ENDEMIC FLUOROSIS IN SAN LUIS POTOSÍ, MEXICO
III. SCREENING FOR FLUORIDE EXPOSURE WITH
A GEOGRAPHIC INFORMATION SYSTEM

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SUMMARY: A Geographic Information System (GIS) coupled with environmental and health data was used for the study of human exposure to fluoride in the city of San Luis Potosí (SLP). The city was divided into four different risk areas. These areas were categorized according to fluoride levels in tap water, fluoride concentrations in well water and dental fluorosis prevalence in children. Fluoride levels in tap water apparently explain the prevalence of dental fluorosis. However, in SLP tap water is not the only source of fluoride. This conclusion was reached by finding that almost one third of the children studied in area 1 were categorized as having moderate or severe dental fluorosis. Area 1 has a mean fluoride level of only 0.9 ppm in tap water. As a whole, this work is an example of how the use of a GIS can be useful for the identification of risk areas in terms of human exposure to fluoride. It also gave further evidence for the presence in SLP of sources of fluoride different from tap water.

Key words: Dental fluorosis; Fluoride exposure; Geographic Information System.

INTRODUCTION

The city of San Luis Potosí (SLP), Mexico, is located in an area where drinking water contains excessive quantities of natural fluoride. Results showed that 61% of tap water samples collected in SLP had fluoride levels above the recommended 0.7-1.2 ppm.1 However, two studies done in SLP showed that risk factors other than drinking water need to be considered in order to explain the total exposure to fluoride. In one study, the prevalence and severity of dental fluorosis in children living in SLP was analyzed.1 It was demonstrated that dental fluorosis increased as the concentration of water fluoride increased. However, in areas of the city with fluoride levels in water lower than 0.7 ppm, a prevalence of 69% was found for total dental fluorosis.1 A second study, done among workers living in SLP who were exposed to fluoride by two pathways (drinking water ingestion and industrial air inhalation), showed through a multivariate regression analysis, that the workplace explained 33% of the fluoride content of urinary samples, whereas tap water ingestion explained only 8%.2 Therefore, in these workers other risk factors have to be taken into account to explain the total content of fluoride in urinary samples.

Geographic information systems (GIS) coupled with environmental and health data, offer tools for the identification of populations at risk.3 Therefore, water ingestion as a pathway of exposure to fluoride could be studied using GIS coupled

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with fluoride levels in tap water and combined with dental fluorosis studies. In the present work, we test this procedure in order to verify that water ingestion is not the only pathway of exposure to fluoride in SLP.

MATERIALS AND METHODS

Population: From different areas of SLP 352 children aged 11 to 13 years were selected randomly. All of them had resided at the same address from birth. After obtaining informed consent from each child's parent, a questionnaire was distributed to investigate sociodemographic and behavioral variables. Prevalence of dental fluorosis was determined in these children following Dean's index. They were classified according to the two most severely affected teeth.

Drinking Water Samples: Tap water samples were collected from 499 homes distributed all over SLP. Among them, the homes of the children in the study were included. Samples were collected in polyethylene bottles. Fluoride levels were quantified within 24 h of sampling, 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 104%.

Geographic Information System: A GIS 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 and health parameters, and demographic distributions. For this work, we used Arc-Info and Arc-View software, which run in a standard personal computer environment.

RESULTS

Four different risk areas were obtained with GIS coupled with fluoride levels in tap water (Map 1). A clear low risk area was detected at the north sector of the city (area 1); whereas a very high risk area (area 4), together with a high risk area (area 3), was located both in the south-southeast and in the northwest sectors of the city. The rest of the city (area 2) was classified as an undefined risk area, considering that high levels of fluoride were found in some locations together with very low fluoride concentrations. Mean fluoride levels in tap water samples collected in each area are depicted in Table 1. It can be observed that 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 (Table 1).

