Environmental Research 167 (2018) 329–340

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Ecological analysis of associations between groundwater quality and hypertension and cardiovascular disease in rural Saskatchewan, Canada using Bayesian hierarchical models and administrative health data

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ARTICLE INFO

Keywords:
Water quality
Arsenic
Hypertension
Cardiovascular disease
Rural Saskatchewan

ABSTRACT

Associations between groundwater quality and the prevalence of hypertension and ischemic heart disease were investigated in rural areas of the Canadian province of Saskatchewan. The partially ecological study was analyzed using Bayesian hierarchical models to account for spatial variability in risk. Exposure measures and health outcomes were estimated based on previously collected water quality surveillance data from public water supplies and private wells and administrative health data. Water quality exposures for each study region were estimated by applying geostatistical techniques to arsenic concentrations and principal component (PC) scores. The PC scores summarized groups of parameters measuring either health standards or aesthetic objectives described by the province. Generalized linear mixed models with a log link assessed associations between water quality and observed count of health outcomes relative to the expected value. The Bayesian models contained uncorrelated and spatially correlated random effects for each geographic region. Effect estimates were controlled for sex and age by stratification of case and expected case counts, for smoking by inclusion of sex- and age-specific prevalence of chronic obstructive pulmonary disease as a surrogate covariate, and for education and income by use of census data.

There was no evidence for associations between groundwater arsenic concentrations in public or private water supplies and increased risk of hypertension or cardiovascular disease. An increase in the second aesthetic objectives PC score from public supplies was associated with a protective effect against ischemic heart disease. This PC value summarized hardness and magnesium Similarly, an increase in the second aesthetic objectives PC in private supplies was associated with decreased prevalence of hypertension.

The results of this study are consistent with others demonstrating a relationship between elevated hardness and magnesium concentrations in drinking water and reduced risk of hypertension and cardiovascular disease. Further investigation is warranted with individual exposure history, particularly with respect to the potential beneficial effect of hard water on the prevalence of hypertension and cardiovascular disease.

1. Introduction

Heart disease was the second leading cause of death in Canada in 2012 (Statistics Canada, 2015a) and is a leading contributor to the economic burden of disease in Canada (Public Health Agency of Canada, 2014). Hypertension, a major risk factor for cardiovascular disease, affected 19.6% of the population in Canada in 2007/2008 (Robitaille et al., 2012) and has been described as a global public health crisis (World Health Organization, 2013). While a variety of lifestyle risk factors have been established for hypertension and cardiovascular disease (World Health Organization, 2003; Yusuf et al., 2001), evidence also suggests that exposure to environmental pollutants contributes to the development of cardiovascular disease (Bhatnagar, 2006). Exposure to arsenic in drinking water has been linked to hypertension (Abhyankar et al., 2012; Abir et al., 2012) as well as ischemic heart disease (IHD) (Moon et al., 2012; Navas-Acien et al., 2005; Tsuji et al.,

Abbreviations: RR, risk ratio; CrI, credible interval; PCA, principal components analysis; PC, principal component; SK, Saskatchewan; RM, rural municipality; ICD, International Classification of Diseases; COPD, chronic obstructive pulmonary disease; SMR, standardized morbidity ratio; DIC, deviance information criterion; P5, 5th percentile; P95, 95th percentile; SD, standard deviation; SE, standard error; RE, random effect

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https://doi.org/10.1016/j.envres.2018.07.038
Received 18 April 2018; Received in revised form 6 July 2018; Accepted 28 July 2018
Available online 31 July 2018
0013-9351/

2014; Wang et al., 2007). While associations between arsenic and hypertension and cardiovascular disease have been demonstrated in areas where arsenic concentrations in groundwater were > 500 μg/L (Chen et al., 1996, 1995; Rahman et al., 1999; Tseng et al., 2003; Wang et al., 2007), there is growing concern that low to moderate (< 100 μg/L) drinking water arsenic concentrations may also be associated with these diseases (Gong and O'Bryant, 2012; James et al., 2015; Moon et al., 2013).

Exposure to arsenic in drinking water could represent an important modifiable risk factor that could help mitigate the burden of hypertension and cardiovascular disease in impacted regions (Abhyankar et al., 2012; Wang et al., 2011). Arsenic concentrations in groundwater can be very high where arsenic occurs naturally in bedrock (Thompson et al., 1999), and drinking water is considered a major route of arsenic exposure globally (Flora, 2015).

In addition to the presence of natural or anthropogenic toxins, other attributes of tap water quality can also affect health. Poor tap water quality can discourage the consumption of tap water, instead favoring the consumption of sugar sweetened beverages (Onufrak et al., 2014), which may increase the risk of cardiovascular disease independent of the effects of increased body weight (Malik et al., 2010). Areas with poor quality drinking water could consequently experience an increase in the prevalence of hypertension and cardiovascular disease mediated by indirect effects of poor quality drinking water especially where the palatability of drinking water is affected. In addition, tap water of poor quality could potentially contribute to the development of hypertension (Tuthill and Calabrese, 1979) directly through natural sodium content of water or the consumption of softened water (Padwal et al., 2005). Though the relationship between salt intake and hypertension is uncertain and complex, reduced salt consumption continues to be recommended for prevention and disease management (Frisoli et al., 2012).

