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Statistical model for performance analysis of DART –A steel wool based arsenic removal water filter installed in various affected villages

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Abstract
This paper reports the results of performance analysis of DART (DRDO Arsenic Removal Technology), a novel house hold water filter providing arsenic free drinking water to the people who are affected by arsenic poisoning of ground water. DART has been developed by DRDO, (Defence Research and Development Organization), India as an utmost required immediate solution to the arsenic affected population, and has also been validated as an economic, easy to maintain and low power consuming solution. These filters were installed in seven affected villages and evaluated in terms of their efficiency to remove arsenic from drinking water. The waste generated from the filter was converted to standard grade impermeable concrete blocks for its disposal complying with EPA's toxicity characteristics and leaching procedure (TCLP), for zero waste generation from construction industries. The primary users, mainly the ladies of the houses covered under this program were trained to operate and maintain the system. A statistical model has also been designed to automatically convert the raw data in a proper format data structure in order to carry out fundamental statistical data analysis by which the life span of the material used for the filtration has been predicted.

Keywords
Affected villages; arsenic removal; drinking water; filter; statistical analysis.

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Introduction

The heavy metal contamination of arsenic in groundwater is a burning problem not only in India but also in other parts of the world as well (Clancy *et al* 2013). Arsenic is known as a deadly poison which directly affects the human body (Pandey *et al* 2007) and may cause different diseases such as skin cancer, cancer of lung, liver, bladder (Chen *et al* 1988), kidney and prostate (Chen *et al* 1990). Numerous reports have clearly suggested that arsenic in drinking water may have adverse health effects (Banerjee *et al* 2013). Depending on age, sex, the dose or period of exposure, as well as the chemical composition of the contaminant, the degree of arsenic toxicity in human body may vary (Goel *et al* 2004). Recent estimates indicate that millions of population of the Gangetic belt of India and in Bangladesh have already been affected by arsenic poisoning (Mukherjee *et al* 2006). West Bengal is known to have very high levels of arsenic in groundwater (Das *et al* 1996) but now the problem is also spreading in other states like Uttar Pradesh (UP), Bihar, Assam, Manipur, Jharkhand, and Chhattisgarh (Acharyya *et al* 2007; Rahman *et al* 2009; Chakraborti *et al* 2013). Likewise, arsenic level in blood, hair and nails of the people from Ballia district of UP has been a concern for quite some time (Coleridge *et al* 2005). Besides India, many other

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countries such as Argentina, Bangladesh, Hungary, Mexico, Pakistan, Thailand and Vietnam are also known to have arsenic contaminated groundwater (Mukherjee *et al* 2006; Ahuja *et al* 2008).

According to WHO, the arsenic level in drinking water has a permissible limit till only 0.01 mg/l or 10 ppb (Yamamura *et al* 2004); whereas the data collected by WHO and several other organizations have shown the presence of as high as 0.05 mg/L - 5 mg/L of arsenic in water (http://www. vigyanprasar.gov.in/dream/jan2007/English-.pdf (accessed on 16/12/2014). Surprisingly, there has been no serious domestic or international attention to the issue of arsenic poisoning in different parts of India (http://stenvironment.com/images/DST%20Report.pdf (accessed on 15/12/2014). Considering widespread emergence of arsenic poisoning, there has been an urgent need to implement relatively simple and affordable arsenic removal technology in the affected backward areas of the country to supply pure drinking water to millions of people(http://stenvironment.com/images/report_on_life_saving_arsenic_removal_technology.PDF (accessed on 16/12/2014). Thus, as a part of the present study, indigenously developed DART (DRDO arsenic removal technology) based filters were installed in seven arsenic affected villages of three different states of India, viz., Bihar, Uttar Pradesh (UP) and West Bengal (WB), and the villagers were trained to operate and maintain those filtration units. Efficiency of those filters was monitored by regular field visits; whereas, the statistical analysis of raw data has been carried out by using a newly designed model to predict life span of the filter material.

