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ESRD and ESRD-DM associated with lignite-containing aquifers in the U.S. Gulf Coast region of Arkansas, Louisiana, and Texas

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Abstract

Balkan endemic nephropathy (BEN) is an irreversible, lethal kidney disease that occurs in regions of the Balkans where residents drink untreated well water. A key factor contributing to the development of BEN may be consumption of dissolved organic matter leached from low-rank coal called lignite. This hypothesis—known as lignite-water hypothesis—was first posed for areas of the Balkans. It is possible that a BEN-like condition exists in the United States (US) Gulf Coast region in parts of the Mississippi Embayment and the Texas Coastal Uplands aquifers —Arkansas, Louisiana, and Texas, for instance—that rely heavily on groundwater from aquifers that contain lignite. This paper utilizes a geographic information system (GIS) to map the distributions of end-stage renal disease (ESRD) in relation to water from lignite-containing aquifers in the tri-state region. Regional patterns emerged from geospatial analysis, indicating that counties that relied on lignite-containing aquifers for their main water source had higher rates of ESRD in comparison to other populations in the state that rely on other water sources, including surface water and groundwater from aquifers not associated with lignite seams. Statewide rates of ESRD and diabetes associated ESRD (ESRD-DM) showed strong correlations to the percent of families at or below poverty level and the percentage of African Americans. These confounding factors somewhat mitigate the association seen between ESRD and lignite-containing regions at the state level. However, at the larger tri-state view, there is a significant ($p = 0.002$) increase in incidence rates when considering both race and poverty. Additionally, no relationship was observed between the rate of public water supply withdrawal from lignite-bearing aquifers and rates of ESRD or ESRD-DM at the state or tri-state regions, supporting the observation that the risk associated with water from lignite-containing aquifers is limited to water from untreated domestic supply.

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Introduction

Balkan endemic nephropathy (BEN) is a chronic renal disease that is confined to Balkan regions, including Bosnia, Bulgaria, Croatia, Romania, and Serbia (Pavlović, 2013; Stiborová et al., 2016). BEN largely occurs in rural areas and primarily affects adults ages 30–50 who are native residents of endemic villages. Numerous members of a single generation or multiple generations living in the same household can be afflicted by BEN, leading to the hypothesis that the etiology is tied to a household's food and/or water supply (Bamais and Botetis, 2008). BEN typically terminates in end-stage renal disease (ESRD) and/or urinary tract tumors (Danilovic et al., 1957). Many environmental and genetic factors have been postulated as contributing factors to BEN (reviewed by Bui-Klimke and Wu, 2014; Stiborová et al., 2016). Some evidence supports the etiology of BEN as a multifactorial condition (Toncheva et al., 1998), with one hypothesis postulating that consumption of naturally contaminated drinking water from lignite beds could contribute to the development of kidney disease (Orem et al., 1999).

The lignite-water hypothesis was first proposed by geologists at the United States Geological Survey (USGS) after researchers observed spatial patterns between Pliocene age lignite deposits and villages plagued with BEN (Feder et al., 1991). Lignite is composed of relatively unmetamorphosed plant material in the early stages of the transformation from peat to anthracite. This organic rich material could give rise to potentially toxic water-soluble organic compounds such as polyaromatic hydrocarbons, heterocyclic compounds such as aromatic amines and thiophenes, as well as cyclic and acyclic aliphatics (Hazai et al., 1988, 1989). Laboratory leaching studies found that Pliocene age coal from endemic regions of the Balkans produced many more water-soluble compounds than did more mature bituminous deposits (Maharaj et al., 2014). In addition, analyses of well water from the endemic regions showed elevated levels of organic contaminants including polyaromatic hydrocarbons (PAHs; Orem et al., 1999). Human stem cells exposed to water extracts of an endemic area also showed increased cellular proliferation and differentiation as compared to controls (Suciu et al., 2005). Furthermore, humic and fulvic acids isolated from an endemic village water sample caused excess cell death or proliferation in human kidney cells when compared to the controls (Bunnell et al., 2007). Together, these studies demonstrate a potential risk associated with compounds derived from lignite products in the water supply.

