

# GEOCHEMICAL EVALUATION OF HYDROGEOLOGIC INTERACTION BETWEEN THE EDWARDS AND TRINITY AQUIFERS BASED ON MULTIPOINT WELL ASSESSMENT IN CENTRAL TEXAS

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## **Abstract**

The Edwards and Trinity Aquifers are major aquifers of Central Texas that provide water supply for over two million people and contain springs that are hydrologically and ecologically important to the region. The Edwards Aquifer overlies the Trinity Aquifer but is geologically juxtaposed along the Balcones Fault Zone. Thus, understanding the hydrologic connection is necessary to effectively and sustainably manage the two aquifers. Previous studies utilizing several different methods such as water-table evaluations, pumping tests, geophysical surveys, dye-tracing experiments indicated the existence of lateral inter-aquifer flow between the Edwards and Trinity aquifers in some areas. However, lateral inter-aquifer flow does not appear significant in the study area - Barton Springs segment of the Edwards Aquifer. Furthermore, the potential for vertical inter-aquifer flow between these formations has not been fully evaluated in this study area. This study focuses on hydrochemical data collected from multipoint wells to assess the degree of vertical interconnection between the Edwards and Trinity Aquifers. Multipoint wells allow the collection of geochemical, head, and permeability data from multiple isolated hydrostratigraphic units within the same borehole. Hydrochemical facies and isotopic signatures

could address the origin of groundwater, and interconnections between different hydrostratigraphic units. The differences in TDS,  $\text{SO}_4^{2-}$ , and  $\text{NO}_3^-$  concentrations between Edwards and Trinity Aquifers are considered statistically significant. The isotopic tracers ( $\delta^{18}\text{O}$  and  $\delta\text{D}$ ;  $^3\text{H}$  and  $^{14}\text{C}$ ;  $^{87}\text{Sr}/^{86}\text{Sr}$ ) provide information on the origin of recharge, residence time of groundwater, and mineral-solution reactions in soils/aquifer rocks in these formations. Hydraulic head data further support limited vertical communication between the aquifers. This study indicates that vertical inter-aquifer flow between the Edwards and Trinity Aquifers is limited in the study area. These implications support independent groundwater management of these two essential aquifer systems in Central Texas.

## **Introduction**

The Edwards and Trinity Aquifers provide water supplies for more than two million people in central Texas for municipal, industrial, and agricultural uses. However, water shortages occur in the Edwards Aquifer due to excessive pumping of groundwater and recurrence of historic droughts in central Texas. Water quality is also at risk from urbanization processes, causing rising levels of pollutants in both surface water and groundwater.

The Trinity Aquifer has increasingly become an important source of water, as the Edwards Aquifer reaches its capacity due to drought restrictions. However, there are contradictory findings of the hydraulic connections between the Edwards and Trinity Aquifers, which have crucial implications for the management of the Trinity Aquifer.

The Trinity and Edwards Aquifers are hydrogeologically juxtaposed by the Balcones Fault Zone (BFZ), where the older Trinity Group limestone lies side by side to the younger Edwards Group. Many faults may form not only effective barriers to inter-formation flow, but also hydraulic conduits connecting shallow and deep aquifers in the multilayered aquifer system (Bense et al., 2013). Recent studies related to pumping tests (Hunt et al., 2010), geophysical surveys (Gary et al., 2011), dye tracing experiments (Schindel and Johnson, 2011), and groundwater modeling efforts (Jones et al., 2011) indicate a significant lateral interconnection between the Edwards and Trinity Aquifers. However, hydraulic head data within the hydrostratigraphic units illustrate limited vertical communication between the aquifers (Smith and Hunt, 2008). Pumping tests of wells in the Trinity Aquifer didn't induce drawdown in nearby Edwards Aquifer wells (Hunt et al., 2010), which suggests that vertical aquifer interflow does not occur under current conditions.

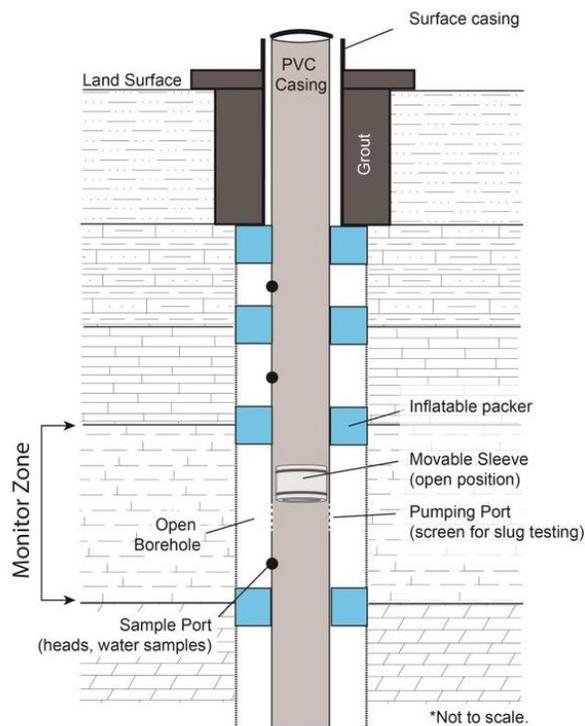
Hydrochemical and isotopic data of groundwater have been extensively used to address critical aspects of the water cycle, such as the origin of groundwater, and interconnections between different hydrostratigraphic units. However, few studies have systematically investigated the evolution of hydrochemical and isotopic signatures across the Edwards and Trinity Aquifers at the same location. The Barton Springs Edwards Aquifer Conservation District (BSEACD) has investigated the geochemical indicators of interaction between the Edwards and Trinity aquifers of Travis and Hays counties in 2016 by installing several multiport wells (Figure 1). Packers were used in the wells to isolate sampling zones to allow measurements to be made in multiple isolated hydrostratigraphic units within the same borehole. Thus, we could evaluate geochemical data to determine unique natural markers for groundwater compositions of each aquifer or hydrostratigraphic unit. The differences in TDS,  $\text{SO}_4^{2-}$ , and  $\text{NO}_3^-$  concentrations between the Edwards and Trinity Aquifers are considered statistically

