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Elevated Fluoride and Selenium in West Texas Groundwater

Paul F. Hudak

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Abstract Fluoride and selenium concentrations, along with total dissolved solids and depth of intake, were compiled, mapped, and analyzed for 634 water wells in the High Plains Aquifer, northwest Texas. Approximately 19% of fluoride observations exceeded the maximum contaminant level (MCL) for drinking water. Additionally, 4% of selenium observations exceeded the MCL for drinking water, and 19% exceeded the recommended limit for irrigation water. Concentrations were considerably higher in the southern part of the study area, especially in relatively deep public supply and irrigation wells. Though human activity may influence fluoride and selenium levels, natural sources largely account for patterns observed in this study.

Keywords Fluoride · Selenium · Groundwater · Texas

Derived mainly from natural sources, high concentrations of fluoride and selenium in water pose potential health problems. Fluoride often originates from the dissolution of fluorite, fluorapatite, various silicates, or volcanic ash (Hem 1985). Human sources of fluoride include fertilizer and steel manufacturing. Fluoride occurs in the teeth, bones, and skin of animals. Fluoride has an important role in forming dental enamel and minerals in bones, but at high concentrations can cause dental fluorosis and harm the central nervous system and bones (Ayoob and Gupta 2006). The maximum contaminant level (MCL) for fluoride in drinking water is 4.0 mg/L (EPA 2003).

Similarly, small amounts of selenium are essential for animals, but excess levels can be toxic. The MCL for selenium in drinking water is 50 µg/L (EPA 2003); however, the chronic criterion for freshwater aquatic life is only 5 µg/L (EPA 2002). Several locations in the western U.S. contain excess selenium in irrigation drainage; at many of these locations, the selenium originates from Upper Cretaceous or Tertiary marine sedimentary rocks (Seiler et al. 2003).

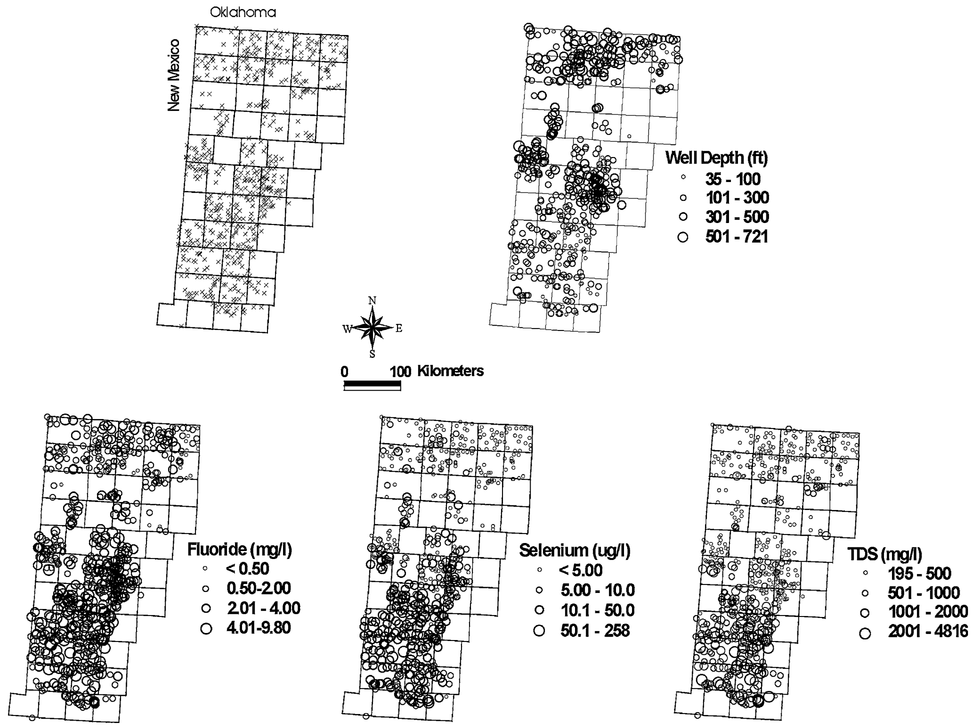
This study's objective was to compile, map, and statistically analyze fluoride, selenium, and total dissolved solids (TDS) levels in the High Plains Aquifer, northwest Texas.

Materials and Methods

The study area occupies extreme northwest Texas (Fig. 1). Gently undulating prairie, cropland, and pasture with ephemeral streams and playas characterize the landscape; common crops are wheat, sorghum, corn, and cotton. Cattle and petroleum production also support the region's economy. Beneath this region, the High Plains Aquifer supplies water for irrigation, households, livestock, and industry (Ashworth et al. 1991). Throughout much of the region, heavy pumping over several decades has lowered the water table by more than 10 m (McGuire 2004). Low annual precipitation (approximately 60 cm), high evaporation (approximately 170 cm), and a deep water table contribute to low aquifer recharge (approximately 1–8 cm) over the study area (Nativ and Riggio 1990). Generally, the water table is deeper, and the aquifer is thicker, in the northern half of the study area (Fig. 1) (Knowles et al. 1984; Nativ 1988). The groundwater discharges to seeps, springs, underlying formations, and production wells.

