Measuring Groundwater Contamination in Agricultural & Urban Areas Using GIS

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Abstract.

This study was conducted with an aim to to gather information on groundwater contamination in agricultural areas and find out how GIS was applied in these studies, assess nutrient and pesticide leaching at the farm scale level and extrapolate the results to the catchments level using GIS techniques and identify high chemical risk area and to assess the relative impact to a specific groundwater resources. The most common application found during the literature review is creating groundwater contamination vulnerability maps. This is done by ranking the input layers according to their impact on groundwater vulnerability. GIS modeling of groundwater contamination has many advantages but it also has a number of drawbacks. The future of GIS and groundwater contamination is optimistic, as groundwater models become more sophisticated GIS will increasingly be a useful resource.

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1. Introduction

Groundwater pollution of aquifers has generated growing interest in recent years. The finding in groundwater of some plant protection products, nitrates, mineral oils and halogenated hydrocarbons is evidence that this is a common phenomenon and derives from many anthropogenic activities (Trevisan, et al., 2000). The contamination of groundwater is a serious problem. Nitrate in groundwater comes from diverse sources such as nitrogen fertilizers, animal wastes, municipal wastes, landfill, septic tanks and soil organic matter (Patni, et al., 1998). Intensive farming activities are the major cause of this phenomenon. Nitrate is one contaminant that is of great concern because it has been proven to cause methemoglobinemia, a disease of infants. Like any scientific research, studies in groundwater contamination generate a lot of data. These data demand lot of time and are often difficult to analyze. The use of Geographical Information Systems (GIS) in analyzing these data make it possible to link or integrate the information that is difficult to associate with any other means. A GIS is a computer system capable of capturing, analyzing and displaying geographically referenced information. To date, several statistical and simulation models used in scientific researches have been developed and can be readily linked or integrated into GIS. GIS is playing a role in:

- Monitoring and documenting natural conditions and detection change.
- Documenting the land areas for various uses.
- Exposing conflicts and conflicting interests.
- Revealing cause & effect relationships.
- Modeling the interaction of various components of the earth’s environment to predict the effects of change.

2. Problem Statement

Groundwater is usually of excellent quality and can be used without costly treatment or purification. It can be inexpensively tapped adjacent to the point of use, thereby saving the cost of transporting water long distances. In other regions, groundwater is often the only available water supply. From the viewpoint of the water cycle, groundwater can be considered as a renewable source, but from the viewpoint of groundwater resource or ecology, the groundwater may not be seen as a renewable source if it is polluted. In particular, large amounts of nitrogenous fertilizers and pesticide and poor utilization efficiency may lead to nitrate leaching, and hence, pollution of groundwater (Tang et al, 2004).

3. Objective

The objective of this term paper is:

- To gather information on groundwater contamination in agricultural areas and find out how GIS was applied in these studies.
- To assess nutrient and pesticide leaching at the farm scale level and extrapolate the results to the catchments level using GIS techniques.
- To identify high chemical risk area and to assess the relative impact to a specific groundwater resources.
- To allow the creation of basic documents for planning, management and protection of water resources at a territorial level.

3. Methodology

The methodology of the term paper will be as follow:

- Title searching.
- Paper collection.
- Literature Review.
- Discussion & Criticize the term paper.
- Conclusion & Recommendation.

5. Study Limitation

- The greatest difficulty comes from the number and complexity of the environmental factors involved.
- Some result from the GIS should be considered relative, rather than absolute.
- The heterogeneous of study area make the assessment difficult.

6. Review of Literature

A study entitled, Regional Assessment of Nutrient and Pesticide Leaching in the Vegetable Production Area of Rattaphum Catchment, Thailand (Chatupot,W and N. Panapitukkul. 2005) used several leaching models and GIS technique. The results indicated that the intensive use of agrochemicals in the vegetable growing area, especially during the rainy season when the groundwater is near the surface, increases the risk of pesticide contamination.

The pesticide impact rating index (PIRI) has been integrated with GIS to enable regional assessment of pesticide impact on groundwater and surface water (Pollock, D. et al, 205). In this study, the impact on groundwater was found to be spatially variable, mainly dependent on soil type and depth to groundwater.

Nitrate, arsenic and chloride pollution of drinking water in northern Greece was studied by applying GIS. The analytical results were related to certain points on the map of the area, thus producing colored representations according to the concentration of corresponding pollutants (Fytianos, F and C. Christophoridis, 2004).