The United States (US) Gulf Coast region presents a similar geologic framework to that of the Balkans. Lignite and subbituminous deposits are found throughout the Gulf Coast (Tully, 1996) and is actively mined in areas of Texas and Louisiana. Lignite deposits in the Gulf Coast are chiefly contained within the Wilcox, Claiborne, and Jackson groups (Schobert, 1995; Hook et al., 2011). Sandstone units associated with these formations like the Sparta Sand and Carrizo-Wilcox Sands serve as regional and local aquifers for many residents (Clark et al., 2011).

It is possible that a BEN-like condition can occur in rural regions of the Gulf Coast for residents that consume untreated private well water from lignite-containing strata. Chakraborty (2017) reported aromatic and aliphatic compounds in well water from rural areas of east Texas that are part of the Carrizo-Wilcox aquifer system. Although the levels

detected were below toxicity thresholds, health effects related to low-level exposure to these coal derived materials have not been investigated. Carlson and Biersel (2008) reported that water samples from lignite-containing aquifers in northwest Louisiana had higher mean values of some inorganic species like strontium, fluoride, boron, and chromium. The authors did not report any correlation between the number and type of organic compounds in these water samples. However, in one study researchers showed a positive correlation between renal pelvic cancers and the number of organic compounds in well water in areas of Louisiana that are part of the Carrizo-Wilcox aquifer system (Bunnell et al., 2003). Despite the potential health hazards, few epidemiological studies exist that investigate the association between renal disease and lignite containing aquifers in the US.

This article describes a study of statewide and regional distributions of ESRD in Arkansas, Texas and Louisiana in the US Gulf Coast region. A geospatial information system (GIS) was used to store, manipulate, analyze and visualize a variety of geologic and geographic data to understand patterns between water withdrawal from lignite-containing aquifers and population characteristics as it relates to occurrences of ESRD. Utilizing a GIS—typically defined as (computer based) applications for storing, manipulating, and projecting data, particularly spatial data—in epidemiology offers researchers a way to statistically evaluate and visualize environmental determinants in public health. While creating a GIS to study public health issues is well established, the geospatial analysis in fields outside of medical and/or health geography and planning is relatively still novel, especially in the emerging field of medical geology. GIS affords the opportunity for interdisciplinary researchers to work together to better understand geologic and environmental factors that might have an impact on public health concerns. This study uses a computer-based GIS to analyze various physical and cultural geospatial attributes and their relation to the lignite-water hypothesis.

Materials and methods

ESRD data

The total number of ESRD and diabetes induced ESRD (ESRD-DM) cases among persons 40 years or older by county was obtained from the United States Renal Data System (USRDS: www.usrds.org) for Arkansas, Texas, and Louisiana in the time period 1998–2007. Per USRDS policy, data were censored for any county with 10 or fewer cases in the time period with zero incidents being reported as such. Censored data were omitted for this analysis.

Census data from the 2000 decennial census were obtained from the American Factfinder database (www.factfinder.census.gov) by county for Arkansas, Texas, and Louisiana. Data extracted were: number of individuals 40 years or older; percent African American or black; percent Hispanic; and percent of families below the poverty level.

Unadjusted rates of ESRD per 10,000 persons (40 years or older) were then calculated for each county.

Aquifers

Water withdrawal by aquifer and county was aggregated from several sources. The United States Geological Survey-Lower Mississippi Gulf website provided data for Arkansas, and withdrawal rates for public supply in 2000 were summed for the coal containing aquifers: Carrizo-Wilcox, Cane River, Cockfield, and Sparta, aquifers. Per capita withdrawal was calculated in relation to the 2000 census for each state. Water withdrawal by aquifer for Texas was obtained through the Texas Water Development Board Website (<http://www.twdb.texas.gov>), and withdrawal for lignite-containing aquifer units include Carrizo-Wilcox, Queen City, Sparta, and Jackson. Lignite-containing aquifers in Louisiana include the Carrizo-Wilcox, Cockfield, and Sparta, and water withdrawal for each aquifer in Louisiana was obtained from the USGS, Lower Mississippi-Gulf Water Science Center.

