Inorganic Pollutants in the Water of Midland and Odessa, Permian Basin, West Texas

Authors: Rodriguez, Jose, Heo, Joonghyeok, Park, Joonkyu, Lee, Seong-Sun, and Miranda, Kristyn

Inorganic Pollutants in the Water of Midland and Odessa, Permian Basin, West Texas

Jose Rodriguez[1], Joonghyeok Heo[1], Joonkyu Park[2], Seong-Sun Lee[3] and Kristyn Miranda[4]

[1]Department of Geosciences, The University of Texas Permian Basin, Odessa, TX, USA.
[2]Department of Civil Engineering, Seoil University, Seoul, South Korea. [3]School of Earth and Environmental Sciences, Seoul National University, Seoul, South Korea. [4]College of Sciences, The University of Texas at San Antonio, San Antonio, TX, USA.

ABSTRACT: The objective of this study is to evaluate the public water contamination in the cities of Midland and Odessa, West Texas. Even though both cities are geographically close, their sources of water for public use are different. For this study, the copper-, lead-, arsenic-, nitrate-, and chromium-level reports in drinking water, provided by the cities from 2008 to 2017, were organized and analyzed using Cubic Hermite Interpolation. The results for each contamination per city were compared and contrasted with the Environmental Protection Agency (EPA) standards. Also, this study proposed possible risks to human health, as well as potential origins of the pollutants. Finally, conclusions about the quality of water for human consumption and possible reasons behind the difference of results between the 2 cities were made.

KEYWORDS: Water quality, groundwater, Midland, Odessa, Permian Basin, Texas

Introduction

Water is imperative for sustaining life on Earth. With supplies of consumable freshwater becoming more and more limited, it is vital to preserve freshwater clean. Groundwater begins as precipitation, which then falls to the surface of the Earth. The water then seeps through the vadose zone into the phreatic zone, where it is stored in permeable bodies of rock, known as aquifers. This infiltration of meteoric water into an aquifer is known as recharge. Precipitation also flows across the land into rivers, lakes, or other surface water bodies, where recharge can also occur, as seepage from these surface waters makes its way into the aquifer below.[1]

The most prominent fresh local aquifers in the state of Texas are the Pecos Valley Alluvium (PVA), Ogallala, and Edwards-Trinity Plateau. All are used for agricultural, industrial, and domestic purposes along with human consumption. Groundwater is a renewable commodity; however, arid climates like West Texas present little natural recharge to the groundwater system.[2] With increased population growth, the demand upon potable water supplies has also increased, making fresh groundwater sources even more scarce and heightening the concern over contamination.

Due to the varied nature of groundwater recharge, there are many possible pollutants that may be present in the water, and the route of pollutants entering aquifers includes the following numerous sources: agricultural runoff into a stream, pesticides applied to crops, and interactions with other rock bodies above or below the aquifer. Groundwater contaminants can be inorganic, organic, biological, or radiological. Among all the different types of water contaminants, inorganics like arsenic, chromium, copper, lead, and nitrate have proven to not only be the most present pollutants in the water but also are the most seriously harmful for human health.[3] Furthermore, previous studies conducted throughout West Texas indicated widespread concerning contamination of aquifers in the region by heavy metals.[4,5]

Although they can be naturally found in water bodies, the major sources of inorganic contaminants are anthropogenic. Agriculture, littering, and industrialization are the main causes behind the rise in the levels of inorganic contaminants in aquifers. Copper and lead can also be introduced to water systems due to corrosion of pipes in old public water systems. The consequences for ingestion of these substances are varied from respiratory problems to cancer and in most of the cases would require medical attention.[3]