A study was conducted to develop statistical models for the assessment of nitrate contamination in urban groundwater using GIS in Seoul, South Korea (Lee, S.M. et al, 2003). The results of correlation and regression analysis indicated that mixed residential and business areas and cropped fields are likely to be the major contributor of increasing NO3-N concentration.

In Cremona, Italy, a study was conducted aimed at the evaluation of the hazard level of farming activities with particular reference to groundwater. Two categories of parameters were considered namely; the hazard factors (HF) which represented all farming activities that cause or might cause an impact on groundwater like use of fertilizers and pesticides, application of livestock and poultry manure, food industry wastewater and urban sludge and the control factors (CF) which adapt the hazard factor to the characteristic of the site such as geographical location, slope, agronomic practices and type of irrigation. The organization, processing and display of all data layers were performed using the GIS ArcView and its spatial Analyst extension. The result showed the potential hazard of groundwater pollution by farming activities in the area.

A study intended to assess the environmental sustainability of animal waste disposal on agricultural soils was conducted in the alluvial plain of the River Chiana in Tuscany, Italy, a particularly sensitive area because of the high vulnerability of shallow aquifer and of the intensive agricultural and breeding activities. The consequences on groundwater of applying animal waste to different kinds of soil and crop arrangements have been simulated by means of the management model GLEAMS (Groundwater Loading Effects of Agricultural Management Systems, ver 2.01) integrated with GIS (Garnier, M. et al, 1998).

7. Overview of one Case Study

There are 2 regions (Figure 1) in the study area that are known to be intensively cultivated. These are the northern and southern valleys. Some samples (locations nos. 4, 7, 16 and 30) registered results above 50 ppm. This is expected because of the intensive application of nitrogenous fertilizers. In the southern valley where intensive cultivation is also being practiced, it was expected to give similar results to that of the northern region. In the contrary, it registered low nitrate values. Further investigations revealed that the wells where the samples were collected were deeper (40-80 m sometimes 80-140m). At great depths, the pollutants cannot easily penetrate. Also, the condition may have lead to denitrification by microorganisms. This resulted in low nitrate levels.

Figure 2 shows a colored representation of Arsenic concentration of the tap water samples and sampling locations. Grouping the samples in relation to their pH values and Arsenic concentration, it was concluded that increased Arsenic values are generally accompanied by increased pH values.

Figure 3 shows a colored representation of the Chloride concentration in drinking water. In the past, it was experienced in the study area, intrusion of seawater into the groundwater aquifers. This increased the salinity of the drinking water. This is indicative of seawater intrusion into the groundwater aquifers. Also, this situation maybe due to the intensive drilling for drinking water. This may had caused the reduction of aquifer level and subsequent subsidence of the earth surface in some villages enabling seawater to penetrate the coastal aquifer.

There were 3 maps produced in this study and were labeled Figures 1, 2 and 3. The maps are colored representations of the analytical results. Figure 1 shows the Nitrate concentrations, Figure 2 shows the Arsenic concentrations and Figure 3 shows the Chloride concentrations. The maps are very useful in the assessment of the pollution of the area.

Most of the tap water samples are characterized as hard. This is common because the underground aquifers in the study area are known to be chalky.

