Arsenic Contaminated Groundwater Has Serious Global Health Consequences

A Case Study from Bolivian Altiplano.

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Abstract

There are many countries throughout the world where the local population's water supply is exclusively obtained from groundwater and river discharge that is contaminated with arsenic. The Bolivian Altiplano which is a drainage basin within the Andes Mountains is an area of major concern; the arsenic levels are frequently well above The Environmental Protection Agency's and The World Health Organizations minimum guidelines. Consumption of arsenic contaminated water can lead to a variety of minor to major health concerns. Mountainous areas are prime locations for identifying significantly high concentrations of arsenic in groundwater due to mountain building processes within their geologic past. Within the mountainous areas, drainage basins where contaminated water coverages, aquifers that are composed of arsenic rich minerals and hydrothermal springs seem to be the locations of the greatest aquatic arsenic concentrations. There is a strong need for public and private opinion to move toward working together so that global and regional challenges can be met with the proper skillsets. It is important for scientist of all disciplines, health professionals, educators and public servants to combat the issue of contaminated well water so that prolonged risky exposure can be mitigated to prevent serious health implications.

Introduction

This case study was constructed with the purpose to examine a locality that suffers from arsenic (As) contaminated freshwater sources to develop site identification principles. These principles can be applied to under surveyed areas around the world so that resources can be effectively utilized. Additionally, within the United States the Environmental Protection Agency (EPA) and individual researchers have found that As is commonly found in groundwater throughout the country that exceed the EPA maximum guidelines ($10 \mu g L^{-1}$)(Sorg et al, 2014). A potential problem area that has exceptionally limited data and is geologically conducive to extremely high As levels are the southern Appalachian Mountains that includes Western and Southwestern Virginia.

Arsenic (As) is a major health concern when it is found in drinking water because of its ability to cause havoc on the human body. Early signs of over exposure include a metallic taste and mild gastrointestinal symptoms. Prolonged consumption of arsenic at levels above the World Health Organization (WHO) guidelines ($10\mu gL^{-1}$) can result in neurotoxicity, cardiovascular disease, gastrointestinal disorders and cancer. Leukemia is the most common type of cancer that occurs from consumption of As contaminated water (Hall, 2002).

Global Scale

Throughout the world the amount of people that are currently affected by dangerous levels of As are totaled at 150 million and this is increased as new affected locations are discovered (Ormachea et al, 2016). Affected areas are found globally; noteworthy regions include Bangladesh, Cambodia, India, Nepal, Viet Nam, Argentina, Bolivia, Chile, Mexico and the United States (http://www.who.int/bulletin/volumes/92/8/13-128496/en/). For a global example of the seriousness of contaminated groundwater, Bangladesh has been an area of active research due to its tremendously high As levels found in groundwater that result in 24,000 adult fatalities yearly when concentrations are greater than 50 μgL^{-1} (Flanagan et al, 2012). Groundwater contaminated with As is also an American problem. The EPA has sampled groundwater in the Northeast, Midwest and Western United States for As. The vast majority of wells sampled have returned As values above the EPA's guidelines (Sorg et al, 2014). One area of the United States that has been studied by researchers for over 15 years is the Northern Appalachian Mountains; the sample sites frequently fall between Northern Maine and Northern Pennsylvania. The majority of samples taken displayed elevated As levels that were over the EPA's guidelines and could possibly be hazardous to consume over long time periods. The highest As values found were located in the Newark Basin that measured 215 μgL^{-1}; The Newark Basin was the most southern sampled area recorded and it extends from New Jersey to Pennsylvania (Peters, 2008).

<u>Arsenic in the Bolivia Altiplano</u>:

More recently apprehensions have grown for populations in South America due to research that has found that affected areas are more wide spread than previously thought and that the As concentrations exceed the WHO guidelines ($10\mu gL^{-1}$) excessively (Ormachea et al, 2016).

This report has been constructed for the purpose of synthesizing more than a decade of geological and hydrological research to better understand the Bolivian Altiplano's water supply and its relationship to natural arsenic found in the ground and surface waters. This will be achieved by describing the regional geology, local climate and hydrological connections to naturally occurring As. The hydrological system will be analyzed in two parts. Water that is found in the hydrothermal environments and rivers, and groundwater used for human consumption and irrigation.