In Texas, numerous studies about public water contamination have been conducted. While Reedy et al[6] led an extensive analysis about water occurring groundwater contamination across Texas, Manz et al[7] conducted a study about the relation of human activities and water contamination in West Texas. The 2 studies also evaluated the harm of water contamination to human health, and proposed solutions to prevent it. Likewise, Honeycutt[8] analyzed the contamination with heavy metals, such as chromium, in aquifers in Texas. With a letter, Honeycutt discussed the work of Collins et al.[9] In his article, Collins warned about the danger of high chromium levels that was found in groundwater of cities of Texas, including Midland, and performed an in-depth analysis on the health problems associated with the consumption of contaminated water. In a study published by Leatham et al,[10] they have also discussed
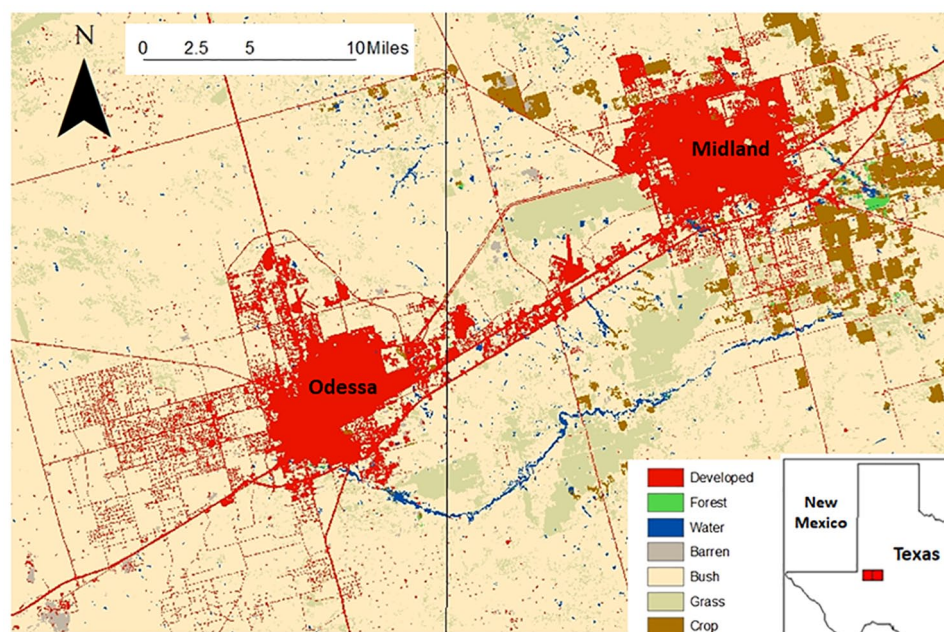
Figure 1. Study location in the cities of Midland and Odessa.

the importance of good water quality in Texas for human health and financial benefits. Leatham showed how polluted water affects agriculture. As agriculture is one of the primary economic activities that generate profit in Texas, Leatham proposed that improving water quantity would greatly increase the state income.

For all the above-mentioned proposes, the intention of this study is to evaluate the water quality of the cities of Midland and Odessa. Levels of copper, lead, arsenic, nitrate, and chromium in drinking water for the last years were analyzed to produce conclusions about the safety of the consumption of water, for the populations of the 2 cities.

Study Area and Methodology

Study area

The study area is located in West Texas, USA, which is part of the Permian Basin (Figure 1). The study area extends across 2 cities of Texas: Odessa and Midland. These areas are predominantly semi-arid climate. In Midland and Odessa, snowfall is not common, and precipitation is mainly due to rainfall.[11] While Odessa had an average annual precipitation of 14.65 inches in 2018, Midland had an average annual precipitation of 14.9 inches.[12] According to the United Nations Environmental Program, the 2 cities can be classified as semi-arid environments, because the annual average precipitation was close to be below 13.78 inches.[13] These dry climate conditions, added to the scarcity of water bodies, make the use of groundwater aquifers imperative. Consequently, groundwater contamination has significant repercussions on public health, due to slow water recharge rates for semi-arid environments.[14]

The land covering the 2 cities is mainly bush, developed, grass, and crop (Figure 1). There is a population growth of more than 18% in Midland and 16% in Odessa from 2008 to 2017.[15,16] Oil and gas production, and other economic activities, also reached a peak during this period, consolidating the Permian Basin as one of the top producers of hydrocarbons in the world.[17] The new coming use of hydraulic fracturing in 2008, a technique that injects fluids to fracture rock reservoirs and enhance the production of hydrocarbons,[18] became widely used.[19] This technique is not only known for directly inserting pollutants to groundwater aquifers but also for introducing contaminants through the interaction of different rock reservoirs.[20]

In the case of Midland and Odessa, municipal wells pull water from the PVA, Ogallala, and Edwards-Trinity aquifers. The PVA is alluvial and eolian sediment deposited during the Cenozoic. The Ogallala is an alluvial aquifer consisting of sand, silt, and gravel. The formation was deposited during the late Miocene to early Pliocene and extends for approximately 450 000 km², ranging from Texas to South Dakota. The Edwards-Trinity Plateau aquifer was formed during the early to middle Cretaceous, with the main water bearing units being dolomite, limestone, and sands.[2] Located in Ector, Martin, and Midland counties, Figure 2 indicates the location of the wells used for the public water systems in Midland and Odessa, provided by the Texas Water Board Development (TWBD).

