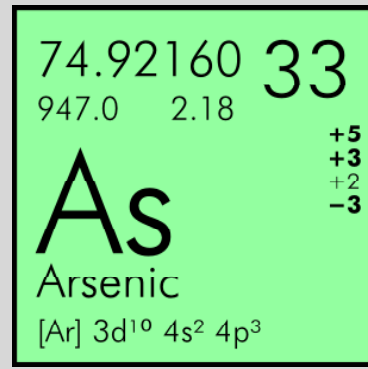




The Occurrence of Arsenic in Groundwater Systems of Western Oregon



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Abstract

Globally, millions of people are exposed to hazardous and potentially deadly concentrations of arsenic in groundwater on a daily basis. Arsenic (As) is a naturally occurring element found in bedrock and regolith that nearly all humans are exposed to via food, air, water, and soil. Although exposure is inevitable, the highest potential for health effects has been identified as arsenic associated with drinking water. Arsenic has been widely recognized as highly toxic and carcinogenic to humans when consumed in an inorganic form. In the Willamette Basin of Western Oregon, there are several localities that possess levels of arsenic in groundwater many times higher than maximum allowable concentrations recognized by the U.S. Environmental Protection Agency. This study provides an overview of the toxic effects associated with arsenic and examines the geologic factors that contribute to its presence in local aquifer systems.

Introduction

Arsenic occurs naturally as the 20th most abundant element in regolith. The majority of Arsenic often remains in its solid state, trapped within mineral complexes, but under a variety of geochemical conditions the element can become mobilized in ground water and make its way into aquifer systems. Many factors affect the mobilization of arsenic, and much remains unknown about the specific mechanisms that influence concentration in groundwater. A variety of known conditions that have been identified which will be discussed henceforth. These conditions differ highly across the Willamette Basin, based on the geochemistry of the particular region, and subsequently create large differentiations in arsenic concentrations in groundwater.

Arsenic is present in each of our bodies, and plays a role in assisting a variety of biochemical processes on a daily basis, but the average human consumes a higher daily dose of arsenic than is required, due in large part to inorganic arsenic consumed in drinking water. In excess, arsenic acts as a highly toxic and carcinogenic substance that can cause a variety of health conditions and diseases. The EPA, recognizing this hazard, has set a legal standard of 10 micrograms per liter in drinking water for most developed countries. The methods which the body uptakes and transforms arsenic, as well as the specific toxicological effects of arsenic are to be discussed to express the dangers of ingesting high levels of arsenic.

