Chapter

# A Call to Action: Incentivizing Arsenic Remediation

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## Abstract

Arsenic is a threat to human health. Long-term Arsenic exposure can lead to numerous cancers and non-carcinogenic diseases. Over 230 million across 107 countries are drinking groundwater Arsenic concentrations above the maximum concentration limit of 10 μg/L. The number of affected individuals is expected to rise in parallel with a growing dependence on groundwater, driven by diminishing surface water quality and quantity. A growing number of people will come in contact with Arsenic-contaminated water at new locations, while excessive pumping, geogenic processes, and industrial sources raise Arsenic concentrations at active groundwater sites. It is time to begin implementing Arsenic remediation techniques to save human lives, boost the global economy, and instill the foundations of a global collaborative framework. The continued research and development of remediation technologies is crucial, but these technologies will remain ineffective unless implemented. This chapter reviews the ongoing Arsenic crisis and suggests a simplified plan of action for resolving this problem. This is a transcontinental endeavor, which must begin with world leaders identifying and engaging new stakeholders. This will require education and awareness campaigns to boost involvement of the public sector, private sector, and the general public.

**Keywords:** Arsenic remediation, human health, groundwater, contamination, developing nations, incentives, water strategy, global collaboration



## 1. Introduction

Globally, there is a growing dependence on groundwater for drinking water, agriculture, sanitation, energy, and industrial processes. The rise in groundwater use is driven by a loss of quantity and quality of surface water sources, such as lakes and rivers. Surface waters are replenished by precipitation, groundwater recharge, and runoff from other water bodies. Quantity is reducing because of increased evaporation rates caused by global warming, increased population demands, and inefficiencies within water infrastructure and agricultural irrigation. Quality is worsening due to industrial and agricultural pollutants, and higher salinity caused by increased evaporation rates (salt constituents remain as surface water evaporates). Surely, groundwater is a practical substitute where surface water is diminishing, but its excessive use brings several challenges.

First, groundwater does not replenish as quickly as surface water; it relies on the vertical seepage of surface waters through permeable ground. Therefore, long-term pumping will lead to a shortage of groundwater, and a further shortage of surface waters which rely on recharge from groundwater sources.

Second, a continued loss of groundwater can lead to land subsidence. This is when land begins sinking due to a loss of supporting water weight beneath it [1]. In the United States, groundwater depletion rates continue to rise and overstress aquifers in both arid and non-arid regions [1]. The U.S. Geological Survey (USGS) approximated 1000 $km^3$ of groundwater depletion between 1900 and 2008, with an average depletion rate of 9.2 $km^3$ per year [1]. But, between 2000 and 2008 alone, the average depletion approached 25 $km^3$ per year [1].

And third, excessive or new groundwater use raises the likelihood of accessing contaminated drinking water. Excessive pumping may cause saline groundwater to migrate inland and upward, resulting in contaminated water supply [1]. Geogenic and industrial groundwater contaminants can, likewise, migrate to current pumping sites, or be encountered when pumping from new sites already hosting such contaminants. In either case, whether the site is old or new, growing groundwater dependence raises the likelihood of human, animal, and plant exposure to contaminants.

Geogenic contaminants are ones which originate from rock materials, through weathering processes that lead to their deposition into an aqueous phase, via natural soil/rock-water interactions [2]. According to the Environmental Protection Agency (EPA), common geogenic contaminants include Iron, Manganese, Chlorides, Sulfates, radionuclides, Fluorides, and Arsenic [3]. It is acknowledged that Fluoride and Arsenic are the two most widespread geogenic contaminants, affecting millions of lives across the world [2]. The latter of these is the primary focus of this chapter.

Due to its wide distribution across Earth's crust, at an average concentration of 5 mg/kg [4] (existing in over 300 known minerals such as Arsenopyrite, Cobaltite, Enargite, Gersdorffite, Löllingite, Orpiment, Pyrite, Realgar, and Tennantite [5]), over 90% of the world's Arsenic pollution comes from geogenic sources [6]. The remaining near-10% of pollution is assumed to come from industrial processes or products: mining activities [4]; preserved wood products [7]; pharmaceutical, glass, microelectronic, and optical industries [7]; and historical use in pesticides and insecticides [7].

Arsenic enters groundwater through mechanisms of weathering, oxidative and reductive dissolution of As-bearing minerals, and competitive exchange of As by other compatible ions like Nitrate, Phosphate, and Bicarbonate [6]. These mechanisms are influenced by pH, presence of organic matter, microbial activity, water table and sediment saturation, groundwater flow direction, topography, and marine transgression [6].

