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Revisiting groundwater chemical processes in a rapidly urbanizing basin

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Abstract

Monterrey procures about 40% of its water supply from groundwater resources, considering several aquifers below and nearby. This city meets semiarid climate conditions with highly variable precipitation rates. The increasing demand for groundwater during drought conditions can deteriorate water quality, raising the energy consumption and costs of lifting, moving, distributing, and treating water. Thus, the major ion content of this resource was assessed, analyzing changes across the Monterrey Basin during the last 11 years to obtain a more robust geochemical concept of the study area. Waters from three wellfields (Buenos Aires, Santiago, Mina) with low mineralization were classified as recharge waters. Waters circulating across evaporite–silicate–carbonate sediments of the Monterrey Basin with gradually increasing salinity were classified as transition zone waters (Metropolitan area) and discharge zone waters (north and northeast of the city). According to this, it can be concluded that groundwater from the different Monterrey sources exhibits high-quality mineralized water, considering the analyzed parameters. Nevertheless, further attention must be paid on nitrate and sulfate occurrence and evolution in the transition and discharge zones.

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Keywords: Urban aquifer; Groundwater chemistry; Monterrey; Mexico

1. Introduction

Currently, about 55% of the world's population of 7.7 billion and about 79% of 133 Mexico's population live in urban areas, respectively. These numbers will continue to rise in the next future. Large urban areas have the advantage of providing a more efficient public transport and housing, centralized electricity, water, and sanitation services.

Further, they offer a workforce and infrastructure that drive the world's economy. However, large population centers and associated industrial and commercial activity can lead to enormous stress on the natural resources of

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a region, the most important being water. It is well recognized that safe water supplies and adequate sanitation and drainage are a fundamental requirement if the growth of the world's largest urban conurbations is to be environmentally sustainable [1,2].

The city of Monterrey (population 4.7 million) in northeastern Mexico - also called the Monterrey Metropolitan Area - represents the country's third-largest urban area and second most important economic center after Mexico City. The urban water supply for domestic, public, industrial and commercial use is provided by surface water (60%) and groundwater sources (40%). Surface water sources include the three dams El Cuchillo, Cerro Prieto and La Boca. Groundwater sources consist of wellfields below and within a short distance from the city [3,4]. In both cases, there is a large amount of energy consumption necessary due to pumping water from dams or wellfields against gravity. In some works, it has been estimated that 37% of the total energy consumption only were needed for the extraction and treatment processes for groundwater, whereas for surface water only 4%, resulting essential to know the quality of the water resources in order to minimize the total energy consumption and related costs of the different processes [5].

This rapidly growing city meets semiarid climate conditions with highly variable precipitation rates. Moreover, its water supply system is considered vulnerable due to the increased reliance on surface water sources [6]. During dry periods, there is a need for extracting more groundwater from below the city and the wellfields nearby. Nevertheless, with an increasing demand for groundwater - therefore an increasing demand for energy - the water quality tends to decline, increasing the costs of lifting, moving, distributing, and treating water, and producing severe stress on water resources that can affect the local hydrological system [4].

The objectives of this study are to (1) map the changes in groundwater chemistry across the Monterrey Basin between 2006 and 2017; (2) evaluate whether specific contaminants are changing across the basin; (3) infer major hydrochemical processes that control groundwater chemistry through multivariate modeling. Mora et al. [4] assessed major ions and trace elements in groundwater supplied to Monterrey Metropolitan Area, using measurements of 2006 and 2012. This study considers new data from 2017 and an additional wellfield, eventually leading to a more robust conception of groundwater quality.

2. Study area

The study area is located in the state of Nuevo León, northeastern Mexico (Fig. 1). According to Köppen classification, the climate is defined as a semi-arid zone (Bhs). The mean annual temperature is 22.3 °C, with a maximum historical record of 48 °C, and a minimum of -7.5 °C. The mean annual precipitation is 622 mm. However, this parameter has varied in the historical record from 240 to 1300 mm.