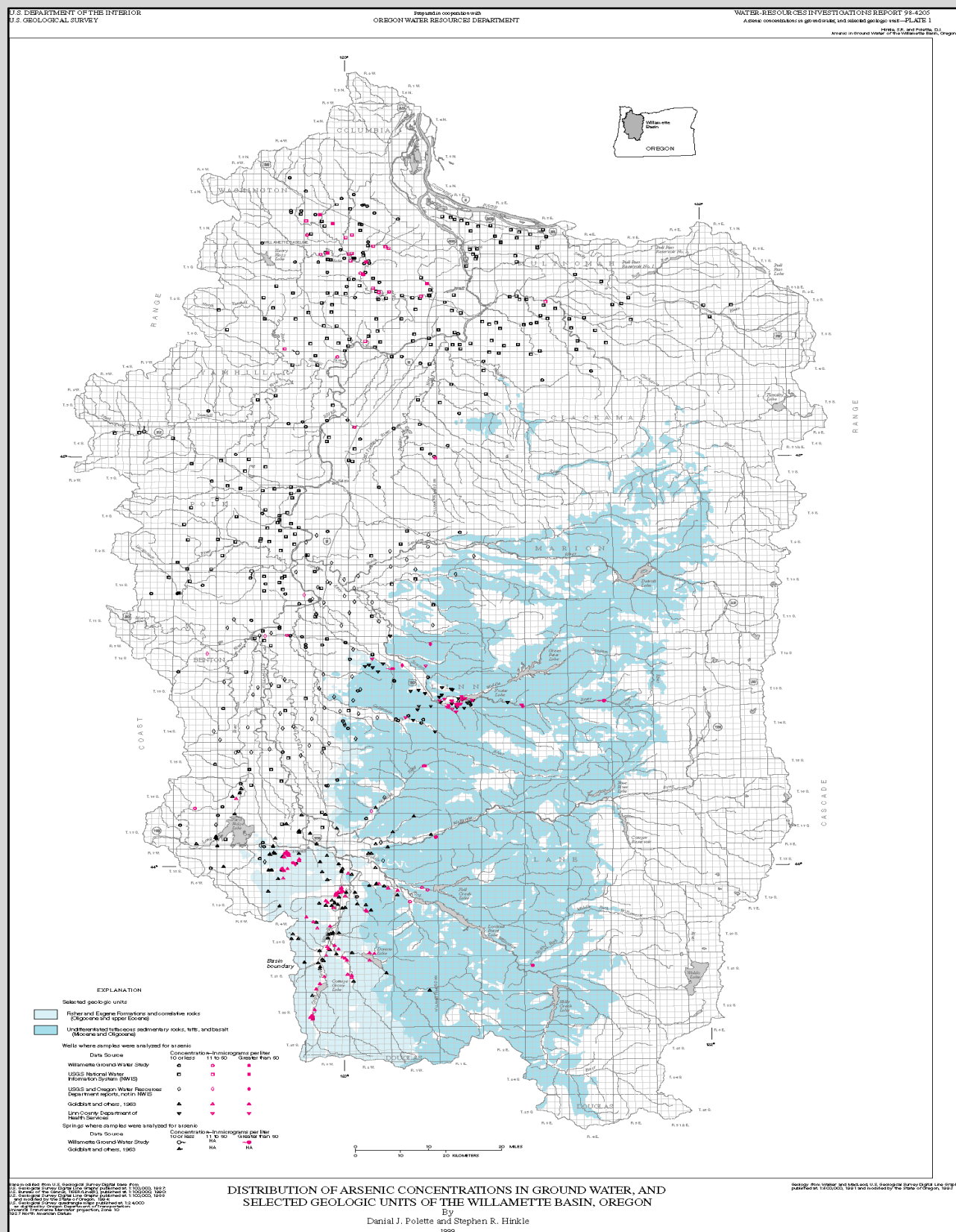


Figure 1. Location Map identifying arsenic concentrations in the Willamette Basin [2]

Project Overview

Geochemical Contribution:

Understanding how arsenic operates in groundwater systems requires some knowledge of the chemical properties of the element. Arsenic is a metalloid that can exist in a variety of oxidation states, meaning that the element is able to donate or accept a highly variable amount of electron density, allowing the element to be able to form stable interactions in many compounds in varying conditions. In Figure 3, we are shown some of the compounds containing arsenic in differing oxidation states, where we see the specific state of arsenic being reliant on the factors of pH and redox potential (Eh). The specific geochemical conditions of a given region, such as chemical composition, oxygen content, permeability, exposure to weathering, erosion, and various other factors, determine how pH and oxidation potential affect the adsorption or desorption of arsenic into ground waters. Within regolith, arsenic acts similarly to sulfur, and is found present in many sulfur containing compounds, such as pyrite (FeS₂) at levels of up to 10% arsenic. Pyrites oxidize readily to release soluble sulfur and arsenic. In other compounds containing high amounts of sulfur, such as coal, arsenic can be found in even higher concentrations. Coal mining and other human activities play a large role in exposing arsenic containing compounds such as pyrite and coal to oxidation and weathering, which allows arsenic to leach into groundwater through acid mine drainage at concentrations of 1000's of micrograms per liter. Arsenic is incorporated into minerals in the formation of igneous rocks, and as metamorphic and sedimentary processes occur over time the minerals become subjected to vast changes in conditions and exposure to geologic processes. Overtime, as regolith is exposed to water, arsenic is often steadily washed out of materials or transported. Due to this, arsenic is often found in higher concentrations in groundwater contained in newer rock formations, and those that have yet to be subjected to extensive weathering. Two of the other main aquifer systems that tend to accumulate high levels of arsenic are strongly reducing aquifers that are derived from alluvial sediments, and inland or closed basins in arid regions. The geochemical factors of a given area can be utilized to help determine where and why arsenic is present in what concentrations.