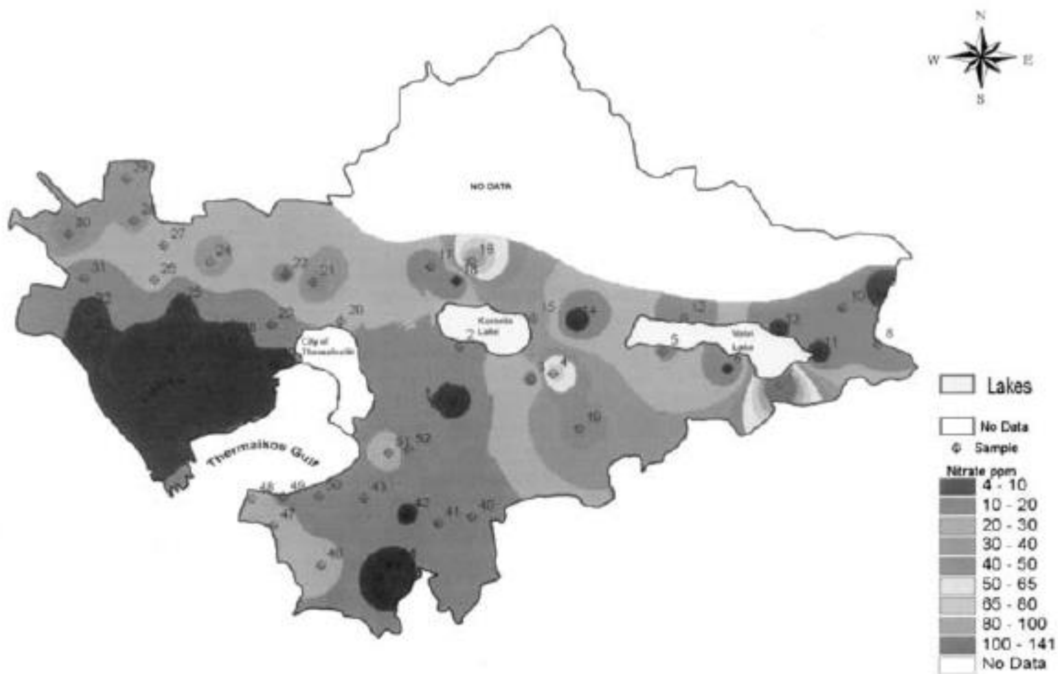

Figure 1. Thessaloniki Prefecture – Nitrate concentration in drinking water (ppm).

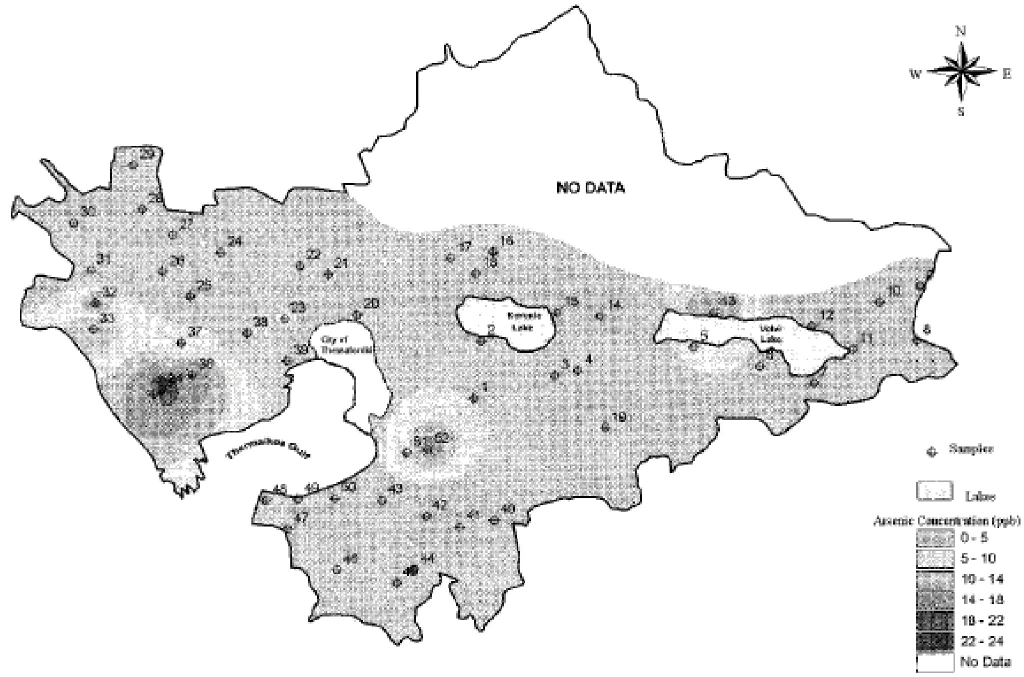

Figure 2. Thessaloniki Prefecture – Arsenic concentration in drinking water (ppm).