Methodology

The Safe Water Drinking Act (SWDA) of 1974 created maximum contaminant levels (MCLs) for municipal water supplies. Based on the SWDA, the Environmental Protection Agency (EPA), along with the Texas Commission of Environmental Quality (TCEQ), enforces these rules to ensure public safety.[21]
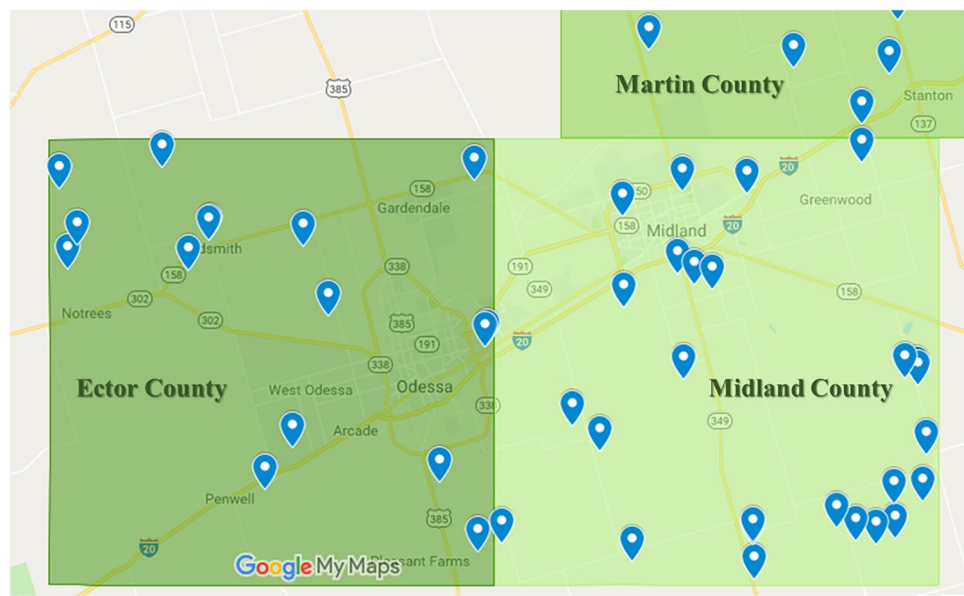
Figure 2. Location of the public water wells in the cities of Midland and Odessa.

Table 1. Pollutant levels from 2008 to 2017 in Midland.

YEAR	COPPER (PPM)	LEAD (PPB)	ARSENIC (PPB)	NITRATE (PPM)	CHROMIUM (PPB)
2008	0.191	1.7	23	1.44	3.4
2009	0.17	2.1	15	1.29	1.7
2010	0.0025	1.3	30.8	1.99	NA
2011	0.115	0	56	3	NA
2012	0.342	4.32	45	2	NA
2013	NA	NA	31	2	NA
2014	NA	NA	28.9	2.11	NA
2015	NA	NA	28	3	1.1
2016	0.26	4.2	5.3	4.44	0.4
2017	NA	NA	22.4	4	1.9

Abbreviation: NA, not available.

Municipalities must routinely test their water supply and report the results to each agency and the public.

For the purpose of this study, the annual water quality reports produced by the cities of Midland and Odessa were used. These reports contain yearly averages of water contaminate levels.[22,23] Copper, lead, arsenic, nitrate, and chromium levels in particles per million (ppm) and particles per billion (ppb) from these reports were analyzed per city from 2008 to 2017 (Tables 1 and 2). Furthermore, the values obtained from the reports were plotted for comparison between cities over time. Finally, curves were generated for each pollutant per city connecting the points on the graphs (Figures 3, 4, 5, 6, and 7), using Cubic Hermite Interpolation (Equation 1). Cubic Hermite Interpolation was the method chosen, because its efficiency to model changes of dispersion and

concentration of pollutants in aquifers has been proven in previous studies[24,25]

$$f(t) = at^3 + bt^2 + ct + d \qquad (1)$$

where

$$a = \frac{-f(t_1) + 3f(t_2) - 3f(t_3) + f(t_4)}{2} \qquad (2)$$

$$b = f(t_1) - \frac{5f(t_2)}{2} + 2f(t_3) - \frac{f(t_4)}{2} \qquad (3)$$

$$c = \frac{-f(t_1) + f(t_3)}{2} \qquad (4)$$

Table 2. Pollutant levels from 2008 to 2017 in Odessa.