Data analysis

Calculated rates along with demographic data obtained from the US Census Bureau were joined with geographic variable shapefiles from the USGS in ArcGIS Desktop 10.4 for the tri-state region. The data were further manipulated and mapped to show spatial patterns and relationships. Raw data is presented in Appendix B.

A generalized linear model was used to interpret the influence of several demographic variables at the county, state, and regional scales. Percent African American, percent Hispanic, and the percent of families below poverty level were introduced as continuous variables, while counties that rely on lignite-bearing aquifers were incorporated as categorical variables.

Results and discussion

Lignite beds are distributed throughout several geologic units in the Gulf Coast region including the Cockfield, Cane River, Sparta, and the Wilcox formations. These formations also serve as local and regional aquifers that supply drinking water to many local residents (Sargent, 2002; Holland, 2004; George et al., 2011). These deposits are exposed at the surface along the western extent of the formation and cut diagonally across the states (Figure 1). They dip shallowly toward the coast and quickly become confined by alluvial deposits.

Domestic well water is almost exclusively withdrawn from shallow groundwater resources (Hosman and Weiss, 1991). In the lignite-containing region of the Gulf Coast, this is limited to two sources: the lignite-containing and alluvial aquifers. In some cases, deep aquifers exist that do not contain coal and are potential sources of water; however, they are unreasonable targets for domestic water supplies due to cost. The 107 counties in the tri-state region that are served by lignite-containing aquifers are shown in Figure 2.

Although BEN is known to occur in areas in the Balkans that rely on untreated well water, water withdrawn from wells for domestic use (i.e. private well water) in the US is not reliably reported from state to state, making associations between domestic well water withdrawal and ESRD difficult to quantify. This study works under the assumption that domestic water is limited to groundwater reserves and the same aquifer(s) as public supply. The counties that rely on lignite-containing aquifers are shown in Figure 2 and are

categorized into three groups for this study. Two groups represent counties that rely (partially or fully) on groundwater from lignite-containing aquifers to meet water supply demands, which are likely mirrored for domestic use. The third group represents control counties that are outside of the lignite-containing region that use other water sources such as surface water or groundwater not in hydraulic connection to the lignite-containing aquifers. For the counties that partially or fully rely on lignite-containing aquifers, actual withdrawal rates vary based on need and availability (George et al., 2011; Kresse et al., 2014). In some cases, the alluvial aquifer water quality may be compromised due to heavy agriculture or industrial activity (Welch et al., 2009), and the water demand is met by groundwater sources coming exclusively from lignite-containing aquifers.

All incidents of ESRD

Aggregations of the county data for all incidents of ESRD are summarized in Figure 3 and Table 1. The national unadjusted ESRD rate for all ages reported by the USRDS is 3.4 incidents per 10,000 persons with the age-adjusted rate being comparable at 3.5 incidents per 10,000 persons. For persons >40 years in the US, the un-adjusted ESRD rate nearly triples to 8.9 incidents per 10,000 persons for (USRDS, 2016). Direct comparisons between our calculated rates and published reports are difficult since an age restriction was imposed for this study, and USRDS reported unadjusted rates by state and age are not delineated. However, our calculated statewide rates are comparable to age-adjusted published reports after factoring in the tripling effect due to the age-restriction imposed.

At the regional and state levels, the counties that rely on the coal containing aquifers show consistently higher rates of ESRD per 10,000 persons than do the regions that rely on other water sources (Table 1). There is a significant difference between the control counties and counties that fully or partially draw water from lignite-containing aquifers. In Arkansas, the difference is most pronounced with a rate of 6.6 incidents per 10,000 persons in control counties and 11.3 incidents per 10,000 persons for counties that fully rely on lignite-containing aquifers ($p = 0.000001$). The trend is not as clear in Louisiana, where although the rates of ESRD are higher, there is not a significant difference between lignite containing aquifers and control counties ($p > 0.05$).

