ASSESSMENT OF THE EXPOSURE TO FLUORIDE FROM DRINKING WATER IN DURANGO, MEXICO, USING A GEOGRAPHIC INFORMATION SYSTEM

Deogracias Ortiz, a Lorena Castro, a Francisco Turrubiartes, b Joel Milan, b and Fernando Diaz-Barriga a
San Luis Potosi, SLP, Mexico

SUMMARY: A Geographic Information System (GIS) coupled with environmental data was used for the study of endemic fluorosis in the city of Durango, Mexico. The city was divided into four different risk areas. These areas were categorized according to fluoride levels in tap water. Mean fluoride levels ranged from 1.54 mg/L in area 1 to 4.70 mg/L in area 4. A level of 5.67 mg/L, the highest fluoride concentration in Durango, was found in area 4. Almost 95% of the 306,652 inhabitants living in this city were exposed to fluoride levels higher than 2.0 mg/L. Exposure doses to fluoride were calculated for all the areas. For example, the maximum estimated exposure doses were 1.86 mg/kg/day for infants, 0.28 mg/kg/day for children and 0.16 mg/kg/day for adults. Taking into account the minimal risk level of 0.05 mg/kg/day calculated by the Agency for Toxic Substances and Disease Registry, a health risk for the city of Durango became evident.

Key words: Durango, Mexico; Fluoride exposure; Fluoride from water; Geographic Information System

INTRODUCTION

As has been previously reported, endemic fluorosis may be a public health issue in Mexico.1-5 Among the cities located in areas where drinking water contains excessive quantities of natural fluoride is Durango, in the northwest of Mexico. Preliminary data obtained in Durango showed that 96% of well water samples collected in the city had fluoride levels above the Mexican National Guideline of 1.5 mg/L.6 However, this study failed to characterize the risk areas for fluoride exposure because of the lack of information regarding the areas of Durango which are fed by each well. The city has 70 municipal wells which are not interconnected. They are distributed all over the city and are the potable water source for a defined area.

Geographic information systems (GIS), coupled with environmental data, offer tools for the identification of populations at risk.3 In the city of San Luis Potosi (SLP), our group used GIS to screen for fluoride exposure.3 As a result of this work, SLP was divided into four different risk areas, where intervention programs were introduced. Considering the products that can be obtained with GIS, we used GIS for the identification of risk areas in Durango. For the present study, fluoride levels in tap water were analyzed.

METHODS

Tap water samples were collected from 212 homes distributed throughout the city of Durango (Figure 1). Samples were collected in polyethylene bottles. Fluoride levels were quantified by adding TISAB buffer to the samples just prior to the analysis with a sensitive specific ion electrode. As an internal quality control program, primary standard reference material was analyzed. Our fluoride recovery was 97.8%.

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a Facultad de Medicina, Universidad Autónoma de San Luis Potosí, Avenida Venustiano Carranza 2405, 78210, San Luis Potosí, SLP, Mexico. Correspondence: Dr Diaz-Barriga.
b Facultad de Ingeniería, Universidad Autónoma de San Luis Potosí.
A Geographic Information System provides a computational platform in which layered, spatially distributed databases can be manipulated easily and whereby selected topological attributes, which may not be known a priori, can be queried to obtain the spatial relationship between environmental/health parameters and demographic distributions. For this work, we used Arc-Info and Arc-View software, which operate in standard personal computer equipment.

The exposure doses were calculated by the following generic equation:
\[
ED = \frac{C \times WI}{BW}
\]
Where:
- \(ED\) = exposure dose (mg/kg/day)
- \(C\) = fluoride concentration (mg/L)
- \(WI\) = water intake (L/day)
- \(BW\) = body weight (kg)

The standard values that were used in estimating exposure are shown in Table 2. For the calculations, we assumed chronic exposure and total bioavailability of fluoride in water.

**RESULTS**

Four different risk areas were obtained using GIS coupled with fluoride levels in tap water (Figure 1, Table 1). A clear low risk area was detected in the south sector of the city (area 1) whereas a high risk area (area 4) was located both in the southeast and in the northeast sectors of the city. However, high levels of fluoride were also found in some locations in the rest of the city. Mean fluoride levels in tap water samples collected in each area are depicted in Table 1. Area 4 not only had the highest mean fluoride level but also had the highest percentage of samples with fluoride levels above 3.0 ppm. In contrast, area 1 had the lowest mean fluoride concentration and none of the samples collected in this area had fluoride levels above 3.0 ppm.