Presence in the Willamette Valley Basin:

As compared to many other parts of the world, Western Oregon contains relatively low concentrations of arsenic in groundwater, yet there are specific regions of the Willamette basin that contain levels in waters much higher than the permitted amount. In a study conducted by Daniel J. Polette and Stephen R. Hinkle [2], groundwater samples were collected at 728 locations across the Willamette basin, as shown in Figure 1. Of the total samples collected, near to 78% of sites tested contained waters that were within the acceptable concentration range of arsenic below ten micrograms per liter. The remaining 22% of the samples were above the allowed range for safe drinking water, with 8% of the samples being above 50 micrograms per liter. These results are expressed in Figure 4. From analyzing the geological aspects of the valley basin, it was identified that high levels of arsenic in the region are primarily correlated with the Fisher and Eugene formations, as well as undifferentiated tuffaceous sedimentary rocks. The Fisher and Eugene formations are relatively young as compared to the surrounding landscape and consist primarily of rhyolitic volcanic rock, relatively high in arsenic content. Groundwater within these formations frequently rises above 100 micrograms per liter, which can be clearly correlated to the geochemical conditions of mineral type, relative age, and exposure as were discussed above.

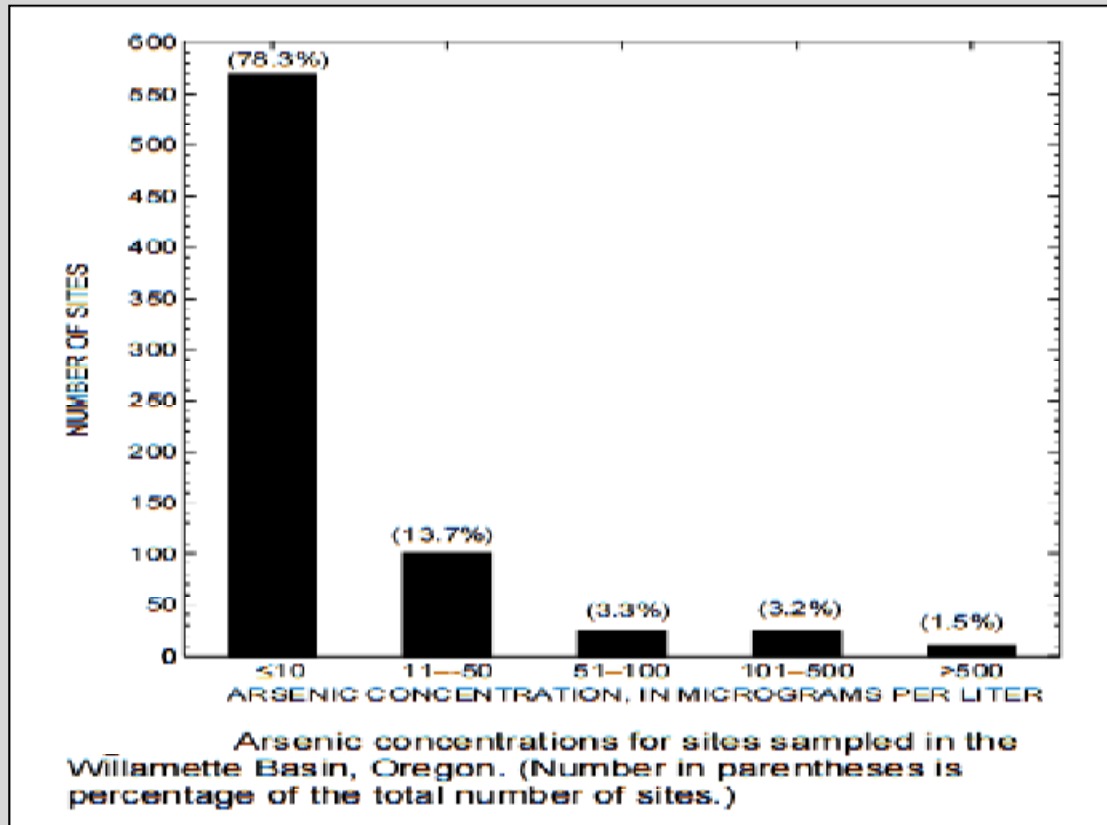


Figure 4. Arsenic concentration at sampled sites [2]

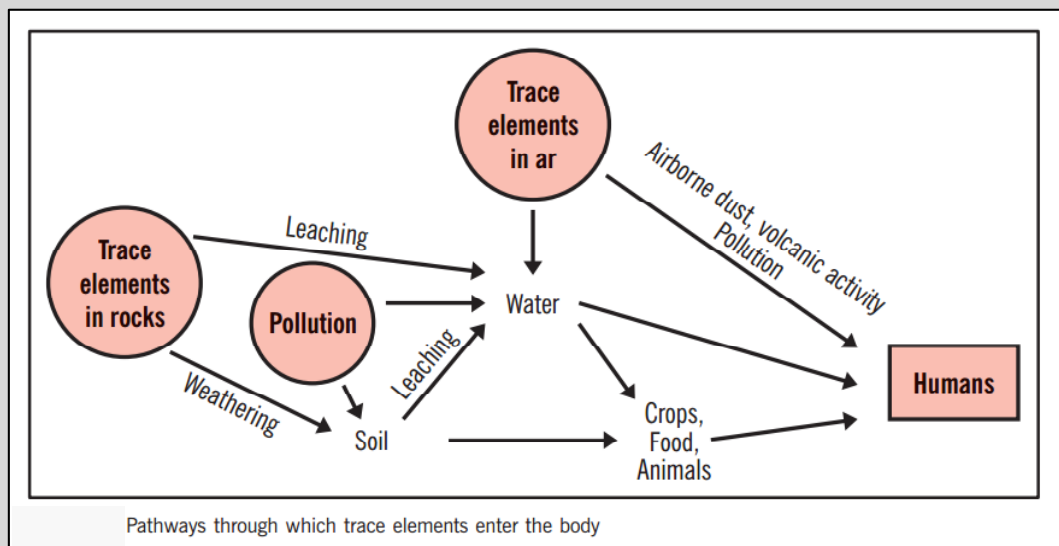


Figure 2. Methods of arsenic transport in the environment [5]

