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Risk hazard mapping of groundwater contamination using long-term monitoring data of shallow drinking water wells

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Abstract

Long-term monitoring data from over 10 000 shallow drinking water wells in the county of Osnabrück (2121 km^2) were used for generating regionalized time-averaged maps of top aquifer contamination. Using these approach local impacts can be distinguished from wide spread contamination with agrochemicals (nitrate, pesticides). Spatial databases of land-use patterns, livestock figures, soil and meteorological data are stored in a Geographical Information System (ARC/INFO). They were overlayed with regionalized aquifer contamination to facilitate the hazard mapping of top aquifer contamination. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Agrochemicals; Geographical information system; Aquifier contamination

1. Introduction

Groundwater is the main source of drinking water in Western Lower Saxony (Germany) which is an area of intensive agricultural land use. The water quality of shallow drinking water wells in the county of Osnabrück has routinely been measured by the local public health department for nitrate, ammonia, and other chemical ingredients and physical properties since 1983. These wells supply approximately 10% of the inhabitants who depend on a good water quality. Over 10 000 wells were monitored, over 3000, i.e. 30% of which were closed due to contamination above the legal standards. The aim of the work is to use the information on the shallow drinking water wells for the determination of the top aquifer contamination. Furthermore, local impacts

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should be distinguished from area specific impacts. By overlaying data regarding livestock figures, climatic records, and soil properties a spatial risk hazard mapping of groundwater contamination with nitrate can be derived. This is the first step in performing a risk management. Short term alternatives such as a connection to the public water supply as well as long term alternatives such as reduction of agricultural land-use are discussed in the work of Berding [1].

2. Data and methods

The local public health department performs the monitoring in order to control the legal standards of drinking water. In the period from 1983 to 1996, nitrate has been measured 32 833 times in 7853 wells, pesticides (*s*-triazine compounds and metabolites) have been detected 11 323 times in 7606 wells, and hygienic parameters such as *Escherichia coli* bacteria have been sampled and bacterial counts taken at 7886 wells 117 027 times. The monitoring has been performed arbitrarily and the monitoring frequency at each well varies in 71% of the cases between 3 and 5 times which means a sampling interval of 2 to 5 yr. The locations of all wells were digitized, attribute information such as depth and well type was added and both were stored in the Geographical Information System ARC/INFO. Median nitrate values were interpolated with Inverse Distance Weighting [2]. Parameters were chosen in such a way that point distance was weighted exponentially in order to create a regionalized view yielding a time-invariant background contamination.

The annual manure production was estimated from livestock figures provided by the state statistical bureau [3] and the animal specific annual manure production [4]. Area specific manure application was calculated on the basis of the manure production on arable land. Meteorological data were collected from waterworks and wastewater treatment plants to compute the daily distribution of recharge and evapotranspiration [5]. The area of arable land was selected by the topographic information system ATKIS and resembles 18 842 polygons with a sum of 1408 km^2 and a mean area of 74 735 m^2. Vectorized soil data of a scale of 1:50.000 from the Lower Saxony Soil Information System NIBIS (Niedersäschsiches Landesamt für Bodenforschung, Hannover) supplied horizontal specific information regarding soil type, bulk density, and humus. The soil data consists of 2977 polygons with a mean area of 752 850 m^2. From these parameters the horizontal specific field capacity was derived using tabular values [6]. From field capacity and water recharge the nitrate leaching for arable land in the winter period of September 1994 to April 1995 was assessed by using regression curves [7].

3. Results and discussion

Pesticides (*s*-triazine compounds and metabolites) were found in 184 wells (2.4%), 25 had concentrations above 0.5 $\mu g/l$ (0.3%). Nitrate was found in almost all of the