Diabetes associated ESRD (ESRD-DM)

Diabetes is the leading cause of ESRD in the US (USRDS, 2016). Rates of diabetes associated ESRD (ESRD-DM) were calculated for each county and compiled for the tri-state region (Figure 4 and Table 2). The USRDS reports national unadjusted ESRD-DM rates for >40 years are 4.2 incidents per 10,000 persons with the rate for all ages being 1.5 incidents per 10,000 or 2.8 times less (USRDS, 2016). Statewide rates of ESRD-DM for all ages are comparable to those calculated for this study once accounting for this age related factor. Similar to ESRD rates, rates of ESRD-DM (Table 2) were higher for the lignite-containing aquifer regions, although the rates were collectively lower than all incidents of ESRD. Additionally, counties in the tri-state region that fully rely on lignite-containing aquifers consistently showed higher rates ($p = 0.000013$) of ESRD-DM as compared to control counties. At the state level, Arkansas ($p = 0.000011$) and Texas ($p = 0.000681$) both showed significantly higher rates of ESRD-DM in counties that rely on lignite-containing aquifers

when compared to the control counties. In all three states, counties that fully rely on lignite-containing aquifers have higher 11 rates of ESRD-DM compared to counties that partially rely on the aquifers, but the difference was not significant in all states ($p > 0.05$).

It is important to note that incidence rates of ESRD-DM are estimated for self-reported diabetics. Many patients either do not report their condition or are simply not aware of the condition, making these estimations tenuous (USRDS, 2016). Also, the reliability and consistency of assigning primary-cause of ESRD has not been well established (USRDS, 2016).

Confounding factors

Rates for both incidents of ESRD and ESRD-DM are consistently higher for the lignite-containing regions compared to the regions without lignite deposits for each county in the tri-state region. However, geographical variations ESRD have been linked to rural/urban environment (Fan et al., 2007), low socio-economic status (Young et al., 1994; Wolf et al., 2011; Patzer and McClellan, 2012), race (Volkova et al., 2008; McClellan et al., 2011), and access to care (Ward, 2009). Race is a well-established factor in development of ESRD, with African Americans being at four-times greater risk for developing ESRD compared to whites (Klag et al., 1997; Martins et al., 2002; Norris and Agoda, 2005). Ethnicity is also a contributing factor with Hispanics at a higher risk for ESRD compared to non-Hispanics (Norris and Agoda, 2005). The influence of poverty, in addition to or separate from race, on the rates of ESRD is difficult to unravel. Some evidence suggests that race plays only a small role compared to economic status (Byrne et al., 1994), but other studies suggest that a greater disparity in ESRD rates are seen between whites and African Americans with increasing poverty (Young et al., 1994; Volkova et al., 2008). Low socioeconomic status (including those living below the poverty * p -value for comparison to “Other water sources” For all states, comparison of fully and partial was not significant, $p > 0.05$ threshold) has been previously associated with inadequate dialysis treatment, reduced access to care, and poor overall health outcomes (Patzer and McClellans et al., 2012).

Three confounding factors were considered for this study: 1) the percent African American, 2) the percent Hispanic, and 3) the percent of families living below the poverty threshold. The spatial distributions of each confounding variable in the tri-state region is shown in Figure 5. Simple spatial consistencies emerge between these variables and the lignite-containing region, and it is clear that these factors play an important role in the development of kidney disease in these states.

A generalized linear model of the tri-state region was used to understand the impact of these demographic variables on rates of ESRD and ESRD-DM and is summarized in Tables 3 and 4. The percent African American and Hispanics both significantly ($p < 0.0001$) influence the rates of ESRD for the tri-state region. In Texas and Louisiana, the percent Hispanic significantly impact the rate of ESRD but not in Arkansas. The percent African Americans also show significant influence over ESRD rates at the tri-state region and are also significant influences at the state level as well.