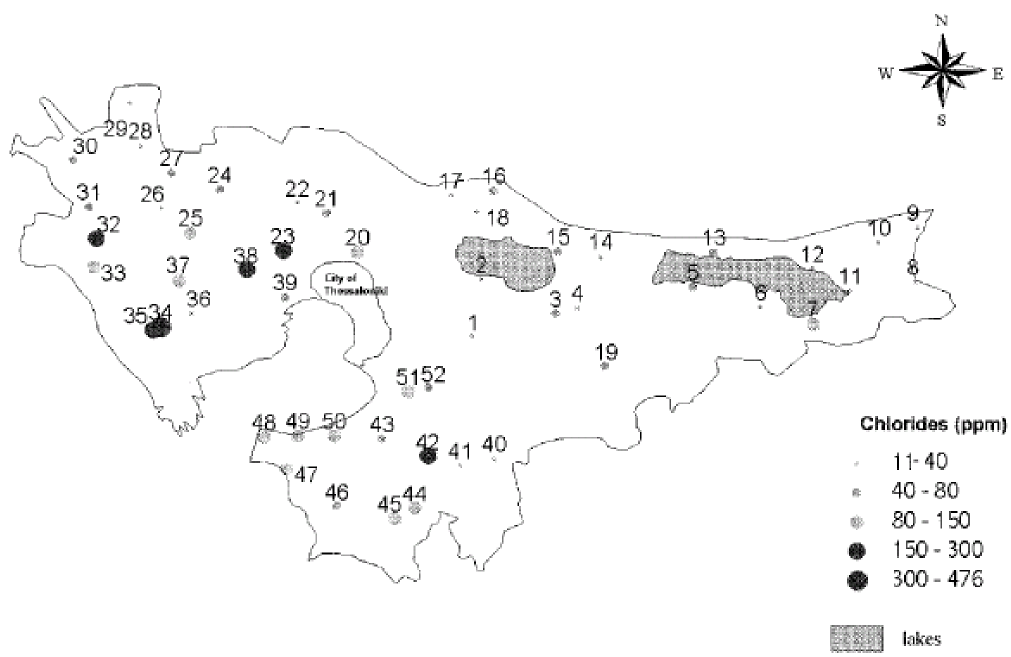

Figure 3. Thessaloniki Prefecture – Chloride concentration in drinking water (ppm).

8. Analysis / Discussion

Groundwater is one of a major source of drinking water in the world. Unfortunately, groundwater is becoming contaminated from industrial, agricultural and domestic use making it unfit for human use. Groundwater flow and contaminant fate and transport modeling is an important component of aquifer remediation studies. This task becomes extremely time consuming when the modeler is required to analyze complex heterogeneous aquifers and manipulate large amounts of input and output data. Geographic Information Systems (GIS), on the other hand, provide a platform in which layered, spatially distributed databases can be manipulated with ease. GIS is used to capture, analyze, and display spatial data, while the models provide the tools for complex and dynamic analysis. Utilizing the GIS platform, the user may develop groundwater flow and contaminant fate and transport modeling applications with relative ease. The familiar format of maps supports the understanding of model results, but also provides a convenient interface to spatially referenced data. Geographic Information Systems are designed to manage, analyze and display all types of spatial data. This capability makes GIS a powerful tool in conducting groundwater assessments. GIS maintains the spatial location of wells, borings, etc., and provides tools to relate the well or boring to data contained in an external relational database. GIS also provides advanced tools for spatial analysis of the related data.

The most common application found during the literature review is creating groundwater contamination vulnerability maps. Modeling groundwater contamination vulnerability can be divided into a handful of steps. The first step is to construct a spatial database of the area of interest containing information that will affect the vulnerability to groundwater contamination. Information layers such as land use, soil characteristic, bedrock geology, topography, recharge, hydraulic conductivity, groundwater levels, well locations and climate were common data layers among the papers reviewed. The combination of these layers enables the vulnerability of an area to be assessed for specific pollutants. Once the groundwater contamination vulnerability map is created a classification of the model into vulnerability classes can be created. This is done by ranking the input layers according to their impact on groundwater vulnerability. In one case low numbers represent high vulnerability and high numbers represent low vulnerability. Finally, the vulnerability score of each of the layers are combined to create a vulnerability index. Vulnerability index can be represented in either a numerical value or a comparison value such as very high, high, low, etc. Another useful technique is to create a number of models of an area. In each of the models one of the variables is weighted more than the other depending on the degree of impact on the system. The different models are then compared to find common trends and patterns. A graphical representation of vulnerable aquifers, combined with graphical representations of potential sources of contamination and public water supplies would allow decision makers to evaluate current land use practices and make recommendations for changes in land use regulations which would better prevent the groundwater from contamination. For example, it may not be considered responsible to build a new chemical plant in the contributing area of a particularly vulnerable aquifer or area of an aquifer. Additionally, such a representation would provide a quick tool for determining possible responsible parties if contamination is found, thereby expediting the remediation process. Another potential benefit from mapping vulnerability is that it aids in the prioritization of remediation sites. Responsible parties must pay for the remediation of a polluted site, however in many cases the responsible party cannot be found.

