Rising solute trends from regional groundwater quality monitoring in an urban aquifer, Nottingham, UK

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Abstract: Historical analyses of chloride, sulphate and nitrate from an urban aquifer (the Permo-Triassic Sherwood Sandstone, Nottingham, UK) are used to assess the anthropogenic effects on temporal water quality variations. Sewage leakage, road-salt application, atmospheric emissions and fertiliser use were seen as the major contributors to rising trends in these solutes. Concerted groundwater management and protection strategies are needed to address these trends.

Key words: urban groundwater, monitoring, quality

Introduction

Urban groundwater levels have been rising sharply in many UK industrialised cities (e.g., Ciria, 1989) have lead to renewed interest in the use of urban groundwater despite concerns regarding its quality. Recent depth-specific monitoring of groundwater quality in the Sherwood Sandstone aquifer underlying Nottingham (UK) using bundled multilevel piezometers (Powell et al., 2003; Cronin et al., 2003) reveals rapid penetration of microbial contaminants that exceeds advective groundwater flow velocities. This is of concern since the aquifer is used extensively for public and private water supplies. To provide a context to depth-specific results, long-term monitoring data (1975–2000) are used to assess regional patterns of groundwater recharge and flow since the hydrochemistry of groundwater over time reflects sources of recharge, geochemical interactions, and flow characteristics of the sampled aquifer. Major anion chemistry presented here derives from 11 monitoring wells and abstraction boreholes that are open over large depth intervals. Solute concentrations thus represent depth-integrated samples of groundwater quality that are inherently biased toward the most transmissive horizons.

Results and discussion

Hydrochemical data, collected by the Environment Agency of England & Wales over the period 1975-2000, from the boreholes in the Nottingham area, were collated and annual medians of chloride, sulphate and total inorganic nitrogen are presented in Figure 1. All

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boreholes are located in urban areas with 3 of the boreholes confined by low-permeability mudstone. Analyses were discontinuous and vary in frequency. All charge balance errors in the dataset were below ± 10 %.

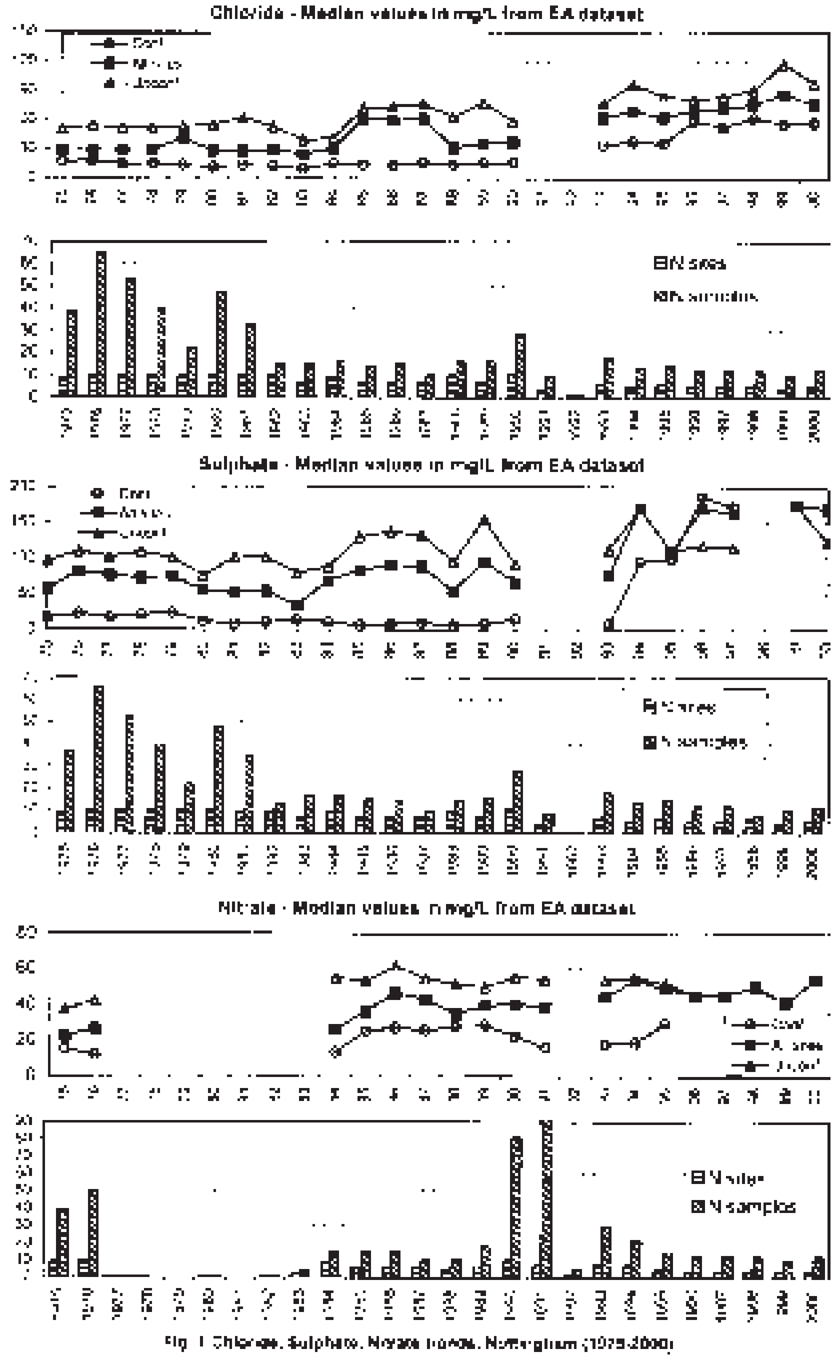

Fig. 1 Chloride, Sulphate, Nitrate trends, Nottingham (1975-2000)