The constant presence of environmental Arsenic is a threat to human health. It is amongst other dangerous contaminants and water-borne diseases which severely stunt the growth of developing nations. Addressing the Arsenic crisis is in our best interest. This is a water problem worthy of attention, since it is expected to worsen with growing global groundwater dependence. In focusing our attention on Arsenic, we can gain experience in water problem solving and global collaboration. The takeaways of this experience are guaranteed to help us resolve other complex problems, such as those addressed by the United Nations (UN) Sustainable Development Goals.

## 2. Arsenic is a threat to human health

Chronic Arsenic exposure causes a number of severe health issues, both carcinogenic and non-carcinogenic. Arsenic exposure can lead to skin cancer, lung cancer, bladder cancer, liver cancer, prostate cancer, leukemia, neurobehavioral abnormalities, diabetes, skin disorders, cardiovascular diseases, and pregnancy complications (e.g. fetal mortality and preterm birth) [8]. Arsenic contamination in water contributes to contaminated soils, agricultural products, and fish, which all further raise the probability of oral ingestion [8].

The majority of Arsenic toxicity in humans is due to inorganic compounds containing pentavalent $As^{5+}$ and trivalent $As^{3+}$ [8]. The $As^{5+}$ form is capable of replacing Phosphate in a number of biochemical reactions, due to its similar structure and properties [9]. Meanwhile, the $As^{3+}$ form is 2 to 10 times more toxic than $As^{5+}$, since it suppresses the activity of over 200 enzymes while bonded with thiol (—SH) groups, affecting the functions of numerous body organs [8].

Key epidemiological evidence regarding Arsenic's carcinogenicity has come from studies conducted in Taiwan, Bangladesh, Chile, and Argentina, where people regularly consume drinking water containing high Arsenic concentrations of 150 μg/L [8]. Scientists have identified unconsolidated sedimentary aquifers, located within younger orogenic belts, as the most highly concentrated sources of groundwater Arsenic [6]. The largest of these orogenic belts are along the entire western coasts of North and South America, and through the top of Africa, southern Europe, central Asia, and South Asia [6].

In February 2018, the World Health Organization (WHO) published a fact sheet on Arsenic [10]. It was estimated that 140 million people across 50 countries drank water with Arsenic concentrations that exceed the maximum concentration limit of 10 μg/L [10] (before 1993, the permissible limit was 50 μg/L [6]). In May 2021 however, a focus paper published to *Geoscience Frontiers* reintroduced that estimate as 230 million people across 107 countries [6].

Of course, the continuity of weathering and industrial process contributes to higher Arsenic content in soil and water. But, the drastic rise in estimated Arsenic-impacted people, from 2018 to 2021, is less likely due to pollution than it is groundwater usage. Our growing dependence on groundwater use, which hydrogeologists refer to as the "Silent Revolution" [11], will contribute to new cases of Arsenic exposure—through excessive pumping at current pumping sites, and Arsenic encounters at new sites.

Currently, Asia and Europe are the most impacted by Arsenic contamination, with 32 and 31 countries affected, respectively [6]. Next come Africa (20 countries), North America (11 countries), South America (9 countries), and Australia (4 countries) [6]. Of the 230 million people affected, 180 million live in Asian countries such as Bangladesh, Pakistan, India, China, Nepal, Vietnam, Thailand, Burma, and Cambodia [6]. This is in stark contrast to 2.1 million people affected across 25 states of the U.S.A. [12].

Withal, every country on Earth can benefit from swift government actions that trigger Arsenic monitoring and remediation.

## 3. Arsenic determination, monitoring, and remediation

We must develop strategies to avoid and alleviate the impacts of Arsenic groundwater contamination. In areas where drinking water contains elevated concentrations, the immediate course of action is to find a safer source of water [13]. If a cleaner source is unavailable, Arsenic removal is recommended [13].

### 3.1 Arsenic determination and monitoring techniques

Each time a new groundwater (or surface water) source is considered, it must be checked for the presence of contaminants or pathogens. The preceding step to groundwater monitoring and remediation is determination. Determining the concentrations of various Arsenic species will guide informed decisions on how to track Arsenic movement, and ultimately, which removal technique to employ.

Known Arsenic determination techniques include Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and High-Performance Liquid Chromatography (HPLC) [14]. These techniques contribute to sampling data that tracks the concentrations and types of Arsenic species (Arsenate and Arsenite) found in water. Arsenate and Arsenite may also be found in soil, along with four soil-Arsenic species: Monomethylarsonic Acid, Dimethylarsinic Acid, Arsenobetaine, and Arsenocholine [14]. Soil species are important to consider because they can migrate into groundwater.

Groundwater monitoring is carried out by special instrumentation in monitoring wells. Example instruments include electronic steel tapes, pressure transducers, and automatic dataloggers, amongst others [15]. These instruments provide information on water level, conductivity, temperature, saltwater intrusion, and aquifer properties, making them a useful asset in testing for pollutants [16].