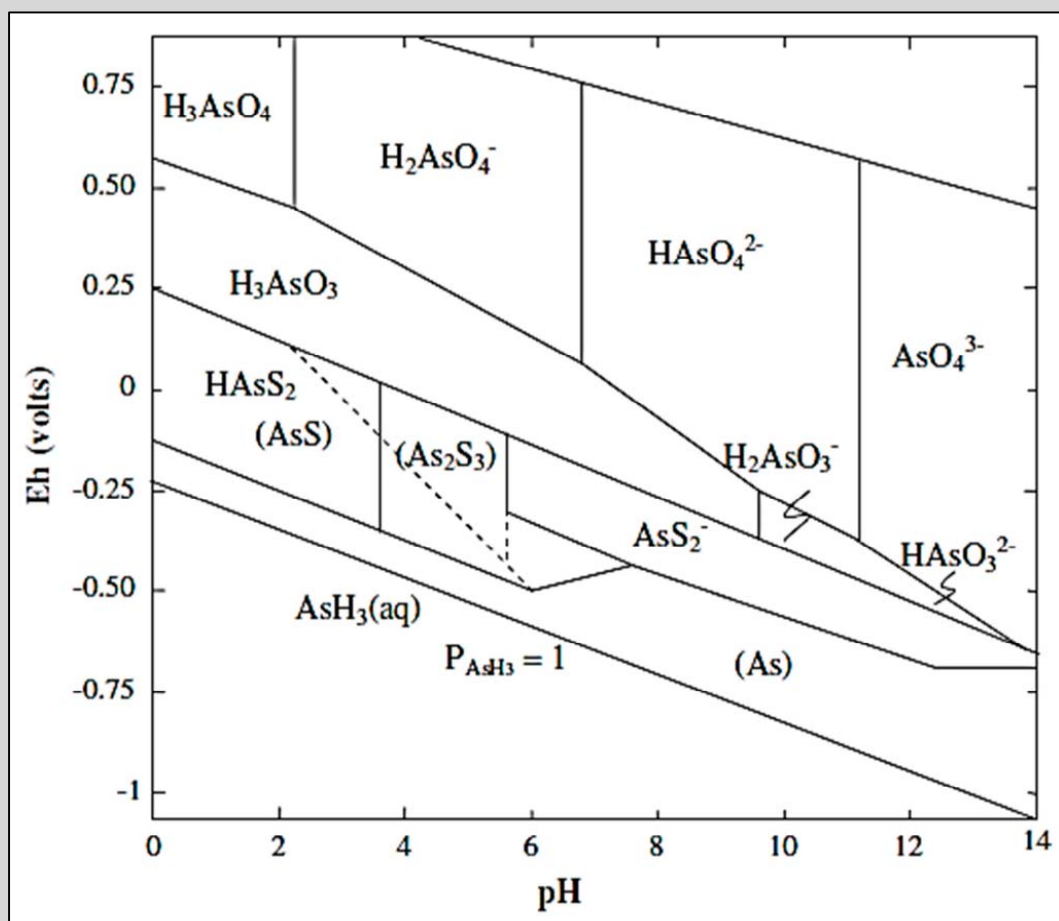


Figure 3. Arsenic in varying forms dependent on pH versus Eh [6]

Toxicology Overview:

When inorganic arsenic is ingested, the body is able to process up to 70% of the element and excrete it in urine without substantial harm to the system. The additional 30% of arsenic remains within the body system, and accumulates in organs such as the kidneys and lungs, as well as hair and skin. As the body interacts with the accumulated arsenic, the arsenic bearing molecules become methylated and bioactivated into reactive radicals that interact destructively with tissues. The metabolic pathway that occurs as arsenic is processed by the body is shown below in Figure 5. Six different arsenic bearing compounds are formed through the process, each possessing its own toxicological effects. The high number of immensely reactive intermediates produced by interactions with arsenic contributes to its highly toxic nature. Prolonged exposure to arsenic can cause a variety of disorders, including conjunctivitis, melanosis, hyperkeratosis, skin lesions, and many others.

