situ'* i.e. within the column. This procedure required 8-10 hrs. Average yield per cycle was around 25,000 litres. Seventeen defluoridation cycles were completed in a span of 4 years. There was no major maintenance problem during this period. There was no complaint from the users either regarding the design or the palatability of treated water. However, community involvement during regeneration was minimal. The unit was dismantled in 1998, as the village community got an access to piped water supply. Similar defluoridation units were independently installed in Madhya Pradesh.

With this installation, there was no provision for regenerant disposal. During this period, UNICEF approach changed from community based to domestic defluoridation units. Hence further modifications, like incorporating provision for disposal of regenerants, were not taken up.

2. Screening of AA

The search for finding solutions for domestic defluoridation and the discontinuation of the grade of AA used during 1991-96, mentioned earlier, led to the development of Domestic Defluoridation Units (DDUs) and to the screening of indigenously manufactured grades of AA for defluoridation application. AA was available in the Indian market but was made for industrial application (e.g. for moisture removal in the petroleum refining process).

Two parameters were considered as important for the application of AA in defluoridation. One was fluoride uptake capacity (FUC) expressed as milligrams of fluoride removed per Kg of AA and the second was reuse potential of activated alumina in multiple defluoridation cycles.

The development of the DDU has been discussed later. All screening tests were carried out in the DDU. Test water for most of the screening studies was prepared by spiking groundwater from the IIT campus with fluoride to a concentration of 10±0.5 mg/l. During 1991-2002, more than 15 grades of locally manufactured AA were screened.

Under these experimental conditions used, FUC ranged from 1500 mg/Kg AA to 2200 mg/Kg AA. Studies have also been carried out on the effect of raw water characteristics as well as AA particle size, empty bed contact time on FUC, with selected grades of AA.

The main result from these studies was the improvement and availability of activated alumina in the desired particle size range. By early 2004, the draft standards of AA suited for use in DDUs have been written (refer box).

Box 1. AA should conform to IS: 9700:1991, Grade 1 and should also meet the following requirements

It should be washed thoroughly with water to remove dust and fine particles. The grain size shall be 0.4-1.0mm. Mechanical grinding not acceptable. The yield of treated water (fluoride < 1.5mg/lit) will be>170 lit per Kg of AA per cycle when raw water having alkalinity 420 mg/lit, pH 7.3 and fluoride content of 10.5+ 0.5 mg/lit is passed through a 3 Kg AA bed with flow rate 9-12 lit per hour.

Under these conditions the fluoride uptake capacity shall not be less than 1800 mg/ Kg of AA. The manufacturer will specify the fluoride uptake capacity (mg/lit) after ten cycles of regeneration, loss of attrition in each regeneration cycle and residual aluminium in treated water due to leaching if any (preferably treated water should be free from residual aluminium) using the test procedure outlined separately. The AA should not impart residual aluminium to treated water.

Source: Draft specifications for Activated Alumina for Domestic Defluoridation – internal report from IIT, Kanpur to UNICEF, New Delhi.

3. Development of Domestic Defluoridation Units - DDUs

DDUs were initially designed on the assumption that 20 litres of treated water was the daily requirement for cooking and drinking for a family. With this criterion, it was expected that 3 Kg. AA would be exhausted in 2 to 3 months if fluoride concentration in water was around 4 mg/lit.

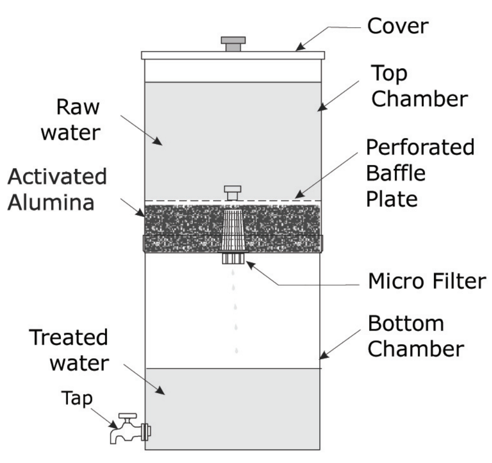

Figure 3. Domestic Defluoridation Unit

The first DDU fabricated in the laboratory consisted of two cylindrical chambers, fabricated from galvanized iron sheet. 3 Kg of AA was taken in the upper chamber (24 cm dia x 27 cm height), which gave a bed depth of 9 cm. A flow control device was fixed at the bottom of the upper chamber, so as to have a flow rate of 8-10 litres per hour.