The primary sources for drinking water and extent of testing varies depending on area of residence in Canada. Approximately 43% of Saskatchewan residents rely on groundwater for domestic use, primarily in rural areas and smaller municipalities (Environment and Climate Change Canada, 2007). It is also estimated that 14% of all Saskatchewan residents obtain household water from private wells (Government of Saskatchewan, 2002); these residents would primarily be among the approximately 40% of the population that live in rural areas (Statistics Canada, 2014). As is the case in many jurisdictions, no regulations govern the safety of private water supplies in Saskatchewan. Owners of private water supplies have sole responsibility for testing and treatment of their water supplies, including associated costs. While provincial agencies do monitor the quality of public drinking water, the requirements for public supplies vary depending on the size of the population served by the supply and the type of water source (Water Security Agency, 2016). Consequently, public water supplies for smaller communities are typically not monitored at an intensity comparable to water supplies in cities. Differential testing and regulation of water supplies for residents of rural areas could increase the likelihood of exposure to poor quality drinking water.

Provinces in Canada establish their own regulations pertaining to drinking water. Saskatchewan established two main categories of drinking water guidelines: legally enforceable standards that govern health hazards (heavy metals, pesticides, microorganisms), and objectives that represent optimal levels of characteristics which primarily affect the aesthetic qualities of drinking water but are not health hazards (Water Security Agency, n.d.). Previous studies have identified wells with elevated concentrations of arsenic (Thompson et al., 1999) and other dissolved minerals which are not considered a risk to health, but affect the palatability of water (Sketchell and Shaheen, 2000; Thompson, 2003). In a 2011 survey of rural Saskatchewan residents, 25% reported concerns about the taste, odor, colour, or cloudiness of their tap water (McLeod et al., 2015). Hardness, the sum of calcium and magnesium concentrations expressed as the equivalent concentration of calcium carbonate, is a common problem in Saskatchewan groundwater (McLeod et al., 2017; Sketchell and Shaheen, 2000; Thompson, 2003). While not considered a health risk, hardness affects palatability as well leading to scale build up in plumbing and fixtures.

The hypothesis motivating this study was that exposure to poor quality drinking water could increase the risk of hypertension or IHD for residents in some areas of rural Saskatchewan, either through direct toxic effects of contaminants identified as health standards (including arsenic), or indirectly though aesthetic objectives that impact water consumption. The primary goal of the present study was to investigate associations between groundwater quality and hypertension and IHD in rural Saskatchewan using a partially ecological analysis of existing water quality surveillance and population-based administrative health data. While results of ecological study designs must be interpreted cautiously, the relative availability of water quality and administrative health data can be advantageous for hypothesis screening compared to the challenges and costs of individual level investigations of such links, especially when long-term exposures are difficult to quantify (Elliott and Savitz, 2008; Künzli and Tager, 1997) and when latent periods for environmental exposures are long (de Vocht et al., 2013; Rothman et al., 2008). This study builds of previously published work summarizing groundwater quality in Saskatchewan (McLeod et al., 2017). Principal components analysis was used to summarize water quality related to health standards and aesthetic objectives, and principal component scores were used as measures of exposure in a novel assessment of potential impacts of mixtures of these classes of contaminants on the occurrence of cardiovascular disease. Bayesian hierarchical models were employed to incorporate possible spatial correlation in the variability of cases of cardiovascular disease, as these models are ideal for sparsely populated areas such as rural Saskatchewan.

The primary objective was to examine associations between groundwater arsenic concentration and hypertension and IHD in rural Saskatchewan. The secondary objective was to examine associations between groups of substances monitored as health standards and substances measured as aesthetic objectives and the prevalence of hypertension and IHD in rural Saskatchewan.

2. Materials and methods

2.1. Study area

The study area was limited to the southern part of Saskatchewan (Fig. 1); because the population and water quality data were very sparse, the northern part of the province was excluded from the study. The study area extent corresponds to the borders of rural municipalities (RMs), an administrative unit that provided the basis for division of the study area into geographic units for analysis; the east, west and southern borders of the study area also correspond to Saskatchewan provincial borders.

2.2. Geographic units for analysis

Rural municipalities provided the basis for division of the study area into geographic units for analysis. In the administrative health data used for the study, residents were assigned a residence code based on place of residence or mailing address. The first 3 digits of the residence code was used to assign study subjects to the RMs. RMs with fewer than 500 residents over the age of 19 years were sequentially aggregated according their RM number. However, some RMs had been historically combined for administrative purposes. An RM with an adult population < 500 was aggregated with an adjacent lower numbered RM where the difference in RM number was < 3; if the RM numbers differed by ≥ 3 the RM was aggregated with the next higher numbered RM.

First Nations reserves (tracts of land set aside for the exclusive use of