However, due to time and financial constraints, it can be difficult to perform consistent monitoring across large areas over time [17]. For this reason, Geographical Information Systems (GIS) software has proven highly useful for Arsenic concentration mapping, over large spatial and temporal scales [17].

Several GIS interpolation methods (Inverse Distance Weighted (IDW), Ordinary Kriging (OK), and Empirical Bayesian Kriging (EBK)) have demonstrated successful application towards groundwater monitoring data in the U.S.A. [17]. One local-scale case study (~900 $m^2$) indicated OK as the most accurate method for predicting Arsenic concentration fluctuation over a 9-month period [17]. Interpolation methods will become an increasingly fundamental part of pollutant monitoring, but will still require in-person sampling to ensure their calibration.

#### *3.1.1 Significance of monitoring at the global scale*

In parallel with contaminant monitoring, our awareness of groundwater withdrawal is exigent. Globally, we must track our water usage to remain informed of its availability.

In his book *Corporate Water Strategies*, Water Foundry CEO William Sarni points to the importance of water-footprinting. Water-footprinting is, essentially, the practice of water accounting [18].

Under the European Union (EU) Water Framework Directive (WFD), Spain was the first country to take advantage of water-footprinting, so it may develop a transparent and multidisciplinary framework for water-policy decisions [18]. Considering the world's growing dependence on groundwater, it can be understood why water-footprinting will become an imperative practice.

The following is a list of six potential water-footprinting tools to explore: Water Footprint Network (WFN), International Standards Organization (ISO) 14046, World Business Council for Sustainable Development (WBCSD) Global Water Tool, Global Environment Management Initiative (GEMI), Water Initiative (General Electric, Water Resources Institute and Goldman Sachs), and Corporate Water Gauge – Center for Sustainable Innovation [18].

Ideally, in the age of Big Data, the culmination of continued water research will grant superior water management capabilities. The growing availability of information and discoveries in fields of hydrogeology, climatology, astronomy, physics, biology, chemistry, and human activity will improve our analytical and predictive methodologies for multi-faceted problems. In the context of water, this will translate to pinpoint accuracy of water resource availability and quality, and contaminant fate and transport.

### 3.2 Arsenic remediation techniques

The global Arsenic crisis can be solved by implementing a combination of existing remediation techniques, at both active and prospective groundwater sites.

To date, a vast number of Arsenic remediation techniques have become well-documented, and continue to grow more efficient. These include conventional techniques, as well as emerging innovations in nanotechnology, and fully sustainable approaches.

#### *3.2.1 Conventional remediation techniques*

Conventional techniques are those which have the longest history of field use. These include: (1) oxidation, (2) coagulation-flocculation, (3) adsorption, (4) ion exchange, and (5) membrane filtration [19].

(1) Oxidation is an often-necessary preceding step for removal. Oxidation converts the trivalent Arsenite ($As^{3+}$) form to the pentavalent Arsenate ($As^{5+}$) form [18], to promote its extraction from groundwater.

Arsenite extraction by means of adsorption and precipitation is difficult, since it is non-charged at pH levels below 9.2 [19]. Arsenate is favorable because of its propensity to adsorb onto solid surfaces, and co-precipitate with metallic cations [13]. Due to the nature of these two Arsenic species, many treatment techniques incorporate a two-step approach with an initial oxidation step, followed by removal [19].

Numerous oxidizing agents can be used: atmospheric Oxygen, Hypochlorite, Potassium Permanganate, UV radiation, and even bacteria (e.g. chemoautotrophic Arsenite-oxidizing bacteria) [19]. Atmospheric Oxygen is frequently used in developing countries, due to its low cost and abundance [20], but it is also very slow, often taking hours or weeks to complete [19].

(2) Coagulation-flocculation is one removal option following oxidation. Positively charged Alum or Ferric agents are incorporated to neutralize the opposing forces which separate colloidal particles [20] (i.e. Arsenic ions dispersed in groundwater). This leads to the formation of larger particles, or flocs, which bind together and clump up as agglomerates [20]. Throughout this process, Arsenic gradually takes the form of an insoluble solid that becomes available for precipitation [19].

Northern Chile has been removing groundwater Arsenic with this approach since 1970 [13]. Through continued research efforts, coagulation-flocculation has become highly effective. It is possible to reduce Arsenic concentrations from 400 μg/L to 10 μg/L, at a rate of 500 L/sec [13]. Still, a major drawback of this technique is the production of large sludge quantities with high Arsenic concentrations [20]. The sludge treatment that follows this is costly, but necessary so as to avoid secondary pollution [19].

(3) Adsorption is a physical process that utilizes solids as a medium for substance removal from liquids and gases [19]. Adsorption often utilizes a vessel or column filled with a packed bed of solid adsorption media, such as activated Carbon, Iron-based adsorbents, nanomaterials, and low-cost agricultural or industrial by-products [20].

