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Co-occurrence of Fluoride and Arsenic in the Groundwater of the Aguascalientes Valley Aquifer, México – State of the Art

Roxana Nicte-Há Hughes Lomelín [(1)], Sonia Tatiana Sánchez Quispe [(2)], Mario Alberto Hernández Hernández [(3)], Liliana García-Romero [(4)]

[(1)] Michoacan University of San Nicolás de Hidalgo, Morelia, Mexico,
2147703a@umich.mx

[(2)] International Association for Hydro-Environment Engineering and Research, Madrid, Spain,
quispe@umich.mx

[(3)] Geophysics Institute, National Autonomous University of Mexico, Mexico City, Mexico
malbher@igeofisica.unam.mx

[(4)] Michoacan University of San Nicolás de Hidalgo, Morelia,
liliana.romero@umich.mx

Abstract

The high concentrations of fluorides and arsenic found in exploited groundwater are an increasing global problem. This problem is accentuated principally in arid and semi-arid regions which depend primarily on groundwater extraction to supply the demands of drinking water of their communities, as is the case of Aguascalientes City, Mexico. The present work gathers and synthesizes the studies and research papers that have been done to determine the fluoride and arsenic concentrations in the groundwater of the Aguascalientes Valley aquifer, as well as those that enumerate the risks to which the communities that use this water are exposed, with the objective of underlining the importance of continuing this research to deepen the knowledge and understanding of the system and the presence of these elements in groundwater, as well as to develop solution strategies to tackle the problem. After an extensive revision of the bibliography, the problem is contextualized into a regional panorama and placed within the national and global outlooks, permitting in this way to give the foundations for future water quality studies in the region.

Keywords: Fluoride; Arsenic; Groundwater; Aguascalientes aquifer

1. INTRODUCTION

Mexico's groundwater is divided administratively into 653 aquifers (CONAGUA, 2018). The Aguascalientes Valley aquifer supplies approximately 94% of the potable water demand of the inhabitants of the State of Aguascalientes (INEGI), 2011), since the geographic and climatological conditions of the region cause superficial sources of water to be scarce.

1.1 Characterisation of the Zone of Interest

1.1.1 General overview

The Aguascalientes Valley aquifer is in the central part of Aguascalientes State, Mexico. It covers an area of 3,129 km^2. The type of climate that prevails in the area is temperate semiarid (BS1kw) according to the Köppen classification, which is defined as having a mean temperature of between 18 and 22°C, and rains in the summer period (in the months belonging to the period of May-October) (CONAGUA, 2020). This region also presents a mean precipitation of 510 mm with a potential evaporation of 2010 mm. Figure 1 shows the location of the aquifer with respect to the State of Aguascalientes and the Mexican Republic.