From this starting point, different versions of DDUs have emerged. The quantity of activated alumina has generally become 4 Kg to 5 Kg and the material used for filter unit includes stainless steel, HDPE (Sintex), PVC, and Terracotta pots.

4 Regeneration of Exhausted Activated Alumina

Regeneration of exhausted AA and its reuse for multiple cycles is one of the main advantages of using AA for defluoridation. Extensive studies were carried out on this aspect. Different regenerants used included alum, HCl, H_2SO_4 and NaOH. The results clearly indicated that efficient regeneration could be achieved with a combination of 1% NaOH and 0.4N H_2SO_4. Some screened grades showed less than 20% loss during 10 defluoridation cycles.

A simple "dip" regeneration procedure, appropriate for a rural set up, was developed. This required the transfer of activated alumina from domestic units to a nylon bag, dipping the bag in 10L 1% NaOH for 8 hours (or overnight) with intermittent mixing. After washing once with raw water to remove excess alkali, the bag with AA was dipped in 10L of 0.4N H_2SO_4 for 8 hrs. This was followed by washing with raw water to raise the pH to 6. The regenerated activated alumina was ready for the next cycle.

The Dip regeneration method has been adapted in many pilot project areas in Rajasthan, A.P and UP. The main limitation of this method appeared to be intermittent mixing and the long time required for regeneration.

Presently the 'Bucket regeneration' procedure' has been developed which addresses the two disadvantages of the Dip method. A plastic bucket with flow control device is used to continuously pass the regenerant over the exhausted activated alumina bed. Studies indicated that the time required for regeneration decreases substantially and changes by changing the flow rate of the regenerants. This method was more user-friendly and could be easily adapted in rural setups.

Photograph 1. Dip Regeneration

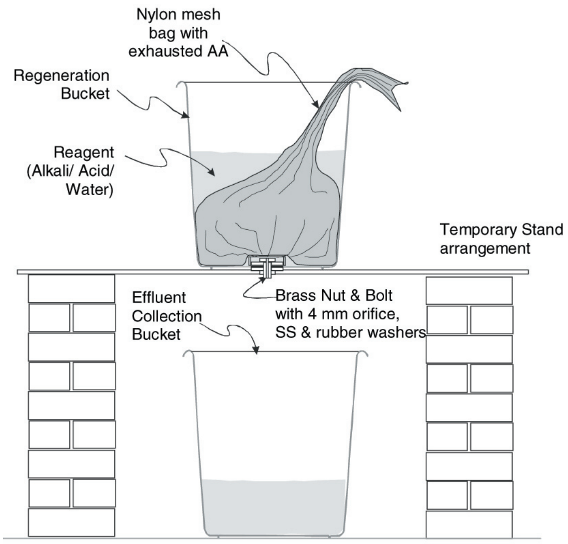

Figure 4. Bucket Regeneration

Initially the regeneration procedure was optimized for 3 Kg activated alumina in the domestic unit. However, since 4 Kg to 5 Kg of AA is commonly being used, studies are being conducted to arrive at the optimal weight of AA (keeping depth of the AA bed constant) and the corresponding optimal regeneration procedure. Results have indicated that the efficiency of reuse steeply decreases with 5 Kg AA, if only 10L 1%NaOH is used for regeneration.

5. Disposal of Spent Regenerants

Regeneration of activated alumina generates spent alkali and acid having extreme pH. Spent alkali regenerant would also be having high fluoride concentration. Safe disposal of these regenerants is thus essential.

Different methods were tried for spent regenerant disposal. They are:

- The addition of $CaCl_2$ to spent alkali regenerant to precipitate fluoride and then mix the supernatant with acid regenerant.
- Simple mixing of spent alkali/ acid regenerants.
- Mixing alkali/acid regenerants and using certain additives like alum or lime to remove fluoride as well as to improve settling properties of the sludge.

Results indicated that overall fluoride removal of more than 85% could be achieved using option 3, mentioned above. Based on these findings, it was recommended that the disposal of spent regenerants could be carried out by mixing spent alkali and acid regenerants, adding lime and settling the sludge for 24 hr. The supernatant solution, with low fluoride and near neutral pH, could then be drained off. Sludge could to be collected periodically, and used for brick making at the village level itself.

This procedure has been adapted in UNICEF assisted pilot project villages in Andhra Pradesh and Rajasthan, for the disposal of spent regenerants.