GIS modeling of groundwater contamination has many advantages but it also has a number of drawbacks. Many of the GIS modeling approaches are simplified and do not take into consideration processes such as preferential flow, hydrodynamic dispersion or absorption-desorption reactions. In some cases the influence of these processes can not be ignored which would make the simple GIS layer method unusable. In some of the papers reviewed these factors were not an issue and therefore were ignored. As with any computer aided mapping, the results are only as good as the data used to develop the system. Errors inherent in GIS are numerous and include errors in source map, digitization, rasterization, and overlay procedures. Finally, calculation of vulnerability index is generalized and highly variable with space and time. In spite of the drawbacks of using a GIS to model groundwater contamination it is quickly becoming a standard for groundwater modeling. The ease with which a GIS can integrate multiple layers is invaluable in modeling groundwater pollution and pollution potential. The future of GIS and groundwater contamination is optimistic, as groundwater models become more sophisticated GIS will increasingly be a useful resource.

9. Summary /Conclusions &Recommendation

PIRI has been fully integrated with a GIS to enable regional assessment of the impact of non-point source pollution on groundwater and surface water resources. GIS provided a tool for preparing spatially distributed input data, processing that data, and visualizing the model results. However, further soil sampling is required to improve the model results. Information on the spatial distribution of *K*oc under local conditions was found to be influential on the results from PIRI-GIS. Future improvements to PIRI-GIS are likely to include an atmospheric drift component, to enable assessment of impact due to spray applications.

The identification of potential high risk farms by ranking soils and agricultural practices could be used to formulate the most appropriate management practices that would result in a reduction of pesticide contamination/leaching to the surface and groundwater resources.

Maps fail to indicate extremely accurate results for the areas between the chosen sampling sites. A greater number of sampled locations would also increase accuracy of these maps. Develop and use analytical techniques to document the occurrence of human waste co-contaminants in nitrate-contaminated, groundwater prevalent herbicides and their transformation products in nitrate-contaminated groundwater and bacterial and viral co-contaminants in nitrate-contaminated groundwater. Modeling without measurement, however, is meaningless. Only carefully calibrated and validated models will be useful to management and policy decision makers.

10. References

Chatupote, W. and N. Panapitukkul, 'Regional Assessment of Nutrient and Pesticide Leaching in the Vegetable Production Area of Rattaphum Catchment, Thailand', Water. Air, and Soil Pollution:Focus(2005) 5: 165-173

Fytianos, K. and C. Christophoridis, 'Nitrate, Arsenic and Chloride Pollution of Drinking Water in Northern Greece. Elaboration by Applying GIS', Environmental Monitoring and Assessment 93:55-67, 2004

Garnier, M. A. Lo Porto, R. Marini and A. Leone, 'Integrated Use of Gleams and GIS to Prevent Groundwater Pollution Caused by Agricultural Disposal of Animal Waste', Environmental Management Vol. 22 No. 5 pp. 747-756

Lee, S. M., K. D. Min, N. C. Woo, Y. J. Kim and C. H. Ahn, 'Statistical Models for Nitrate Contamination in Urban Groundwater Using GIS', Environmental Geology(2003) 44:210-221

Patni, N. K., L. Masse and P. J. Yui, ' Water Quality-Groundwater Quality under Conventional and No tillage: Nitrate, Electrical Conductivity and pH', J. Environ. Qual. 27, 869-877.

Pollock, D. W., R. Kookana and R. L. Correll,' Integration of the Pesticide Impact Rating Index with a Geographic Information System for the Assessment of Pesticide Impact on Water Quality', Water, Air, and Soil Pollution (2005) 5:67-68

Tang, C, J. Chen, S. Shindo, Y. Sakura, W. Zhang and Y. Shen. 2004. Assessment of groundwater contamination by nitrates associated with waste water irrigation: A case study in Shijianghuang Region in China. Hydrological processes 18

Trevisan, M., L. Padovani and E. Capri, 'Nonpoint-Source Agricultural Hazard Index: A Case Study of the Province of Cremona, Italy', Environmental Management Vol. 26, No. 5, pp. 577-584

Appendices