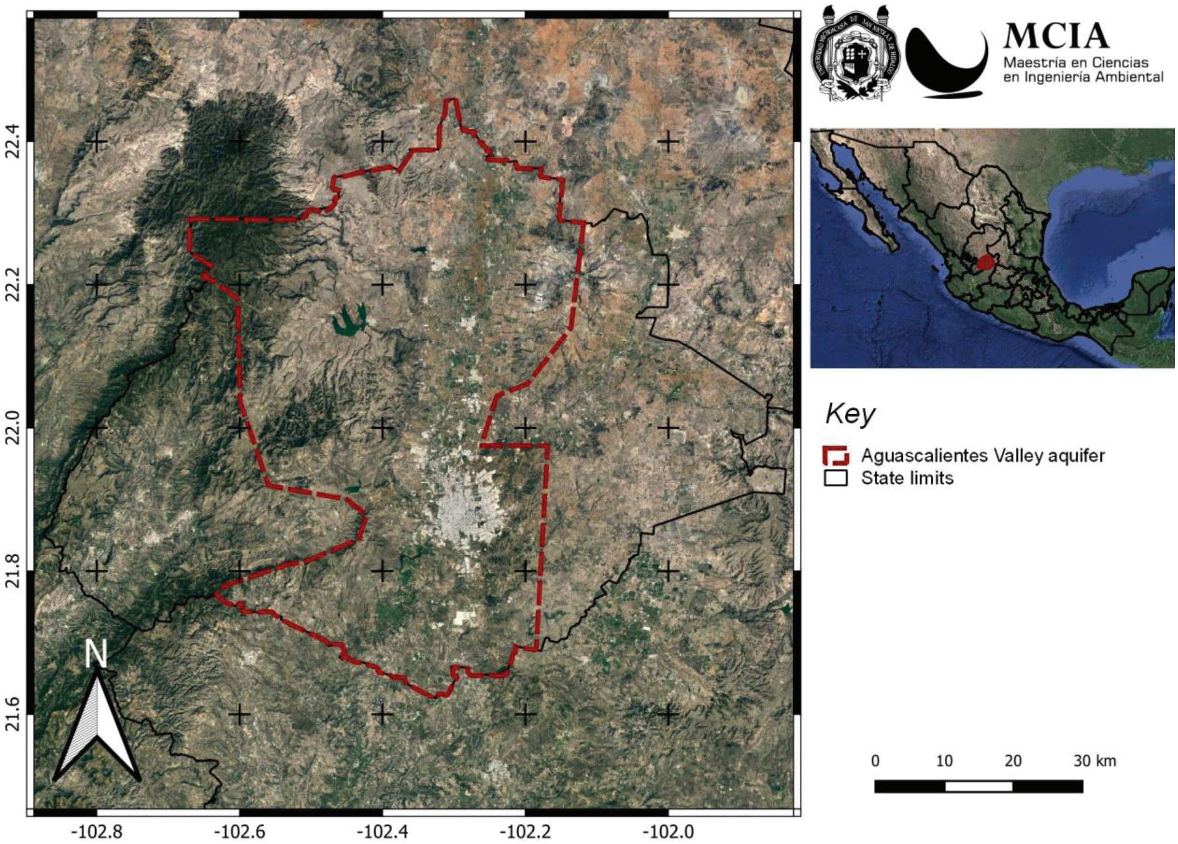

Figure 1. Location of the Aguascalientes Valley aquifer[1].

Aguascalientes State has a population of 1,425,607 inhabitants. Of its territorial extension (5,680 km^2 (Aguascalientes State Government, 2019)), almost 50% is destined to agricultural practices (INEGI, 2016). The volume of water conceded by the National Water Commission for agricultural use is 470.6 hm^3, which represents approximately 75% of the demand of potable water in the State. The remaining extracted volume is divided between urban (domestic) use (20%) and industrial use (5%) (CONAGUA, 2021b).

1.1.2 Geology

The ground which makes up the aquifer and the region surrounding it is represented by the events that gave origin to the Sierra Madre Occidental ridge, with different characteristics between layers. Metamorphosized units from the Cretaceous Age are present, as well as units of volcanic origin from the Tertiary Age. The Quaternary Age units consist of basalts and alluvial material.

The oldest unit corresponds to a volcanic-sedimentary sequence made up of andesites, sandstone, and shale. Upon it lies a unit made up of limestone and shale. Both these units present low-grade regional metamorphism. In the southeast part of the aquifer, a layer of rhyolitic tuff emerges, as well as basaltic flows.

In the region of the Sierra Madre Occidental ridge, there are two igneous sequences: an inferior one constituted principally of intermediate igneous rocks (pyroclastic and ignimbrite flows); and a superior and more recent ignimbrite layer. Then, due to the emergence of the Trans-Mexican Volcanic Belt, older andesitic rocks and rhyolitic tuff can be found.

Clayey sandstone, conglomerate layers, and lithic tuff fill the tectonic trenches. On top, oligomictic and polymictic conglomerates are present, over which lie basaltic spills and basaltic tuff. In some places, andesitic porphyry is also present.