YEAR	COPPER (PPM)	LEAD (PPB)	ARSENIC (PPB)	NITRATE (PPM)	CHROMIUM (PPB)
2008	NA	NA	NA	0.44	NA
2009	0.144	2.74	NA	0.17	NA
2010	NA	NA	NA	0.47	NA
2011	NA	NA	3.4	0.26	NA
2012	0.184	3.15	NA	0.31	NA
2013	NA	NA	3	0.46	0.799
2014	0.169	2.55	1.5	0.74	0.68
2015	NA	NA	0.63	0.453	0.78
2016	NA	NA	1	1	NA
2017	0.143	2.78	1	0.494	NA

Abbreviation: NA, not available.
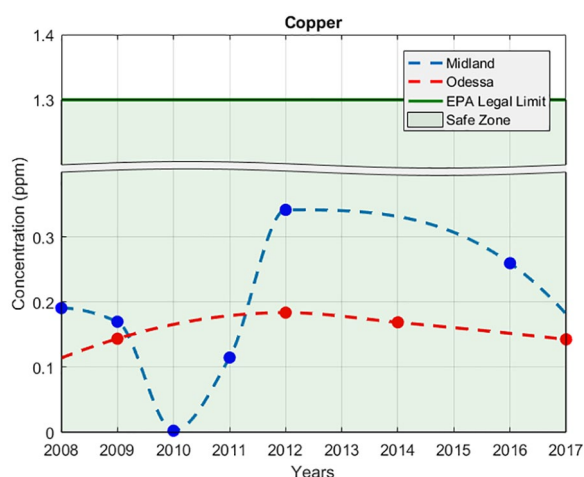
Figure 3. Copper levels from 2008 to 2017 in Midland and Odessa.
Abbreviation: EPA, Environmental Protection Agency.
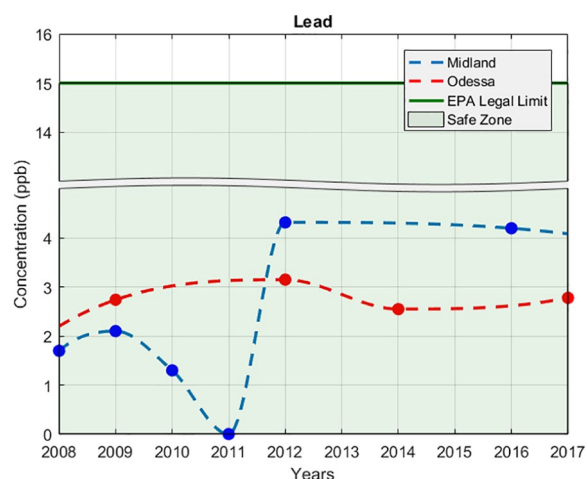
Figure 4. Lead levels from 2008 to 2017 in Midland and Odessa.
Abbreviation: EPA, Environmental Protection Agency.
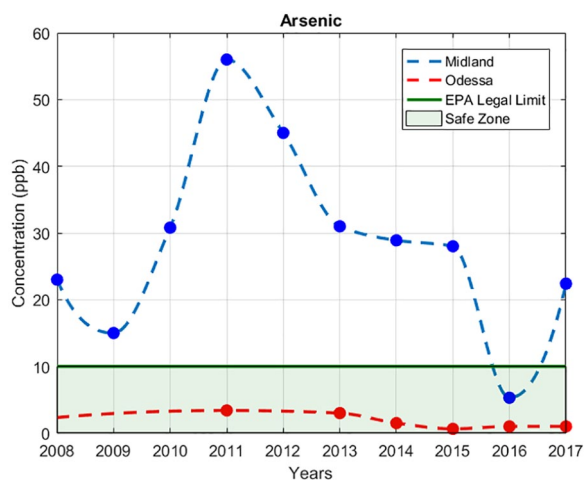
Figure 5. Arsenic levels from 2008 to 2017 in Midland and Odessa.
Abbreviation: EPA, Environmental Protection Agency.
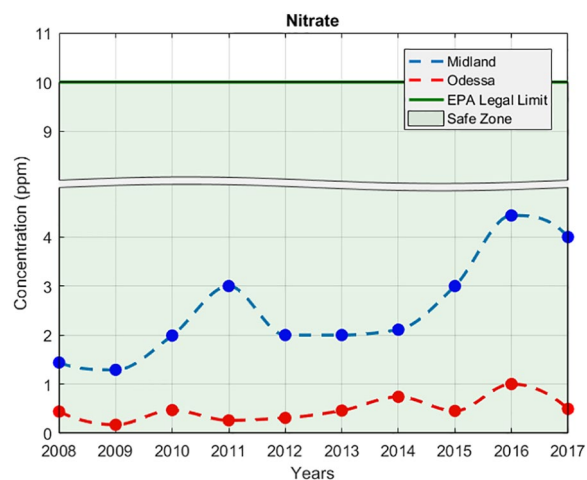
Figure 6. Nitrate levels from 2008 to 2017 in Midland and Odessa.
Abbreviation: EPA, Environmental Protection Agency.