The geology of the studied zone is defined in the southwestern area as a mixture of limestone, conglomerate and shale rocks, which belong to the Sierra Madre Oriental mountain range and host the Buenos Aires wellfield and the Santiago system. The Monterrey Metropolitan aquifer is situated in the central part consisting of shales on the valley borders and of fluvial and alluvial sediments [7–9]. Finally, in the northwestern area is found the Mina wellfield placed over an alluvium area bordered by limestones.

3. Materials and methods

Forty groundwater samples, one spring and two surface water samples were taken in July 2017 from the Santiago system, Buenos Aires wellfield, Mina wellfield, and the Metropolitan aquifer. The physicochemical parameters pH, electrical conductivity, dissolved oxygen, oxidation–reduction potential, salinity, total dissolved solids, and temperature were measured in the field using portable meters. Alkalinity was measured on-site by acid titration with H_2SO_4 until the endpoint of pH 4.3. Water samples were collected and stored in pre-cleaned HDPE plastic bottles. Samples for cations and anions were filtered (0.45 μ m). In addition, samples for cations were acidified with ultrapure HCl to pH < 2. A principal component analysis (hierarchical cluster analysis - HCA) was performed applying varimax rotation to elucidate factors controlling groundwater chemistry.

4. Results and discussion

4.1. Changes in groundwater chemistry over time

In order to evaluate changes over time in the chemistry of groundwater, the Kruskal–Wallis test (K–W) was used in 3 different zones of the basin: the Monterrey metropolitan aquifer (MMA), the Buenos Aires wellfield (BA)



Fig. 1. Map showing the location and geology of the study area, sampling points by groups in the different wellfields, and the delimitation of the urban area.

and the Santiago system (ST). The test was used to compare if there are significant differences (p-value < 0.05) between the years 2006, 2012 and 2017 (Table 1).

The results demonstrate that for BA wellfield, there are no significant differences in temperature, Ca, Mg, Na, and HCO_3 ; nevertheless, pH and K show a decrease over time, and Cl and SO_4 a two-fold increase of concentrations between 2012 and 2017. For the MMA, there are no significant differences between the different parameters over time except for reduced K concentrations in 2017. For ST, similar to MMA, there are no differences in all three sampling campaigns for all physicochemical parameters, except for K and HCO_3 . These show a decreasing trend.

4.2. Groundwater chemistry across the basin

Groundwater samples obtained from the supply system of Monterrey city had neutral to moderately alkaline pH values ranging from 6.75 to 8.19 (average of 7.21), temperature values ranging from 20.35 °C to 32.05 °C (average of 25.81 °C) and electrical conductivity values varying between 369 and 2227 μ S/cm. According to the physicochemical parameters and ion concentrations, four groups were identified from the HCA (Fig. 2). Their distribution is shown in Fig. 1.

According to the Piper diagram (Fig. 3a), the sample groups can be described as follows: Group 1 is located in Mina wellfield and four samples from MMA near Las Mitras mountain range. Samples in the area of Mina are a calcium-mixed water type, whereas MMA samples are calcium-bicarbonate water type (TDS = 527 ± 147 mg/l). Group 2 is in the alluvial valley in the MMA and is considered as a transition zone between recharge and discharge areas (TDS = 521 ± 41 mg/l). This group is situated in an evaporite–silicate–carbonate mixing zone (Fig. 3b, c) due to interaction with different geological strata along the groundwater flow path. Group 3 is placed in the discharge area of the MMA in the northeastern region of the city (TDS = 1057 ± 237 mg/l). This group shows a higher mineralization as a result of the longer transition times of water in the underground and possible admixture of surface waters. Group 4 contains samples from BA and ST groundwater supply featuring a calcium bicarbonate

Table 1. Temporal comparison of physicochemical parameters of groundwater samples in different areas of the Monterrey Basin. Note: K-W indicates the significance level (p) of Kruskal–Wallis test; BA = Buenos Aires, MMA = Monterrey Metropolitan Aquifer, ST = Santiago System.