Materials and methods

Specification of DART based water filter

DART based arsenic removal filter considered in this study uses steel wool as a reactant material and the principle of co-precipitation as well as adsorption is followed. The schematic of the water filter (patented technology) as shown in Figure1 along with its working principal and laboratory evaluation has already been reported in details elsewhere (Misra2004; D e b e t a l 2 0 0 8 ; h t t p : / / i n n o v a t e - i n d i a - org.webs.com/Day1_Session 2_Dr. Mishra.pdf (accessed on 15/12/2014, patents Indian No.221708, Vietnam1-2008-00790, UK 12065148). The filters are fabricated in stainless steel, clay and plastic and have been designed in two flow rates viz. 15 liters per hour (LPH) and 30 LPH. However, the 15LPH, stainless steel filters are much sturdier, durable. They are also easily acceptable and popular amongst the users (Figure2) and hence were used for the study. The technology has been transferred to S. B. Equipments, New Delhi and Shiva Engineering Pvt. Ltd Kolkata.

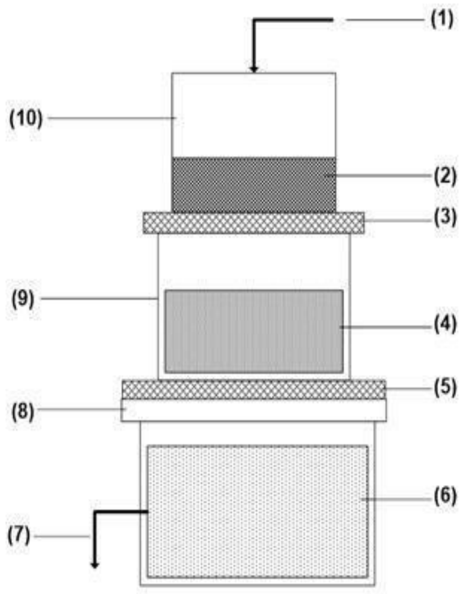

Figure 1: Arsenic removal filter assembly. (1) Inlet for Water, (2) Material as reactant, (3) and (5) Very Fine Cloth Filters, (4) Treated and separated Sand, (6) Clean Water,
(7) Water Outlet, (8) Container of cleaned water (9) Sand box, (10) Reactant Material box (Deb *et al*., 2008; Misra *et al*., 2008).

Figure 2: DART based water filters with a filtration capacity of 15 liters per hour (from left stainless steel, clay and plastic at right).

Salient Features of the Filters

Some of the main characteristic features of the filter are as given below.

- Requires no Power (electricity or battery)
- Maintenance free and sturdy
- Worthwhile

- Environmentally safe
- Easy to use
- Easy waste management

Analysis of arsenic in the water samples

Routine water sample analysis in the field was carried out using Merck field test kits and the results of arsenic analysis were further validated in the raw and filtered water samples as per standard ASTM (ASTM D2972 - 15) method (http://www.astm.org/Standards/D2972.htm) employing Hydride Generator (HG) attached to Atomic Absorption Spectrophotometer (AAS) at NABL certified laboratory, Indian Institute of Toxicology Research, Lucknow and Department of Geology and Environmental Systems management, Presidency University, Kolkata.

Maintenance of the filter

For maintenance of the filters, nothing is required except the periodic washing. The material and the sand which are present in the 1st and 2nd containers are placed in the filter material bags which can be easily removed and the regular washing of the stainless steel containers is very easy. The filters can be easily washed periodically, once a week using the filtered water. The same material and the sand can be used at least for two years and no replacement is required.

Villages considered for field study

The list of the seven villages selected for the field studies where the filters have been installed and data collected for their performance evaluation have been given below: -

- Rannuchak (District Bhagalpur, Bihar State, India),
- Tiwaritolla (District Ballia, UP State, India),
- Arbandi (District Nadia, WB State, India),
- Sahebdangapur (District Nadia, WB State, India),
- Harinadi (District Nadia, WB State India),
- Chandkuri (District Nadia, WB State India), and
- Nrisinghapur and (District Nadia, WB State, India).