As water passes through the bed of material, Arsenic and other impurities adsorb onto the surfaces of the adsorbent column [20]. Eventually, the column becomes saturated with water and impurities, requiring regeneration via exposure to 4% caustic soda (NaOH) [20]. The result of this is caustic waste water with high Arsenic concentration [20]. As with sludge from coagulation-flocculation, this creates a secondary problem, since waste water must be neutralized to prevent Arsenic waste generation [20].

(4) Ion exchange is a physical–chemical process which transfers ions between a solution phase and a solid resin phase [21]. This technique is commonly used for water softening and Nitrate removal in drinking water treatment systems [21].

The resin itself is usually an elastic three-dimensional hydrocarbon network, with a high quantity of ionizable groups electrostatically bound to the resin [21]. These groups are "exchanged" for ions bearing similar charge, but stronger selectivity for the resin [21]. Arsenite groups must be oxidized to Arsenate in order for this method to be effective [21].

(5) Membrane filtration technologies are designed to be selectively permeable: membrane structures permit some molecules to diffuse through, while blocking others [22]. Membrane filtration can be used to filter bacteria, salts, and heavy metals in water [22]. Membrane thickness, pore size and spacing, and material are key design parameters influencing molecular selectivity, diffusivity rate, and membrane durability.

Current reverse osmosis and nanofiltration membranes can operate at 40–400 psi (276–2,760 kPa), while rejecting 96–99% of both Arsenate and Arsenite species in water [22]. The ability to mitigate both Arsenate and Arsenite with high efficiency will prove useful for future point-of-use treatment.

#### *3.2.2 Nanotechnology for arsenic remediation*

In addition to conventional approaches, the 21st century has witnessed the emergence of nanotechnology-based remediation techniques. Nanotechnology is the branch of science dealing with materials at dimensions of approximately 1–100 nm [23].

Nano-sized materials (nanomaterials) are advantageous in water remediation applications—particularly adsorption for contaminant removal [24]. This is because nanomaterials offer high surface area, high number of active sites, porous structures, magnetic nature, and photocatalytic activity [25].

The predominant mechanism of Arsenic adsorption is via complexation and ligand exchange on nanomaterial surfaces [25]. As such, nanomaterials make for excellent media in fixed bed adsorption vessels [20]. Media such as Cupric Oxide nanoparticles, Iron Oxide-based nanoparticles, $TiO_2$ nanoparticles, $ZrO_2$ nanoparticles, and Zero-Valent Iron (ZVI) nanoparticles have been investigated for Arsenic removal from water [20]. A comprehensive review of nanomaterials for Arsenic water remediation is provided by [25].

Overall, the high adsorption properties of nanomaterials translate to accelerated remediation rates, lower costs, less material usage, and a lower generation of hazardous by-products [24]. The high efficiency of nanomaterials makes them ideal for expedited remediation efforts in regions most severely impacted by Arsenic remediation (i.e. India and Bangladesh) [24].

#### *3.2.3 Sustainable solution highlight: phytoremediation*

Sustainable remediation solutions are ones which are low-cost, utilize little material, produce no waste by-product, and generate zero emissions. For this reason, phytoremediation is a viable option for long-term Arsenic removal.

Phytoremediation is a simple, cost-effective, environmentally-friendly approach for removing Arsenic from aquatic environments [26]. Particularly in developing regions of the world, this is a great alternative where complex manufacturing is unavailable for the fabrication of other remediation technologies. Phytoremediation uses living plants such as ferns, shrubs, and herbs used to remove Arsenic from soil-water systems, or to render it less toxic [27].

A worthwhile remediation strategy for the future is to build more constructed wetlands (CWs) that incorporate phytoremediation. CWs are artificial wetlands used for the treatment of contaminated surface and sub-surface water [26]. A 2019 study, conducted by [28], tested this strategy with a 355-hectare (3.55 $km^2$) CW in France [28]. Results showed that Arsenic was mitigated at the CW outlet, with an approximate efficiency of 23% [26]. The efficiency of contaminant removal in similarly artificial ecosystems is still poorly-documented [28], so their potential has yet to be fully realized.

There is still much to learn in the field of phytoremediation, such as the application of different species, transgenic plants, and antistress responses [26]. In one case study, soil samples from Thailand were used to explore the effectivity of 36 plant species [27]. The study identified two species of fern (*Pteris vittata* and *Pityrogramma calomelanos*), one herb species (*Mimosa pudica),* and one shrub species *(Melastoma malabrathricum*) as some of the most efficient plants for phytoremediation [27]. Amongst these plants, the ferns most proficiently accumulated Arsenic from soil, attaining concentrations of up to 8350 mg/kg (dry soil mass) [27].

