Radon behavior in springs and wells around Cuitzeo lake, Lerma river basin, Mexico

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RESUMEN
Se determinó radón en manantiales y pozos en zonas urbanas y agrícolas alrededor del lago de Cuitzeo, en la cuenca del río Lerma, México. Se estudiaron también los elementos mayores y traza. El ²²²Rn se midió por el método de centelleo líquido, los elementos mayores con análisis químicos convencionales y los elementos traza por espectrometría de masas (ICP-MS). Los valores promedio de las concentraciones de radón oscilaron entre 0.88 y 3.66 Bq L⁻¹, indicando un tránsito rápido entre la zona de recarga y el afloramiento en los manantiales. Los valores de los elementos mayores y traza se discuten considerando las características geológicas de los sitios en estudio.

PALABRAS CLAVE: Zona volcánica, agua subterránea, radón, composición química, elementos traza disueltos.

ABSTRACT
Radon was determined in springs and wells from urban and agricultural zones around Cuitzeo lake, in the Lerma river basin, Mexico. Major and trace elements were also studied in the water samples. The measurement techniques included the liquid scintillation method for ²²²Rn, conventional chemical analysis for major components and ICP-MS for metallic trace elements. The average radon concentration values were relatively low, ranging from 0.88 to 3.66 Bq L⁻¹ indicating a rapid transit from recharge to the output of the springs. The major and trace elements are discussed considering the geological characteristics of the studied sites.

KEYWORDS: Volcanic zone, groundwater, radon, chemical composition, dissolved trace elements.

INTRODUCTION

The geological characteristics of aquifers are essential parameters generating differences between the concentration levels of physical parameters, chemical species and radionuclides in the water samples (Segovia et al., 1999). Radon gas is considered as one of the natural radioactive elements with greater mobility in the terrestrial crust (Corbett and Burnett, 1997). Conventional chemical analysis of water does not put the emphasis on the study of water dissolved gases; however, their determination is important, due to their capacity to react. In the case of radon, being a noble gas with low interaction capacity, its presence can provide information concerning the radioactive elements present on the rock, the water origin and flow mechanisms; aquifers can be classified according to their ²²²Rn concentration (Hamada, 2000).

Groundwater may contain high amounts of ²²²Rn generated as a product of the ²³⁸U natural radioactive series decay. Once the groundwater flows to rivers or lakes, the radon content significantly decreases due to degassing and limited regeneration since little amounts only of radium are generally dissolved in surface water (Annamäki et al., 2000; Kito and Kuhland, 1995; Paulus et al., 1998).

The assessment of major and trace elements in groundwater is important to reconcile the exploitation of natural resources with the protection of the environment. Pollution of surface waters can percolate to the substrata and contaminate aquifers. Measurement of the mentioned parameters together with microbiological organisms can provide information concerning a given zone’s state of pollution.
Cuitzeo lake is located in the northern part of Michoacan State in Mexico. The region belongs to the middle part of the Mexican Neo Volcanic belt. The basin is part of the upper Lerma river, whose watershed is one of the most polluted in Mexico (De Cserna and Álvarez, 1995).

With the aim to evaluate the transport of contaminants to the aquifers in the zone, radon, major and trace elements together with biological parameters were determined from several wells and one spring whose waters are used for drinking water supply of the nearby towns around Cuitzeo lake.

**EXPERIMENTAL**

**The sites**

Recent volcanism has occurred at Michoacan State, the youngest volcano, Paricutin, was born in 1943. The main regional geological formations are from Tertiary and Quaternary periods. Michoacan hydrology is composed by the upper Lerma river, the central lakes zone and the Balsas river. The Cuitzeo basin, in the northern part of the State, having 3977 km² is one of the largest lakes of the zone. A fork of the Lerma river flows to the Yuriria lake and reaches Cuitzeo in its northern part. The main landform of the sampling zone is formed by the Cuitzeo depression. The weather is moderate with summer rains (May-October) giving an average annual precipitation of 906 mm and a temperature range from 10 to 28 °C.