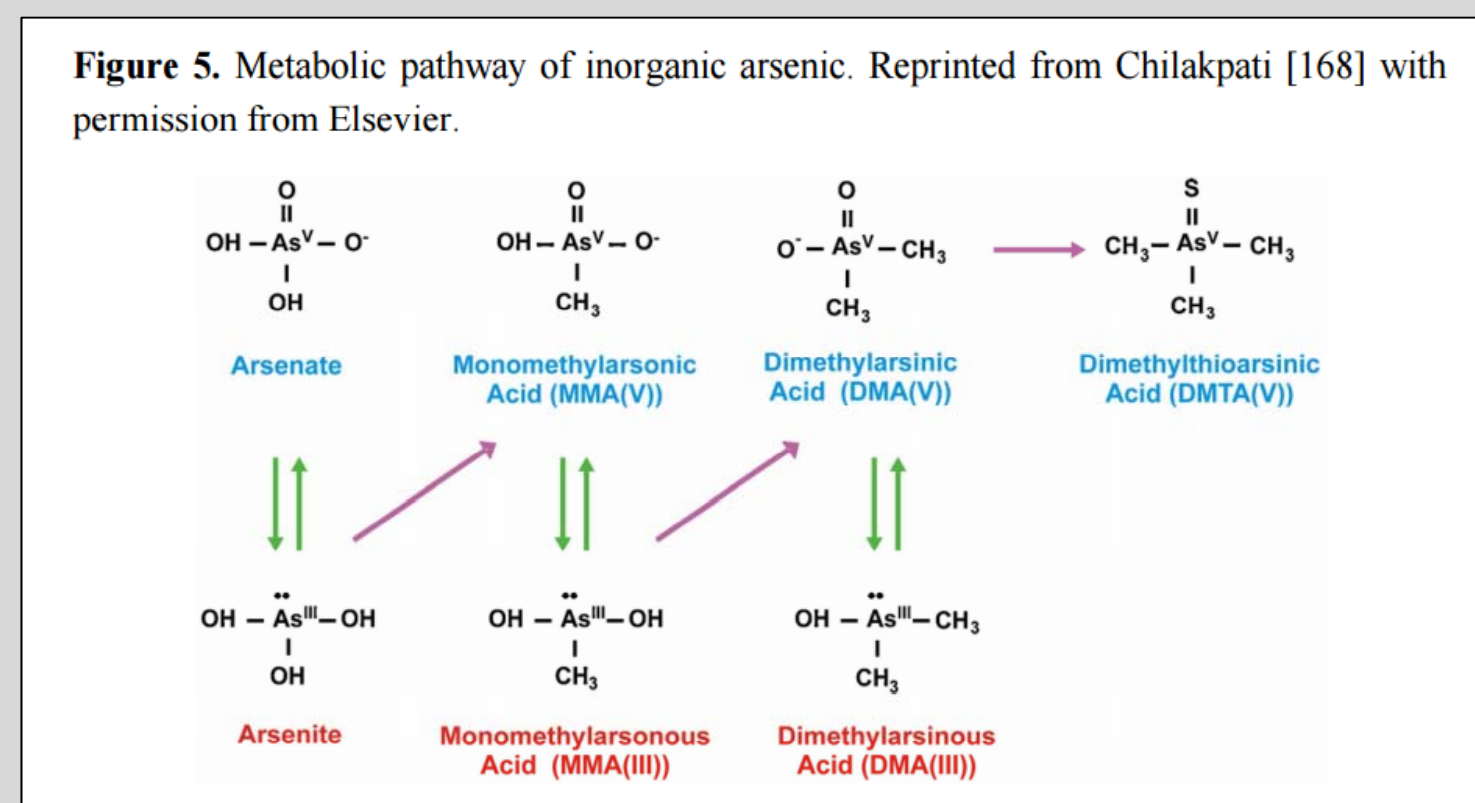


Figure 5. Metabolic pathway of inorganic arsenic [3]

Discussion

A variety of methods have been developed to remove arsenic from drinking waters. These techniques, their relative efficiency, cost, and advantages/disadvantages are shown below in Table 1. Arsenic (III) proves to be the form of arsenic which is both harder to remove from water and the most toxic form in biological systems. No system has yet to be capable of completely removing arsenic from contaminated water, only at so high of an efficiency, so water of high enough initial concentration of arsenic may remain above the permitted level even after treatment.