Filter installation and data collection

Total 2100 filters were installed in the above-mentioned villages as per the following protocol

1. Firstly, the affected villages were made aware of the contamination problem in water by conducting awareness programs.
2. The family members especially ladies of some selected houses were trained for the operation and maintenance of the filters like how to use and take care of it.
3. The raw and filtered water testing was done on regular basis bythe use of field water testing kits.
4. Few of the randomly collected samples of source and filtered water were sent for testing at an authorized laboratory (NABL accredited).

Few pictures presented in Figure 3 give a glimpse of the afore said implementation program. Likewise, minimum and maximum arsenic concentrations in raw water in all the seven villages under study have been presented in Figure 4. Similarly, in Figure 5, number of families using filters and the total water volume consumed per family in the whole study period is presented.

Figure 3: Door to door survey, water tasting, operation and maintenance training.

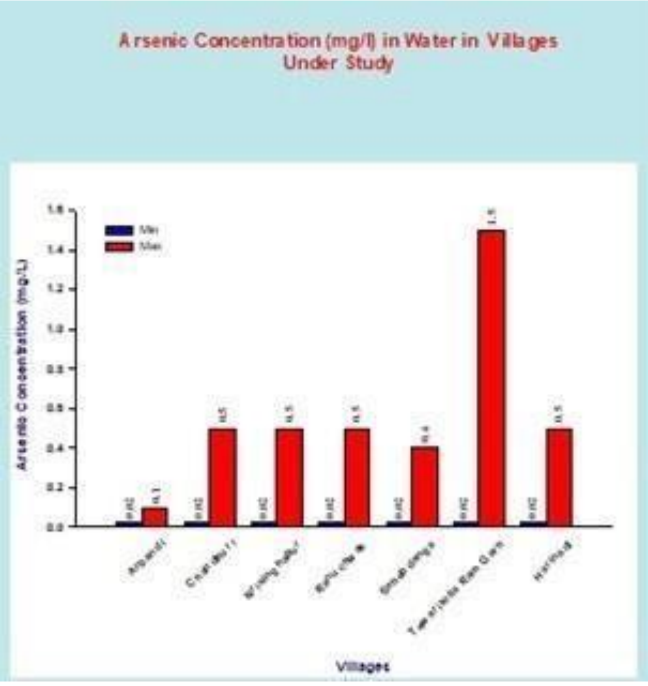

Figure 4: Minimum and maximum arsenic concentration in raw water in all the seven villages under study and

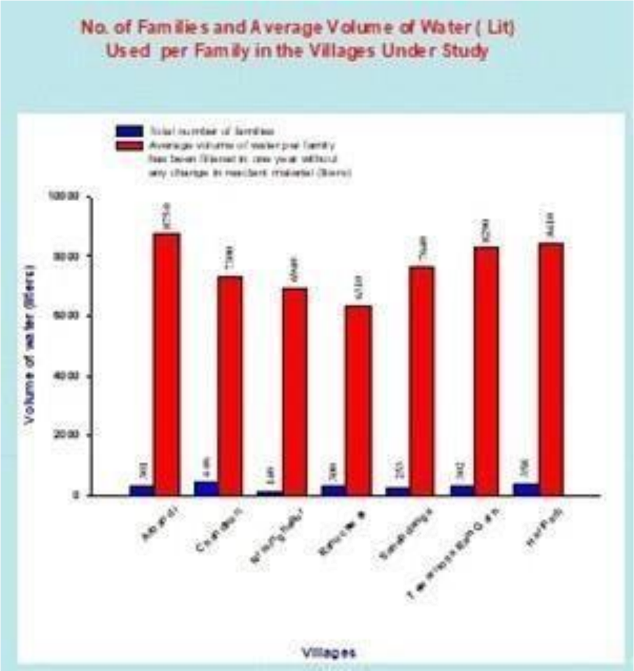

Figure 5: Number of families using filters and the total water volume during the study per family.

