ISOTOPIC COMPOSITION OF GROUNDWATER AND PRECIPITATION IN NEBRASKA, USA

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Introduction

Groundwater is vital worldwide for water supply, agriculture and industry. Nearly 60% of all water use in Nebraska is from groundwater. Over 90% of groundwater is used for irrigation in Nebraska, which has the largest area of irrigated land in the United States. Many Nebraskans depend on groundwater for drinking water, both from private wells and municipal wells. The sustainability of groundwater resources is dependent on groundwater recharge. The recharge processes, as well as climatic patterns, influence the stable isotope signatures.

Based on weekly samples collected at two monitoring stations managed by the National Atmospheric Deposition Program (NADP), Harvey (2001) and Harvey and Welker (2000) presented an overview of isotopic composition of precipitation in Nebraska. Two stations, located in Mead and North Platte (Figure 1), were monitored from 1992-1994 and 1989-1994, respectively. This data illustrated patterns in the isotopic composition of precipitation, both spatially and seasonally.

To better understand the recharge processes, over 789 groundwater samples were collected across Nebraska in 2011 and their isotopic signatures analyzed. While other studies have evaluated isotope ratios (seasonal ratios) (Jasechko et al., 2017; Sanchéz-Murillo and Birkel., 2016), in this study we compared the precipitation signals. The objective of this study was to investigate recharge characteristics based on stable isotope signatures of groundwater and comparisons of the isotopic composition of groundwater and precipitation across Nebraska.

Methods

Site Description

The inner continental location of Nebraska, about 1,500 km from the Gulf of Mexico, Pacific and Atlantic Oceans, contributes to the observed climate variability, which varies from moist sub-humid climate in the eastern portion to dry, semi-arid climate in the western portion of the state. Average yearly temperatures show a NW-SE gradient ranging from 6.9ºC in the northwestern portion to 11.0ºC in southeastern. Seasonal variation is characterized by hot summers, with July mean daily temperatures of 23.6ºC and cold winters, with mean temperatures of -5.5ºC in January (Owenby and Ezell, 1992; Frankson et al., 2017). Precipitation distribution across the state has a similar trend, varying from 370 mm/year in the western border with

Figure 1. The High Plains Aquifer underlies the majority of the State of Nebraska (red outline). Locations of the precipitation monitoring stations in North Platte (left) and Mead (right).

Wyoming and up to 900 mm/year in the southeastern border along the Missouri river (Lawson et al., 1977). Most of the precipitation falls during the spring and summer months, but seasonal precipitation is widely variable (Frankson et al., 2017).

For the two stations, temperature measured during the period 1989-1994 was quite similar to the 30-year normal values. Harvey (2001) and Harvey and Welker (2000) assumed that the isotopic composition for the period should be representative of normal precipitation with respect to temperature effects.

The Mead station ^{18}O ranged from -23.6 to -0.7‰ and ^{2}H ranged from -172.0 to -0‰. The North Platte station ^{18}O ranged from -30.5 to +1.7‰ 9 and ^{2}H ranged from -228.0 to +11.0‰. These values were found to be consistent with those interpolated for regional studies, which shows a similar gradient with more depleted values observed in the west portion, with a progressive enrichment towards the east (Vachon et al., 2010). Most parts of enriched precipitation, which fell during the summer season, were associated with warm moisture from the Gulf of Mexico, while depleted values were associated with westerlies from the Pacific Ocean. In terms of seasonal variation, a clear "U Shape" is observed, with more depleted values associated with winter season precipitation and enriched values during the summer. This led to a good correlation between isotopic composition and temperature, regardless of the temporal scale (weekly or monthly). Mead ($^{2}H = 7.4^{18}O + 7.32$) and North Plate Meteoric Walter Line ($^{2}H = 7.66^{18}O + 4.96$) exhibit an inclination similar to that calculated for Global Meteoric Water Line (GMWL), while interception is quite lower, probably effect of different moisture sources.