significant. Isotopic tracers ( $\delta^{18}\text{O}$  and  $\delta\text{D}$ ;  $^3\text{H}$  and  $^{14}\text{C}$ ;  $^{87}\text{Sr}/^{86}\text{Sr}$ ) demonstrate the origin of recharge, residence time of groundwater, and mineral-solution reactions in soils/rocks in these formations. This study indicates that vertical inter-aquifer flow between the Edwards and Trinity Aquifers is limited in the study area. This implication supports independent groundwater management of these two essential aquifer systems.

### Hydrogeologic Setting

The Edwards Aquifer of central Texas is subdivided into the Northern, Barton Springs, and San Antonio segments. The smallest segment, the Barton Springs segment of the Edwards Aquifer, is the subject of this paper. The main source water of Barton Springs is the Edwards Aquifer. The Middle Trinity Aquifer is the primary source of groundwater west of the BFZ.

In the Barton Springs segment of the Edwards Aquifer and nearby areas, the Trinity units are exposed in the contributing zone; the Edwards units outcrop in most areas of the recharge zone and are confined to the east by overlying low permeability units. Further east, the Edwards Aquifer is highly saline (Figure 2). Groundwa-

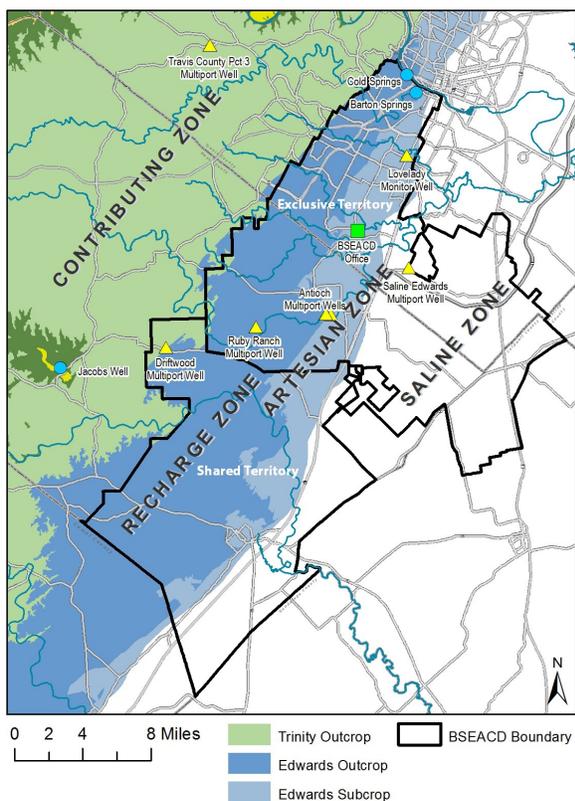


**Figure 1.** Schematic view of the multiport well components for the top monitoring zone (Hunt et al., 2016).

ter samples from different aquifers were collected from three multiport wells in Hays County, referred to here as the Antioch, the Ruby Ranch, and the Driftwood multiport wells (Figure 2). The Antioch well is located in the artesian zone, the Ruby Ranch well is located in the recharge zone, and the Driftwood well is located in the contributing zone/recharge zone boundary.

The multiport well approach allows the sampling of multiple known and isolated hydrostratigraphic units within the same borehole. A total of 21 and 13 independent zones within the Edwards Aquifer, Upper and Middle Trinity Aquifers were isolated at the Antioch and Ruby Ranch multiport wells, respectively (Figure 3). The Driftwood multiport well has 12 sampling zones within the Upper and Middle Trinity Aquifers (Figure 3). The spring and well samples from the Lower Trinity Aquifer in the research area were sampled, measured, and utilized for statistical analysis in this study.

As shown in Figure 3, the outcrop of the study area is the Edwards group, which belongs to the Edwards forma-



**Figure 2.** Geologic map of the Barton Springs segment of the Edwards Aquifer (central Texas) with well locations.

tion. The Glen Rose formation is further subdivided into Lower and Upper units. The Upper Glen Rose is a series of alternating dolomite, shale, and limestone beds, which belong to the Upper Trinity. The Lower Glen Rose is predominately a massive shell fragment limestone with rudist and reefs present for its lower section (Stricklin et al., 1971). The Lower Glen Rose, Hensell Sand, and Cow Creek formations belong to the Middle Trinity. The Trinity Aquifer within the study zone is generally unconfined.