The volcanic events manifested themselves until the Pleo-Quaternary Age, after which rhyolitic ash and lapilli was deposited with massive stratification, as well as fine sands. There is also alluvial material, made up principally of gravel, sands, and silt. (CONAGUA, 2020).

Figure 2 represents the geological composition of the State of Aguascalientes.

[1] Source: Author's own creation, modified in *QGIS* using information provided by the CONAGUA (2021a) and the INEGI (2021).

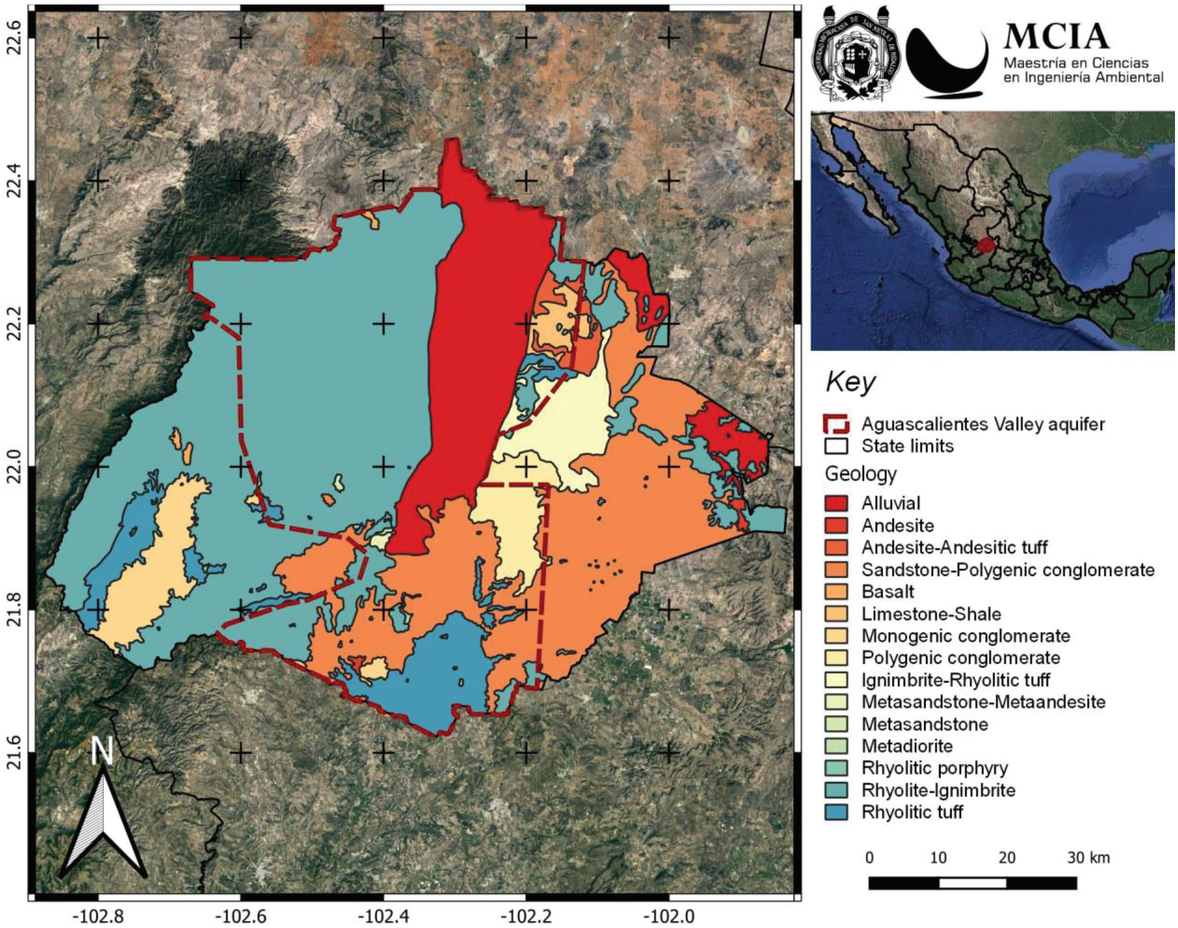

Figure 2. Representation of the geological composition of the Aguascalientes Valley aquifer and Aguascalientes State.[2]

