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Temporal evolution of depth-stratified groundwater salinity in municipal wells in the major aquifers in Texas, USA

Sriroop Chaudhuri *, Srinivasulu Ale

Texas A&M AgriLife Research, Texas A&M University System, P.O. Box 1658, Vernon, TX 76385, United States

HIGHLIGHTS

- Groundwater salinization increased significantly over time in six out of nine major aquifers.
- Persistent salinization hotspots were identified in west, south and north-central Texas.
- Salinization was mainly caused by abundance of chloride and sulfate in the hotspots.
- High salinization occurred at shallow depths (<50 m) in west Texas and at deeper depths (>150 m) in rest of the state.
- Groundwater mixing, irrigational return flow, ion exchange, seawater intrusion, and evaporation caused salinization.

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ABSTRACT

We assessed spatial distribution of total dissolved solids (TDS) in shallow (<50 m), intermediate (50–150 m), and deep (>150 m) municipal (domestic and public supply) wells in nine major aquifers in Texas for the 1960s–1970s and 1990s–2000s periods using geochemical data obtained from the Texas Water Development Board. For both time periods, the highest median groundwater TDS concentrations in shallow wells were found in the Ogallala and Pecos Valley aquifers and that in the deep wells were found in the Trinity aquifer. In the Ogallala, Pecos Valley, Seymour and Gulf Coast aquifers, >60% of observations from shallow wells exceeded the secondary maximum contaminant level (SMCL) for TDS (500 mg L^{-1}) in both time periods. In the Trinity aquifer, 72% of deep water quality observations exceeded the SMCL in the 1990s–2000s as compared to 64% observations in the 1960s–1970s. In the Ogallala, Edwards–Trinity (plateau), and Edwards (Balcones Fault Zone) aquifers, extent of salinization decreased significantly ($p < 0.05$) with well depth, indicating surficial salinity sources. Geochemical ratios revealed strong adverse effects of chloride (Cl^-) and sulfate (SO_4^{2-}) on groundwater salinization throughout the state. Persistent salinity hotspots were identified in west (southern Ogallala, northwest Edwards–Trinity (plateau) and Pecos Valley aquifers), north central (Trinity-downdip aquifer) and south (southern Gulf Coast aquifer) Texas. In west Texas, mixed cation SO_4–Cl facies led to groundwater salinization, as compared to Na–Cl facies in the southern Gulf Coast, and Ca–Na–HCO_3 and Na–HCO_3 facies transitioning to Na–Cl facies in the Trinity-downdip regions. Groundwater mixing ensuing from cross-formational flow, seepage from saline plumes and playas, evaporative enrichment, and irrigation return flow had led to progressive groundwater salinization in west Texas, as compared to ion-exchange processes in the north-central Texas, and seawater intrusion coupled with salt dissolution and irrigation return flow in the southern Gulf Coast regions.

1. Introduction

Groundwater fulfills about 23% of the total freshwater need in the United States (U.S.) (USGS, 2005). About 19% and 98% of public supply and domestic water demands, respectively in the U.S. are met from groundwater sources (USGS, 2005, 2009). However, degrading potable groundwater quality is a growing concern in the U.S. as >15% of domestic wells in the nation are at risk due to high total dissolved solids (TDS) concentrations (USGS, 2009).

The TDS is a manifestation of several dissolved constituents and considered as a measure of salinity and overall indicator of water quality, relating to taste and palatability. The TDS levels greater than the secondary maximum contaminant level (SMCL) of 500 mg L^{-1} can cause substantial damage to plumbing fixtures (WHO, 1996). Water with TDS concentration above 1000 and 3000 mg L^{-1} is considered as brackish and moderately saline, respectively (USDA, 2007). As TDS is a manifestation of different dissolved constituents, interpretation of groundwater

Abbreviations: MCL, maximum contamination level; SMCL, secondary maximum contaminant level; TWDB, Texas Water Development Board; TDS, total dissolved solids; US EPA, United States Environmental Protection Agency; USGS, United State Geological Survey.

* Corresponding author. Tel.: +1 940 552 9941; fax: +1 940 552 2317.
E-mail addresses: schaudhuri@ag.tamu.edu, sriroopchaudhuri2@gmail.com (S. Chaudhuri).

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salinization warrants a multivariate approach. In this regard, Piper trilinear diagram (Piper, 1994) has frequently been used to understand broad groundwater hydrochemical classes and elucidate regional differences in water types (Khairy and Janardhana, 2013; Hunau et al., 2011; Ravikumar et al., 2010). Ionic ratios have also been used in different water quality studies to understand hydrochemical processes, sources of solutes, mechanisms of contamination, and regional differences in groundwater chemical types (Kottegoda et al., 2007; Ghabayen et al., 2006; Boschetti et al., 2005).