<table>
<thead>
<tr>
<th>Areas</th>
<th>No. of samples</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
<th>Percentage of samples &gt; 3.0 ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>130</td>
<td>0.90</td>
<td>0.40</td>
<td>0.3 - 2.4</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>205</td>
<td>1.69</td>
<td>0.88</td>
<td>0.2 - 5.8</td>
<td>9.7</td>
</tr>
<tr>
<td>3</td>
<td>53</td>
<td>2.37</td>
<td>0.76</td>
<td>0.9 - 4.2</td>
<td>17.0</td>
</tr>
<tr>
<td>4</td>
<td>111</td>
<td>3.29</td>
<td>0.65</td>
<td>1.2 - 4.5</td>
<td>79.3</td>
</tr>
</tbody>
</table>

Results in mg/L are shown for each area, as the arithmetical mean (mean) with the standard deviation (S.D.). Areas were defined according to Map 1.
MAP 1. Risk areas according to fluoride levels in tap water. In this map of the city of San Luis Potosi, each risk area is represented with numbers, and the sample points are indicated with symbols. Fluoride concentrations in tap water:

- ■ 0 - 0.7 mg/L;
- ♦ 0.71 - 1.5 mg/L;
- ▼ 1.51-2.99 mg/L;
- ▲ > 3.0 mg/L.
In order to find an explanation for the fluoride concentration distribution, found in distinct areas of SLP, 55 wells were analyzed for fluoride content. Groundwater is the only source of drinking water for 95% of the population in this city. The results were placed in the GIS and a logical result was obtained (map 2). Of the 10 wells with fluoride levels lower than 1.0 ppm, eight were located in area 1. Except for two wells, all of the wells in areas 3 and 4 had fluoride levels above 3.0 ppm. In conclusion, fluoride content in tap water samples can be explained by the distribution of fluoride in the aquifer of SLP. However, an important consideration has to be taken into account: as the municipal water distribution system combines water from wells with different fluoride levels, it is not unusual to find fluoride concentrations in tap water lower than those reported in municipal wells.

Although this was an important conclusion, further studies were needed to determine the distinct distribution of high fluoride waters in the southeast and northwest sectors of SLP, and of low fluoride waters in the north sector. Therefore, a distribution model of the aquifer was placed in the GIS (Map 3). An interesting issue became evident: the abatement cone of the aquifer was located in the northwest sector of the city, where the water table was found at 180 m. In the southeast, the water table was found at 120 m. In both sectors a direct correlation was obtained between fluoride levels and water temperature (see discussion section). Therefore, the origin of fluoride may be related to a deep regional flow of thermal waters, already described in the aquifer.5

With a clearer view of the aquifer, dental fluorosis studies were done in children selected from different areas. Results were placed in the GIS and are presented in Table 2 (data from area 2 is not depicted as it was not clear enough). It is shown that the percentage of children with dental fluorosis increases as the fluoride concentration in tap water increases. For example, area 1 with a mean fluoride level of 0.9 ppm in tap water had a prevalence of 74% for total dental fluorosis; whereas area 4 with a mean fluoride level of 3.29 ppm in tap water had a 96% prevalence for total dental fluorosis. The differences among areas were even greater when only the percentage of children with moderate plus severe dental fluorosis was considered (Table 2).

By examination of data obtained in the west sector (which belongs to area 2), conclusions about the presence of other sources of fluoride different from tap water, can be achieved. Table 3 shows a higher prevalence of total dental fluorosis in the west of SLP when compared to area 3. The higher prevalence found in the west sector, was a result of a higher percentage of children in the category of very dental fluorosis.

<table>
<thead>
<tr>
<th>Areas</th>
<th>Fluoride level in tap water*</th>
<th>No. of studied children</th>
<th>Dental fluorosis categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Normal</td>
</tr>
<tr>
<td>1</td>
<td>0.90</td>
<td>100</td>
<td>26</td>
</tr>
<tr>
<td>3</td>
<td>2.37</td>
<td>47</td>
<td>17</td>
</tr>
<tr>
<td>4</td>
<td>3.29</td>
<td>51</td>
<td>4</td>
</tr>
</tbody>
</table>

Areas were defined according to Map 1. * Mean fluoride level in tap water mg/L. The results of dental fluorosis are presented as percentages.
MAP 2. Risk areas according to fluoride levels in well water. Each risk area is represented with numbers, and the sample points are indicated with symbols.