**Sampling**

The sampling sites are located around the Cuitzeo lake, between 101° 10' and 101° 20' W and 19° 58' 00'' and 19° 58' 23'' N at an average altitude of 1850 m. The samples were obtained from Jeruco, Cuitzeo 2, Cuitzeo 3, Copandaro, Panteón and El Salitre boreholes ranging from 60 to 120 m depth, continuously pumped to provide the drinking water supply of the nearby towns. In Los Baños, spring water was also monitored (Figure 1).

Three sampling campaigns of water for radon determination were performed from March to August, 2001. The samples were taken in carefully cleaned HDPE (high density polietylene) containers tightly closed to avoid degassing. Aliquots of 125 mL sample and 10 mL pure toluene were immediately transferred to a separator funnel and vigorously shaken for 5 minutes for radon separation. When the mixture resettled in two phases, the organic phase was transferred into a counting vial to which 10 mL of INSTAGEL scintillation solution was added (Olguin et al., 1993).

One litre water samples were taken in plastic polyethylene bottles for major chemical components such as Cl⁻, SO₄²⁻, total alkalinity and SiO₂. A 500 mL sample having 3 mL HNO₃ was used for the analysis of Na⁺, K⁺, Ca²⁺ and Mg²⁺.

The sampling for trace elements dissolved in the water was performed in 60 mL HDPE bottles previously washed and decontaminated with HNO₃; one day before the sampling the bottles and covers were rinsed three times and filled with deionized water. In the field two samples were taken at each place, one with the water sample and the other with deionized water used as a field blank. The samples were filtered under a laminar flow hood and acidified with ultrapure HNO₃.

**Measurement techniques**

**Radon**

The water samples were analysed for solubilized ²²²Rn with a Packard TRI-CARB 2700TR scintillation detection system. The results are reported in Bq L⁻¹. Corrections for decay of radon and decay and growth of the daughter products in the samples were necessary (Olguin et al., 1993).

**Physical and chemical parameters**

In the field, electrical conductivity was determined with a conductimeter (Conductronic PC18). Temperature and pH were determined with a Schott pH-Meter CG 837, calibrated before each measurement using a pH 4 buffer solution. Dissolved oxygen was also measured in situ using an YSI Model 57 oximeter.

**Chemical analyses**

Major elements were analysed by standard methods, as given in APHA-AWWA-WPCF (1995). The accuracy of the analyses was checked by the ionic charge balance (lower than 10 % difference).

**Trace elements**

Trace elements were determined at µg L⁻¹ levels using an ICP-MS (Inductively Coupled Plasma, Mass Spectrometer) VG Plasma Quad 2 Turbo Plus. Calibration was performed with 5 and 10 µg L⁻¹ solution containing all the elements to be analysed. A 10 µg L⁻¹ ¹ⁱ⁵In and ²⁰⁹Bi solution was used as internal standard in order to correct instrumental drift (Morton et al., 1996).

**Bacteriological analysis**

Samples for determination of total and faecal coliforms were taken in sterilised glass bottles and determined by the standard total coliform fermentation techniques at 35 ± 0.5
Radon in springs around Cuitzeo

and 44.5 ± 0.5 °C respectively, during 24 hours (APHA-AWWA-WPCF, 1995).

RESULTS AND DISCUSSION

The $^{222}$Rn concentration obtained at the 7 sampling sites is shown in Figure 2. Average radon values were relatively low ranging from 0.88 to 3.66 Bq L$^{-1}$ indicating that the rocks have a low content of $^{226}$Ra and/or a rapid transit from recharge to the output of the springs. The higher values correspond to Cuitzeo 2 in a local geological region with monogenetic volcanism composed of pyroclastic flow deposits from Cuitzeo lake. The lowest radon content corresponds to El Salitre and Copandaro having continental recent superficial deposits of alluvial and lacustrine origin. The studied

Fig. 1. Location of the sampling sites around Cuitzeo lake.

Fig. 2. $^{222}$Rn concentration obtained at the 7 sampling sites.
wells behave quite similarly as far as $^{222}\text{Rn}$ content is concerned.