Figure 7. Chromium levels from 2008 to 2017 in Midland and Odessa. Abbreviation: EPA, Environmental Protection Agency.

$$d = f(t_2) \qquad (5)$$

and

$$t_1 < t_2 < t_3 < t_4 \qquad (6)$$

Results and Discussion: Inorganic Pollutants

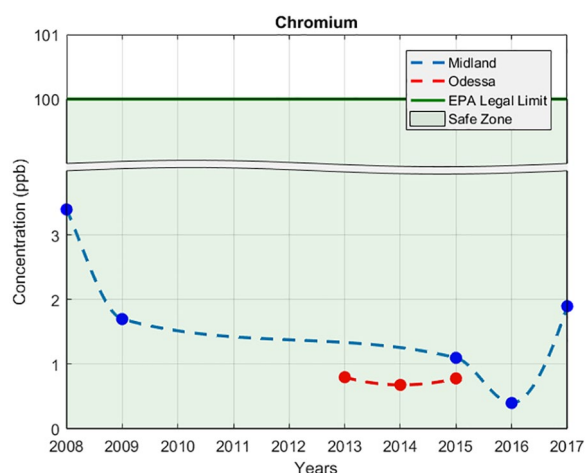Levels of certain pollutants for some years were not possible to obtain from the water quality reports provided by the cities of Midland and Odessa. Chromium levels were not constantly shown on the reports; nitrate and arsenic levels were shown constantly on the reports for most of the years. Values for lead levels were only seen on the reports for each city when lead levels were shown as well.[22,23] As copper and lead levels in water are tested using similar techniques,[26] this conformity might also indicate that copper and lead levels in water are only periodically shown to the public.

Copper

Copper is a metal that can be commonly found in nature. It is also widely used in pipes and drainage systems.[27] According to the EPA, copper in water systems is mainly due to corrosion of household plumbing, but it is also due to erosion of natural deposits.[21] Both the cities of Midland and Odessa experienced low copper levels in water from 2008 to 2011. After the levels of copper reached a peak in 2012, they both were expected to experience a slight progressive reduction during the next 5 years.

Copper starts being highly harmful for human consumption when its level overpasses 1.3 ppm. Gastrointestinal and renal problems are known to occur with consumption of copper.[28] Nevertheless, exposure to low levels of copper, like the ones reported in the cities of Midland and Odessa since 2012, are proven to cause similar effects over prolonged periods of time.[27]

Lead

From air sprays to household items, lead is a metal that is present in a great variety of daily use products. Lead is rarely found in nature, and when it is, it is normally due to human activities.[27] Lead is normally found in water systems because of the corrosion of household plumbing and leakage of chemicals to the underground.[28] The lead concentration in the water of the city of Odessa was calculated to be relatively stable in the 10 years of the analysis. For the city of Midland, after having shown lower concentration values than the city of Odessa, the lead concentration in water experienced a high peak in 2012 and was calculated to remain the highest for the rest of the years of the study.