Unlike race or ethnicity, the percentage of families below the poverty level presents a strong and consistent control over the rates of ESRD and ESRD-DM in the tri-state region. It should be noted that poverty thresholds calculated for the census data are not adjusted for the cost of living across the US, and the poverty threshold for a family of four in 1999 was an annual income equal to or less than \$17,029. An average of 12.4% of Americans lived below the poverty level in 1999, and Texas (15.4%), Arkansas (15.8%) and Louisiana (19.6%) all exceeded the national average (Bishaw and Iceland, 2003). Many of the counties that represent the highest population of families living below the poverty level are living in lignite-containing regions of the states (Figure 5, C).

Public water supply withdrawal

Two statistical tests, Spearman rank correlations and a generalized linear model, were used to evaluate the influence of water withdrawal from lignite-containing aquifers on ESRD and ESRD-DM. Water withdrawal in millions of gallons (Mgal) per capita for those counties that rely on lignite-containing aquifers grouped by full or partial dependence is presented in Figure 6. A Spearman rank correlation, a nonparametric test that shows covariance between two rank variables, was performed between the amount of water withdrawn from lignite-containing aquifers and rates of ESRD and ESRD-DM (Table 5). Although higher overall rates of ESRD are associated with counties that withdraw water from lignite-containing aquifers (Tables 1 and 2), there was no correlation between ESRD and water withdrawal for public supply for counties that partially or fully rely on lignite-containing aquifers (0.13973, $p = 0.4615$), or those that rely on the lignite-containing aquifers only (0.07843, $p = 0.7648$) (Table 5). This observation supports the initial lignite-water hypothesis (Feder et al., 1991), which states that the risk is limited to those residents who rely on domestic well water and is not linked to public supply withdrawal or consumption.

In the generalized model of ESRD and ESRD-DM, water withdrawal from lignite-containing aquifers was introduced as a categorical variable with counties either utilizing the aquifer or not. Counties that rely on the lignite-containing aquifer showed a significant positive association with ESRD ($B = 1.427$, $p = 0.002$) and ESRD-DM ($B = 1.316$, $p < 0.0001$), even when considering the confounding variables discussed above. Separating the counties by full or partial reliance on the lignite-containing aquifers did not show a statistically significant influence on rates of ESRD or ESRD-DM.

Although the Spearman correlation between direct withdrawals did not show a significant correlation to rates of ESRD or ESRD-DM, the generalized model shows that there is residual impact related to water withdrawal from lignite-containing aquifers in addition to racial and ethnic risk factors. The relative size of the impact also may point to a risk that is not linked to the public supply, which serves the majority of Gulf Coast residents. Rural residents in areas of low physician density have been shown to have higher rates of ESRD (Fan et al., 2009). Residents most likely to be at risk as described in the lignite-water hypothesis are rural residents whose water is exclusively drawn from private wells. The compounding effect of several factors in these areas may lead to higher rates of kidney disease.

Conclusions

This is the first epidemiological evidence for a BEN-type syndrome in the US that correlates lignite-containing aquifers to ESRD. In the Gulf Coast region of Texas, Arkansas, and Louisiana, statistically higher rates of ESRD and ESRD-DM are associated with counties that depend on lignite-containing aquifers. This association may be significantly influenced, however, by ethnicity, race and poverty in the same region. Although these confounding factors mask the affect at the state level, there is a small but significant influence at the regional level. Race specific rates of ESRD should be considered to better understand the relationship between race and rates of kidney disease in the region. Additionally, as the initial lignite-water hypothesis suggests, the association between ESRD and water quality compromised by organic compounds leached from lignite-associated aquifers seems to be limited to domestic supply water since no relationship to the public water supply tied to the lignite-containing aquifers was observed. Limitations associated with available datasets and methods to constrain the target area, hinder epidemiological studies exploring the lignite-water hypothesis in the US. Future studies should extend to include other states that share the hydrogeologic features to Texas, Louisiana, and Arkansas like Mississippi, and Alabama as well as portions of North and South Dakota. Additionally, integration of GIS into these types of analyses can help identify areas that are most likely at risk while simultaneously compiling various physical and cultural spatial attributes, leading to a more robust understanding of the results and limitations of the study.

