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Technology Transfer and Evaluation of ACI Arsenic and Pathogen Removal System for Safe Drinking Water Supply in the Pinal de Amoles Municipality of Queretaro, Mexico

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Abstract: Continuous consumption of arsenic adversely affects human's health. There are countless communities that depend on water containing arsenic in toxic levels, but which lack effective means to remove the contamination. The objective of this research is to test the efficacy of a low-cost filtering system designed by Aqua Clara International (ACI) to remove arsenic and pathogens. This system requires no external sources of energy nor any chemicals to treat the water. Seven systems were installed between 2016 and 2017 in remote and low-income villages located in the Sierra Gorda in Pinal de Amoles, Queretaro. The team comprised members of the Universidad Autonoma de Queretaro, the Council for Water at the State of Queretaro, the Health Council at the State of Queretaro and scientists from ACI. Water samples were analyzed in the field using a Rapid Arsenic Testing Kit and were compared against the analysis made to the samples in a certified Laboratory. Results indicate that ACI's filters work properly in the field, there was no presence of arsenic once the water was treated by the installed systems, and the Rapid Arsenic Testing Kit may be used in the field because of its sensitivity to and precision for arsenic concentration.

Keywords: arsenic water treatment; filtration; hollow membrane; media filters; rural communities

1. Introduction

World-wide concerns about water quality have grown while at the same time there has been a decrease of water available for human consumption. When the water services and sanitation are insufficient, inappropriately managed, or even nonexistent, a population is exposed to preventable risks to their health. In addition, heavy metals represent a considerable added risk for the health and environment [1].

Arsenic is listed among the top ten chemicals of public health concern [2]. As it is considered carcinogenic for humans. In certain regions, epidemiological evidence shows health alterations due to the constant consumption of water contaminated by arsenic that affects the respiratory, the gastrointestinal, the cardiovascular, and the nervous systems [3].

Inorganic arsenic has been shown to be naturally present at high levels in various countries, but among them, Argentina, Bangladesh, Chile, China, India, Mexico, and the United States have the highest concentrations [2,4,5]. In Mexico, some states have shown data for arsenic concentrations above standard levels: Nayarit, Chihuahua, Veracruz, Puebla, San Luis Potosi, Hidalgo, and Nuevo

Leon [6-7]. Regrettably, in many places the only source of available drinking water contains dissolved arsenic (As) in toxic levels [8]. This condition prompted the current study to evaluate a removal mechanism.

There are various methods used to remove or reduce arsenic levels based on chemical processes applied alone, simultaneously, or sequentially. Among them are: oxidation reduction, coagulation-filtration, coagulation-filtration combined with oxidation with non-thermal plasma, coagulation-flocculation, precipitation, electrocoagulation, adsorption, ion exchange, liquid and solid phase separation, physical exclusion, use of solar zero-valent iron, membrane technologies, and biological processes [8-13]. Some methods have only been applied in the lab, and researchers have concluded that the reliability of the technology and the laboratory analysis are mandatory, before any field application is attempted [14,15]. Other solutions have been developed, applied and evaluated in different locations and circumstances; regrettably, such solutions are located in either rural or urban areas with centralized water supply systems or are only applied at household scale.

In Latin American countries, among them Mexico, many populations depend on water that contains arsenic in toxic levels; these communities are generally located in rural or peri-urban areas. These places are highly or very highly marginalized and remote; in addition, their members are dispersed about the geographic area.

Documentation of the arsenic contamination in Mexico and the state of Queretaro has concluded that some aquifers of the state are naturally polluted, while others are anthropologically polluted due to mining [16]. Future research is required to determine the nature of the contamination source of each aquifer. It is imperative to implement local systems of purification in marginalized areas that allow the population access to non-contaminated water to be used for drinking, cooking and basic hygiene at a lower cost than the commercial applications available in developed areas.

The purpose of the project was to evaluate the efficacy of the installations of hydraulic systems developed by Aqua Clara International (ACI), a non-governmental organization (NGO) of the USA. These systems rely on gravity to move water through their filters; they do not require external sources of energy or any chemicals to purify water by removing mainly arsenic and pathogens present in the water. The results of seven installations carried out in the municipality of Pinal de Amoles, Queretaro during 2016 and 2017, and the evaluation data of each site is presented. Therefore, analyses of raw water and purified water where obtained. Likewise, a Rapid Arsenic Test Kit was used in the field and its results are compared against results obtained in a laboratory.