Results and discussion

Compilation of the raw data

For carrying out the statistical analysis, the format of the data has been designed and compiled from the raw data of the three main representative villages out of the above mentioned seven different villages under study for the evaluation of the efficiency of arsenic removal filter.

The format mainly deals with:

- A number of water samples collected in a village.
- Arsenic concentration in source water in mg/L.
- The volume of arsenic-free water used before 1st time maintenance (wash) of filter material.
- The volume of arsenic-free water used before 2nd time maintenance (wash) of filter material.
- The volume of arsenic-free water used before 3rd time maintenance (wash) of filter material.
- The volume of arsenic-free water used before 4th time maintenance (wash) of filter material.
- The volume of arsenic-free water used before changing the reactant material in the filter.

All these values are calculated from the date of installation of the filters which had been still working at the time of data collection. So, all raw data were compiled manually in step by step manner and arranged in the following format data structure that contains eight different fields as mentioned above. Schematic representation of the format has been given in Table 1. After compiling all raw data and arranging in the format data sheet (Table 1) that contains different parameters for different samples, every data sheet was saved in a Text file format. Compilation of all data generated standard data sheet for eight fields and operated on various statistical data analysis.

Table 1: Schematic representation of the format used to compile raw data for statistical analysis. Data field for the first sample from Tiwaritala village, Ballia, UP.

Sl. No.	Arsenic Level in raw water (mg/L)	Vol. of Arsenic free water used before 1st wash Filter-1 (Liters)	Vol. of Arsenic free water used before 2nd wash Filter-1 (Liters)	Vol. of Arsenic free water used before 3rd wash Filter-1 (Liters)	Vol. of Arsenic free water used before 4th wash Filter-1 (Liters)	Vol. of Arsenic free water before change material in Filter-1 (Liters)	Monthly consumption of Vol. of arsenic free water used (Liters)
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Statistical analysis of collected data (Ross *et al* 2009)

The data from the three villages namely Tiwaritala (Ballia, Uttar Pradesh), Ranuchwak (Bihar) and Arvandi (West Bengal) have been considered for the analysis. For Tewaritala village, the arsenic level (AL) data and the corresponding volume of water filtered till the change of material in the filter (CMF) have been taken into consideration and the interval plot, as well as the regression line, was drawn. 61 cases of data were available where the change of material had taken place. First interval plot has been drawn for this data and 95% confidence interval for each of the mean values of CMF (change of material in the filter) corresponding to each AL value. Since the sample size was small (less than 30), 95% confidence interval is:

$$\left[\bar{X} - \frac{S}{\sqrt{n}} t_{\frac{\alpha}{2}},\ \bar{X} + \frac{S}{\sqrt{n}} t_{\frac{\alpha}{2}}\right] \qquad \text{(Equation 1)}$$

Where α, $\bar{\chi}$ is the mean of sample and S is designated as standard deviation. Sample size denoted as n and is the value for random variable $t_{\frac{\mu}{2}}$ following student's t distribution

such that:

$$P(t > t_{\frac{\alpha}{2}}) = \frac{\alpha}{2}. \qquad \text{(Equation 1)}$$

It has been observed that in this case, for any value of AL sample size was small. The interval plot generated from this analysis has been presented in Figure 6. From this plot, it was observed that with respect to different arsenic levels the average filtered water volume until the change of material was more or less the same. On average, the filtered water volume until the change of material was approximately 25,000 liters.

Further, it was tried to fit within a regression line between AL and CMF by the least square method. As regression equation of the variable X on Y is given by:

$$y = \bar{y} + r\frac{S_y}{S_x}(x - \bar{x}) \qquad \text{(Equation 1)}$$

where $\bar{x}$ sample stands for the variable X and $\bar{y}$ is the sample mean for the variable Y, while sample standard deviations are S_x, and S_y corresponding to X and Y, respectively and r is the sample correlation coefficient.