Regional Geology

The Andes Mountains stretch the length of South America; Bolivia is one of many countries that is home to a portion of the mountain range located in South America. Within Bolivia there are two separate portions of the range. These two ranges are differentiated by being named West and East Cordilleras. In the middle of the two parallel mountain ranges is the Altiplano or "high lands". The Altiplano is a depositional area that consists of lakes, rivers and salt flats that reach 3600 to 3900 meters above sea-level. The surface water is comprised of an endorheic system made up of mainly many small rivers that discharge into the Titicaca and Poopo Lakes. The Poopo Lake system is the site of interest for many hydrogeologist and geochemist due to its high level of As that have surface and subsurface sources (Ramos et al, 2014).

The geology surrounding the Altiplano is very complex because of a rich geological history. The two mentioned cordilleras formed under different geological conditions (Ormachea et al, 2013). The Western Cordillera is a young volcanic mountain range that is still very active and is comprised of metamorphic and igneous rock (Ormachea et al, 2016). The Western Cordillera's lithology formed from high pressure and heat caused by the active margin located on the western side of South America. Common minerals found along the western range formed by the orogeny and that reached Lake Poopo are sphalerite and galena. The Eastern Cordillera is comprised of sedimentary rock that has been folded and faulted throughout the thrust belt that reach 5000 meters above sea-level (Ramos et al, 2014). The Eastern Cordillera lithology includes Silurian and Ordovician sandstone, siltstones and quartzite. There are also Paleocene mudstones, limestones and sandstones located in the eastern range. Within the Altiplano lake, Pleistocene fluvial sediments are common. During periods of cyclical glaciation coarsing upward sequences that range from lake clays to large gravels were deposited and are now used as

modern aquifers inside the Altiplano. Most recently during the Holocene, unconsolidated alluvial and colluvial deposits transported from the mountain tops fill in the basin (Ormachea, et al, 2016).

Regional Climate

The area surrounding Lake Poopoo is categorized as a semi-arid climate that receives 300-400mm of rainfall per year. Maximum rainfall values are found to occur closer to the Eastern Cordillera. The majority of the precipitation transpires during the wet summer period that start in November and end usually in March. The wet period can accumulate up to 500mm of precipitation. The winters can be rather dry that extends from April to October that will produce only 250mm of rain. The average temperature for the Altiplano near Lake Poopo is 6-8 degrees Celsius; however, daily temperatures can vary greatly. During the time frame from 1990-2010 the evapotranspiration values have been calculated to be 1241mm per year and 103mm averaged monthly (Ramos, et al, 2014).

Weather on the Altiplano can be extreme; warm summer days that reach 20 degrees Celsius and can be coupled with nights that drop near 0 degrees Celsius. Sandstorms and tornados are common wind events that erode and transport surface sediments throughout the plain. Also, floods and droughts are regular occurrences that are dependent on the season. Anthropogenic actives that include deforestation and over grazing from livestock can perpetuate the windblown and river transported erosion that soil experiences (Ramos et al, 2014; Ormachea, et al 2016).

Arsenic in Groundwater

The majority of the wells found in the Altiplano are hand dug either with shovels or hand augers. The wells used for human consumption are either centralized to be shared by the community or smaller wells can be located within dwellings (Ormachea et al, 2015). On occasion the wells found in dwellings are utilized for small scale irrigation techniques. The method of water extraction varied for daily use and also field sampling. The variability was dependent on the existing extraction method used by the locals (either pumps when available or by lowered buckets) (Ormachea et al, 2013).

A large variation in depth to ground water was observed at different locations in the Altiplano. The range of depth values recorded were 0.68 meters to 8.33 meters from shallowest to deepest respectfully. Groundwater temperature was also wide-ranging, from the same locations where the depths were measured, the temperature ranged from 9.7 degrees Celsius to 20.7 degrees Celsius (Ormachea et al, 2013).

Well water found in the Altiplano is highly contaminated with As. Near or above 90% of all drinking water wells measured within the Altiplano are found to have elevated As concentrations that exceed the WHO guidelines. Deeper wells are not used frequently for residential use; however, the deep aquifer wells that were measured found As values of roughly 15μgL^{-1} (Ormachea et al, 2016) . Shallow aquifers are a much larger problem due to the fact that they are widely utilized and are significantly more contaminated. It is common to find As concentrations in swallow wells to be above 100 μgL^{-1} . Some superficial wells are found to have As concentrations as high as 400 μgL^{-1} . More comprehensive studies that survey a larger area of the Altiplano rather than isolated around Lake Poopo have concluded that not enough information is known to be able to accurately map As contaminated water within the aquifer that has the intended purpose of predicting where the highest As concentrations will be found (Ramos et al, 2012).