P. F. Hudak (✉)
Department of Geography and Environmental Science Program, University of North Texas, P.O. Box 305279, Denton, TX 76203-5279, USA
e-mail: hudak@unt.edu

Fig. 1 Along rows, from top left to lower right: Study area in northwest Texas (*lines*, county boundaries; *x*, sampled water well); well depths; fluoride concentrations; selenium concentrations; and TDS concentrations



The High Plains Aquifer consists of sand, gravel, clay, silt, and caliche, with generally higher clay and silt content toward the southern part of the study area (Seni 1980). Underlying sedimentary bedrock of terrigeneous and shallow marine origin produce poorer quality water; these formations are a potential source of fluoride, selenium, and other dissolved solids (Mehta et al. 2000) in the High Plains Aquifer. Upward leakage from underlying Cretaceous marine formations probably influence higher dissolved solids concentrations found in the southern part of the study area (Nativ 1988; Hopkins 1993). Oilfield brine, historically discharged to pits and injection wells, has contaminated groundwater in the aquifer (Hart 1992). The High Plains Aquifer also includes intermittent layers of volcanic ash (Gutentag et al. 1984), a potential source of fluoride and other solutes.

In this study, fluoride (mg/L), selenium (μg/L), TDS (mg/L) and depth (ft) were compiled for 634 wells in the High Plains Aquifer. These wells were used mainly for individual households (262 wells), irrigation (150 wells), public supply (120 wells), and stock (71 wells). Other uses were industrial, commercial, institutional, and power. Some wells were not used for any purpose other than monitoring. Data were collected from 2004 to 2007; the most recent observation was used for wells with multiple sampling dates. Samples were taken directly from each well and delivered to an analytical lab following standard protocols (Nordstrom 2003).

Respectively, the data were mapped and analyzed with ArcView (Environmental Systems Research Institute, Redlands, California). Rank correlations were used to evaluate associations between non-normally distributed variables. Kruskal–Wallis tests were used to detect concentration differences among well types.

Results and Discussion

Table 1 lists ranges of values measured for well depth, fluoride, selenium, and TDS. Typical for water quality data, medians were closer to minimum than maximum values. Generally, deeper wells occupied the northern half of the study area (20 northernmost counties in Fig. 1), due to a deeper water table and thicker saturated zone. Mapped selenium, fluoride, and TDS concentrations displayed similar patterns, with generally higher concentrations in the south (Fig. 1). Consistent with mapping observations, there was a statistically significant, direct correlation between all pairs of water quality variables (Table 2).

Maximum fluoride and selenium concentrations were more than two and five times their respective MCLs. The maximum TDS concentration was nearly ten times the secondary standard of 500 mg/L (EPA 2003) for drinking water. One in five observations exceeded 1000 mg/L TDS. Overall, 59% of fluoride samples exceeded the secondary standard of 2 mg/L (EPA 2003), and 19% of samples exceeded the primary standard of 4 mg/L. For selenium, only 4% of observations exceeded the 50 μg/L MCL for drinking water. However, 19% of selenium values exceeded an advisory limit of 20 μg/L (Fipps 1996) for irrigation water.

Table 1 Summary of depth and chemical measurements

	N	Minimum	Median	Maximum
Well depth (ft)	491	35	247	721
Fluoride (mg/L)	610	0.08	2.4	9.8
Selenium (μg/L)	63	<1	6.4	258
TDS (mg/L)	610	195	445	4816

Table 2 Matrix of rank-correlation coefficients[a]

	Fluoride	Selenium	TDS
Selenium	0.609		
TDS	0.566	0.774	
Well depth	−0.399	−0.506	−0.633

[a] All coefficients statistically significant, $\alpha = 0.01$

A statistically significant, inverse association between each water quality parameter and well depth (Table 2) reflected generally higher concentrations in shallower wells prevalent in the south. This pattern is consistent with solute sources in Cretaceous marine rocks directly underlying the southern part of the study area. Upward hydraulic gradients, amplified by pumping from the High Plains Aquifer, would facilitate solute movement into the High Plains Aquifer. Volcanic ash deposits, among others constituents of the High Plains Aquifer, may also contribute to observed fluoride concentrations.

Generally, higher solute concentrations occurred in (deeper) irrigation and public water supply wells (Table 3). This pattern is also consistent with solute sources in underlying bedrock formations; deeper wells in northern and southern parts of the study area are closer to these formations.

Other possible sources of fluoride, selenium, and TDS in the High Plains Aquifer of Texas include oilfield brine, fertilizer, and irrigation return flow. However, fluoride and selenium are not major constituents of oilfield brine. Potentially, fertilizers and irrigation water could contribute fluoride (from fluorapatite) and selenium (from evaporative concentration) to the High Plains Aquifer. However, broad areas of the study area are fertilized and irrigated; if those were major sources of fluoride and selenium, higher concentrations would likely occur throughout the study area.

Fluoride and selenium are not routinely removed from well water used for drinking or irrigation. Regularly testing and filtering (reverse osmosis) water with unacceptably high concentrations of these solutes could reduce exposure risks. Other options include pumping groundwater from less impaired wells or consuming bottled water. Irrigation water with high selenium concentrations may also harm wildlife. Restricting applications of selenium-bearing water would reduce this risk.

Table 3 Probability values from Kruskal–Wallis tests

Solute	Probability	Highest to lowest categories
Fluoride	0.000	2, 4, 1, 3, 5
Selenium	0.059	2, 4, 3, 5, 1
TDS	0.811	2, 4, 1, 3, 5
Well depth	0.000	2, 4, 3, 1, 5

1 domestic, *2* irrigation, *3* industrial, *4* public, *5* stock

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