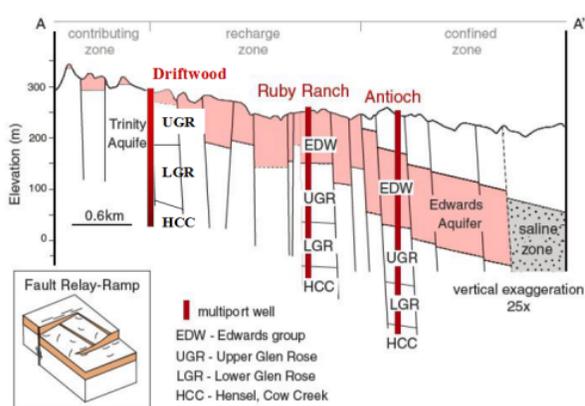
### Data Analysis and Visualization

Charge balance error (CBE) is used to validate the quality of water analyses, and acceptable CBE should be within  $\pm 5\%$  for further analyses. The CBE was calculated based upon the following equation:

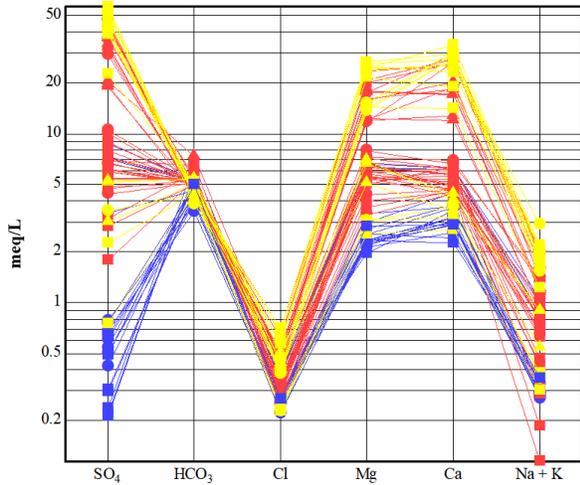
$$CBE = \frac{\sum \text{Cations} - \sum \text{Anions}}{\sum \text{Cations} + \sum \text{Anions}} \times 100$$

We utilized major cations ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Sr}^{2+}$ ) and major anions ( $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$ ) to calculate CBE. The CBE is mostly clustered within  $\pm 5\%$ , with very few outside of  $\pm 5\%$ . Thus, the multiport well hydrochemical dataset is acceptable for general hydrochemical characterization.

Relative concentrations of anions and cations for these groundwater samples are shown in the Schoeller diagram (Figure 4). For cations, there is an increasing trend for



**Figure 3.** Cross section from contributing zone, recharge zone to confined zone along with diagram of fault structure that could facilitate lateral communication between aquifers. Map and cross section are adapted from Wong et al. (2014).



**Figure 4.** Schoeller diagram for the multiport well hydrochemical dataset. Blue=Edwards Aquifer, Yellow=Upper Trinity, Red=Middle Trinity, Square=Ruby Ranch well, Circle=Antioch well, Triangle=Driftwood well.

Ca<sup>2+</sup> and Mg<sup>2+</sup> from the Edwards to the Trinity Aquifer; for anions, there are similar concentrations of HCO<sub>3</sub><sup>-</sup> and Cl<sup>-</sup>, however, there is a trend towards SO<sub>4</sub><sup>2-</sup> dominance in the Trinity Aquifer.

The Durov diagram is a visualization of major ions in two ternary graphs (similar to a Piper diagram) with two additional parameters (TDS and pH). As shown in the Durov diagram (Figure 5), most samples of the Edwards Aquifer are Ca<sup>2+</sup>-HCO<sub>3</sub><sup>-</sup> type with a trend toward Ca<sup>2+</sup>-SO<sub>4</sub><sup>2-</sup> type in the Upper and Middle Trinity Aquifers. The pH shows more variability for the Edwards Aquifer, and there is an increasing trend for TDS in the Upper and Middle Trinity Aquifers.

### Multiple Comparisons

In order to assess differences statistically, multiple comparison procedures are applied for the TDS and concentrations of ions among different aquifers. Comparing means utilizing ANOVA tests are based on the theoretical assumption of normality, i.e., normal distributions of hydrochemical data among all aquifer types.