Techniques	Removal Efficiency of As (II)	Removal Efficiency As (V)	Relative costs	Advantages	Disadvantages
Coagulation/Co-Precipitation	Less than 30%	Greater Than 90%	Low	Monitoring is not required. Low costs. Chemicals are easy to manufacture.	Toxic sludge disposal. Skilled operators are required.
Alum Coagulation	Less than 30%	Greater Than 90%	Low	Chemicals are having low cost.	Low efficiency against As (II). Toxic sludge disposal.
Iron Coagulation	60% to 90%	Greater than 90%	Low	Low cost. Good efficiency. Very simple operation. Common chemicals.	Medium removal of As (II). Pre-oxidation may be required.
Enhanced Coagulation	60% to 90%	Greater than 90%	Low to Medium	High removal efficiency of Arsenic as well as organic matter and metal hydroxides.	Emerging technique, not proven on practical scale
Activated Alumina	60% to 90%	Greater than 90%	Medium	Commercially available. High efficiency. Low maintenance cost. No daily sludge disposal.	Every time re-adjustment of pH is required. Hazards residue disposal is quite challenging.
Iron based Sorbents (BS)	30% to 60%	Greater than 90%	Low to Medium	Plenty of possibilities. There is no re generation.	It requires pH control, replacement of media after exhausting and regular testing to provide safe operation.
Reverse Osmosis	60% to 80%	60% to 90%	High	High removal efficiency. No solid waste. Removes other contamination too. Chemicals are not required.	High running costs. Regular maintenance is required. Re-adjustment of water quality is required.
Nano-filtration	60% to 90%	60% to 90%	High	High removal efficiency.	Large capital is needed. High running costs.

Table 1. Removal techniques for inorganic arsenic [1]

Conclusion

In the regolith and aquifer systems beneath our feet, to the water that comes out of our tap, the toxic and carcinogenic metalloid arsenic can be found. This specific concentration of this element in groundwater has been shown to be reliant on a large variety of geochemical conditions. In local aquifer systems of Western Oregon, high levels of arsenic are found in select locations, affected in large part by local geology and human activities. The consumption of high levels of inorganic arsenic in drinking water has been shown to have extensive negative health affects that cause disease and death around the world.

Due to the vast array of conditions that are known and not yet known to affect the mobilization of arsenic into aquifer systems, determining whether a specific aquifer system will contain arsenic remains difficult and requires extensive testing. As more awareness and testing of arsenic in groundwater occurs, we may begin to better understand the mechanisms and conditions that lead to arsenic contamination in aquifer systems.

References

- [1] Ashish, Kumar. "Effect of Arsenic Contamination in Potable Water and Its Removal Techniques." *International Journal of Water and Wastewater Treatment* (ISSN 2381-5299) *Int J Water Wastewater Treat* 1.2 (2015) Web. 8 May 2016.
- [2] Hinkle, Stephen R., and Daniel J. Polette. "Arsenic in Ground Water of the Willamette Basin, Oregon." *Water-Resources Investigations Report* 98-4205 (1999): n. pag. *OREGON WATER RESOURCES DEPARTMENT*. Web. 8 May 2016.
- [3] Martin, Rachael, Kim Dowling, Dora Pearce, James Sillitoe, and Singarayay Florentine. "Health Effects Associated with Inhalation of Airborne Arsenic Arising from Mining Operations." *Geosciences* 4.3 (2014): 128-75. Web. 8 May 2016.
- [4] Naidu, R., and P. R. Nadebaum. "Geogenic Arsenic and Associated Toxicology Problems in the Groundwater-Soil-Plant-Animal-Human Continuum." *CSIRO Land and Water* PMB.No. 2 (2003): 37-44.
- [5] Selinus, Olle. "Medical Geology: An Emerging Speciality." *Geological Survey of Sweden* (2004): 8-15.
- [6] Smedley, P. L., and David G. Kinniburgh. "Arsenic in Groundwater and the Environment." *Essentials of Medical Geology* (2012): 279-310. Web. 8 May 2016.