It is believed that groundwater As concentrations are related to water residence time within the aquifer, local geology and precipitation. Researchers that have conducted measurements of groundwater believe that the longer a body of water is in contact with As rich bedrock the higher the As values will be measured in the water. Many volcanic rock types in the area are known to contain an average of 5.7mgL^{-1} which can affect the groundwater greatly. In the case of groundwater, precipitation is believed to delude As concentrations within the aquifer (Ormachea et al, 2013).

Arsenic in Surface Water

There are two main categories of surface water sources in the Altiplano and they are heated hydrothermal inputs and river discharge.

Hydrothermal inputs have been measured for a variety of qualities. They are found to range in PH from 6.8- 8.3. The thermal water is believed to mix with cool groundwater that increase the redox value to an average of +172mV. Electroconductivity is wide ranging but generally has high values that range from 1,860-75,810 μScm^{-1} . Temperature of the hydrothermal springs range from 40-75 Celsius. Bicarbonate is also found in high concentrations (429-1892mgL^{-1}) due to the weathering of limestones located in the Eastern Cordillera. Bicarbonate is important to identify because it has a strong correlation with As concentrations and is believed to facilitate the mobility of As through adsorption competition. A large majority of the thermal water inputs are contaminated with As values that exceed the WHO regulation and are found to peak at roughly 65μgL^{-1} (Ormachea et al, 2015).

In the Altiplano rivers are widely used for irrigation and only moderately used for consumption. However, because the rivers are transportation for ground and hydrothermal water it is important to monitor their health. The three main rivers located in the high plains are the Marques, Sevaruyo and the Cortadera Rivers. Water samples were obtained from each river and analyzed in the same manner. The rivers tend to be slight alkaline with PH values that hover around 8.5 on average (Ramos, et al 2012). The conductivity of the river water ranges from 452-2076 µS. Bicarbonate is also identified in the rivers at levels that average almost 500 mgL^{-1}. Concentrations of As vary from 8.6 – 117.4 μgL^{-1}. The higher than expected As concentrations found in headwaters are deemed to be caused by As mobility from volcanic sediment and the adsorption/desorption relationship with sediments along the Eastern Ridge (Ormachea et al, 2016).

Discussion

Most of the freshwater that is utilized by the population located in the Altiplano either from groundwater or rivers are highly contaminated with As well above the WHO guidelines. The multiple sources of As in the hydrological system, complex geological lithology and seasonally variation in precipitation make it very difficult to predict where As values will be most dangerous in the future (Ramos et al, 2014).

Some findings are clear. Nearly 90% of the water used for human consumption is contaminated with As (Ormachea et al, 2016). Water inputs from hydrothermal activity, groundwater

discharge or retention that occurs seasonally and runoff all influence the water quality that is available to the population. Dangerously high values of As can be found in all three intertwined systems (Ramos et al, 2012). The high As concentrations are caused mainly by naturally processes but can be accelerated by human activity (Ormachea et al, 2015).

Surface water is not considerably altered by the groundwater's As concentrations due to the fact that As is frequently found at higher values at the surface than in the deep aquifers. The highest contributor to As contamination is degraded country rock that already has high values of As containing minerals but now is acting as modern sediments. The majority of sediments in question are volcanic in origin and As is released by the breakdown of mafic minerals. While the As travels through a complex water system it interacts with carbonates and silicates that reduce As adsorption and increases its mobility (Ramos et al, 2012; Ormachea et al, 2013).

After comparing information from the Bolivian Altiplano, the Northern Appalachian Mountains and Non-basin/ Mountain data points I believe that to deploy resources responsibly, sample sites that have a geological history of mountain building and also are home to hydrothermal activity should be given preference as research sites because of their increased likelihood to have higher than average As concentrations (Peters, 2008) (Ormachea, 2016) (Ramos, 2012). Within Virginia's boarders, drainage basins, hydrothermal springs that are part of the Southern Appalachian Mountains are both available for research and may be currently a neglected public health concern. To accomplish these goals public servants, geographers, health professionals, and scientists should collaborate to identify and correct the public health issue (Allen and Akpinar-Elci, 2016).

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