2. Materials and Methods

2.1. Study Zone

Queretaro has 18 municipalities, with 2 038 372 habitants, of which 70% correspond to the urban area and 30% to the rural area. The 51% of the state's surface has a dry and semi-dry climate located in the central region, and the rest has a sub-humid warm climate (located in the Sierra Madre Oriental) and sub-humid temperate climate (located in the south, center and northeast of the state) [17].

The state of Queretaro is in 16th place in Mexico for levels of marginalization; it represents 17,601 people living in 215 low-income communities. Most of the areas have problems with drinking water shortages due to their isolation from the developing cities. Also, the water available usually contains bacterial and other harmful contaminants.

The communities that received the technology developed by ACI belong to the municipality of Pinal de Amoles (Figure 1), part of the mountainous region known as the Sierra Gorda. The municipality located at 153km from the state’s capital, in the northern region of the State, in a mountainous area with steep slopes, plains and plateaus, and 1,200 switchbacks from the main highway. It has an extension of 705.4km^2, which represents 6.04% of the state’s surface. In 2015, Pinal de Amoles was categorized with a high degree of poverty, as a high rural priority area of attention and was in the first place of degree of marginalization (it has the highest degree), compared with the rest of the municipalities of the state of Queretaro [18]. The main areas to focus include improving household water access and drainage services and reducing educational lagging.

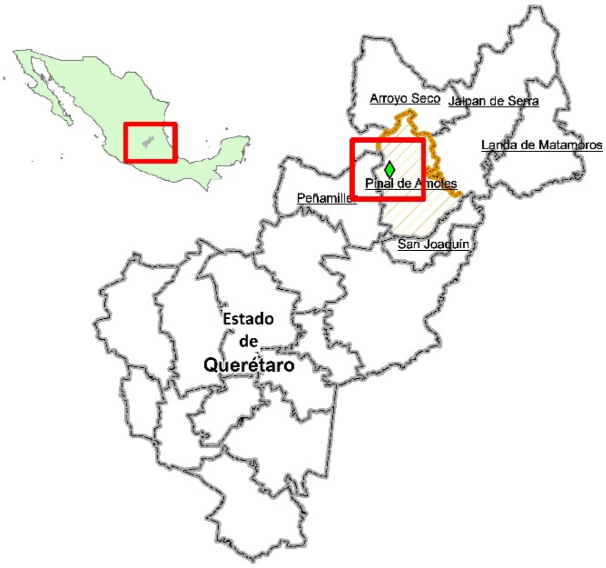

Figure 1. Location of the municipality of Pinal de Amoles.

2.2. Technology of Aqua Clara International (ACI)

The Universidad Autonoma de Queretaro (UAQ) and Aqua Clara International (ACI) headquartered in Holland, Michigan, USA, have an agreement that promotes the transfer of ACI technology to the UAQ so its members, teachers, technical personnel, and students, have the capability to serve as the source for providing drinking water to the inhabitants of the state of Queretaro.

The ACI technology is the result of four years of laboratory experimentation followed by validation studies in the field. Aqua Clara's laboratory is contained in the Michigan State University Bio-economy Institute; in addition to its engineers and scientists, the university assigns an analytical chemist to the Aqua Clara team. The initial formulation of the technology's media was developed in the Aqua Clara laboratory and confirmed by field testing in Nicaragua [19], removing arsenic contamination levels from 45ppb to 0-1ppb. Further laboratory refinement of the technology, based on these field studies, resulted in subsequent field testing through systems installed in schools in the Nalbari region of Assam, India [20], where arsenic concentrations up to 150ppb, are present in ground water accessed via wells. The application of the ACI technology resulted in final concentrations of 0-1ppb. Finally, the partnership of Aqua Clara and UAQ led to field tests of revised systems in Queretaro, resulting in both school and household units now being installed in multiple locations in both Mexico and Nicaragua, with Aqua Clara responding to requests for the technology from additional countries.