Due to the high toxicity of lead, concentrations higher than 15 ppb are not allowable in water systems. Health problems associated with lead contamination are physical and mental disease for infants and renal problems for adults.[28] Although below the safety limit, the levels of lead found in the water of Midland and Odessa in the last 6 years analyzed can still represent a hazard for the population of the cities.[27]

Arsenic

Arsenic is a toxic substance that is commonly found in nature. Most of the arsenic that is found in public water systems comes from rock formations. Human activities like mining and agriculture can also deposit arsenic to water systems.[29] The arsenic levels from the city of Odessa never reached concentrations higher than 5 ppb. Dissimilarly, the arsenic levels in the water in the city of Midland reached concentrations higher than 20 ppb during most of the study. Comparing the curves generated for the 2 cities, and due to the more detailed data provided by the water quality reports,[22,23] it is possible to state that Midland had a much higher amount of arsenic in water during the 10 years of the study.

Even though arsenic is a naturally occurring substance, it is highly toxic for human consumption. Therefore, very low concentrations in drinking water (10 ppm) can be dangerous. The negative effects of arsenic to human health are serious and varied. Exposure to arsenic can cause skin damage, circulatory problems, and cancer.[28] As the city of Midland only presented arsenic levels in water lower than 10 ppm in 2016, this poisonous substance has been actively representing a hazard for the population of Midland.

Other potential inputs of arsenic in public water occur when petroleum hydrocarbon releases create reducing environments allowing for its mobilization because of oil production.[17,29] With the advancement of horizontal drilling and hydraulic fracturing, previously untouched shale strata were now viable, greatly increasing the amount of recoverable reserves. As a result, rig count dramatically rose to nearly 500 at the end of 2011 and oil prices peaked at over $100 per barrel, ultimately allowing production to reach 1 million barrels per day.[28] In

addition, associated oil field facilities grew to account for the increase in production. These factors resulted in a considerable change in both economic growth and water quality in Midland.

Nitrate

Nitrate is a naturally occurring substance fundamental for any organism. Nitrate is also the result of human activities like agriculture, farming, and septic systems.[30] As weathering also increases nitrate levels in water systems, weather can also be the reason for nitrate levels to rise.[31] Comparing the 2 curves generated, nitrate levels in water for the city of Midland were always approximately more than 1 ppm higher every year than in the city of Odessa. Although they showed different values of magnitude at any time, it is possible to spot a certain correspondence in the curves generated for the 2 cities. The 2 curves seem to increase and decrease coordinately during certain periods of the study.

Even though nitrates are normally present in most water systems, they can represent a problem when their values exceed 10 ppb. Infants are more sensitive to high nitrate levels than adults. After consuming water with high nitrate content, they can develop respiratory problems that can risk their lives.[28] For the Midland-Odessa population, the nitrate levels never represented a risk during the 10 years of the study.

In addition, nitrates contaminate groundwater from agricultural runoff from either animal wastes or inorganic natural fertilizers.[5,30] They are commonly associated in fertilizers, due to its relative low cost and abundant availability. These can reach the groundwater through leaching in the subsurface. Furthermore, runoff from surface spills or infiltration from animal wastes may have resulted in these elevated concentrations.[28] Once the nitrate contaminant has reached the aquifer, there is no natural remediation processes that can occur to decrease the concentrations in public and groundwater.

Chromium

Chromium is an important industrial metal that is found in water systems due solely to human activities.[32] Discharge from steel factories is the main reason behind chromium contamination in water systems.[28] Due to the lack of data for the city of Odessa, the Cubic Hermite Interpolation method could not generate a complete curve of the chromium levels in water for the city of Odessa.[33] Therefore, an accurate comparison of the concentration of the pollutant in the water of the 2 cities is not possible. However, from 2013 to 2015, it is possible to observe that the concentration of chromium was considerably lower in Odessa.

Unlike other chemical substances, chromium is not excessively harmful to human health. When chromium is found in levels above 0.1 ppm, it causes skin problems like allergic dermatitis.[28] Even though chromium contamination does not represent a life-threatening risk, the values for the city of Midland are far above the safe concentration, which can represent risk after a long term of exposure.[32]

