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Estimating groundwater vulnerability to nonpoint source pollution from nitrates and pesticides on a regional scale

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Abstract One of the major sources of groundwater pollution in the midwest United States is nonpoint source (NPS) pollution resulting from agricultural production. GIS-based techniques were developed and tested to provide groundwater vulnerability maps to agricultural NPS pollution (pesticides and nitrate) for regional areas. The results were evaluated within the GIS using nitrate and pesticide contamination in well water data to determine the accuracy of the vulnerability maps. The vulnerability maps were more accurate that currently accepted techniques. The approach developed and the resulting maps are useful for development of regional groundwater protection plans, as policy analysis tools and in targeting NPS pollution control measures.

INTRODUCTION

Groundwater is an important resource in much of the Midwestern USA. It supplies drinking water for over 95% of the rural population and over 50% of the urban population in this region. Protection of the groundwater in the Midwest USA has become a significant concern. A study by US Environmental Protection Agency (US EPA, 1992) found that over half of the wells in the USA contained detectable nitrate levels and approximately 5% contained detectable pesticides. An Indiana Department of Environmental Management study (IDEM, 1989) found similar results within the state of Indiana. One of the major potential sources of groundwater contamination in this region is agriculture. However, the vulnerability of groundwater in this region to agricultural nonpoint source (NPS) pollution is not well understood. Vulnerability maps commonly available are rather crude (1:2 000 000 scale) and are of questionable value. The goal of this work is to develop a technique that will provide improved groundwater vulnerability to agricultural NPS pollution maps for regional areas.

METHODOLOGY

The technique developed to estimate groundwater vulnerability to agricultural NPS pollution used DRASTIC, SEEPAGE, and SPISP combined with GIS as starting points. DRASTIC is a groundwater quality model for evaluating the pollution potential of large areas using the hydrogeological settings of the region (Aller *et al*., 1985, 1987). DRASTIC considers various hydrogeological settings which influence the pollution potential of a region. A hydrogeological setting is defined as a mappable unit with common hydrogeological characteristics. DRASTIC employs a numerical ranking system that assigns relative weights to various parameters.

The hydrogeological settings which make up the acronym DRASTIC are [**D**] Depth to water table; [**R**] Recharge (net); [**A**] Aquifer media; [**S**] Soil media; [**T**] topography (slope); [**I**] Impact of vadose zone; and [**C**] Conductivity (hydraulic).

Each DRASTIC factor is assigned a weight based on its relative significance in affecting pollution potential. Each factor is further assigned a rating for different ranges of the values. The typical ratings range from 1 to 10 and the weights from 1 to 5. The DRASTIC index, a measure of the pollution potential, is computed by summation of the products rating and weights of each factor. The higher the DRASTIC index, the greater the relative pollution potential. The DRASTIC numerical index can be further divided into four categories: low, moderate, high, and very high contamination potential.

The System for Early Evaluation of Pollution potential of Agricultural Groundwater Environments (SEEPAGE) model is a combination of three models that was adapted to meet SCS (Soil Conservation Service, recently renamed the Natural Resources Conservation Service) needs to assist field personnel (Richert *et al*., 1992). SEEPAGE considers various hydrogeological settings and physical properties of the soil that affect the groundwater vulnerability to pollution potential. SEEPAGE considers soil properties in more detail than DRASTIC. The factor values and fact layers are assigned numerical weights which are multiplied and summed similar to DRASTIC.

The DRASTIC and SEEPAGE approaches were also modified to consider additional data including land uses, nutrient use (fertilizer and livestock wastes), and pesticide use. It was anticipated that the consideration of these additional factors would improve the ability to predict the locations for which groundwater is most susceptible to agricultural NPS pollution.

SPISP (Soil Pesticide Interaction Screening Procedure) is a technique developed by the Soil Conservation Service for use in water conservation planning (Goss & Wauchope, 1992). It considers pesticide properties and soil properties in predicting vulnerability of water. The properties/data considered are combined using algorithms to produce a vulnerability estimate.

The GIS data layers used for implementing DRASTIC, SEEPAGE, and SPISP for Indiana were collected at a scale of 1:250 000. Sources of data included the STATSGO GIS database (soil properties developed by the Soil Conservation Service); water depth point data (a water depth surface was created within the GIS); digital elevation map (US Geological Survey); hydrogeological settings maps (developed by the Indiana Geological Survey); and geology (developed by the Indiana Geological Survey). Enhancements were made to the above techniques by considering additional spatial information including land use, fertilizer and livestock waste use, and pesticide use. Fertilizer, livestock waste and pesticide use data were available at the county level and these data were distributed within counties based on land uses. Additional details concerning the data can be found in Navulur *et at*. (1995).