The systems for arsenic and pathogen removal installed in this research have three stages: The first stage is the pretreatment, where via a sand pre-filter the coarse particles and parasites are removed and turbidity is reduced. (Due to the quality of the incoming water sources, the sand pre-filter was only needed to be installed in two of the communities.) The second stage consists of moving the water through pathogen removing filters. Here, water passes through a 75 micron roughing filter of 75 microns, and then through two hollow membrane filters 250mm-long of 0.1 microns which retain microorganisms (Figure 2). The hollow membrane filters have a pore diameter smaller than the typical size of the bacteria, which is 1-3 microns, obtaining a removal efficiency of 99.9999% of bacteria.

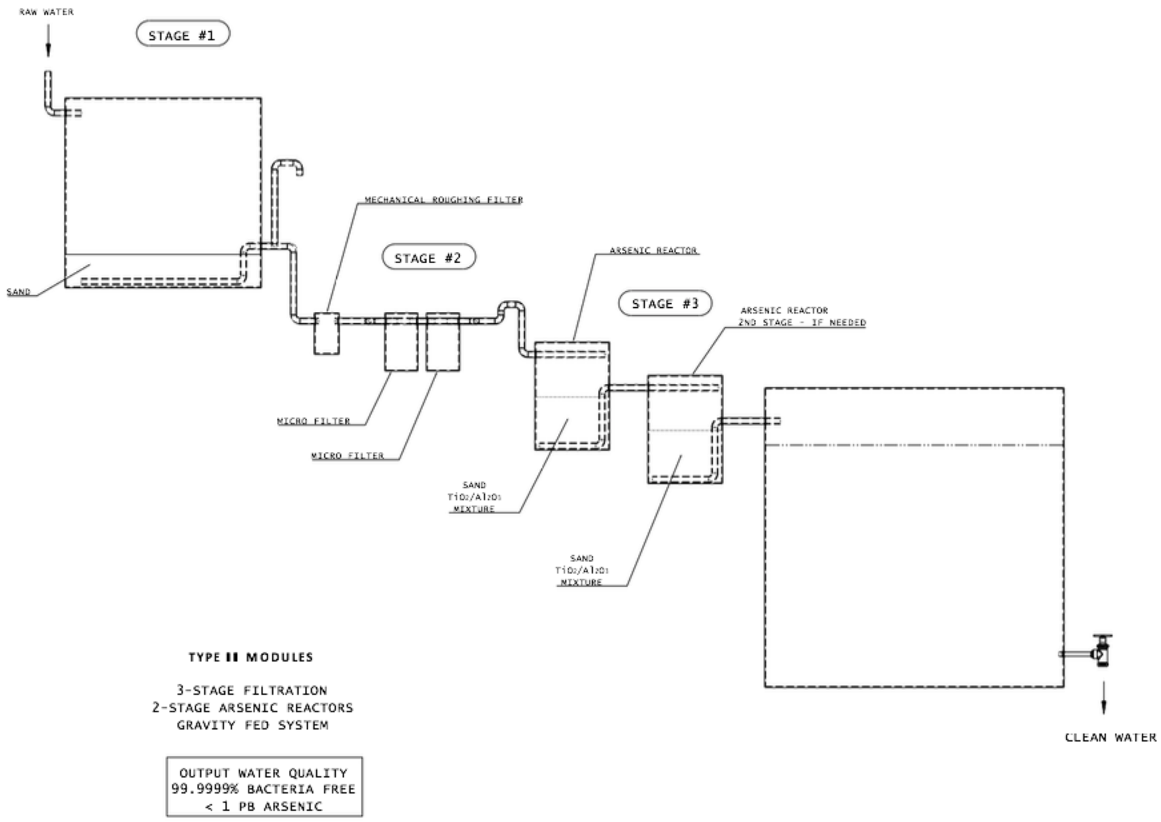

Figure 2. Three stage manifolded bacterial/arsenical removal system.

In the third stage, the water passes through a volume of 0.02 or 0.04m^3 of an adsorbent media, which consists of agglomerated nanoparticles of titanium dioxide (TiO_2), supported by two grades of silicon dioxide (Figure 2). The TiO_2 adsorbs the arsenic or any heavy metal and retains it while the water passes through the media. This compound is also a disinfectant and could remove bacteria too, but because such removal is accomplished by the hollow membrane filters, the media can be focused on the removal of arsenic. Finally, the water flows by gravity to a storage tank, which has a faucet at the bottom for filling clean and dry containers.