Groundwater withdrawal accounts for about 59% of the total and 36% of municipal (domestic and public supply) water supplies in Texas (George et al., 2011). However, a myriad of water quality issues have been reported from around the state raising serious concerns over groundwater use due to rise in concentration of species such as sulfate (SO_4^{2-}), chloride (Cl^-), fluoride (F^-), and nitrate (NO_3^-) (Ashworth et al., 1991; Hopkins, 1993; Hudak, 2000; Chaudhuri et al., 2012; Chaudhuri and Ale, 2013b). Previous hydrogeologic investigations from Edwards–Trinity (plateau) (Anaya, 2004), Pecos Valley (Anaya and Jones, 2004; Jones, 2008), Edwards (Balcones Fault Zone) (Collins et al., 2002), Gulf Coast (Chowdhury and Mace, 2007), Ogallala (Mehta et al., 2000a,b), Carrizo–Wilcox (Fogg et al., 1991), Hueco–Mesila Bolson (Mace et al., 2001), Trinity (Mace et al., 1994, 2000), and Seymour (Chaudhuri and Ale, 2013b) aquifers in Texas have expounded on groundwater salinity. These studies, however, lacked depth-stratified long-term evaluation of groundwater salinization with specific reference to potable use. The objective of this study was to offer a qualitative overview of the spatial (horizontal and vertical) and temporal (1960s–1970s vs. 1990s–2000s) extent of groundwater salinization in the municipal wells in nine major aquifers in Texas. To achieve this goal, the study was divided into three subtasks to (1) map TDS concentrations in the aquifers at different well-depths, (2) assess salinity based on drinking water quality standards, and (3) highlight the major geochemical assemblages in certain aquifers that led to groundwater salinization. As the importance of groundwater resources continue to rise in the future, findings of this study will aid the groundwater and natural resources managers as well as general public to understand geographic distribution and relative extent of groundwater salinization of the state's drinking water resources and plan for appropriate management actions.

2. Materials and methods

About 76% of land area in Texas is underlain by nine major and 21 minor aquifers, which supply about 60% of the total water used in the state (TWDB, 2007). The major aquifers in Texas are of sedimentary origin, ranging from Cretaceous to Quaternary age.

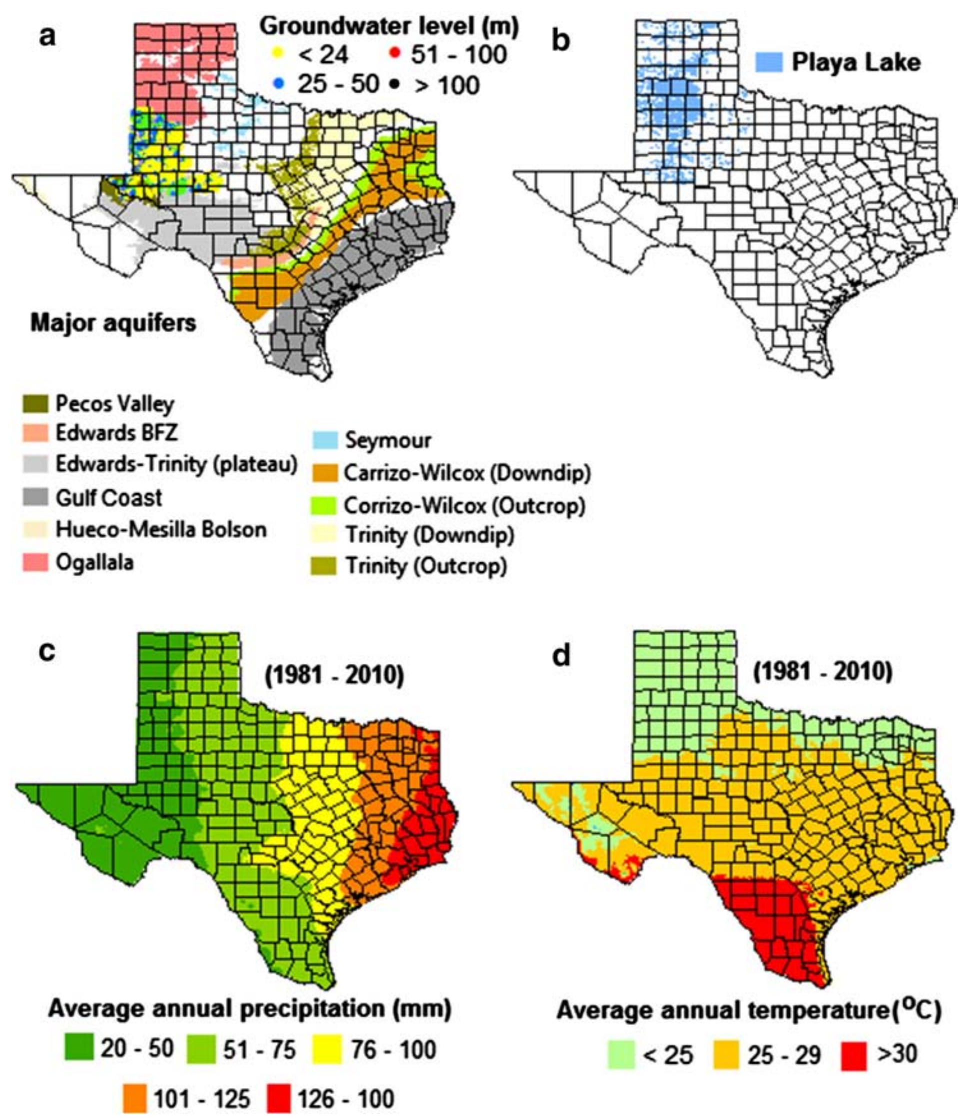

Fig. 1. Distribution of a) the major aquifers and depth to groundwater level in west Texas for wells monitored between 2000 and 2010, b) playas, c) average (1981–2010) annual precipitation, and d) average (1981–2010) annual temperature in Texas.