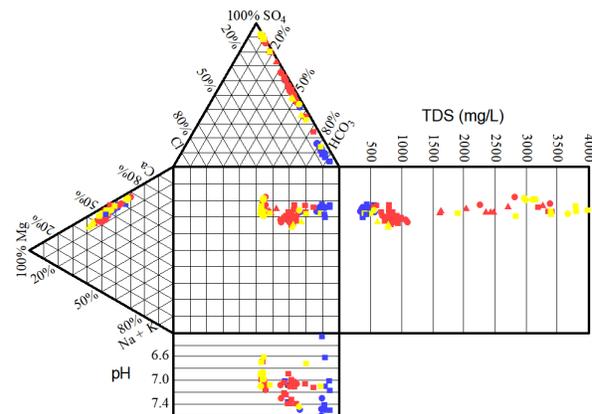
We take distributions of TDS as an example here. From the histogram plot for all TDS data (Figure 6A), the TDS is skewed to the lower values. The normal Q-Q plots for TDS data (Figure 6C) illustrate that TDS data are not normally distributed for all aquifers. The histogram plot of all log TDS data (Figure 6B) illustrates that the log TDS data are much more symmetrical than the original TDS data. The

normal Q-Q plots for log TDS data (Figure 6D) demonstrate that the log TDS data are closer to normally distributed than original TDS data for all aquifers. There are similar log-normal distributions for other cation/anion concentrations. Therefore, log transformation for TDS/cation/anion data is performed for further ANOVA tests.

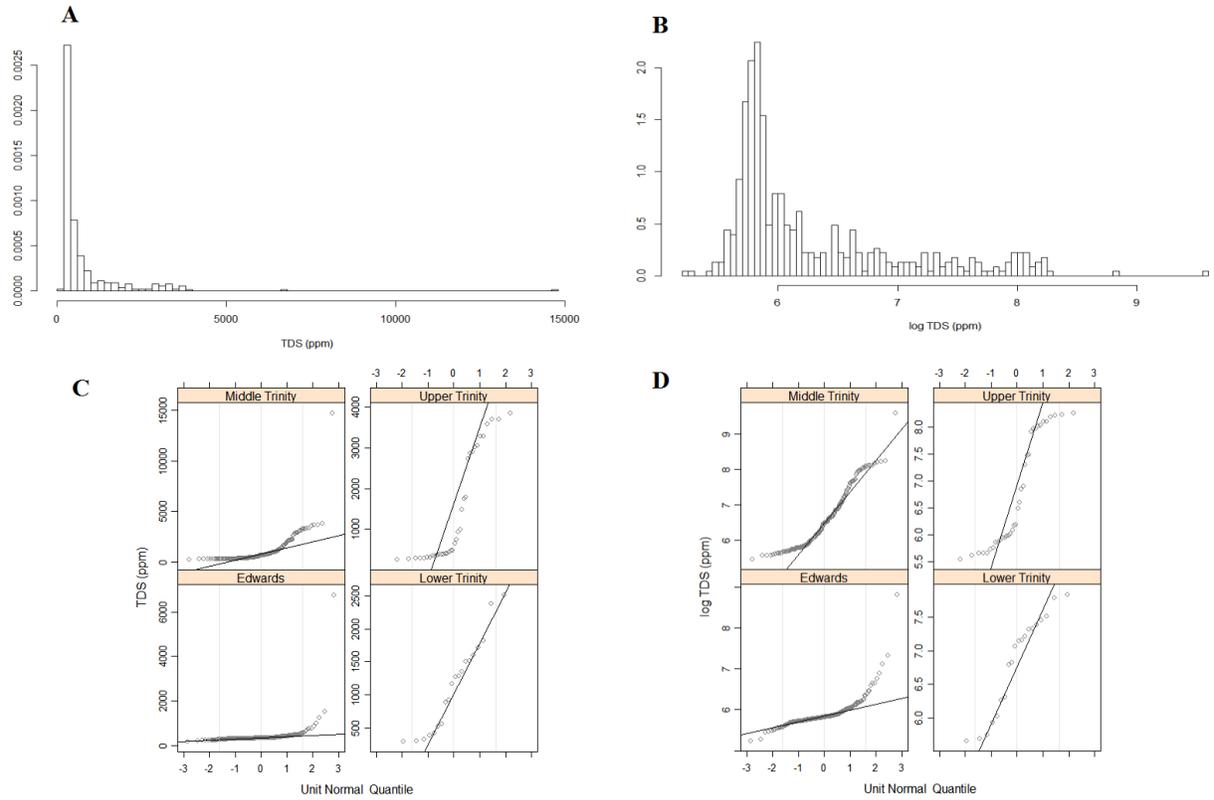
The S-L plot for log TDS data (Figure 7A) indicates the residual variances are consistent for three Trinity Aquifer groups, but the residual variance is lower for the Edwards Aquifer group. The residual plot for log TDS data (Figure 7B) illustrates the residual distributions vary from the four different Aquifer types, but all groups are approximately symmetric against the estimated group averages. The normal Q-Q plot of the ANOVA model residuals (Figure 7C) indicates a likely normal residual distribution for log TDS data, which further confirms the normal distribution assumption. Similarly, the log cation/anion data approximately meet the assumptions to perform ANOVA tests.

The visualization of multiple comparisons for TDS data by aquifer types is shown in Figure 8. The boxplots of TDS data by aquifer types (Figure 8A) indicate the mean of the log TDS is different between the Edwards and Trinity Aquifers. The Tukey multiple comparisons (Figure 8B) indicate there are similar means of the TDS for the three Trinity Aquifer units, but TDS of the Edwards Aquifer is lower than all the three Trinity Aquifer units.