The amount of media that is placed in the system depends on the concentration of arsenic in the water and the projected daily usage. This system has demonstrated that it can remove arsenic amounts up to 1000ppb in laboratory testing designed by ACI at Michigan State University.

The filter media is calibrated to be used for at least during two years, considering the remoteness of the target villages. At the end of this period, the media is replaced; it is certified by the U.S. EPA to not leach out the arsenic retained. Once depleted, it can be safely placed in landfills or otherwise discarded.

This project was feasible with the support of teachers and students of the School of Engineering of the UAQ, and scientists of Aqua Clara International. Besides them, personnel of the National Council of Water (CONAGUA) served as witnesses of the systems installed, and personnel of the Health Council at the State of Queretaro (SESEQ) were responsible for the first contact with the communities and follow-up visits to the installed systems in Pinal de Amoles, Queretaro.

3. Results and Discussion

The seven systems were installed at locations in Pinal de Amoles with populations ranging from 185 to 580 habitants, usually installing two systems per visits since March 2016 and until April 2017. Due to confidentiality of data, the names of the communities are not presented in this article.

In these target communities, alternative sources of water are available. However, its habitants report that such sources are intermittent or, due to the dispersion of the households, it is not feasible to supply all the houses with such sources.

Once the systems were installed, samples of water before and after treatment were taken. In field the Quick Rapid Arsenic Test Kit was used in order to obtain results in 17 minutes, and all analysis were made in duplicate. This kit has been used in the field by ACI's scientists and is manufactured by Industrial Test Systems, Inc., an American company located in South Carolina. Other samples were analyzed in a laboratory certified by the Entidad Mexicana de Acreditacion, A.C. (EMA): Ingenieria y Estudios Ambientales, S.A, de C.V. (INESA) of Queretaro.

Table 1, shows the results obtained by the two analysis methods during the installation phase of the project. The Rapid Arsenic Test Kit has a strip which is colored and compared against a table of colors Easy-Read where white is 0 and 0.005mg/L is the first color, so the results table was written a value of <0.004mg/L, if the strip was not colored. For the community C, due to the color being slightly darker than 0.010mg/L, the researchers opted for a value of 0.011mg/L. The correct operation of the removal of arsenic in the last four locations could not be detected. In D, the filling tank was connected to an alternate spring instead of that the source that is allegedly contaminated. In E, the water is stored in an open storage dam and there was rain the week prior to the installation, and locations F and G also appeared to be affected by rains which diluted the source surface waters.

Table 1. Arsenic values at ACI technology installation phase in selected communities in Pinal de Amoles, Queretaro, Mexico.

Community	Inflow (mg/L)		Outflow (mg/L)	
	Kit	**Lab**	**Kit**	**Lab**
A	0.500	0.500	0.005	0.007
B	0.020	0.017	< 0.004	< 0.005
C	0.011	0.012	< 0.004	< 0.005
D	< 0.004	< 0.005	< 0.004	< 0.005
E	< 0.004	< 0.005	< 0.004	< 0.005
F	< 0.004	< 0.005	< 0.004	< 0.005
G	< 0.004	< 0.005	< 0.004	< 0.005

Community A has been given more importance due to 120 arsenic poisoning cases presented in 2015, the highest arsenic concentration levels detected and its remote geographic location. For this location, two sets of pre-treatment water were obtained. The first set generated through use of the Quick Rapid Arsenic Test Kit, was judged to be at approximately 0.35mg/L. An approximation was necessary as the test results are shown in gradations of color on kit's Easy-Read Color Chart, in this case one color level was 0.30mg/L and the next was 0.40mg/L. Judging the color on the test strip, which appeared to be midway between the two colors, yielded the 0.35mg/L estimate. The water sample taken at the same time and analyzed by the Queretaro laboratory produced a result of 0.34mg/L or 340ppb. The second set of measures was obtained two days after the first set when the system installation was to be completed, see Table 1. The arsenic contamination level identified through use of the Quick Rapid Arsenic Test Kit and samples were analyzed by the INESA laboratory are shown in Table 1. In January 2018, water was once again analyzed in the field obtaining 0.10mg/L arsenic concentration. Results obtained between 2015 and 2018 show a constant fluctuation of the arsenic concentrations, reinforcing speculation that rain/drought cycles affect water contamination levels.