On their own, phytoremediation plant species are a promising means of Arsenic removal. But, one downside to phytoremediation is that it takes longer than other remediation techniques. Most heavy metal accumulating plants take about five years to uptake significant levels of contamination, since they grow slowly and their roots only penetrate the topsoil (5–20 cm) [29]. Fortunately, a worthy solution to this problem lies in mycorrhizal networks.

### *3.2.4 Mycorrhizae to accelerate phytoremediation*

Mycorrhizae are symbiotic relationships between plant and fungi species [30]. Fungi colonize the root system of plants, providing both increased water and nutrient absorption capabilities [30]. Meanwhile, plants provide fungi with carbohydrates formed during photosynthesis [30].

A study by [29] demonstrated mycorrhizal networks at the roots of two accumulator plants, *Pteris vittate* and *Cynodon dactylon*, through the addition of *Glomus mosseae* and *Glomus intraradices* fungi [29]. Both the *Pteris vittate* and *Cynodon dactylon* experienced significantly higher biomass and Translocation Factor (TF) for Arsenic uptake from soil.

TF is a metric used to quantify Arsenic (or other metal) uptake through the plant; TF is determined through the following ratio: $[\text{Metal}]_{\text{aboveground tissue}}/[\text{Metal}]_{\text{belowground tissue}}$ [29], where [Metal] is the mg/kg concentration of the metal species, aboveground tissue refers to stems and leaves of the plant above ground, and belowground tissue refers to plant roots closest to the metal species.

To further progress the phytoremediation approach, the author of this chapter recommends continued studies in the area of mycorrhizal inoculants. Indeed, fungal species introduce a tremendous improvement to an already impressive, sustainable approach. In continuing this area of research, great advancement potential lies with fungi species from the company Dr. Janerette's Eco-Friendly Fungi.

Since April 2021, the author has had the privilege of interning under co-founder and CEO of this company, Dozie Mbonu. Both Dozie and co-founder Dr. Carol A. Janerette, a world-renowned botanist and environmental expert, have extensive knowledge in mycorrhizae. Dr. Janerette's Eco-Friendly Fungi can provide fungi which guarantee supreme nutrient uptake, water absorption, root health and longevity, and tolerance to high soil temperatures, toxic heavy metals, extreme pH levels, and transplant shock [31].

To date, the company has achieved superior results in the categories of crop yields and multi-harvests. One reason for this is that plants with Dr. J's Fungi can grow exponentially longer roots, and wider aboveground biomass, on a scale unlike any other. Crop growth has been attained even in infertile grounds, such as the abandoned anthracite coal mine in Plymouth Township, Luzerne County, Pennsylvania, U.S.A.

Partnerships with Dr. Janerette's Eco-Friendly Fungi would guarantee advancements in phytoremediation technology, in addition to reforestation efforts, and an eradication of global food scarcity.

## 4. Incentivizing global arsenic remediation

To mobilize the partnerships, funding, and curated efforts of global Arsenic remediation, the author offers three primary incentives: (1) eliminate human health threats by progressing clean water infrastructure, (2) boost the global economy, and (3) instill a framework for future global-scale collaborative efforts.

### 4.1 Incentive #1: eliminate human health threats

In addressing the Arsenic crisis, we can significantly reduce human health exposure to Arsenic, similar contaminants, and even pathogens. If we plan accordingly, the same remediation technologies for Arsenic may have overlapping purpose in the removal of Fluorides, Iron, Manganese, Chlorides, Sulfates, or radionuclides. At the same time, we can expand our database of groundwater quality and quantity in the regions we act. Compiling such a database across 107 countries would be highly beneficial towards our future water management objectives.

While working in Arsenic-impacted regions, we can remain proactive on the challenges of water-borne illnesses and water scarcity. These challenges are a more common topic of discussion than Arsenic, since they affect a larger percentage of the global population.

The WHO reported, in June 2019, an estimated 785 million people lacking complete access to basic drinking water services [32]. Furthermore, at least 2 billion people use a feces-contaminated drinking water source—this contributes to the transmission of diseases such as diarrhea, cholera, dysentery, typhoid, and polio [32]. It is estimated that these diseases cause 485,000 diarrheal deaths each year [32].

Without proper drinking water and wastewater infrastructure, it becomes impossible to escape disease. This is a dismal truth, but, fortunately, it has been the focus of many UN agencies and initiatives, along with various government and non-government organizations across the globe. There is no denying how invaluable our continued Water, Sanitation, and Hygiene (WASH) efforts are. However, it is equally important to simultaneously address contaminants of growing concern like Arsenic. Groundwater dependence will lead to an emergence of Arsenic and similar contaminants, in parallel with newly established WASH services.