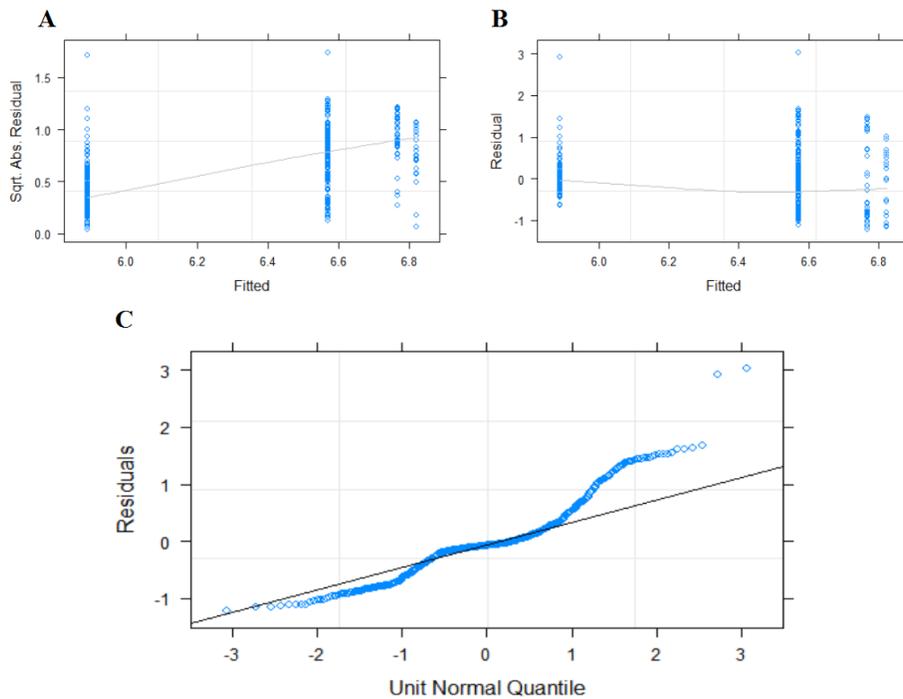
Thus, TDS in the Edwards and Trinity Aquifers are distinct and likely reflect different groundwater residence



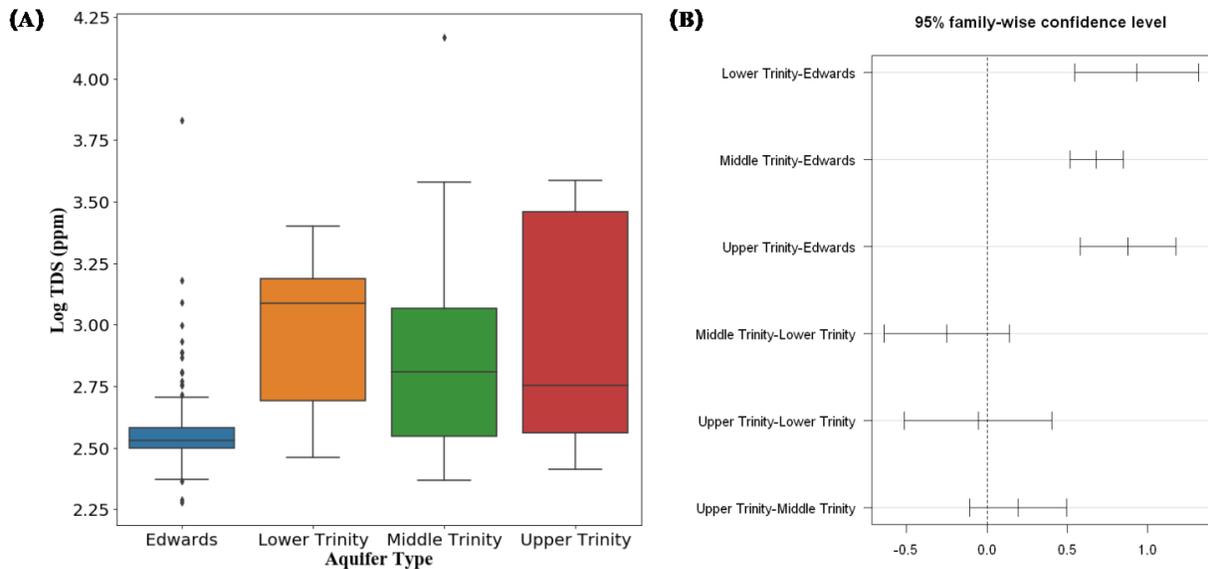
**Figure 5.** Durov diagram for the multiport well hydrochemical dataset. Blue=Edwards Aquifer, Yellow=Upper Trinity, Red=Middle Trinity, Square=Ruby Ranch well, Circle=Antioch well, Triangle=Driftwood well.



**Figure 6.** Histogram plots for the TDS (A) and log TDS (B) for all samples; normal Q-Q plots for TDS (C) and log TDS (D) of different Aquifer types.



**Figure 7.** The S-L plot for log TDS: square root of the absolute values of residuals against the estimated group averages (A); the scatter plot of the residuals against the estimated group averages (B); the normal Q-Q plot of the ANOVA model residuals (C).