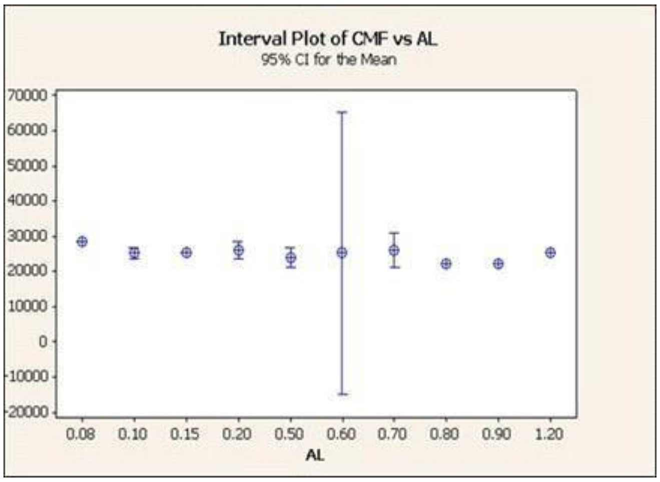


Figure 6: The interval plot of volume of water filtered till the change of material in the filter (CMF) vs. the arsenic level (AL).

The regression line between AL and CMF has been presented in Figure 7. From the regression line it has been observed that though the average volume of water till the change of material in the filter was more or less same with respect to different arsenic levels; as the arsenic level in water increases, the volume of water till the change of material gradually decreases. The correlation coefficient between AL and CMF is -0.108. The equation of the regression line has been given below:

CMF = (25494 - 1800 AL) .... (Equation 4)

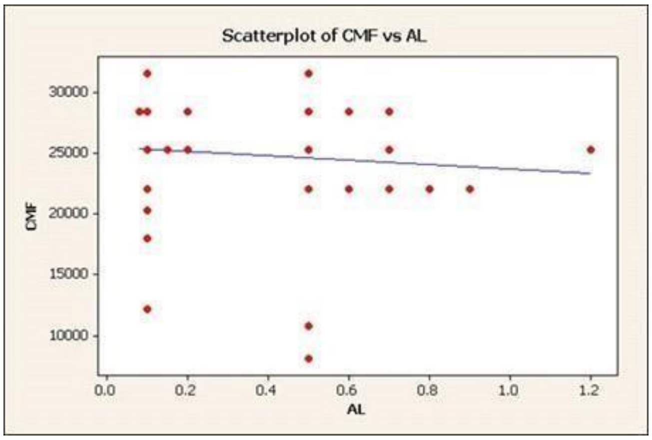
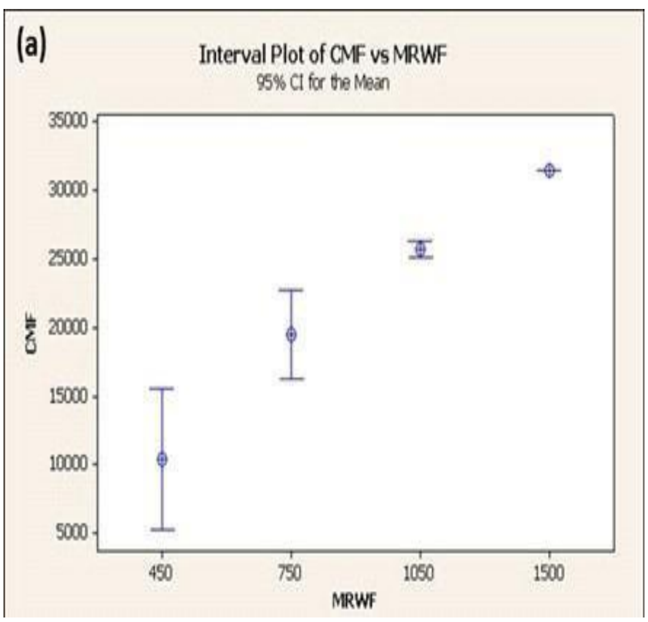


Figure 7: The regression line between the arsenic level (AL) and volume of water filtered till the change of material in the filter (CMF).