### 4.2 Incentive #2: boost the global economy

Water is one of the greatest determining factors for a singular nation's prosperity. Thus far, water's availability has dictated which countries are industrialized or still developing.

As stated by current World Bank Group President David Malpass: "Clean water is a key factor for economic growth. Deteriorating water quality is stalling economic growth, worsening health conditions, reducing food production, and exacerbating poverty in many countries" [33]. The August 2019 World Bank Report found that a lack of clean water access limits economic growth by one-third [33].

When water comes from cleaner, more accessible sources, people spend less time and effort to physically collect it, freeing the opportunity to be productive in other ways [32]. For example, women and girls in Sub-Saharan Africa walk an average of 6 kilometers (3.7 miles) each day to gather clean water [34]. Between all women and girls of Sub-Saharan Africa, an estimated 200 million hours is spent collecting water every single day—this is over 22,800 years of daily activity lost to collecting water which is not guaranteed to be clean [34]. Undoubtedly, clean water sources closer to home would empower women to explore income-generating opportunities [35], contributing to a country's economic growth.

Better water sources also translate to lower health expenditures, since people can remain more economically productive with a lower likelihood of falling ill, and lower incurring medical costs [32]. In the context of children, access to improved water would guarantee better long-term health and, accordingly, better school attendance [32], translating to an increased output of societal members pursuing personal dreams and ambitions. The direct result of this is a more productive society which, over the course of several generations, would produce a more productive nation.

Truly, the importance of helping developing nations is too often underestimated. According to Jim Yong Kim, Former President of the World Bank Group: "global development extends far beyond charity and has a greater impact on the global economy than most people think" [36].

Following the 2008–2009 financial crisis, strong economic growth in developing nations became an "engine" for the global economy, contributing to about 50% of all global growth [36]. Additionally, a significant portion of U.S.A. exports go to emerging markets and developing economies [36].

Considering the fact that the U.S.A.'s trade partners (e.g. China, France, Japan, Mexico, Canada, Germany, and the United Kingdom) also profit off of exports to developing nations, it becomes heavily apparent that the prosperity of developing nations is crucial to the global economy. The U.S.A. relies on its trade partners for economic growth, and vice versa.

When countries participate in the exchange of goods, economic growth ensues. Thus, it is in our best interest to ensure global water security and clean water resources.

Arsenic is a growing threat to human health, and its removal would have an uplifting economic effect on both developing and industrialized nations. Water is the ultimate determinant of economy.

### 4.3 Incentive #3: develop a global collaborative framework

Resolving the Arsenic crisis comes easy once we overcome its preceding obstacle: convincing one another to collaborate.

Unquestionably, this becomes a largely philosophical puzzle. Despite being of the common *Homo sapiens* species, we are largely divided on our ideas of social identity and morality, amongst many others. These divisions are influenced by the space–time perspectives and experiences of every single individual that has ever existed on Earth. Our values overlap in many ways, and conflict in just as many. Yet, amongst our many differences, water is an unavoidable commonality.

If there is any cause worth uniting over, it is water. Water keeps us alive. Without water, there is no life. Humans, animals, plants, bacteria; nothing in this world can survive without water.

Most of this world is privileged to be born into clean water access, but a staggering percentage is not. The battle for clean water is being fought heavily, by a great number of organizations and communities across the world, but it is still not enough. Often, these valiant efforts face great adversity through a lack of resources (material, financial, and/or labor) to install clean water services. The solution to this is the influx of support from worldwide public and private sectors, water and non-water industries, and the general public.

The power of such a joint effort has yet to ever be realized. Now, more than ever, we have the collective resources to spread information and implement technologies at an international level. Since the beginning of time, planet Earth has had all resources necessary to resolving the world water crisis. It is a mere matter of gathering said resources, and implementing them where needed. As a united species, made up of diverse individuals and experiences, we can figure this out.

In taking on a challenge as humanity, rather than as individual countries and affiliated social groups therein, we will gain insurmountable experience in global collaboration. We stand to gain immense efficiency as a species.

Designating and proclaiming a challenge to overcome (e.g. the global Arsenic crisis), and taking a truly committed approach to resolve it, would provide novel takeaways on the flow pathways of material resources, financial resources, and labor, within interconnected dimensions.

Our new experiences and knowledge on how we worked together, and the routes we took for communicating and distributing resources, can be applied towards all 17 of the UN Sustainable Development Goals. These goals address water sanitation and hygiene, world hunger and poverty, climate action, ecological health, clean energy, sustainable cities and infrastructure, gender equity, health and well-being, quality education, and the formation of global partnerships. These goals define and outline the current biggest challenges we are to face as humanity. Establishing partnerships now would serve us well in the mission to resolve all 17 of these Sustainable Development Goals.