| Zone | Year | n | T (°C) | K-W | рН | K-W | Ca (mg/L) | K-W | Mg (mg/L) | K-W | Na (mg/L) | K-W |
|------|------|----|------------|-------|-------------|-------|---------------|-------|---------------|-------|-------------|-------|
| BA | 2006 | 5 | 22.20±1.26 | | 7.46±0.06 | 0.019 | 71.74±1.29 | 0.054 | 13.08±3.49 | 0.099 | 3.67±1.51 | 0.106 |
| | 2012 | 4 | 21.78±0.45 | 0.206 | 7.49±0.18 | | 71.15±1.60 | | 11.08±0.61 | | 3.00±0.69 | |
| | 2017 | 9 | 22.99±1.39 | | 7.26±0.11 | | 74.76±3.78 | | 9.97±2.06 | | 2.33±0.85 | |
| MMA | 2006 | 9 | 26.11±2.79 | | 7.23±0.31 | 0.166 | 136.10±52.10 | 0.460 | 21.75±13.77 | 0.112 | 56.10±66.80 | 0.202 |
| | 2012 | 7 | 26.44±2.80 | 0.787 | 7.38±0.32 | | 159.90±64.10 | | 27.90±15.67 | | 73.80±72.50 | |
| | 2017 | 23 | 26.38±2.28 | | 7.13±0.18 | | 129.58±41.32 | | 16.50±5.90 | | 37.75±35.73 | |
| ST | 2006 | 8 | 19.13±2.54 | | 7.31±0.49 | 0.088 | 120.70±40.90 | 0.258 | 5.56±1.82 | 0.27 | 6.52±4.59 | 0.083 |
| | 2012 | 6 | 20.64±1.31 | 0.487 | 7.68±0.22 | | 101.10±41.00 | | 7.60±3.72 | | 4.06±1.63 | |
| | 2017 | 4 | 20.89±0.64 | | 7.57±0.44 | | 82.79±14.52 | | 6.09±2.57 | | 2.58±0.39 | |
| Zone | Year | n | K (mg/L) | K-W | CI (mg/L) | K-W | SO₄ (mg/L) | K-W | HCO₃ (mg/L) | K-W | NO₃ (mg/L) | K-W |
| BA | 2006 | 5 | 0.86±0.16 | | - | 0.009 | - | 0.045 | 241.80±51.40 | 0.310 | - | 0.229 |
| | 2012 | 4 | 0.71±0.07 | 0.001 | 2.05±0.51 | | 22.85±8.22 | | 214.80±32.70 | | 1.10±0.22 | |
| | 2017 | 9 | 0.47±0.09 | | 3.91±1.24 | | 42.37±19.56 | | 244.51±6.04 | | 1.27±0.33 | |
| MMA | 2006 | 9 | 2.00±1.37 | | 58.80±59.00 | 0.470 | 130.40±117.50 | 0.554 | 352.60±76.50 | 0.100 | 6.57±4.40 | 0.084 |
| | 2012 | 7 | 2.11±0.68 | 0.000 | 97.00±85.40 | | 200.60±168.90 | | 302.60±88.00 | | 8.41±6.60 | |
| | 2017 | 23 | 0.87±0.48 | | 70.60±62.20 | | 165.00±127.70 | | 306.50±46.22 | | 11.65±6.35 | |
| ST | 2006 | 8 | 0.72±0.33 | 0.038 | 6.18±5.03 | 0.068 | 78.70±67.2 | 0.854 | 358.30±113.70 | 0.017 | 0.41±0.15 | 0.587 |
| | 2012 | 6 | 0.62±0.16 | 0.036 | 2.31±1.02 | | 75.20±63.60 | | 215.50±43.30 | | 0.51±0.17 | |
| | 2017 | 4 | 0.38±0.05 | | 1.94±0.13 | | 62.50±52.00 | | 223.00±20.20 | | 0.48±0.18 | |



Fig. 2. Dendrogram with an imaginary horizontal line (phenon line) to define four groups of water samples based on a hierarchical cluster analysis.