Isotope Data Collection and Analysis

In the summer of 2011, 798 groundwater samples were collected across Nebraska by the Natural Resource Districts (NRDs). The 23 NRDs across the state are responsible for managing the natural resources for the state. Samples were analyzed for δ^{2}H and δ^{18}O of water by cavity ring down laser spectroscopy method, using a Picarro analyzer. The exact location of sampling sites are known for 682 of the samples. Of these 682 samples collected, all but 78 had well depth information documented. Using ArcGIS, the data was interpolated using the Inverse Distance Weighted tool. This method of interpolation estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. The closer a point is to the center of the cell being estimated, the more influence, or weight, it has in the averaging process.

Results

For the 604 samples where well depth information was available, the depths ranged from less than 15 m to 210 m with 71% at depths from 15 to 75 m (Figure 2). There was not a strong systematic variation with depth (ground elevation minus the elevation at the bottom of the screen), thus the average isotopic values for co-located wells (e.g., well nests) were used for the interpolation of the groundwater isotopes (Figure 3).

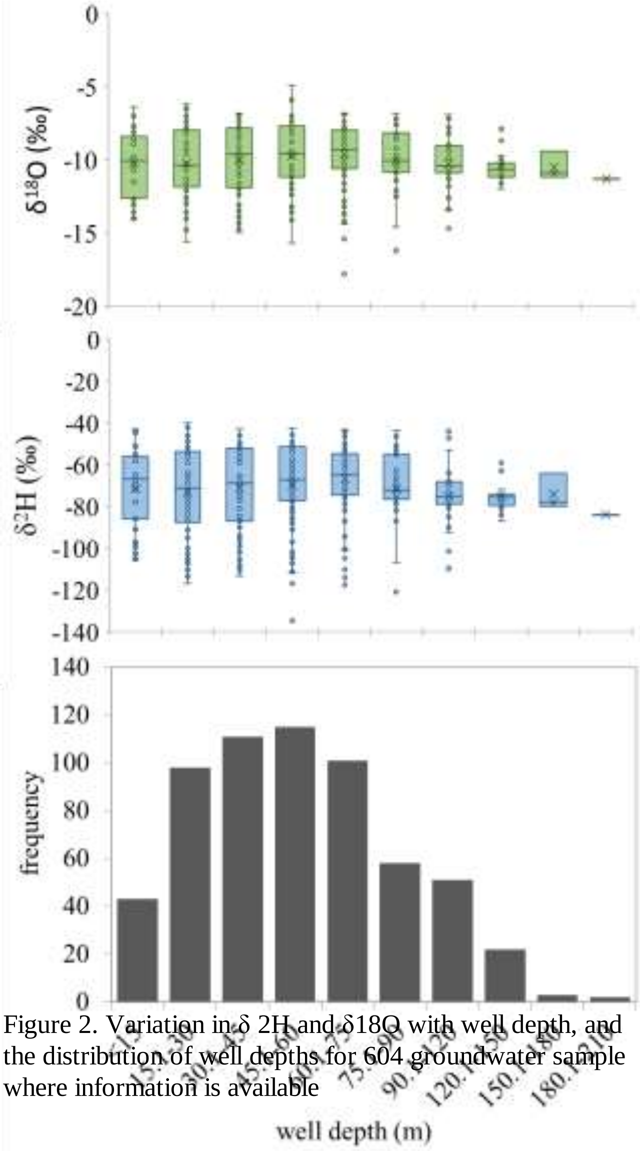

Figure 2. Variation in δ 2H and δ18O with well depth, and the distribution of well depths for 604 groundwater sample where information is available

The isotopic composition of the groundwater samples ($^2H = 8.27^{18}O + 11.64$) was similar to the calculated GMWL (Figure 3.) The intercept of the groundwater is slightly lower than the GMWL due to differences in moisture sources. The mean annual precipitation values become more depleted moving from southeast to northwest across the state. The groundwater isotope composition follows a similar pattern of becoming more depleted in the northwest. Values of $\delta^{18}O$ ranged from -17.8 to -3.1‰ (mean value -9.85±2.1‰), δ^2H ranged from -134.7 to -30.8‰ (mean value -70.0±19‰). Using the isotopic precipitation values from the Bowen data set the weighted average composition of precipitation during the growing season was δ^2H = -62.85‰ and $\delta^{18}O$= -8.63‰. Weighted growing season precipitation values are similar to the groundwater composition indicating the majority of groundwater recharge occurs during the summer months. Comparison of the isotope compositions suggests that groundwater isotopic composition is more depleted compared to the average annual precipitation in western and northeastern Nebraska and more enriched compared to precipitation in parts of south-central and southeastern Nebraska. This indicates that the percentage of recharge during the summer months may vary throughout the state.