**Figure 8.** Boxplots for log TDS by aquifer types (A) and Tukey multiple comparisons for the means of the log TDS by aquifer types (B).

time of interactions with limestone bedrock, and to some extent the differences in lithology. The lower TDS of the Edwards Aquifer indicates its younger groundwater age (Kuniansky et al., 2001).

The visualization of multiple comparisons for  $\text{NO}_3^-$  concentrations by aquifer types is shown in Figure 9. There are similar means of  $\text{NO}_3^-$  concentrations for the three Trinity Aquifer units but apparently higher  $\text{NO}_3^-$  concentration in the Edwards Aquifer.

There is no mineralogical source of nitrate in these aquifers. Excess nitrogen in water could come from natural sources (organic matters from leaves and animal waste) and anthropogenic sources (fertilizer, livestock, wastewater, septic systems, and industrial wastes). The higher nitrate concentrations in the Edwards Aquifer might indicate potential sources of contamination. The Edwards Aquifer is unconfined in the recharge zone where active interaction between surface water and groundwater takes place. Therefore, the Edwards Aquifer is much more vulnerable to pollution than confined Trinity Aquifer.

The visualization of multiple comparisons for  $\text{SO}_4^{2-}$  concentrations by aquifer types is shown in Figure 10. Similar to  $\text{NO}_3^-$  concentrations, there are similar means of  $\text{SO}_4^{2-}$  concentrations for the three Trinity Aquifer units; compared with  $\text{NO}_3^-$  concentrations,  $\text{SO}_4^{2-}$  concentrations in the Edwards Aquifer are much lower.

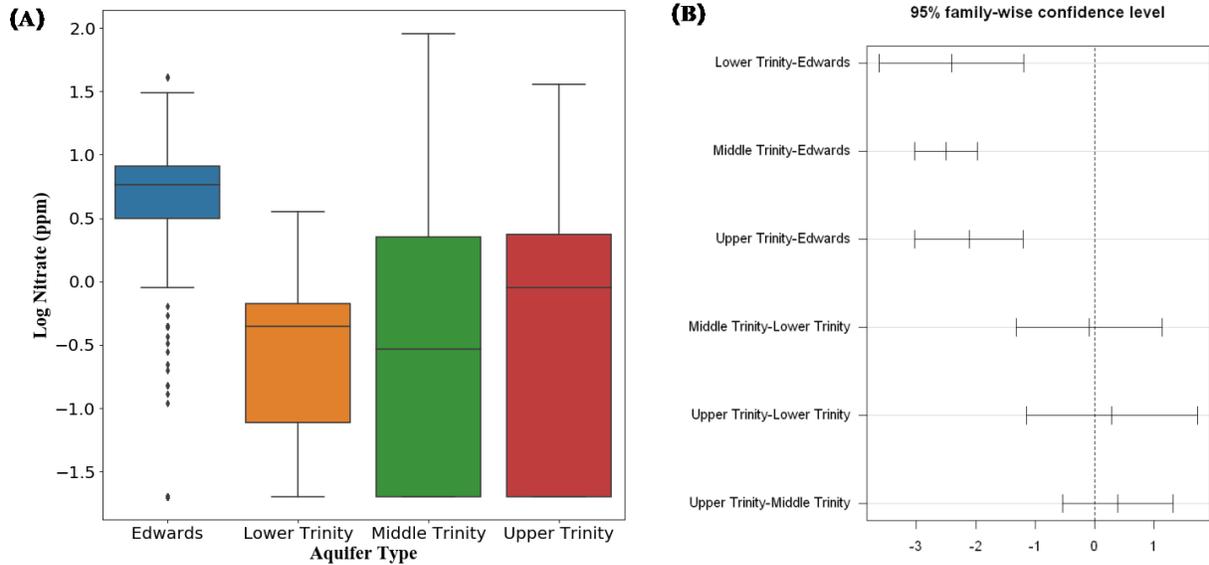
Sulfate concentrations are identical among Upper, Middle, and Lower Trinity Aquifers. This indicates that gypsum layers exist in the three Trinity Aquifer units or there are possible vertical flows among the three Trinity Aquifer units. Much lower sulfate concentrations in the Edwards Aquifer than all three Trinity Aquifer units suggest that vertical groundwater flow between the Edwards and Trinity Aquifers is likely limited.

All ANOVA tests were performed by R in RStudio environment. The ANOVA results for log TDS are presented in Table 1. The differences in TDS concentrations between the Edwards and Trinity Aquifers are considered statistically significant at significance level  $\alpha=0.001$ .