DRASTIC, SEEPAGE, and SPISP were implemented within the grid module of ARC/INFO (ESRI, 1992). The categories within data layers and the data layers used in DRASTIC and SEEPAGE were assigned weights based on suggestions from DRASTIC and SEEPAGE documentation. The weights were combined within ARC/INFO to produce a numerical index map with the index indicating the level of vulnerability. The numerical maps were reclassified into four qualitative categories based on suggestions in DRASTIC and SEEPAGE documentation. THE SPISP procedure was implemented using mathematical operations between data layers. A graphical user interface was also developed using ARC/INFO's AML to allow users to use different data layers and to adjust the weighting schemes used in DRASTIC, SEEPAGE, and SPISP and recomputed groundwater vulnerability.

RESULTS

The maps resulting from the modified DRASTIC, SEEPAGE, and SPISP approaches for Indiana are shown in Fig. 1. The area of each qualitative vulnerability category by technique is shown in Fig. 2. The DRASTIC results are significantly different from DRASTIC results of Aller *et at.* (1987) that were generated at 1:200 000 scale. At the 1:2 000 000 scale, DRASTIC indicates that nearly all of Indiana has a high groundwater vulnerability. At the 1:250 000 scale use in this work, most of Indiana was predicted to have a moderate vulnerability. The differences are due to the large variation between the DRASTIC inputs at the 1:2 000 000 and 1:250 000 scale.

The conventional DRASTIC and SEEPAGE results were compared with nitrate detections in wells sampled across Indiana (data were compiled by the US Geological Survey). The nitrate detections were categorized into four categories: Low 0-5 ppm; Moderate 5-15 ppm; High 15-30 ppm; Very high > 30 ppm. Results are shown in Tables 1 and 2. The modified DRASTIC (includes consideration of land uses and nitrates from fertilizer and livestock wastes) results are shown in Table 3. All three indices do a reasonable job, with most nitrate detections falling in the moderate and high categories of the indices. When evaluating these data, one should remember that other sources of nitrates and processes not considered by these simple techniques may be responsible for detections. For example, point sources such as fertilizer spills and septic systems have been identified in several cases in the study area as being responsible for observed nitrate detections.

The DRASTIC, SEEPAGE, and SPISP results were compared with well monitoring data that had been analysed for pesticides. Two detection databases were used – one compiled by the US Geological Survey and one compiled by the Farm Bureau. Approximately 400 wells were sampled in the USGS dataset and 860 wells in the Farm Bureau dataset with more than 90% of the wells falling in the medium and high vulnerability categories for all three indices. Pesticides were detected in approximately 9% of the wells in the USGS data and approximately 15% of the wells in the Farm Bureau data. Figures 3 and 4 show the distribution of pesticide detections by each of the indices. For all three indices, most of the pesticide detections fall within the moderate and high vulnerability categories. The SPISP index performs the best, although DRASTIC and SEEPAGE also seem reasonable. It is interesting to note that SEEPAGE predicts low vulnerability for approximately 20 detections in the Farm Bureau data. These areas deserve additional attention to understand why pesticides are being detected in these locations while SEEPAGE predicts these areas to have low vulnerabilities to such occurrences.

The DRASTIC, SEEPAGE, and SPISP approaches for predicting groundwater vulnerability performed reasonably well for both nutrients and pesticides. The maps resulting from these indices are being used to target groundwater protection efforts. Areas predicted to have moderate, high and very high vulnerabilities are being investigated in more detail. Additional monitoring wells are being installed using the vulnerability maps to target wells in areas suspected to have higher vulnerabilities. Approaches that better consider factors important to groundwater contamination but not considered in the simple indices used are being used in combination with GIS to refine estimates of vulnerability.

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Table 1 Comparison of conventional DRASTIC ratings with observed nitrate detections.

Observed	Low	Moderate	High	Very High
Low	25	146	138	0
Moderate	1	17	63	0
High	0	2	18	2
Very high	0	2	2	1

Table 2 Comparison of conventional SEEPAGE ratings with observed nitrate detections.

Observed	Low	Moderate	High	Very High
Low	9	183	117	0
Moderate	2	22	57	0
High	0	2	20	0
Very high	0	2	3	0

Table 3 Comparison of modified DRASTIC ratings with observed nitrate detections.

Observed	Low	Moderate	High	Very High
Low	86	85	138	0
Moderate	6	11	63	0
High	0	1	20	1
Very high	0	2	2	1