Handpump and Domestic defluoridation units for rural areas, Pros and Cons

Extensive literature is available on the application of AA technology for defluoridation of drinking water in large treatment units. As mentioned earlier, this approach may not be feasible in developing countries, especially in rural areas and defluoridation solutions are needed only at the handpump or domestic levels. The advantages of this approach are:

- A lower cost for treatment, as only a limited volume of water is required (for cooking and drinking) to be treated.
- The lower requirement of treated water correspondingly lowers the need for treatment of chemicals which finally results in generation of lower volumes of sludge.

However success of these approaches depend upon the treatment reliability and motivation of consumers to use only the treated water for cooking and drinking, (as the untreated water is also available) as well as on various other factors.

Presently all handpump defluoridation installations, based on AA technology, are either experimental units or under the supervision of Govt. authorities. Past experience with other community units, such as iron removal, defluoridation using the Nalgonda technology, have not been generally encouraging. This is mainly due to lack of ownership by user communities and the consequent reluctance to take over management responsibility, leading to a lack of maintenance at local level by users. Other related issues are funding for maintenance, community involvement and awareness in creation of the defluoridation facility and the degree of institutional willingness to relinquish control over the installations. Under the circumstances, the sustainability of these systems under community management does not appear very encouraging.

Activated alumina in a handpump unit has to be periodically regenerated depending upon raw water characteristics, its fluoride concentration and amount of AA taken in the unit. There are two alternatives for the regeneration of activated alumina. One is "in situ" regeneration and the other option is by removing AA from the unit and transporting it to a regeneration centre. Regeneration of activated alumina leads to 6 to 8 bed volumes of wastewater. If the first option is chosen there should be a facility near the handpump for collecting the wastewater and its proper disposal. Second option may be attractive, only if many handpump units are in close proximity. Then there can be a central regeneration facility. However, such a facility would have to be institutionally operated.

Convenience of access plays a major part in water source preference of users, even disregarding considerations of source potablity. Handpump units may not be popular, where aquifer level is not deep. In such places users would be having shallow hand pumps within their homesteads and they would not prefer to get the treated water from the community hand pump.

Domestic units are the "point of use" units with a higher degree of individual ownership as DDUs have to be wholly or partly paid for. This might ensure better maintenance of these units if adequate regeneration facilities are simultaneously set up at the village level. However, as in the case of handpump based units, sustainability of the technology depends on the effective back-up facility for regeneration. Awareness creation is still necessary for users to be convinced of the importance of periodical regeneration. Since regeneration will be carried out at a central place, wastewater handling and disposal can be better managed.

Pilot Project in Andhra Pradesh

Kadiri Mandal of Ananthapur District, Andhra Pradesh has been a chronically affected high fluoride area. In the first half of the 1990s, the Satya Sai Trust of Puttaparthy had constructed a huge comprehensive piped water supply scheme, covering over 250 villages. This scheme could not reach 69 villages in the vicinity of Kadiri. The pilot project on Domestic Defluoridation Units (DDU) started in these villages in 1998-99 with assistance from UNICEF to a local NGO, Mytry Social Service Society who ran a Rural Sanitary Mart in Kadiri. The project was implemented in three phases:

- Phase 1 of the pilot project started in 1998 in 6 villages, using activated alumina and plastic containers. 300 units were supplied, at a cost of Rs. 410 per unit, given to user households at Rs. 250 per unit and Rs. 50 per unit to SC/ST (Scheduled caste/Scheduled tribes) households.
- Phase 2 was implemented during 1999-2000, in 25 additional villages, where 2000 DDUs, made of two stainless steel chambers were distributed. Unit cost was Rs. 1000, given at Rs.250 per unit to below-poverty-line (BPL) families and at Rs. 400 per unit to above-poverty-line (APL) families.
- Phase 3 was an expansion to 25 more villages, with stainless steel containers and the same cost and subsidy structure as in Phase 2. 1800 units were distributed in 2000-01 and 1000 units were distributed in 2001-02.

During Phase 1 of the project, regeneration facilities were set up at the Panchayat Raj Engineering Department premises in Kadiri. In Phase 2, this facility was brought to the level of the Rural Sanitary Mart and in Phase 3 of the project, regeneration facilities have been set up at village level. During the third phase of the project supply of DDUs to Mytry was delayed and Mytry began to source raw materials directly and assemble filters.

By June 2003, Mytry had 60 dealers in Andhra Pradesh and 20 in Karnataka and had marketed roughly 60,000 filters through this network. Mytry was well advanced in its preparation for establishing its own manufacturing facility for stainless steel containers and micro filters in Kadiri and were contemplating the possibility of manufacturing it own activated alumina (AA).