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Figure 1. Coal deposits in the U.S. (bottom, left) and in tri-state region of Arkansas, Texas, and Louisiana.

Figure 2.

The extent of the Mississippi Embayment and Texas Coastal Upland aquifers (left) includes the Carrizo-Wilcox, Sparta, Cane River, and Cockfield aquifers that contain lignite. The counties that rely on these aquifers (right) are divided into three groups based on public water withdrawal rates to identify counties where the lignite-containing aquifers are available to meet water demands. Reliance on these aquifers for public use is likely mirrored for domestic supply and are classified as: (1) counties that rely on lignite-containing aquifers only (fully, dark blue), (2) counties that partially rely on lignite-containing aquifers (partial, light blue), and (3) counties outside of the lignite-containing region that use other water sources (control, unshaded areas).

Figure 3.

Rates of all incidents of ESRD, calculated per 10,000 persons 40+ years. The three classifications are represented as in Figure 2: (1) counties that rely on lignite-containing aquifers only (fully, hatched), (2) counties that partially rely on lignite-containing aquifers (partial, dashed), and (3) counties outside of the lignite-containing region that use other water sources (control, unshaded areas). Control average rate (Other water sources) = 8.1 ± 3.5 ($n = 280$). Data for counties colored in white were suppressed from the USRDS and no rate was calculated.

Figure 4.

Rates of ESRD-DM, calculated per 10,000 persons 40+ years. The three classifications are represented as in Figure 2: (1) counties that rely on lignite-containing aquifers only (fully, hatched), (2) counties that partially rely on lignite-containing aquifers (partial, dashed), and (3) counties outside of the lignite-containing region that use other water sources (control, unshaded areas). Control average rate (Other water sources = 4.0 ± 3.4 ; $n = 269$). Data for counties colored in white were suppressed from the USRDS and no rate was calculated. Data for counties colored in white were suppressed from the USRDS and no rate was calculated.

Figure 5. Distribution of percent African American (A), percent Hispanic (B), and percent of families below the poverty level (C) in the tri-state region for 1999.

Figure 6. The rate of public water supply withdrawal by county from lignite-containing aquifers in millions of gallons of water per capita (Mgal per capita) for the year 2000.

Table 1

County rates of ESRD per 10,000 persons 40+ years in the tri-state region (Arkansas, Louisiana, and Texas), 1998–2007 by reliance on lignite-containing aquifers.

	<i>n</i>	Rate	<i>p</i> [*]
TRI-STATE REGION	387	8.9 ± 5.1	
Water Source			
Rely on lignite-containing			
aquifers	107	11.1 ± 4.4	0.000000
fully	47	11.7 ± 5.0	0.000010
partially	60	10.5 ± 3.8	0.001310
Other water sources	280	8.1 ± 5.1	-
ARKANSAS	75	8.1 ± 3.5	
Water Source			
Rely on lignite-containing			
aquifers	30	10.5 ± 3.7	0.000000
fully	17	11.3 ± 4.1	0.000001
partially	13	9.5 ± 3.0	0.008141
Other water sources	45	6.6 ± 2.3	-
LOUISIANA	63	13.0 ± 3.4	
Water Source			
Rely on lignite-containing			
aquifers	21	13.8 ± 3.8	0.178803
fully	9	15.1 ± 3.5	0.102066
partially	12	12.8 ± 3.9	0.975035
Other water sources	42	12.5 ± 3.2	-
TEXAS	249	8.1 ± 5.3	
Water Source			
Rely on lignite-containing			
aquifers	56	10.3 ± 4.6	0.000310
fully	21	10.6 ± 5.7	0.024536
partially	35	10.2 ± 3.9	0.012982
Other water sources	193	7.5 ± 5.4	-

* *p* –value for comparison to “Other water sources”

For all states, comparison of fully to partial was not significant, *p* > 0.05

Table 2

County rates of diabetes associated ESRD per 10,000 persons 40+ years in the tri-state area (Arkansas, Louisiana, and Texas), 1998–2007 by reliance on lignite-containing aquifers.