As for another 200, 300, 4,000, or 10,000 years into the future, there is no telling what challenges will come to light. What is certain, however, is that global collaboration will lead us to our solutions.

## 5. Plan of action

The chapter author has created a simplified problem-solving approach that can be applied towards complex problems. Though this model will evolve, the presented format leaves appropriate space for the overarching considerations of a multifaceted endeavor. This model is a four-step process, which follows:

1. Identify the Problem. Identify (A) why it is a problem, (B) what caused it, and (C) how to address it.

2. Brainstorm Solutions. For each potential solution, determine (A) the approach via (i) resource (materials, financial, labor) acquisition, (ii) design and manifestation, (iii) installation and maintenance; (B) the external parties which will become involved, their intended role, how to recruit them, and how to keep them engaged; and (C) the impacts of each solution on (i) progress towards solving the ultimate objective, on (ii) those that will participate (internal and external parties) in solving the problem, and on (iii) those that will be liberated of the problem.

3. Coordinate efforts and spread awareness. Ensure all parties agree on the brainstormed solution(s) and how to implement them. Decide how information and data will flow between parties, while maintaining constant transparency. Furthermore, keep the general public informed on all news in progress—good or bad.

4. Take action, take notes, and spread further awareness. Employ solutions and make note of their impacts. Repeat current solutions and refine as needed. Continue brainstorming new solutions to adapt to the evolving situation. Spread awareness of each action taken to gather further support, for both current and upcoming solutions.

This model can be repurposed to fit the context of solving the global Arsenic crisis, as shown below. Note: at this time the model does not reflect the details to steps such as partnership formation or finance acquisition. Instead, the model is intended to provide an overview of what to expect when addressing the Arsenic problem.

1. The number of people exposed to Arsenic-contaminated groundwater is rising.

   A. Exposure to Arsenic at elevated concentrations (above 10 μg/L) leads to a number of carcinogenic and non-carcinogenic health effects. This is causing illness and deaths across 107 countries, blocking potential social and economic growth worldwide. Addressing the Arsenic crisis will be a leap in the effort to provide universal access to water and sanitation services.

   B. The quantity and quality of many surface water sources is diminishing, in parallel with growing population demands and changing climate, leading to an increased global dependence on groundwater. This raises the likelihood of human exposure to Arsenic at elevated concentrations, either by excessive pumping at current sites, or by encounter of Arsenic at new sites. Meanwhile, ongoing geogenic and industrial processes contribute to the number of dissolved Arsenic species in groundwater.

   C. In the short-term, Arsenic must be removed from areas where alternative sources of clean water are unavailable. Removal efforts will be aided by the continued collection of groundwater monitoring data. Also, stricter government controls must be implemented to prevent further Arsenic pollution from industrial processes.

   For the long-term: phytoremediation and artificial ecosystems will mitigate Arsenic in soil-water environments; collected groundwater and contaminant data will aid in the tracking of Arsenic migration; and global warming must be decelerated and reversed to prevent the rising evaporation rates which endanger surface water quantity and quality.

2. Proposed solution: Utilize groundwater monitoring and remediation techniques to track and remove Arsenic.

   A. (i) Materials for each technology can continue to come from current suppliers to research and industry institutions. Financial resources will be attained through continued identification and engagement of stakeholders, reallocation of public and private sector funding, and donations from the general public. Increased labor can come from the general public, employing individuals to work in jobs for the manufacture and operation of each technology, as well as in field maintenance jobs at the point-of-use.

   (ii) For each technology, design parameters will continue to evolve at the research level, through meticulous lab and field studies. Continued design evolution will lead to reduced material and financial costs, less waste generation, and lower emissions during fabrication. The fabrication process for these technologies will be determined by the parties which design them.

(iii) Install remediation technologies in all areas where people are affected by elevated Arsenic concentrations. Maintenance operations will be taught to the communities where remediation is implemented; this will require a transitional period where stakeholders stay in these regions and educate communities until they are fully independent.

B. The external parties for this solution include any individual or group who is not already contributing, in some capacity, towards the efforts of universal water and sanitation services. The intended role of external parties will be decided by the organizations which recruit them.

Spreading awareness of this problem and creating financial incentives such as green bonds and prize competitions may entice new research and industry institutions, and the general public, to contribute. Once new contributors are involved, maintaining their consistent engagement will become a challenge. It is crucial to provide real-time data on a local and global level so all parties observe the progressing impacts of their efforts.

C. (i) The end-result of this solution is the elimination of Arsenic health risks to humans. Concurrently, the Arsenic remediation technologies may remove other contaminants, such as Fluoride, from the same sites. The remediated regions will experience boosts to their economic prosperity, precipitating economic growth worldwide. Ultimately, substantial effort will have been made towards expanding clean water access for humanity.