Fig. 3. (a) Piper diagram (b) Ca/Na vs. Mg/Na scatter plot, (c) Ca/Na vs. HCO₃/Na scatterplot.

| Group | T (°C) | pН | TDS (mg/L) | Ca (mg/L) | Mg (mg/L) | Na (mg/L) |
|------------|-------------------|--------------------|------------------------|------------------------|-------------------------|-------------------|
| 1 (n = 11) | 30.24 ± 0.95 | 7.26 ± 0.13 | 526.66 ± 146.83 | 104.04 ± 10.29 | 11.59 ± 1.72 | 40.23 ± 26.90 |
| 2 (n = 12) | 24.90 ± 0.74 | 7.14 ± 0.10 | 520.53 ± 41.57 | 111.10 ± 9.11 | 15.89 ± 3.07 | 23.11 ± 3.17 |
| 3 (n = 7) | 26.84 ± 1.80 | 6.98 ± 0.17 | 1056.64 ± 236.61 | 181.89 ± 36.95 | 21.40 ± 7.13 | 80.49 ± 38.32 |
| 4 (n = 13) | 22.34 ± 1.60 | $7.35~\pm~0.28$ | 291.37 ± 31.61 | 77.23 ± 8.78 | 8.77 ± 2.82 | $2.41~\pm~0.73$ |
| Group | K (mg/L) | Cl (mg/L) | NO ₃ (mg/L) | SO ₄ (mg/L) | HCO ₃ (mg/L) | |
| 1 (n = 11) | 0.89 ± 0.45 | 82.76 ± 53.26 | 2.23 ± 1.13 | 125.24 ± 47.55 | 256.01 ± 4.14 | |
| 2 (n = 12) | 1.08 ± 0.42 | 40.62 ± 5.75 | 11.22 ± 2.69 | 101.62 ± 16.37 | 299.03 ± 28.02 | |
| 3 (n = 7) | 0.77 ± 0.49 | 151.74 ± 52.96 | 17.02 ± 7.57 | 327.39 ± 120.75 | 349.78 ± 46.83 | |
| 4 (n = 13) | $0.44~\pm~0.09$ | 3.31 ± 39 | 1.03 ± 0.47 | 48.56 ± 32.03 | 237.899 ± 15.26 | |

Table 2. Average and standard deviation values of the chemical parameters of groups according to HCA.

water type. These samples are located in recharge zones and represent the least mineralized waters of all four groups $(TDS = 291 \pm 31 \text{ mg/l})$. More details of the different parameters are shown in Table 2.

4.3. Groundwater processes controlling chemistry

The most important process which controls the chemistry of groundwater is associated with the water-rock interaction. According to geology, samples from BA wellfield suggest a significant interaction with the calcites and dolomites from the Sierra Madre Oriental. Water from this zone is less mineralized due to a short water-rock interaction distance. The water samples from ST suggest an interaction of water with silicate and evaporitic rocks. For the MMA, water indicates an interaction with evaporites, calcites, and silicates along the groundwater flow direction. High NO₃ concentrations in this zone are attributable to anthropogenic activities such as sewage leakage (e.g., [10,11]). Finally, water from Mina wellfield results suggests a possible interaction with gypsum, calcite and silicates.

Groups 1 and 4 were identified as recharge waters, and groups 2 and 3 as mixing waters. In general, a dissolution trend prevails among different groups. The general dominance in anions is $HCO_3 > SO_4 > Cl > NO_3$, while in cations Ca > Na > Mg > K for groups 1, 2 and 3, whereas for group 4 Ca > Mg > Na > K.