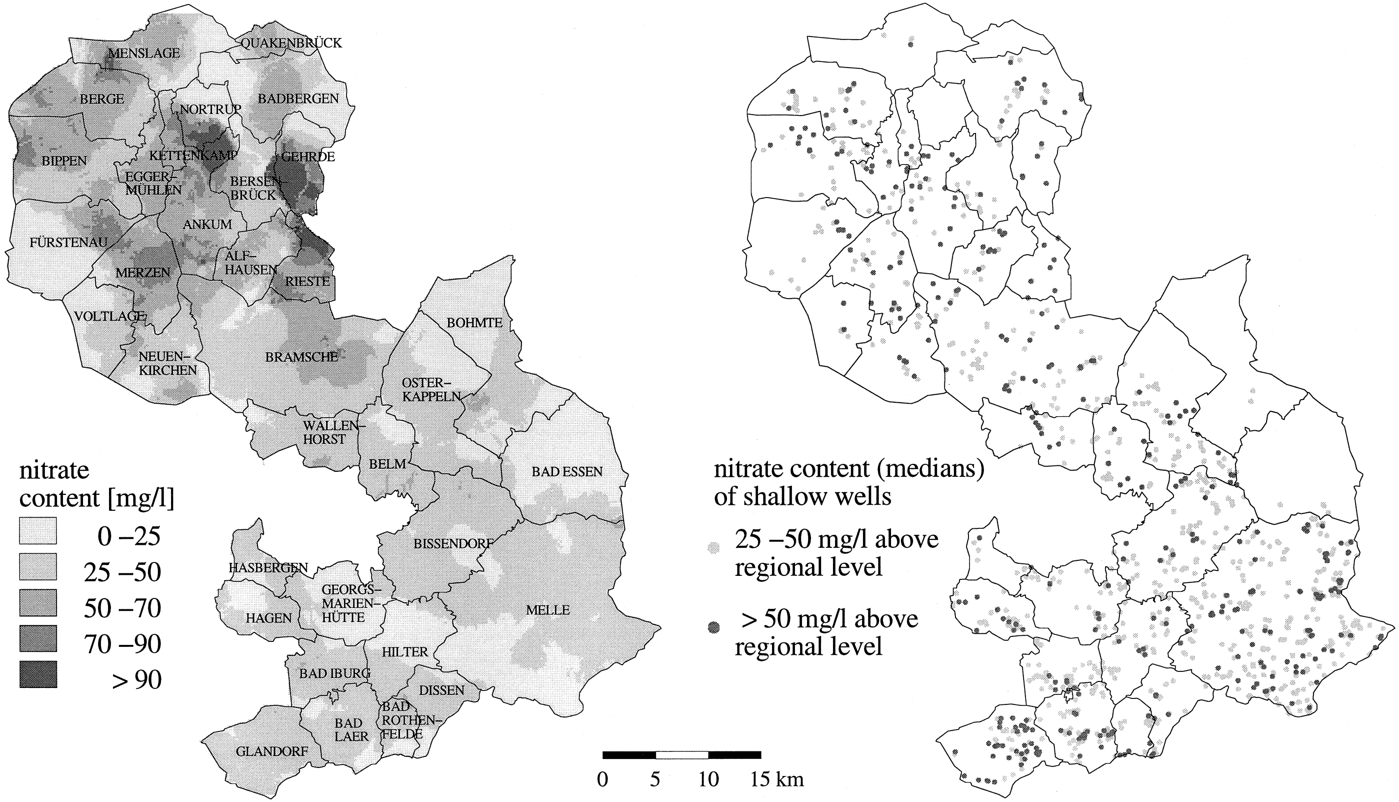

Fig. 1. Nitrate contamination in the district of Osnabrück; a) background contamination through IDW-interpolated medians; b) locations where medians considerably exceed the background contamination.