Likewise, the data of monthly average water volume filtered (MRWF) and the corresponding water volume filtered till the change of material in the filter (CMF) have been considered for the village Tiwaritala. The interval plot and the regression line between these two have been made and they have been presented as Figure 8a and 8b, respectively. Figure 8a describes the average value of CMF also increases with the increase in MRWF value. That means, more the water used regularly, more the volume of water filtered till the change of material. From the regression line presented in Figure 8b, it has been seen that there is a positive relation between two variables. That means if the average filtered water volume increases the filtered water volume till the change of material will also increase. The correlation coefficient between these two variables is 0.844; which means, there is a high correlation between these two variables. The equation of the regression line is given below:

CMF = (3596 + 20.7 MRWF)................................(Equation 5)



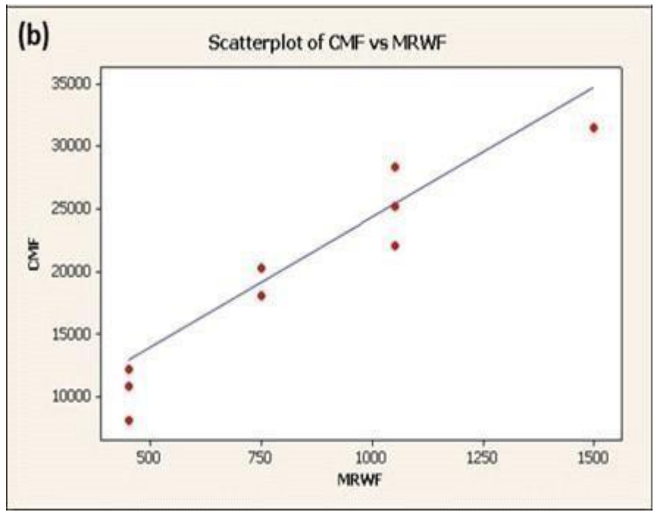


Figure 8a &8b: (a) The interval plot and (b) the regression line showing the relationship between MRWF and the corresponding water volume filtered till the CMF applicable for the village Tiwaritala.

In a similar note, for Arvandi village the data of MRWF and the CMF are considered. Only three data points were available for this analysis. Surprisingly, as shown in Figure 9, the three data points are collinear and there is a perfect positive correlation between the two variables. The correlation coefficient between MRWF and CMF is 1.000. The equation of the regression line in this case is:

CMF= (-0.00000 + 21.0 MRWF)… ....(Equation 6)

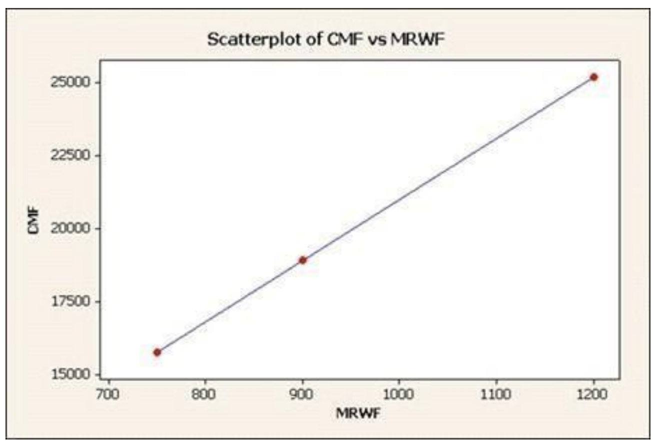


Figure 9: Regression line between the data of MRWF and the corresponding volume of water filtered till the CMF obtained for Arvandi village.