Conclusions

This study has evaluated the public water contamination in the cities of Midland and Odessa from 2008 to 2017. Based on the data collected, Midland shows a higher level of contamination across time. This difference can be explained, because the 2 cities get water from different aquifers. While the city of Midland gets water almost entirely from the Edwards-Trinity Plateau aquifer,[34] the city of Odessa gets water from both the Ogallala aquifer and the Edwards-Trinity Plateau aquifer.[35] This difference in the pollution levels of the water between the cities might indicate that the Edwards-Trinity Plateau aquifer is presenting higher contamination than the Ogallala. According to the EPA guidelines, the water for the last year analyzed, from the 2 cities, are generally safe for consumption.[28] A more complete and extensive data set of information will increase the effectiveness of computational methods to predict the behavior of the concentrations of contaminants in the water.[33,36] When it comes to the reasons behind the contaminations of the aquifers, all the pollutants analyzed, present in the water of Midland and Odessa, are proven to be either partially or mainly originated due to human activities.[27,29,30,32]

Author Contributions

KM checked for the data accuracy and collected detailed information on the study area. JR calculated the water quality level, developed the methodology, and analyzed the results with arguments. JH designed the structure, made revisions, and contributed for the overall paper. JP made critical revisions and developed the arguments for the paper. All authors reviewed and approved of the final manuscript.

REFERENCES

1. Fetter CW. *Applied Hydrogeology*. Upper Saddle River, NJ: Prentice Hall; 2001.
2. George P, Mace R, Petrossian R. Aquifers of Texas. http://www.twdb.texas.gov/publications/reports/numbered_reports/doc/R380_AquifersofTexas.pdf. Updated 2011.
3. Sharma S, Bhattacharya A. Drinking water contamination and treatment techniques. *Appl Water Sci.* 2017;7:1043-1067. doi:10.1007/s13201-016-0455-7.
4. Assadian NW, Esparza LC, Fenn LB, et al. Spatial variability of heavy metals in irrigated alfalfa fields in the upper Rio Grande River basin. *Agric Water Manag.* 1998;36:141-156. doi:10.1016/S0378-3774(97)00054-1.
5. Hudak PF. Nitrate, arsenic and selenium concentrations in the Pecos Valley Aquifer, West Texas, USA. *Int J Environ Res.* 2010;4:229-236. doi:10.22059/IJER.2010.14.
6. Reedy RC, Scanlon BR, Walden S, Strassberg G. *Naturally Occurring Groundwater Contamination in Texas Final Contract Report Prepared for the Texas Water Development Board*. http://www.twdb.texas.gov/publications/reports/contracted_reports/doc/1004831125.pdf. Up-dated 2011. Accessed March 27, 2019.
7. Manz LR, Sarkar D, Hammond WW. Water resources and water quality in the Rio Grande Valley of Texas: current status and future projections. *Environ Geosci.* 2005;12:193-206. doi:10.1306/eg.04260404005.
8. Honeycutt ME. Hexavalent chromium in Texas drinking water. *Toxicol Sci.* 2011;119:423-424. doi:10.1093/toxsci/kfq347.
9. Collins BJ, Stout MD, Levine KE, et al. Exposure to hexavalent chromium resulted in significantly higher tissue chromium burden compared with trivalent chromium following similar oral doses to male F344/N rats and female B6C3F1 mice. *Toxicol Sci.* 2010;118:368-379. doi:10.1093/toxsci/kfq263.

10. Leatham DJ, Schmucker JF, Lacewell RD, Schwart RB, Lovell AC, Allen G. Impact of Texas water quality laws on dairy income and viability. *J Dairy Sci*. 1992;75:2846-2856. doi:10.3168/jds.S0022-0302(92)78048-5.

11. Kimmel TM, Nielsen-Gammon J, Rose B, Mogil HM. The weather and climate of Texas: a big state with big extremes. *Weatherwise*. 2016;69:25-33. doi:10.1080/00431672.2016.1206446.

12. U.S. Climate Data. www.usclimatedata.com Up-dated 2019. Accessed April 15, 2019.

13. UNEP. United Nations Conference on environment and development. https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf. Up-dated 1992.

14. Heo J, Yu J, Giardino JR, Cho H. Water resources response to climate and land-cover changes in a semi-arid watershed, New Mexico, USA. *Terr Atmos Ocean Sci*. 2015;26:463-474. doi:10.3319/TAO.2015.03.24.01(Hy).

15. U.S. Census Bureau. *Population Estimates*. Suitland-Silver Hill, MD: U.S. Census Bureau; 2017.

16. U.S. Census Bureau. *Population Estimates*. Suitland-Silver Hill, MD: U.S. Census Bureau; 2008.

17. Krauss C. Land rush in Permian Basin, where oil is stacked like a layer cake. https://www.nytimes.com/2017/01/17/business/energy-environment/exxon-mobil-permian-basin-oil.html. Up-dated 2017. Accessed May 24, 2019.