Communities D, E, F, and G had high levels of arsenic reported by governmental agencies, the reason they were included in this initiative. The water source has been tested by the researchers once in October 2016. Field and lab testing indicate values above 0.50mg/L and 0.531±0.071mg/L, respectively. It is speculated that the aquifers supplying the source water in these communities may be affected by periodic weather or other natural changes; this speculation will be the basis for further research.

Regarding pathogen removal, water was analyzed regarding total and fecal coliforms; inflow and outflow results show no presence of total and fecal coliforms except for community E (240 most-probable number MPN/100 mL, 43MPN/100 mL, respectively, were identified in the inflow and no presence was detected at the outflow); therefore, no tables are presented regarding these results.

Afterwards, follow-up evaluation of the installed systems in May 2018 occurred using the Quick Rapid Arsenic Test Kit in the field (Table 2). Results indicated that over time the systems are still working as expected. The system installed in community A presented better results than the initial installation, due to the addition of a cascading system of two media reactors installed in January 2018 to ensure maximum arsenic removal.

Table 2. Arsenic values at ACI technology follow-up evaluation phase in selected communities in Pinal de Amoles, Queretaro, Mexico.

Community	Inflow (mg/L)	Outflow (mg/L)
A	> 0.500	< 0.004
C	< 0.004	< 0.004
F	< 0.004	< 0.004
G	0.005	< 0.004

The UAQ researchers responsible for the technical implementation of the systems developed their experience through ACI training as part of the transfer and adoption process of the technology from ACI in Queretaro. As part of the training process, identification of the affected communities was done with the priority defined by personnel of the SESEQ and the CONAGUA. Training was provided twice a year by ACI personnel. An initial visit was done to each community with support of the SESEQ ensuring the cooperation of the inhabitants and a preliminary diagnosis of the arsenic levels and pathogens was required due to the lack of information available. The turbidity and arsenic concentrations present the water guided the design of the system, including the size of the As reactor and the need for a pre-filter. Once the system was installed, a final installation diagnosis was made; therefore, samples are taken to be evaluated with the Rapid Arsenic Testing Kit and at the laboratory. When required, due to the levels of As, the amount of media was increased, placing an additional As reactor in a cascading fashion. To ensure the transfer of the system to the community, their members were trained on how to correctly use and maintain the system, which consists in the backwash of the filters located in the second stage of the treatment. Finally, follow-up evaluation is made in order to warranty the correct functioning of the system.

The project that led to this paper depends on the inter-institutional team that allows the problem of Arsenic in drinking-water supply to be approached from different areas of expertise. As indicated in the paper, the work involved inter-disciplinary, inter-sector and inter-institutional collaborations. Aside from the benefit of water quality issues to be resolved from different areas of expertise, incorporation of varied relevant stakeholders to serve as witnesses for sustainable technology adoption by the end-users. The ACI technology, from the outcome of this work indicates that water quality management of drinking-water sources can be improved upon the inter-institutional approach may also facilitate, among others, funding and roles sharing; technology development, research – such as studies into feasibility, efficiency and adoption protocol – and technology transfer. Therefore, it is possible to have new sources of funding and scale the impact to benefit even more people with low-cost technologies to safeguard the general public health.

4. Conclusions

This study confirmed that the ACI technology had been properly transferred to the Universidad Autonoma de Queretaro and was implemented successfully by the inter-institutional team and continues to be generating non-contaminated drinking water in six of the seven communities of the state of Queretaro that had significant levels of arsenic present in their source water. (The system that is not currently in use is due to alternative water sources installed by the government for the community, which is now the only available water source for this community since the project started in 2016.) There was no presence of arsenic and pathogens once the water was treated by the installed systems. Further, through testing performed at an accredited laboratory, this project confirmed that the Rapid Arsenic Testing Kit is an appropriate field test because its sensitivity to and precision for arsenic concentration mirror that of a certified laboratory.

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Conflicts of Interest: The authors declare no conflict of interest.

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