Results of the statistical data analysis were based on the data collection of three villages. Moreover, the data has been used from the filters where the material change has taken place and in most of the cases change of material was not required as they had been still working. The results clearly confirm that as the arsenic level (AL) increases in water the volume of arsenic-free water filtered till the material change in the filter (CMF) decreases slowly and as the monthly use of filtered water (MRWF) increases the volume of arsenic-free water used till the material change in the filter (CMF) also increases. It has been observed that there is an almost perfect positive correlation between monthly use of filtered water (MRWF) and the volume of arsenic-free water until the change of material in the filter (CMF). It is also found that as the arsenic concentration changes in water, the mean volume of water used until the change of material in the filter does not change much. From the statistical analysis it has been observed that if the initial arsenic concentration ranges between 0.01 to 1.2mg/L, the average life of the filter is about 2 years and the total volume of water filtered could be as high as about 25000 L. In Table 2, different literature reports on arsenic removal filters have been summarized. From this table, it can be concluded that the approach of the present study was different from already known methods and it has very good arsenic removal efficiency.

Table 2: A summary of As removal filters investigated

Sl. No.	Filter material	Filtration capacity	Flow rate	Influent arsenic concentration	Effluent arsenic	Reference
1.	Zerovalent iron and sand	90 L of water	1 L/h	440 µg/L	Below 50 µg/L	Leupin *et al.*, 2005 (a1)
2.	Coarse river sand with wood charcoal and Composite iron matrix, and Brick chips	-	20-30 L/h	1139-1600 µg/L	2-30 µg/L	Hussam *et al*., 2007(a5)
3.	Iron oxide-coated sand	-	1.29 L/h	500 µg/L	5 µg/L	Thirunavukkarasu *et al*., 2002 (a2)
4.	Steel wool and sand	25000 L of water	20-30 L/h	10-1200 µg/L	Arsenic free water	Present study (Patented)

Conclusions

Total 2100 filters developed by using novel DRDO arsenic removal technology (DART) were installed in 7 arsenic affected villages of 3 provinces of India. Principal users, the ladies of the families selected for this study, were trained to operate and maintain the filtration systems. The waste generated by the filter was disposed of in accordance with EPA's TCLP (toxicity characteristics and leaching procedure) protocol by using impermeable concrete blocks. From statistical analysis of arsenic removal data, it can be concluded that if arsenic concentration in input water ranges between 0.01 to 1.2 mg/L, the life of the arsenic removal filter based on DART is more than two years or the total water that can be filtered without changing the filter material is notless than 25000liters.

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References

Acharyya, S. K. & Shah, B. A. Groundwater arsenic contamination affecting different geologic domains in India—a review: influence of geological setting, fluvial geomorphology and quaternary stratigraphy. *J. Env. Sci. Health Part A.* 2007,42, 1795-1805.

Ahuja, S. Arsenic contamination of groundwater: Mechanism, analysis, and remediation. John Wiley & Sons, USA 2008.

Banerjee, M., Banerjee, N., Bhattacharjee, P., Mondal, D., Lythgoe, P. R., Martínez, M., Pan, J., Polya, D. A. & Giri, A. K. High arsenic in rice is associated with elevated genotoxic effects in humans. *Sci. Repo.* 2013,3, 2195.DOI: 10.1038/srep02195.

Chakraborti, D., Rahman, M. M., Das, B., Nayak, B., Pal, A., Sengupta, M. K., Hossain, M. A., Ahamed, S., Sahu, M. & Saha, K. C. Groundwater arsenic contamination in Ganga–Meghna–Brahmaputra plain, its health effects andan approach for mitigation. *Env. Eart. Sci.* 2013,70, 1993-2008.

Chen, C.J., Wu, M.M., Lee, S.S., Wang, J.D., Cheng, S.H. & Wu, H.Y. Atherogenicity and carcinogenicity of high-arsenic artesian well water. Multiple risk factors and related malignant neoplasms of blackfoot disease. *Arterioscl. Thrombo.Vasc. Biol.* 1988,8, 452-460.

Chen, C.J. & Wang, C.J. Ecological correlation between arsenic level in well water and age-adjusted mortality from malignant neoplasms. *Cancer Res.* 1990,50, 5470-5474.