Chloride, sulphate and nitrogen were selected to assess long-term temporal solute variations because they are regarded as conservative and records were available over a significant period (i.e., 1975-2000). The aerobic nature of the Nottingham Sherwood Sandstone aquifer means that the predominant forms of sulphur and nitrogen are sulphate and nitrate though there is a possibility of denitrification in confined areas of the aquifer. Possible sources and sinks of these solutes are given in Table 1 and highlight the predominance of anthropogenic sources.

Table 1. Possible sources and sinks of the various solute species

Species	Possible Sources	Possible Sinks
Cl^-	Halite dissolution, precipitation, fertiliser, borehole acidisation techniques using HCl, sewage, saline mixing, road de -icing, industrial use of sodium hypochlorite, landfill leachate	
SO_4^{-2}	Precipitation (acid rain from a nearby coal -burning power station), gypsum dissolution, ammonium sulphate fertiliser, sewage, industrial use of sulphuric acid, landfill leachate	Sulphate reduction
N-species	Precipitation (low levels), fertiliser e.g. $(NH_4)_2SO_4$, or $(NH_4)_2NO_3$, sewage, NO_3 leached from soil, industrial acids, landfill leachate	Reduction, sorption of ammonia, plants, microbial metabolism

Median concentrations of chloride in both confined and unconfined wells have gradually increased from ~30 mg/L to ~80 mg/L over 25 years (Fig. 1). Although the hydrochemistry of individual boreholes can indicate site-specific contamination, median values reported in this study reflect the impact of effectively diffuse contaminant sources such as leakage from pressurised water mains and sewers as well as application of road salt. Yang et al. (1999) estimated that the contribution to groundwater chloride levels from mains and sewage leakage in Nottingham is ~40 mg/L. These recharge sources are likely to be the most significant contributor to the rise in chloride concentrations.

Sulphate concentrations show a large difference between confined and unconfined areas with the overall increase from ~80 mg/L to ~160 mg/L. Median sulphate concentrations recorded at all sites are greater than 100 mg/L after 1994 (Fig. 1). Stable isotope ratios of sulphur ($^{34}S/^{32}S$) from depth-specific monitoring in Nottingham indicate that sulphate concentrations derive primarily from a combination of atmospheric sources (e.g., emissions from coal-burning stations) and sewage (Taylor pers. comm., 2003).

The average value for nitrate from 19 records in the Nottingham area between 1882 and 1970 is 29 mg/L. Median values in the confined zone generally remain below this value though unconfined zone wells are often > 50 mg/L (Fig. 1). Some wells are influenced by site-specific contamination (including TNT manufacture near one well) but it is more likely that, similar to chloride, leaky sewers are a major factor in elevated nitrate concentrations. Yang et al., (1999) computed the total nitrogen contribution to groundwater from leaky mains and sewers to be ~4.9 mg/L as N. Observed microbial contamination confirms that sewer leakage occurs within the city (POWELL ET AL., 2003). Diffuse sources such as fertilisers have also added significantly to rising nitrate levels in other urban areas and contribute to the trends in Fig. 1.

Records of water-quality monitoring like those used in this study are commonly collected in order to comply with monitoring requirements and are occasionally used to identify contaminated wells. This study clearly shows rising solute concentrations on a regional basis. It also shows that monitoring programmes have been reduced in scale over successive years. Both of these trends are worrying and require proactive action to alter them. Concerted groundwater management and protection strategies are needed to address the observed deterioration of groundwater quality and in monitoring activities. Recent efforts toward depth-specific monitoring can usefully inform regional assessments of groundwater quality as such data not only constrain the rate at which contaminants loaded at the surface or near-surface penetrate urban aquifers but also determine the opportunity for remediation.

CONCLUSIONS

Major anion (Cl^-, SO_4^- and NO_3^-) concentrations from 11 boreholes in the Nottingham (UK) show significant increases over the period from 1975 to 2000. Boreholes situated in the unconfined area of Nottingham exhibit the highest solute concentrations. Deterioration of groundwater quality in Nottingham arises from anthropogenic loading and is considered to derive principally from sewage leakage, atmospheric emissions, road-salt application and fertiliser use. Long-term monitoring of the hydrochemistry of urban groundwater assists in identification of key threats to water quality and complements more recent, depth-specific monitoring data that indicate the rates at which identified recharge or contaminant sources penetrate urban aquifers.

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