The results regarding major elements are shown in Table 1. The higher values for pH, Cl-, F-, Na+ and CO$_3^{2-}$ were found at El Salitre having almost the highest temperature. Jeruco showed the higher conductivity, total alkalinity, HCO$_3^-$, SO$_4^{2-}$, K+, Mg+ and the second in Na+ after El Salitre. Cuitzeo 2 and 3, had differences in major elements content. Na+, K+ and Cl- were half at Cuitzeo 3 as compared to Cuitzeo 2, which are 1 km apart and a striking one order of magnitude higher SO$_4^{2-}$ value was found at Cuitzeo 2. These results indicate some differences in the water quality of these two very close boreholes. The type of water is shown in the Piper diagram (Figure 3) indicating differences between the boreholes: Jeruco and Cuitzeo 2 are of Na+-Mg+-HCO$_3^-$ type; Cuitzeo 3, Mg$^{2+}$-Ca$^{2+}$-HCO$_3^-$ type; Copándaro and Panteón, Ca$^{2+}$-Na$^+$-HCO$_3^-$; Los Baños Na$^+$-HCO$_3^-$ and finally, a quite different one El Salitre of Na$^+$-Cl$^-$ type.

Adams et al., (2001) reported the behaviour of prevailing Ca$^{2+}$-HCO$_3^-$ type of waters in higher lying areas while in topographycal flat areas Na$^+$-Cl$^-$ type waters dominated. In the case of Cuitzeo, Israde-Alcántara (1999) explains a connection on the SW part of the Cuitzeo lake with the Zacapú zone, through a channel, indicating that El Salitre position has the lowest topography of the Cuitzeo zone. It has also been reported by Marini et al. (2001) that Ca$^{2+}$-HCO$_3^-$ facies coupled with low salinity are typical of first stages of interaction between meteoric waters and rocks. This interpretation together with the low radon concentration values could support a rapid transit of the water recharge to the discharge zone.

Trace elements (Table 2) indicate differences between the sampling sites. El Salitre had one or two orders of magnitude higher B and Mn content as compared to all the other sites. The differences between Cuitzeo 2 and 3 are also evident.

Examples of bimodal diagrams Li-B, Rb-Sr and Sr-Ba (Figure 4) indicate that each well and spring differentiates even for several samplings. Los Baños and El Salitre, located at the SW of the lake have low Sr content as compared with Jeruco (NE shore) with high Rb-Sr values. The presence of andesitic and basaltic lavas and ignimbrites at Jeruco seems to be a factor for these differences between the N and S shores of the lake. Extreme values of Ba-Sr and Rb-Sr correspond to Los Baños for the lower values and Jeruco for the largers. Los Baños, having the higher temperature, has also high F- and Na$^+$ and the lowest total alkalinity. The B-Li diagram indicates that Jeruco, Panteón, Copándaro, Cuitzeo 2 and Cuitzeo 3 had similar B values with differ-