1.2 Over-exploitation of the Aguascalientes Valley Aquifer

For many years, the volume extracted from the Aguascalientes Valley aquifer has been greater than the natural recharge volume, with an estimated deficit of 100.4 hm^3 per year (CONAGUA, 2020). It has been determined, therefore, that the aquifer is overexploited (SEMARNAT, 2012). This overexploitation has resulted in the descent in pumping levels, which are lower in the south region of the Valley, principally in Aguascalientes City.

The Secretary for Environment and Natural Resources in Mexico (SEMARNAT) (2012) has determined that if this same pace of overexploitation continues, the groundwater may become contaminated and its quality may degrade, due to the increase in concentrations of harmful elements to health, such as arsenic or fluoride, on account of the extraction of older water found at deeper levels which circulates through fractured volcanic rock.

The overexploitation of aquifers in which there are already natural concentrations of toxic elements, such as arsenic and fluoride, can increase these concentrations (Armienta & Segovia, 2008). The concentrations of fluoride and arsenic in groundwater have been a central point in measurements done to determine the quality of the water for domestic use, since the presence of these elements determine the risk of chronic-degenerative disease in the population (Habitat, Environment, and Sustainability Commission, 2016).

1.3 Health Implications of Fluoride and Arsenic in Drinking Water

The ingestion of water with high concentrations of fluoride and arsenic can result in health problems that go from mild complications to graver afflictions and even death.

[2] Source: Author's own creation, modified in *QGIS* using information provided by the CONAGUA (2021a), the INEGI (2021), and the Mexican Geological Service (2005).

Ingesting water with high concentrations of fluoride can result in a bone condition known as fluorosis; milder cases appear as yellowing spots on the teeth and weakened enamel (dental fluorosis), while a graver affliction causes the hardening of bones and joints (skeletal fluorosis). Fluoride has been found to reduce IQ levels and decrease intellectual functionality in children, as it has an impact on brain development (Ortega-Guerrero, 2009, Alarcón-Herrera et al., 2013). It also affects other areas of the body as well, namely the liver, kidney, heart, lungs, brain, thyroid, chromosomes, nervous system, and reproduction abilities (Chandrajith et al., 2020).

Chronic exposure to high concentrations of arsenic, on the other hand, results in epidermic, cardiovascular, renal, haematological, and respiratory problems. It is a highly toxic and carcinogenic element.

Endemic chronic hydroarsenicism and hydrofluorosis is prevalent in various parts of Mexico (Ortega-Guerrero, 2009). There are also studies that demonstrate the presence of dental fluorosis in the State of Aguascalientes (Hernández-Montoya et al., 2003, Betancourt-Lineares et al., 2013).

The World Health Organization sets the maximum permissible limits of fluoride and arsenic concentrations in drinking water at 1.5 mg/l and 0.01 mg/l, respectively (WHO, 2006), while Mexican regulations set them at 1.5 mg/l and 0.05 mg/l, respectively (Official Mexican Norm NOM-127-SSA1-1994).

1.4 Sources of Arsenic and Fluoride in Groundwater

Most high As and F concentrations occur in geothermal and volcanic areas, due to the water quality conditions that favour the migration of both elements (Alarcón-Herrera et al., 2013).

Most large-scale As and F pollution in groundwater has geological and water-rock interaction origins, although there is some evidence that occasionally it can come from anthropogenic sources (e.g., the use of fertilizers and pesticides in agriculture) (Navarro et al., 2017).