Clancy, T. M., Hayes, K. F. & Raskin, L. Arsenic waste management: A critical review of testing and disposal of arsenic-bearing solid wastes generated during arsenic removal from drinking water. *Env. Sci. Technol.* 2013,47, 10799-10812.

Coleridge, S. T. Arsenic–India's health crisis attracting global attention. Cur. Sci. 2005,88, 683-684.

Das, D., Samanta, G., Mandal, B. K., Chowdhury, T. R., Chanda, C. R., Chowdhury, P. P., Basu, G. K. & Chakraborti, D. Arsenic in groundwater in six districts of West Bengal, India. *Env. Geochem. Health* 1996,18, 5-15.

Deb, P. C., Misra, K., Companywala, M. T., Srivastava, A.& Sharma, S. Filtering device for the removal of arsenic from water. 2008, Patent: UK 12065148.

Goel, R., Kapoor, S., Misra, K. & Sharma, R. Removalof arsenic from water by different adsorbents. *Ind. J. Chem. Technol.* 2004, 11, 518-525.

Hussam, A. & Munir, A. K. M. A simple and effective arsenic filter based on composite iron matrix: Development and deployment studies for groundwater of Bangladesh. *J. Env. Sci. Health Part A* . 2007, 42, 1869–1878.

http://innovate-india-org.webs.com/Day 1 _ Session 2 _ Dr% 20 Mishra. pdf (accessed on 15/12/2018).

http://stenvironment.com/images/DST%20Report.pdf (accessed on 15/12/2018).

http://stenvironment.com/images/report_on_life_saving_arsenic_removal_technology.PDF (accessed on 16/12/2018).

http://www.vigyanprasar.gov.in/dream/jan2007/English-.pdf (accessed on 16/12/2018).

Leupin, O., Hug, S. & Badruzzaman, A. B. M. Arsenic removal from Bangladesh tube well water with filter columns containing zerovalent iron filings and sand. *Environ. Sci. Technol.* 2005, 39, 8032-8037.

Misra, K., Companywala, M., Sharma, S., Srivastava, A. & Deb, P. A simple and environmentally safe process for arsenic remediation–laboratory and field evaluation. Proceedings of the Pre-Congress Workshop "Natural Arsenic in Groundwater", 32nd *International Geological Congress, Florence, Italy*, 2004, 273.

Misra, K., Kumar, S. & Kumar, V.A process for producing potable water. 2008, Patent No. 221708.

Mukherjee, A., Sengupta, M. K., Hossain, M. A., Ahamed, S., Das, B., Nayak, B., Lodh, D., Rahman, M. M. & Chakraborti, D. Arsenic contamination in groundwater: a global perspective with emphasis on the Asian scenario. *J. Health Popul. Nutri.* 2006, 24, 142-163.

Pandey, P. K., Yadav, S. & Pandey, M. Human arsenic poisoning issues in central-east Indian locations: biomarkers and biochemical monitoring. *Int. J. Env. Res. Pub. Health.* 2007, 4, 15-22.

Rahman, M., Naidu, R. & Bhattacharya, P. Arsenic contamination in groundwater in the Southeast Asia region. *Env. Geochem. Health.* 2009, 31, 9-21.

Ross, S. M. Probability and statistics for engineers and scientists, 4th edition. 2009, Elsevier academic press,. http:// ihome. ust. hk/~ zlong/ IELM 2510 / IELM 2510 textbook.pdf (accessed on 25/12/2018).

Thirunavukkarasu, O. S., Viraraghavan, T. & Subramanian, K. S. Arsenic removal from drinking water using iron coated sand. *Water Air Soil Pollu.* 2002, DOI: 10.1023/A:1022073721853.

Yamamura, S., Bartram, J., Csanady, M., Gorchev, H. G. & Redekopp, A. Drinking water guidelines and standards. World Health Organization, Geneva, Switzerland, 2004.