<table>
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<tr>
<th>Sample Date</th>
<th>T (°C)</th>
<th>E.C. (µS cm$^{-1}$)</th>
<th>pH</th>
<th>T. A. (mg L$^{-1}$ CaCO$_3$)</th>
<th>CO$_3^{2-}$</th>
<th>HCO$_3^-$</th>
<th>Cl-</th>
<th>SO$_4^{2-}$</th>
<th>F-</th>
<th>SiO$_2$</th>
<th>Na+</th>
<th>K+</th>
<th>Ca$^{2+}$</th>
<th>Mg$^{2+}$</th>
<th>Bal (%)</th>
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<td>Jeruco</td>
<td>270301</td>
<td>24</td>
<td>1072</td>
<td>345.10</td>
<td>3.31</td>
<td>414.29</td>
<td>52.30</td>
<td>99.40</td>
<td>0.57</td>
<td>72.34</td>
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<td>98.22</td>
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<td>667</td>
<td>8.35</td>
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<td>4.11</td>
<td>372.79</td>
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<td>56.37</td>
<td>14.00</td>
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<td>483</td>
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<td>255.25</td>
<td>3.76</td>
<td>303.76</td>
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<td>3.92</td>
<td>0.20</td>
<td>64.10</td>
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<td>965</td>
<td>7.68</td>
<td>263.41</td>
<td>0.76</td>
<td>319.83</td>
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<td>28</td>
<td>490</td>
<td>7.27</td>
<td>249.12</td>
<td>0.28</td>
<td>303.36</td>
<td>4.30</td>
<td>1.45</td>
<td>0.32</td>
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<td>7.72</td>
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<td>32</td>
<td>947</td>
<td>8.01</td>
<td>175.60</td>
<td>1.07</td>
<td>212.06</td>
<td>166.50</td>
<td>42.73</td>
<td>3.38</td>
<td>79.91</td>
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<td>13.70</td>
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<td>481</td>
<td>8.04</td>
<td>142.93</td>
<td>0.93</td>
<td>172.48</td>
<td>58.90</td>
<td>16.06</td>
<td>2.05</td>
<td>46.79</td>
<td>99.60</td>
<td>1.96</td>
<td>11.87</td>
<td>0.55</td>
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</table>
Fig. 3. Piper diagram of the sampled waters.

Table 2

Trace elements (µg L⁻¹) in the water samples from the 7 sites.

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<thead>
<tr>
<th>Sample</th>
<th>Date</th>
<th>Li</th>
<th>B</th>
<th>Mn</th>
<th>Co</th>
<th>Ni</th>
<th>Cu</th>
<th>Zn</th>
<th>As</th>
<th>Rb</th>
<th>Sr</th>
<th>Mo</th>
<th>Cs</th>
<th>Ba</th>
<th>Pb</th>
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<td>Jeruco</td>
<td>270301</td>
<td>124.080</td>
<td>324.110</td>
<td>0.299</td>
<td>0.243</td>
<td>1.153</td>
<td>3.544</td>
<td>12.086</td>
<td>5.973</td>
<td>22.951</td>
<td>812.480</td>
<td>1.003</td>
<td>0.211</td>
<td>122.550</td>
<td>0.267</td>
<td>14.952</td>
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<td>103.750</td>
<td>313.500</td>
<td>0.208</td>
<td>0.159</td>
<td>0.679</td>
<td>1.134</td>
<td>5.486</td>
<td>2.529</td>
<td>22.325</td>
<td>794.840</td>
<td>0.876</td>
<td>0.220</td>
<td>120.330</td>
<td>0.161</td>
<td>14.624</td>
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<tr>
<td>Cuitzeo 2</td>
<td>270301</td>
<td>12.801</td>
<td>214.330</td>
<td>0.031</td>
<td>0.193</td>
<td>1.413</td>
<td>2.777</td>
<td>7.374</td>
<td>1.914</td>
<td>20.573</td>
<td>500.630</td>
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<td>20.664</td>
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<td>12.051</td>
<td>341.190</td>
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<td>28.944</td>
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<td>344.940</td>
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<td>El Salitre</td>
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<td>2192.700</td>
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<td>0.058</td>
<td>0.539</td>
<td>1.169</td>
<td>4.045</td>
<td>8.290</td>
<td>22.613</td>
<td>218.190</td>
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<td>1.556</td>
<td>86.284</td>
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<td>129.320</td>
<td>991.890</td>
<td>0.251</td>
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<td>0.090</td>
<td>0.919</td>
<td>1.696</td>
<td>16.851</td>
<td>4.950</td>
<td>35.291</td>
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<td>5.073</td>
<td>1.489</td>
<td>0.098</td>
<td>0.864</td>
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</table>
ences in Li, almost one order of magnitude between the extremes Jeruco and Cuitzeo 3. El Salitre had the maximum B, one order of magnitude higher than all the other samples. The temperature, water type, high boron and lithium contents suggest that El Salitre and Los Baños are part of the same system.

No microbiological contamination was found in the studied samples.

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