Arsenic concentrations in groundwater may be enriched by evaporation, making regions with semi-arid conditions more liable to exhibiting higher concentrations of this mineral in groundwater. It is also released under oxidizing conditions in aquifers, as As-bearing sulphide minerals, such as arsenopyrite, are oxidized (Kumar et al., 2020).

Fluorides are released based on mineral dissolution. High concentrations of fluoride can be found in sedimentary deposits, as well as in areas with igneous and metamorphic rocks. Its release is also influenced by semi-arid conditions, as the resident time of the water in the bedrock is longer; fluoride concentration may also be enriched through evaporation (Kumar et al., 2020). Fluoride mobility is also determined by various chemical factors of the groundwater itself, i.e., pH, HCO_3^- concentrations and alkalinity (Chandrajith et al., 2020).

Co-occurrence of these two minerals is caused principally by geological sources, although the aridity of the region and over-exploitation of aquifers may also play a role (Kumar et al., 2020).

2. ARSENIC AND FLUORIDE IN THE AGUASCALIENTES VALLEY AQUIFER

2.1 Arsenic in the Aguascalientes Valley Aquifer

In 2002, Trejo Vázquez & Bonilla Petriciolet evaluated the concentrations of arsenic in the extraction wells that supply drinking water to Aguascalientes City. In this study, they found that the concentrations of arsenic in two-thirds of the wells, while below the Mexican recommendations, surpassed the limits set by the WHO. They developed a preliminary spatial distribution of the concentrations, and based on the maximum and minimum determined concentrations, calculated the exposure dose in different individuals. They also estimated the risk levels of developing skin cancer, and found that, on comparing this information with that of other epidemiological studies done in different cities, the concentrations of arsenic suggest a public health problem.

2.2 Fluoride in the Aguascalientes Valley Aquifer

Trejo-Vázquez & Bonilla-Petriciolet (2001) determined the fluoride concentration in the extraction wells that supply the drinking water to Aguascalientes City. In this paper, they developed a spatial distribution of the determined concentrations, and showed that 40% of the wells had concentrations greater than regulations permit.

Hernández-Montoya et al. published a paper in 2003, in which they conclude that most school-aged children suffer from dental fluorosis and cavities due to the high concentrations of fluoride in the drinking water, in this manner confirming the presence of a public health problem in this State.

In 2007, García Díaz & Trejo Vázquez, undertook a new study in which they updated the fluoride concentrations present in the drinking water extracted from the aquifer; the results show that more than 80% of the sampled wells contain concentrations of fluoride greater than the maximum permissible limits.

Trejo Vázquez et al., in 2008, determined by sampling potable water at household outlets that there are concentrations of fluoride exceeding in 500% the limits set by Mexican regulations. The health risks were also evaluated, concluding therefore that there is a severe public health problem due to the excessive intake of fluorides.

2.3 Co-occurrence of Arsenic and Fluoride in the Aguascalientes Valley Aquifer

Alarcón-Herrera et al. demonstrate in a 2020 paper the correlation between high fluoride concentrations in aquifers found in arid regions, including Aguascalientes. They also spatially distribute fluoride and arsenic concentrations onto a map of the Mexican Republic. The State of Aguascalientes is presented on the map as having high concentrations of both fluoride and arsenic.

3. CONCLUSIONS

In the bibliographic revision done of available literature about high fluoride and arsenic concentrations in the Aguascalientes Valley aquifer, a scarcity in the research was found. The studies presented in this review are enough to conclude that there is indeed a public health problem due to these high concentrations in the groundwater; however, very few studies have been conducted to really understand the behaviour of these elements in the aquifer. It is therefore recommended to advance the research in this field, updating the data bases that already exist, and bringing more attention to the risks posed by the ingestion of these elements in the drinking water. Also, as the aquifer is already over-exploited, and this condition is very likely to continue due to the impacts of climate change, it can be concluded that these concentrations will continue to increase; consequently, it is important to find alternative sources of potable water or determine long-term solutions that will ultimately provide higher-quality water to the population.

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