18. William N, Jasinski R, Nelson E. Hydraulic fracturing process and compositions. https://patents.google.com/patent/US5551516A/en. Up-dated February, 1995. Accessed May 25, 2019.

19. Testa SM. *Historical Development of Well Stimulation and Hydraulic Fracturing Technologies*. http://www.searchanddiscovery.com/documents/2017/60053testa/ndx_testa.pdf. Up-dated 2017. Accessed May 25, 2019.

20. Myers T. Potential contaminant pathways from hydraulically fractured shale to aquifers. *Groundwater*. 2012;50:872-882. doi:10.1111/j.1745-6584.2012.00933.x.

21. US EPA. Safe Drinking Water Act (SDWA). https://www.epa.gov/sdwa. Up-dated 2017. Accessed March 9, 2019.

22. City of Midland, Texas. Water quality reports. https://www.midlandtexas.gov/Archive.aspx?AMID=36. Accessed March 9, 2019.

23. City of Odessa, Texas. Water quality reports. https://www.odessa-tx.gov/government/departments/utilities/water-quality-reports. Accessed March 9, 2019.

24. Czernuszenko W, Rowinski PM. *Water Quality Hazards and Dispersion of Pollutants*. Berlin: Springer Science+Business Media; 2005.

25. Ahlfeld DP, Pinder GF. Solving stochastic groundwater problems using sensitivity theory and hermite interpolating polynomials. *Dev Water Sci*. 1988:179-184. doi:10.1016/S0167-5648(08)70335-6.

26. Okiei W, Ogunlesi M, Adio-Adepoju A, Oluboyo M. Determination of copper and lead in water samples from Zamfara state, Nigeria by linear sweep anodic stripping voltammetry. *Int J Electrochem Sci*. 2016;11:8280-8294. doi:10.20964/2016.10.06.

27. MDH. Lead and copper in drinking water. https://www.health.state.mn.us/communities/environment/water/docs/contaminants/leadcopper.pdf. Up-dated 2008. Accessed March 9, 2019.

28. US EPA. National primary drinking water regulations. https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations. Up-dated 2017. Accessed March 9, 2019.

29. State Department of Health Division of Environmental Health Office of Drinking Water. Arsenic in drinking water. http://www.nsf.org/. Up-dated 2011. Accessed March 9, 2019.

30. St M, Aitken G, Eugene R, Richerson P, Pendleton R, Stewart S. *Nitrate in Drinking Water*. DWSP. http://www.oregon.gov/DEQ/wq/programs/Pages/DWP.aspx. Up-dated 2017. Accessed March 9, 2019.

31. Marchetto A, Barbieri A, Mosello R, Tartari GA. Acidification and weathering processes in high mountain lakes in Southern Alps. *Hydrobiologia*. 1994;274:75-81. doi:10.1007/BF00014629.

32. Fan AM. *Public Health Goal for Chromium in Drinking Water*. https://ntp.niehs.nih.gov/ntp/htdocs/chem_background/exsumpdf/hexavalentchromium_508.pdf. Up-dated 1999. Accessed March 9, 2019.

33. Heo J. The impact of climate change on hydrology with geomorphology in North-east Texas. *J Earth Sci Eng*. 2018;8:1-7. doi:10.17265/2159-581X/2018.01.001.

34. Ashworth JB, Christian PC. *Evaluation of Ground-Water Resources in Parts of Midland, Reagan, and Upton Counties, Texas*. https://www.twdb.texas.gov/publications/reports/numbered_reports/doc/R312/R312.pdf. Up-dated 1989. Accessed March 21, 2019.

35. Blandford TN, Blazer DJ. *Hydrologic Relationships and Numerical Simulations of the Exchange of Water between the Southern Ogallala and Edwards-Trinity Aquifers in Southwest Texas*. https://www.twdb.texas.gov/publications/reports/numbered_reports/doc/R360/Ch05.pdf. Up-dated 2004. Accessed March 21, 2019.

36. Heo J, DeCicco JM. Spatial and temporal analysis of carbon sequestrations in the conterminous United States. *J Energ Power Eng*. 2018;12:169-176. doi:10.17265/1934-8975/2018.04.001.