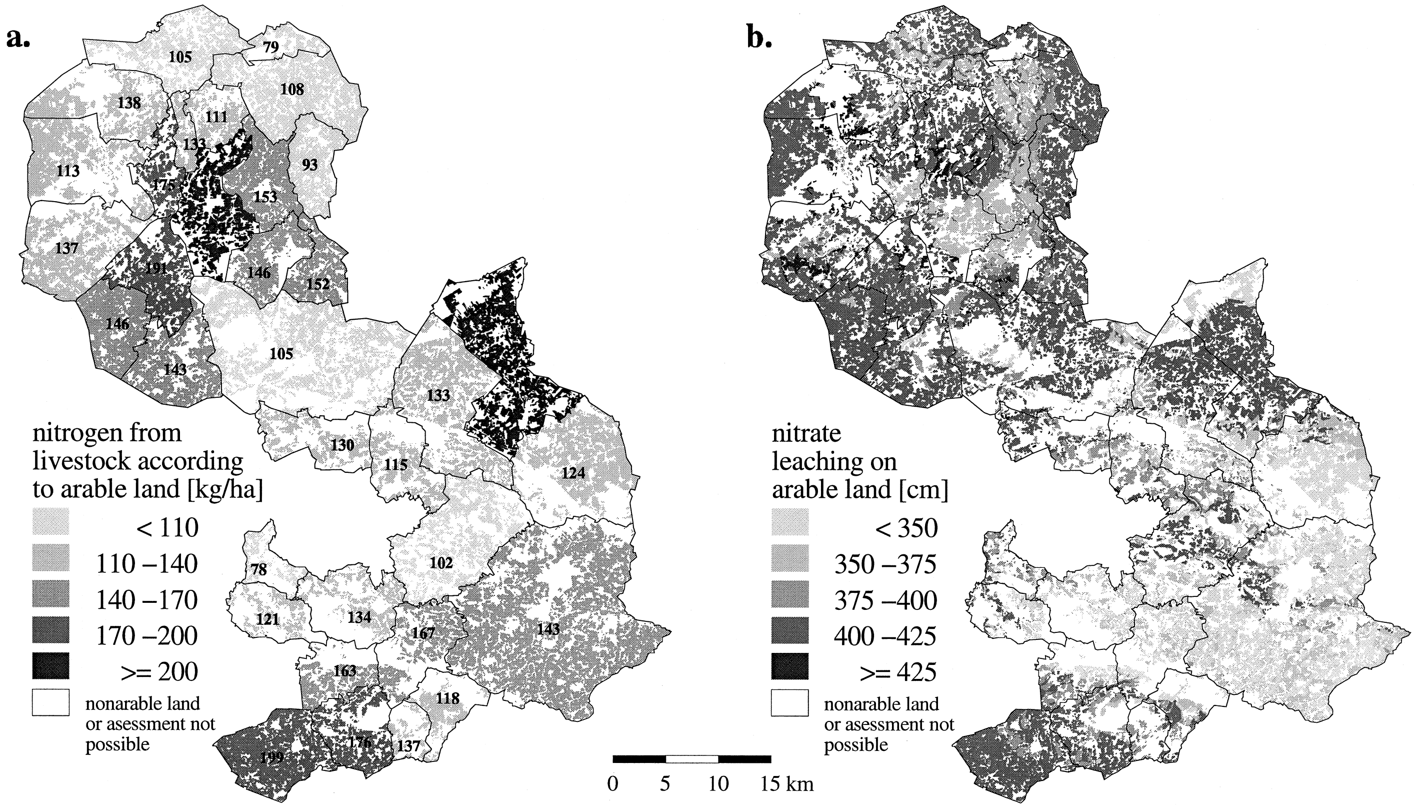

Fig. 2. a) Nitrogen from livestock according to arable land (1991); b) vertical nitrate displacement in soil (period 1 September 1994–30 April 1995).

7853 shallow drinking water wells still in operation. A total of 3430 wells (43.7%) had nitrate levels above the regulatory standard of 50 mg/l at least once, 1297 exceeded 90 mg/l (16.5%).

Fig. 1a represents the regionalized interpolation of nitrate medians at the well locations and shows that the top-level aquifer, especially in the central northern part of the Osnabrück county, exceeds the legal standard of 50 mg/l,and sometimes even 90 mg/l. Most shallow wells in the southern county have lower nitrate levels; however, several locations approach or exceed the standard. The lowest nitrate contents were detected in hilly areas covered with forests and in deep wells. Fig. 1a illustrates a time-averaged background nitrate contamination and allows the determination of well locations exceeding the regional level as it is done in Fig. 1b. Furthermore, local impacts, e.g. from dung heaps or leaking sewers can be sorted out. Fig. 2a shows the nitrogen production from livestock on arable land with respect to the community borders. In the northern part, where intensive livestock farming is widespread, high rates exist similar to those in the southwest. In the central district and in the northern margin the rates are partly much lower. Mineral fertilizers are not yet accounted for, but even without this additional input many communities already reach the legal standard of 170 kg N/ha. Fig. 2b shows the nitrate leaching (only arable land) in the period from September 94 to April 95. In the center and eastern part of the district, vertical nitrate transport is smaller in clay soils, which are mainly located in hilly landscapes. Higher values were computed for the southwest. In the flat area of the northern district with sandy and locally distributed loamy and silty soils, nitrate transport is much higher but also more variable. The winter period 1994–1995 was a season with high precipitation (516 mm) and low evapotranspiration (113 mm), i.e. estimated leaching rates are at the upper level. A simultaneous consideration of Fig. 2a and b shows a high contamination risk in some northern parts that can also be found in Fig. 1a. The risk analysis in the northern east, which is underestimated, may be caused by earlier not considered impacts. Moreover the southern corner and regions in the center east show high risk which cannot be found in the regionalized nitrate contamination map.

4. Conclusion

The county of Osnabrück is an area of intensive agricultural land use especially of intensive livestock farming resulting in a high amount of nitrogen production by the livestock. High production ratios of nitrogen by livestock and a high risk of nitrate leaching are reasons for the considerable exceeding of legal standards in the central northern part of the district. Geographically referenced data can be used for the classification of areas with a high contamination risk in the top aquifer. The comparison of detected contaminations and the areas of high contamination risks show accordances in several areas but also some discrepancies. A consideration of long-term averaged data also in climatic data and nitrogen production rates seems to be necessary for the verification of the approach. This facilitates the prediction of contamination risks to regions without monitoring data.

Acknowledgements

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