5. Conclusion

Chemical properties of groundwater used for water supply for the Monterrey Metropolitan Area were analyzed in order to identify changes over time and processes which control the chemistry. The statistical analysis, in general, demonstrates that there are no significant differences in the parameters measured over time in the different zones of the study area, which allows maintaining the current water treatment strategy without the need to incorporate new processes that require higher energy demands. In this research, an additional exploitation area was included for the chemical analysis (Mina wellfield) with respect to previous reports from the study area. It is necessary to perform a cost–benefit analysis of this source, because despite of having an excellent water quality, the energy needs for extraction, transport and distribution of this source possibly are elevated in comparison to other sources. The HCA indicates 4 chemical groups of water with increasing salinity, which is in agreement with the general groundwater flow direction. Low mineralized waters are found in the recharge areas located in Buenos Aires and Santiago. These waters then circulate across the Monterrey Basin, interacting with alluvial/fluvial sediments,and thereby increasing the concentrations of Na, K, Cl, and SO₄, and in consequence TDS. Additionally, an increasing trend of NO₃ has been identified along the flow path from the Buenos Aires wellfield to the northeastern area of the city, which can be attributed to leakages in the urban sewage system. On the other hand, the Mina wellfield has an excellent water quality due to the surrounding geological conditions with no significant evidence of anthropogenic influences.

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References

- Howard KWF. Urban groundwater issues—An introduction. In: Howard KWF, Israfilov RG, editors. Curr. Probl. Hydrogeol. Urban Areas. Dordrecht: Urban Agglom. Ind. Centres, Springer; 2002, p. 1–15.
- Schirmer M, Leschik S, Musolff A. Current research in urban hydrogeology A review. Adv Water Resour 2013. http://dx.doi.org/10. 1016/j.advwatres.2012.06.015.
- [3] Aguilar-Barajas I, Sisto NP, Ramírez Orozco A. Agua para monterrey logros, retos y oportunidades para Nuevo León Y México. first ed.. Monterrey: Agencia Promotora de Publicaciones, S.A. de C.V.; 2015.
- [4] Mora A, Mahlknecht J, Rosales-Lagarde L, Hernández-Antonio A. Assessment of major ions and trace elements in groundwater supplied to the Monterrey metropolitan area, Nuevo León, Mexico. Environ Monit Assess 2017;189:394. http://dx.doi.org/10.1007/s10661-017-6096-y.
- [5] Smith K, Liu S, Liu Y, Liu Y, Wu Y. Reducing energy use for water supply to China's high-rises. Energy Build 2017;135:119–27. http://dx.doi.org/10.1016/j.enbuild.2016.11.033.
- [6] Sisto NP, Ramírez AI, Aguilar-Barajas I, Magaña Rueda VClimate threats. Water supply vulnerability and the risk of a water crisis in the Monterrey Metropolitan Area (Northeastern Mexico). Phys Chem Earth A/B/C 2016;91:2–9. http://dx.doi.org/10.1016/j.pce.2015.08.015.
- [7] CONAGUA (Comision Nacional del Agua). Actualización de la disponibilidad media anual de agua en el Acuífero Campo Mina (1908). Mexico: Estado de Nuevo León; 2015.
- [8] CONAGUA (Comision Nacional del Agua). Actualización de la disponibilidad media anual de agua en el Acuífero áRea Metropolitana de Monterrey (1906). Mexico: Estado de Nuevo León; 2015.
- [9] CONAGUA (Comision Nacional del Agua). Actualización de la disponibilidad media anual de agua en el Acuífero Campo Buenos Aires (1907). México, D.F.: Estado de Nuevo León; 2015.
- [10] Divers MT, Elliott EM, Bain DJ. Constraining nitrogen inputs to urban streams from leaking sewers using inverse modeling: Implications for dissolved inorganic nitrogen (DIN) retention in urban environments. Environ Sci Technol 2013;47:1816–23. http: //dx.doi.org/10.1021/es304331m.
- [11] Pastén-Zapata E, Ledesma-Ruiz R, Harter T, Ramírez AI, Mahlknecht J. Assessment of sources and fate of nitrate in shallow groundwater of an agricultural area by using a multi-tracer approach. Sci Total Environ 2014;470–471:855–64. http://dx.doi.org/10. 1016/j.scitotenv.2013.10.043.