(ii) Both the internal and external parties will benefit from this endeavor. Research and industrial institutions will have received new grants which accelerate field studies and breakthroughs in current technologies. Meanwhile, all involved parties will have gained valuable collaborative experience, with takeaways on financial flows and camaraderie that can be revisited and/or revised for future endeavors at the global scale.

(iii) Those liberated of Arsenic exposure will experience gains in health, water infrastructure, and economy. The impacts of remediation will be more significant in developing nations, where Arsenic poisoning is most severe. Here, a greater number of people will be brought to good health—both the current and future generations of each family will benefit.

3. Mobilization and partnership formation.

Before the solution is embarked on, it must be fully realized and communicated amongst *all* members of the parties which intend to commence it. It is recommended that this begins with the United Nations, the World Health Organization, European Union, federal governments, and foreign-equivalents of the Environmental Protection Agency and Center for Disease Control. These are the parties which can influence transcontinental action.

Once these initial parties agree on the solution, they must expand their spheres of influence. This will be done through partnerships with government and non-government organizations (NGOs), and not limited to experts in the agriculture, utilities, education, information, healthcare, arts & entertainment, marketing, financial, construction, manufacturing, engineering, and policy sectors.

Such partnerships will make it possible to spread education and awareness of the Arsenic problem, so there becomes a widespread recognition of the problem and a higher willingness to contribute material, financial, and labor resources.

4. Implement remediation technologies and keep the world informed.

   The public sector, private sector, and general public will become emotionally invested in the Arsenic problem as they learn of it and follow its progress. Publicizing it on mainstream and social media outlets will be an effective means of raising awareness. Albeit, there is always the danger of public division when such issues become publicized, even when an extensive network of factual evidence exists (i.e. climate change). Nevertheless, this need not impede us from embarking on necessary action. Progress must be publicized truthfully and frequently, regardless of how it is received.

The author's goal is to bring this model, and its future iterations, to the attention of world leaders and water professionals. To that end, the chapter author is a stakeholder, committed to driving change by catalyzing action.

## 6. Conclusions

This chapter was written to address the growing concern of human health exposure to Arsenic in elevated concentrations. The following are the key takeaways of this review:

- Arsenic is a threat to human health. Above the concentration of 10 μg/L in water, chronic Arsenic exposure can lead to cancers of the skin, lung, bladder, liver, prostate, and blood, in addition to neurobehavioral abnormalities, diabetes, skin disorders, cardiovascular diseases, and pregnancy complications.

- The number of Arsenic-impacted people is expected to rise, in parallel with growing global groundwater dependence. Population demands, and diminishing quantity and quality of surface water is leading to a growing global dependence on groundwater. People are encountering Arsenic-contaminated groundwater at (a) new sites because they do not have enough information about where to collect clean water, and at (b) ongoing sites through excessive pumping that promotes the uptake of contaminant species. Also, the continuation of geogenic processes and industrial Arsenic release contribute to the concentrations of Arsenic in soil and water.

- Arsenic monitoring and determination will help track the spread and existence of contaminants in groundwater sources. GIS and water-footprinting will be recognized as necessary tools in the future of water.

- There are numerous Arsenic remediation techniques which can already be implemented to begin saving lives. The conventional techniques of oxidation, coagulation-flocculation, adsorption, ion exchange, and membrane filtration, as well as innovations in nanotechnologies and phytoremediation, are all worthy of worldwide implementation.

- Implementing existing remediation techniques will contribute to their further research and development, through field studies and data acquisition.

- Phytoremediation is the most sustainable approach. Phytoremediation is inexpensive and generates no waste nor emissions. Additionally, mycorrhizal networks can significantly boost the Translocation Factor and biomass of phytoremediation plants. Dr. Janerette's Eco-Friendly Fungi is a company which can provide fungal species for the advancement of lab and field studies of phytoremediation.

- There are three primary incentives for launching worldwide remediation efforts: (1) eliminating human health threats of Arsenic exposure and other contaminants, (2) boosting the global economy, and (3) developing a global collaborative framework.

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## Conflict of interest

The author declares no conflict of interest.

## Note from author

Helping humans live better, more fulfilling lives will lead to the progression of humanity and societies worldwide. The resulting benefits of such actions, alone, are incentive enough to pursue them.

Even if we stood to gain nothing; even if our collaborative efforts served absolutely no benefit to us, why let that stop us? Is it the fear of losing money? The fear of investing our time? For, if it is a matter of money or time, imagine it was your water at stake.

Water, above time, is the most valuable resource one can own.

What value does time hold, in the absence of water?

Time, with tainted water, is torture.

And, time with no water at all, does not exist.

Do not let go of this precious resource. Educate yourself on all that goes into its cleansing and conservation, so you may project your knowledge through a love that helps others, and yourself, gain greater value from your time.

Thank you for your time.

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