Fluoride concentrations in well water:
- ☒ 0 - 0.7 mg/L
- ▼ 0.71 - 1.5 mg/L
- ▲ 1.51 - 2.99 mg/L
- ☆ > 3.0 mg/L
MAP 3. Distribution model of the aquifer. The risk areas according to fluoride levels in tap water are represented with numbers. The sample points are indicated with symbols. The level of the table water in the aquifer in different areas of the city of San Luis Potosi is represented with lines (the levels are shown in meters by the numbers in each line). Fluoride concentrations in tap water:

- **0 - 0.7 mg/L;**
- **0.71 - 1.5 mg/L;**
- **1.51 - 2.99 mg/L;**
- **> 3.0 mg/L.**
mild plus mild dental fluorosis, and a lower percentage of children with no
evidence of dental fluorosis. The singularity of the result is that fluoride levels in
tap water samples in the west sector were lower than those in area 3 (Table 3).

### TABLE 3. Comparison of area 3 and the west area of San Luis Potosi
Fluoride levels in tap water samples and prevalence of dental fluorosis in children

<table>
<thead>
<tr>
<th>Areas</th>
<th>Fluoride level in water ppm</th>
<th>Dental fluorosis categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Normal</td>
</tr>
<tr>
<td>3</td>
<td>2.3 (0.9 - 4.2)</td>
<td>17</td>
</tr>
<tr>
<td>West</td>
<td>1.5 (0.6 - 3.8)</td>
<td>43</td>
</tr>
</tbody>
</table>

Areas were defined according to Map 1. Fluoride levels in water samples are the means of 53 samples in area 3 and 67 samples in the west, with ranges in parentheses. The results of dental fluorosis are presented as percentages.

### DISCUSSION

GIS coupled with environmental and health data was useful for the study of human exposure to fluoride in SLP, as a division of the city into four different risk areas was obtained (Map 1). These areas were categorized according to fluoride levels in tap water (Table 1), fluoride concentrations in well water (Map 2), and dental fluorosis prevalence in children (Table 2). Results were clear enough for the definition of three areas. However, area 2 was classified as an undefined risk area, since fluoride levels in water samples and dental fluorosis prevalence in children were present in a wide range.

GIS was also useful for the specific location of areas with very high levels of fluoride in water. By placing in the GIS a distribution model together with fluoride concentrations in tap and well water, two “hot spots” for high levels of fluoride were found. One of those was located in the south-southeast sector of the city and the other in the northwest sector. Previous studies had characterized, in the aquifer, a deep regional flow with high temperature water that is also rich in fluoride. In order to verify the origin of fluoride levels in the hot spots, the water temperature was determined in well samples. A direct correlation was found for temperature and fluoride levels in samples of the 55 wells studied in this work. The highest temperatures were obtained in wells from the very high risk area 4 (mean temperature of 36°C), followed by the high risk area 3 (32.5°C), area 2 (30°C) and the low risk area 1 (28.1°C). Therefore, the temperature of groundwater may reflect the vertical movement of deep thermal waters in the areas where the hot spots for fluoride were located.

Fluoride levels in tap water apparently explain the prevalence of dental fluorosis. However, in SLP, tap water is not the only source of fluoride. This conclusion was obtained by finding that almost one third of the children studied in area 1 were categorized as having moderate or severe dental fluorosis. This high percentage appeared in an area that has a mean level of only 0.9 ppm of fluoride in tap water. Furthermore, the west of the city, which is the sector with the highest socioeconomic level and where almost 80% of the population drink bottled water,
has a dental fluorosis prevalence higher than area 3. Interestingly, area 3 has a higher level of fluoride in tap water than the west sector.

Other sources of fluoride in SLP may be: beverages (soft-drinks, bottled juices, etc.), food cooked with polluted water and bottled water (preliminary results of our group are showing that fluoride levels in some brands are higher than 2.0 ppm, whereas most brands have fluoride levels lower than 1.0 ppm). In addition, a risk factor on which we are centering our attention is the custom of using boiled water for reconstituting infant formulas (boiling the water increases the fluoride concentration proportionally to the loss of volume1).

This work is an example of how the use of a GIS can be useful for the identification of risk areas in terms of human exposure to fluoride. It also gives further evidence for the presence, in SLP, of sources of fluoride different from tap water.

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