Figure 2 shows the distribution of population in each area. It is interesting to note that 95% of the inhabitants of Durango are heavily exposed to fluoride. For example, 17.5% of the population (54,186 inhabitants) live in area 4, which has a mean fluoride level in tap water of 4.70 mg/L. In order to give an idea of the magnitude of the exposure, in Table 2 we present the exposure doses. Minimum and maximum exposure doses were calculated, taking into account the minimum and the maximum level of fluoride in tap water found for the city of Durango. The minimum exposure dose for infants and the maximum exposure dose for infants, children and adults were higher than 0.05 mg/kg/day, which is the minimum risk level (MRL) estimated by the Agency for Toxic Substances and Disease Registry (ATSDR).7

**Table 1. Fluoride levels in tap water samples collected in different risk areas of Durango**

<table>
<thead>
<tr>
<th>Area</th>
<th>n</th>
<th>MEAN</th>
<th>SD</th>
<th>RANGE</th>
<th>% of samples&gt;3.0 ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9</td>
<td>1.54</td>
<td>0.55</td>
<td>1.0 - 2.7</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>49</td>
<td>2.63</td>
<td>0.42</td>
<td>1.0 - 3.9</td>
<td>14.3</td>
</tr>
<tr>
<td>3</td>
<td>111</td>
<td>3.57</td>
<td>0.46</td>
<td>2.0 - 4.5</td>
<td>90.1</td>
</tr>
<tr>
<td>4</td>
<td>43</td>
<td>4.70</td>
<td>0.36</td>
<td>3.6 - 5.6</td>
<td>100</td>
</tr>
</tbody>
</table>

Results in mg/L are shown for each area, as the arithmetical mean (mean) with the standard deviation (SD). Areas were defined according to Figure 1.
Figure 1. Risk areas according to fluoride levels in tap water.
In this map of the city of Durango, each risk area is represented with numbers and the approximate locations of the homes where the water samples were collected are shown with dots.

Figure 2. Population distribution in the risk areas
The bars represent the number of inhabitants in each of the risk areas for fluoride exposure in Durango.
Table 2. Estimation of Exposure Doses for Fluoride in SLP

<table>
<thead>
<tr>
<th>Example</th>
<th>Source of water</th>
<th>L/day</th>
<th>Fluoride (mg/L)</th>
<th>Fluoride intake (mg/kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant (6 kg)</td>
<td>Boiled water⁷</td>
<td>1.00</td>
<td>2.00b</td>
<td>0.33 1.86</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11.2b</td>
<td></td>
</tr>
<tr>
<td>Children (20 kg)</td>
<td>Tap water</td>
<td>1.00</td>
<td>1.0</td>
<td>0.05 0.28</td>
</tr>
<tr>
<td>Adult (70 kg)</td>
<td>Tap water</td>
<td>2.00</td>
<td>1.0</td>
<td>0.02 0.16</td>
</tr>
</tbody>
</table>

For the calculation of the fluoride intake we used the minimum fluoride level (1.0 mg/L) and the maximum fluoride level (5.6 mg/L) found in the city of Durango (Table 1).

a The source of boiled water for infants is the water used in the reconstitution of milk formulas.

b Considering that in boiled water, fluoride levels increase proportionally to the loss of volume, the concentration of fluoride in tap water was doubled. This value represents the maximum range obtained after a survey done in San Luis Potosi.

DISCUSSION

A GIS coupled with environmental data has been shown to be useful for the study of human exposure to fluoride. In Durango, 70 municipal wells, which are not interconnected, are the sources of the tap water. However a map of the area served by each well is lacking. Therefore, in this work, the study of fluoride levels in tap water was preferred to define the risk areas. Using GIS and mapping in it the fluoride levels in tap water, a division of the city into four different risk areas was obtained (Figure 1). The main result, however, is that almost 95% of Durango's population is exposed to high levels of fluoride. Almost 300,000 persons live in areas with fluoride levels higher than 2.0 mg/L. By calculating the exposure doses to fluoride, it can be concluded that a health risk exists for these individuals.

Exposure doses to fluoride from tap water were estimated for infants, children and adults (Table 2). For infants in their first semester of life (body weight 6 kg), we applied the risk factor of boiling the water, since the main source of water for infants is that used in the reconstitution of milk formulas. The dose estimated for this group was between 0.33 mg/kg/day and 1.86 mg/kg/day. At these levels a clear risk for dental fluorosis is evident. For example, in San Luis Potosi, in an area where the exposure dose for infants is 1.1 mg/kg/day, a prevalence of 84% was found for moderate to severe dental fluorosis.

Exposure doses from water were also calculated for children (20 kg body wt) and adults (70 kg body wt). In children, the doses were between 0.05 mg/kg/day and 0.28 mg/kg/day. Whereas in adults the doses ranged between 0.02 and 0.16 mg/kg/day. These doses were then compared with safety doses. For example, ATSDR has calculated a MRL of 0.05 mg/kg/day for chronic oral exposure, based on a lowest observed adverse effect level (LOAEL) of 0.48 mg/kg/day (at the high end of an uncertainty factor of 10) for increased nonvertebral fracture rate in osteoporotic women. Therefore, the maximum exposure dose to fluoride for the adults in Durango living in area 4 (the area with the highest fluoride levels in water) is three times higher than the ATSDR's MRL. How serious a health risk this dose...
represents is a question that deserves further research. However, our calculations did not take into account other sources of fluoride, and therefore the real exposure doses in Durango are no doubt higher than the figures presented in Table 2.

In light of our results, a public health program is needed for the city of Durango. Epidemiological surveillance for dental and skeletal fluorosis will help determine the health risk in those areas of the city exposed to elevated fluoride levels. Furthermore, a source of potable water (low-fluoride or fluoride-free) has to be made available to the population. This requirement is especially important, since preliminary analysis of bottled water sold in Durango shows that it also has high levels of fluoride. The health program has to be designed taking into account all the fluoride sources, including diet.

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