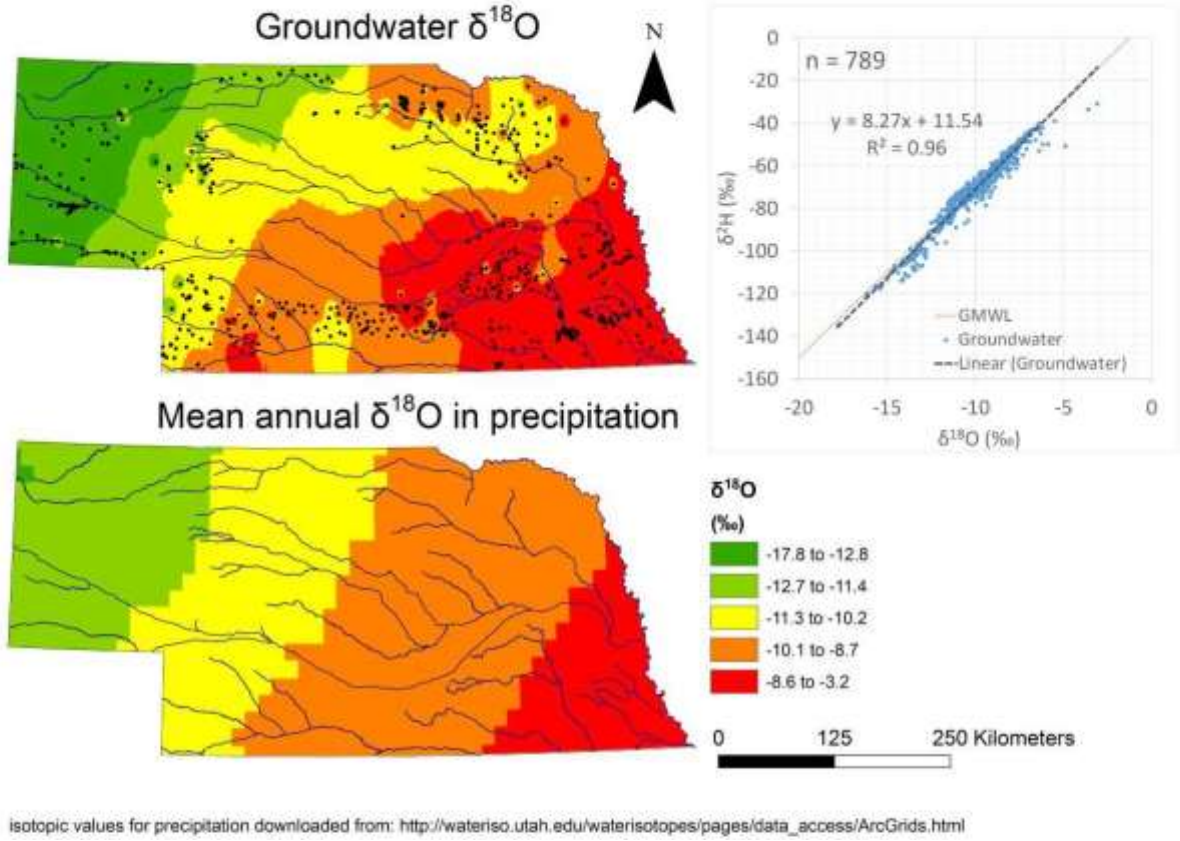

Figure 3. Isotopic values ($\delta^{18}O$) for groundwater and annual precipitation. GMWL is Global Meteoric Water Line.

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