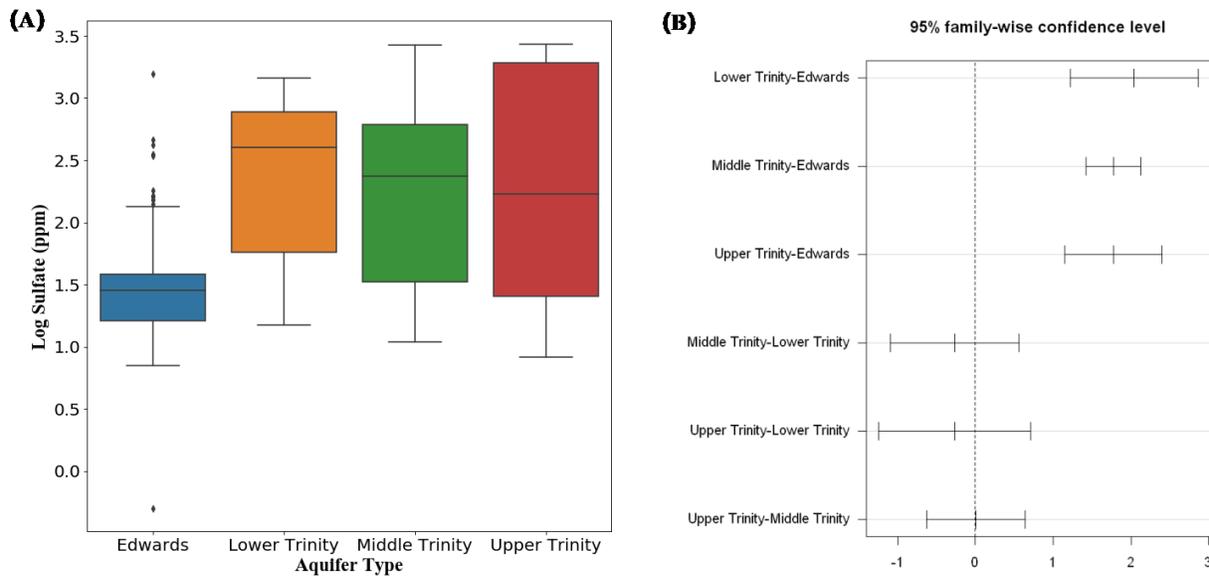
Similarly, there is also sufficient evidence to support the claim that at least one means of the log  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ , and  $\text{Cl}^-$  concentrations for the four aquifer types are different at significance level  $\alpha=0.001$ .

### Isotopic Signatures

Water isotopes are reliable tracers of the origin of water vapor and residence time of groundwater. From the  $\delta^{18}\text{O}$ - $\delta\text{D}$  cross plot (Figure 11), there is a significant overlap for groundwater of different aquifers, which provides little information about the source or mixture of these aquifer waters. However, the isotopic signatures of all aquifer types have identical  $\delta^{18}\text{O}$  values as long-term average precipitation of  $-4.1\%$  (Pape et al., 2010), which indicates little evaporation occurs during recharge to these aquifers.



**Figure 9.** Boxplots for  $\log \text{NO}_3^-$  by aquifer types (A) and Tukey multiple comparisons for the means of the  $\log \text{NO}_3^-$  by aquifer types (B).



**Figure 10.** Boxplots for  $\log \text{SO}_4^{2-}$  by aquifer types (A) and Tukey multiple comparisons for the means of the  $\log \text{SO}_4^{2-}$  by aquifer types (B).

There is a good linear relationship between <sup>3</sup>H and <sup>14</sup>C (Figure 12), which indicates regional mixing between young and old groundwater and possible contributions of very young water in both Edwards and Trinity Aquifers (Darling, 2017).

The <sup>14</sup>C dating is not a reliable groundwater dating method in karst aquifers (Maloszewski and Zuber, 1991) because the fossil carbon of the calcite/dolomite in the aquifer would contribute to bicarbonate ions. The high

<sup>3</sup>H signature of groundwater might indicate the large portion of surface-water recharge, and the low <sup>3</sup>H signature of groundwater indicates less influx of young water. Therefore, the Lower Trinity Aquifer might receive limited surface water recharge.

Sr isotope variations in groundwater have been used to trace flow paths and specific mineral-solution reactions in soils and aquifer rocks. The differences in <sup>87</sup>Sr/<sup>86</sup>Sr among groundwater require either (a) differences in

Source	Degree of Freedom	Sum of Squares	Mean Square	F Ratio	P Value
Between	3	62.79	20.930	51.25	<2e-16***
Within	450	183.76	0.408		
Total	453	246.55			

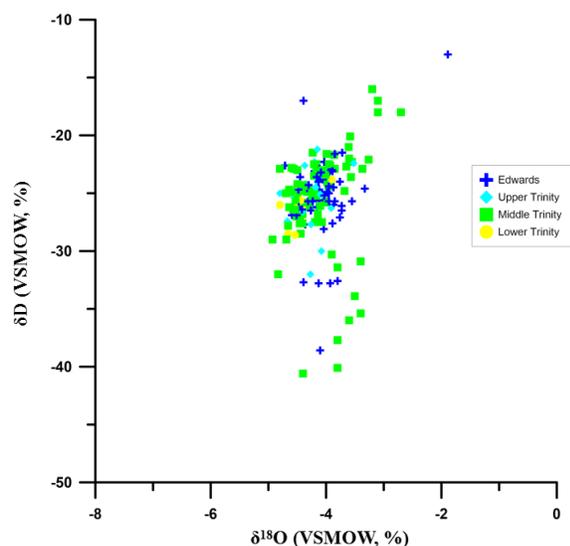
**Table 1.** The ANOVA table for comparison of means of the log TDS for four aquifer types.