	<i>n</i>	Rate	<i>p</i> [*]
TRI-STATE REGION	375	4.5 ± 3.5	
Water Source			
Rely on lignite-containing			
aquifers	106	5.7 ± 3.3	0.000013
fully	46	6.3 ± 3.6	0.000067
partially	60	5.3 ± 3.0	0.026447
Other water sources	269	4.0 ± 3.4	-
ARKANSAS	66	3.9 ± 1.6	
Water Source			
Rely on lignite-containing			
aquifers	29	4.8 ± 1.7	0.000011
fully	16	5.1 ± 1.6	0.000037
partially	13	4.4 ± 1.9	0.017952
Other water sources	37	3.2 ± 1.1	-
LOUISIANA	62	6.2 ± 1.9	
Water Source			
Rely on lignite-containing			
aquifers	21	6.8 ± 2.4	0.084868
fully	9	7.7 ± 2.5	0.023554
partially	12	6.1 ± 2.2	0.953866
Other water sources	41	5.9 ± 1.5	-
TEXAS	247	4.2 ± 4.0	
Water Source			
Rely on lignite-containing			
aquifers	56	5.8 ± 4.1	0.000681
fully	21	6.6 ± 4.8	0.004216
partially	35	5.3 ± 3.6	0.083317
Other water sources	191	3.8 ± 3.8	-

*
p –value for comparison to “Other water sources”

For all states, comparison of fully and partial was not significant, $p > 0.05$

Table 3

Results from a generalized linear model showing the effect of lignite-containing aquifers on the rate of ESRD in the tri-state area.

Parameter	B	95% Confidence Interval		p*
		Lower	Upper	
% African American (Tri-state)	-	-	-	<0.0001
% African American (TX)	0.147	0.078	0.216	<0.0001
% African American (AR)	0.126	0.077	0.175	<0.0001
% African American (LA)	0.164	0.117	0.211	<0.0001
% Hispanic (Tri-state)	-	-	-	<0.0001
% Hispanic (TX)	0.073	0.049	0.097	<0.0001
% Hispanic (AR)	0.115	-0.033	0.264	0.129
% Hispanic (LA)	0.455	0.097	0.814	0.013
Percent families below poverty level (Tri-state)	0.232	0.141	0.322	<0.0001
Rely on groundwater from lignite-containing aquifers (partially or fully)	1.427	.509	2.345	0.002

Table 4

Results from a generalized linear model showing the effect of lignite-containing aquifer on the rate of diabetes associated ESRD in the tri-state region.

Parameter	B	95% Confidence Interval		p*
		Lower	Upper	
% African American (Tri-state)	-	-	-	<0.0001
% African American (TX)	0.059	0.008	0.109	0.024
% African American (AR)	0.043	0.007	0.079	0.020
% African American (LA)	0.082	0.047	0.116	<0.0001
% Hispanic (Tri-state)	-	-	-	<0.0001
% Hispanic (TX)	0.066	0.048	0.084	<0.0001
% Hispanic (AR)	0.113	0.002	0.224	0.045
% Hispanic (LA)	0.257	-0.004	0.518	0.054
Percent families below poverty level (Tri-state)	0.141	0.075	0.208	<0.0001
Rely on groundwater from lignite-containing aquifers (partially or fully)	1.316	0.647	1.984	<0.0001

Table 5

Spearman rank correlations for water withdrawal for public supply by county for those counties that rely fully or partially on lignite-containing aquifers.

	Rate ESRD (all)	Rate ESRD-DM
Fully rely on lignite-containing aquifers	−0.00391 <i>n</i> = 46 <i>p</i> = 0.9794	−0.17018 <i>n</i> = 45 <i>p</i> = 0.2637
Partially rely on lignite-containing aquifers	−0.10859 <i>n</i> = 60 <i>p</i> = 0.4089	−0.17783 <i>n</i> = 60 <i>p</i> = 0.2638
All counties that withdraw from lignite-containing aquifers	0.00534 <i>n</i> = 105 <i>p</i> = 0.9569	−0.08520 <i>n</i> = 104 <i>p</i> = 0.3898