For the pilot project area, Mytry had a very elaborate system of follow-up of DDU users. Village-wise records of DDU users were available, with a serial number allotted to each DDU user. A brief family history was recorded for each user at the time of giving the DDU. A computerised database was used to generate information on when regeneration was due for a user or group of users in a village. Post cards were mailed to each user a few days before regeneration was due. Since regeneration required a large quantity of fresh water, filling of overhead tanks at regeneration centres in villages was coordinated with regeneration dates. Regeneration in a village was done for all users at one time in a campaign mode. Within the project area, regeneration service was provided at Rs.25 per unit. Each household had its DDU Card, where the DDU serial number and the dates of regeneration were noted.

The pilot project implementation had a significant awareness campaign component. Mytry developed posters, stickers and wall paintings giving messages about fluorosis, nutritional needs, defluoridation, etc. Mytry also used Field Test Kits for monitoring fluoride content in water at the village level and had back-up confirmation facilities available with their own laboratory at Kadiri. Mytry has generally adhered to the technical specifications provided by IIT Kanpur in assembling DDUs and in establishing regeneration facilities.

Mytry has seen the DDU as a good commercial opportunity and are gradually integrating their supply chain to bring all components of DDU under their direct control. Initially they concentrated on developing their marketing setup and now that a definite private sector (and full cost) demand has been generated, they are establishing their own manufacturing facilities. However, Mytry also see the commercial potential of the regeneration market and have kept their investment alive in this aspect. In order to be able to sell larger numbers of DDUs, Mytry is concentrating on establishing its marketing network in the smaller towns of Andhra Pradesh. This strategy has not only provided relative larger numbers of users, it has also made establishing regeneration facilities commercially viable. Though Mytry has established good monitoring systems in its UNICEF assisted pilot project areas, it would seem that its control on regeneration for independent rural sales has been somewhat diluted. While it has a network of 60 dealers, there are 46 regeneration centres. Availability of water, disposal of effluents, the relatively long time required for the current regeneration process, were some of the practical problems being faced by Mytry.

Pilot project in Rajasthan

Rajasthan has a total of 32 districts of which 22 were considered fluoride affected. Roughly 16,560 villages were affected by high fluorides. UNICEF has assisted two NGOs, SWACH and SARITA in establishing pilot projects in Dungarpur since 1996. This programme has expanded to include one more NGO, and has spread to 120 villages in Dungarpur. So far, roughly 1800 DDUs have been procured by UNICEF and distributed in Dungarpur. In order to narrow down the nature of the high fluoride problem, UNICEF assisted the State PHED with water quality mapping of all drinking water sources in 6 districts so far. Water quality testing of ALL drinking water sources in a village has led to the identification of drinking water sources with fluoride content above the permissible limit (1.5 mg/lit), and identification of villages which had no safe source at all. This provided a basis for prioritising the remedial measures to be taken. By mid 2003 the State Health Dept. was mapping the extent of dental fluorosis by surveys of rural schools.

By mid- 2003, a total of about 24,000 DDUs had been distributed in 5 districts of Rajasthan, mainly through governmental agencies. There is no major private initiative as yet in Rajasthan for manufacturing and distributing DDUs.

Initially in the pilot project, DDUs were assembled by SWACH by procuring all necessary components except the AA, which was procured by UNICEF. SWACH concentrated on placing a stainless steel bucket with AA and a micro-filter placed on a stand as the upper filter chamber of the DDU. These DDUs were then distributed to households in the project area. SWACH also procured 500 DDUs from Maitri of Andhra Pradesh and went on to develop a special PVC container for a DDU with Sintex. Though PVC DDUs have been in use, SWACH did not view its popularisation as a commercial opportunity. Recently SWACH is in the process of establishing a Social Marketing Centre at Jaipur and are considering the commercial marketing of DDUs, at least recovering full cost.

SWACH operate 234 regeneration centres. While the centres operate at a reasonable level, some of them might not be satisfactory as regards handling of the hazardous chemicals used for regeneration.

In villages where all/most existing sources have been found with high fluorides, school roof top rain water harvesting systems have been established in 50 school with a traditional "Tanka", ground level storage tank. In such situations differential water use (drinking water from safe sources, water for other needs from high fluoride sources) has also been promoted with UNICEF assistance.

Department of Science and Technology have supported the development of a handpump based community defluoridation units based on AA.

[1]The defluoridation technique was named "Nalgonda" after a district in central Andhra Pradesh, known for high fluoride content in groundwater.

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