Note. Significance levels: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘.’ 1

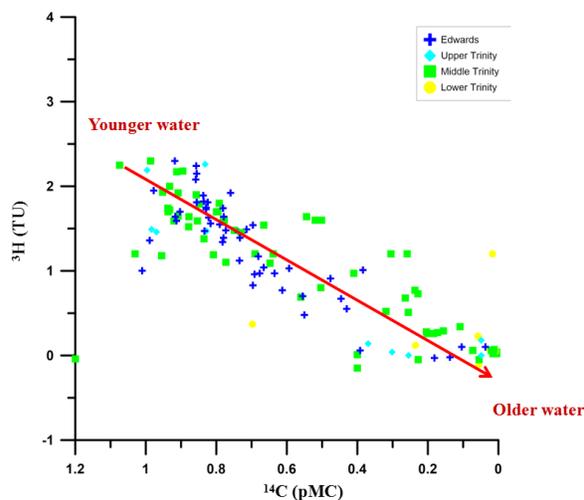
mineralogy along flow paths or (b) differences in relative abundances of Sr weathered from the same suite of minerals.

As shown in Figure 13, the Sr isotope for all aquifer types generally falls between values for host carbonates (mean  $^{87}\text{Sr}/^{86}\text{Sr}=0.7076$ ) and exchangeable Sr in overlying soils (mean  $^{87}\text{Sr}/^{86}\text{Sr}=0.7088$ ). Higher  $^{87}\text{Sr}/^{86}\text{Sr}$  might indicate interaction with silicate materials, which are abundant in middle and lower Trinity Aquifers (Wong et al., 2014).

High Sr concentrations, i.e., higher Sr/Ca ratio occur in groundwater from the Edwards Aquifer, which indicates the progressively long residence time and increasing amounts of calcite/dolomite recrystallization in the Edwards Aquifer. During the drought period, the interaction time between groundwater and bedrocks increases. The preferential dissolution of dolomite and precipitation of calcite might occur in the downdip parts of the Edwards Aquifer (Hovorka et al., 1995). Thus, climate conditions, mineral and crystallization have certain influences on Sr/Ca ratios of groundwater.



**Figure 11.**  $\delta^{18}\text{O}$  against  $\delta\text{D}$  for all groundwater samples by different aquifers.

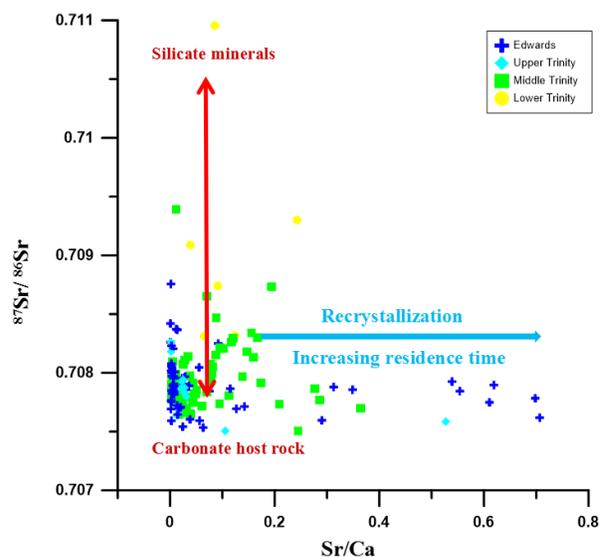


**Figure 12.**  $^{14}\text{C}$  vs.  $^3\text{H}$  regional mixing trend for all groundwater samples by different aquifers.

## Conclusions

Most water samples of the Edwards Aquifer are  $\text{Ca}^{2+}\text{-HCO}_3^-$  type. The Upper and Middle Trinity Aquifers are generally  $\text{Ca}^{2+}\text{-SO}_4^{2-}$  type, which might be caused by the dissolution of gypsum layers in the three Trinity Aquifer units.

The differences in TDS,  $\text{SO}_4^{2-}$ , and  $\text{NO}_3^-$  concentrations between the Edwards and Trinity Aquifers are considered statistically significant. TDS and  $\text{SO}_4^{2-}$  concentration of the Edwards Aquifer are lower than all three Trinity Aquifer units; however,  $\text{NO}_3^-$  concentration is higher in the Edwards Aquifer.



**Figure 13.** Sr/Ca ratios vs.  $^{87}\text{Sr}/^{86}\text{Sr}$  for all groundwater samples by different aquifers.

The isotopic tracers ( $\delta^{18}\text{O}$  and  $\delta\text{D}$ ;  $^3\text{H}$  and  $^{14}\text{C}$ ;  $^{87}\text{Sr}/^{86}\text{Sr}$ ) provided information on the origin of recharge, residence time of groundwater, and mineral-solution reactions in soils/aquifer rocks in unconfined Edwards Aquifer and confined Trinity Aquifer formations.

The geochemical data from the multiport wells indicates that vertical inter-aquifer flow between the Edwards and three Trinity units (Upper, Middle, and Lower) is limited in the study area. This implication supports independent groundwater management of these two important aquifer systems.

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