Geographic information system-based selection of health risks for waterborne disease resulting from environmental exposure to wastewater

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Abstract

Local decision makers need an unbiased process to determine small communities at risk from inadequate wastewater treatment. The geographic information system (GIS) enables decision makers to identify impacted communities and establish a fair and equitable approach to allocation of resources for remediation strategies. The use of GIS in this manner is demonstrated for Tennessee, USA, but the methodology is applicable broadly. GIS was used to develop methodology for identifying communities with a population of 10,000 or less in which there existed public health, water quality and/or aesthetic impacts associated with inadequate wastewater treatment. The GIS approach, normalized by population, identified communities with the highest ranking problems, as well as control communities that had no known health, water quality or aesthetic problems due to inadequate wastewater treatment.
Keywords: rural communities, wastewater treatment, health risk, interaction of social and environmental issues, geographic information system.

1 Introduction

A geographic information system (GIS) was used to develop methodology for identifying rural Tennessee communities with a population of 10,000 or less in which there existed public health, water quality, and/or aesthetic impacts associated with inadequate wastewater treatment. Potential results of inadequate or inappropriate wastewater (sewage) treatment can be summarized as follows [1]:

- Physical, biological and chemical contamination of air/soil/water, particularly polluting the groundwater/surface water destined to become someone's drinking water source;
- Human health-threatening illnesses and diseases;
- Detrimental impact on aquatic and animal life; and
- Undesirable effects on the aesthetic quality of life.

Water can become polluted with three general types of contaminants. Insoluble matter, toxic chemicals and disease-causing organisms all threaten the safety of the nation's water supply. Insoluble debris ranges from very large solids to smaller particles that remain suspended in water. Solids are composed of chemicals that are not dissolved in water or that result from the living or dead cell mass of organisms (such as algae) in the water. In industrialized nations, toxic chemicals are a serious threat to rivers and lakes and, in some cases, contaminate underground water sources as well. Discharges from industrial production, pesticide runoff from agricultural areas and, to a lesser extent, improper disposal of household chemicals contaminate water sources and cause concern for public health. Disease-producing infectious agents in water can cause major epidemics, such as typhoid and cholera. Diseases caused by both bacteria and viruses can be carried by water.

Ingram [2] divides water pollutants into two broad categories: nuisance pollutants and health-threatening pollutants. Nuisance pollutants cause discomfort or inconvenience. They can cause water to taste, smell or look bad, or they can render soap and washing less effective but, otherwise, do not cause human health problems. The main nuisance minerals are calcium and magnesium (water hardness), iron and manganese (staining), and hydrogen sulfide gas (rotten-egg odour). Aesthetic factors that measure water contamination but do not necessarily pose a threat to human health include colour, turbidity, salinity, and foul taste and odour. Health-threatening water pollutants are biological (microorganisms) or chemical (toxic minerals and metals, organic chemicals, radioactive substances, and additives).

Once released in water, pollutants contaminate not only the water, but also the soil, air, and plant and animal life. Pollutant interchanges occur where water and soil, water and air, and air and soil meet in nature. Therefore, it is difficult to study air pollution, soil pollution or water pollution as separate subjects.

From a literature review and project team experience, the team theorized that the prime indicators of inadequate wastewater treatment were health risks, violations of water quality standards, and aesthetic impacts. The purpose of the project was to develop an unbiased method to assist decision makers in identifying Tennessee communities, with populations less than 10,000, that were the most negatively impacted by these indicators.

2 Community identification

Small communities with a population of 10,000 or less within the state of Tennessee were identified using U.S. Census data. Excluding Metropolitan

Statistical Areas (MSAs), data processing located 329 census-designated places (CDPs) in Tennessee with populations less than 10,000. Metropolitan areas contain either a place with a minimum population of 50,000 or a U.S. Census Bureau-defined urbanized area and a total metropolitan area population of at least 100,000. A metropolitan area comprises one or more central counties and also may include one or more outlying counties that have close economic and social relationships with the central county. MSAs are a type of metropolitan area that is relatively freestanding, not closely associated with other metropolitan areas. Typically, these areas are surrounded by nonmetropolitan counties. MSAs were eliminated from further study for this project because these areas were more representative of urban places than they were of rural communities, and they exceeded the population size designated in this project.

Each community was uniquely identified. The Federal Information Processing Standard (FIPS) code, contained within the Topologically Integrated Geographic Encoding and Referencing system (TIGER) database, is a place code that identifies each city, town, borough, village or CDP. The FIPS code database contains varied information, including place name, total population, number of households, land area, water area, latitude and longitude. The FIPS code database was used to link with other databases. Sewered, unsewered and control communities were categorized according to use of on-site treatment (*i.e.* septic tanks, mound systems, wetlands, etc.), wastewater treatment by publicly owned treatment works (POTWs), or no treatment (*i.e.* privies, sewage running into ditches, etc.).

2.1 Sewered communities

In Tennessee, data on health risks, violations of water quality standards, and aesthetic impacts are available for communities that own or operate POTWs. The Tennessee Department of Environment and Conservation (TDEC) keeps records on Tennessee POTWs. TDEC designates plants treating more than one million gallons per day (mgd) as "major" systems and those treating less than one mgd as "minor" systems, fig. 1.

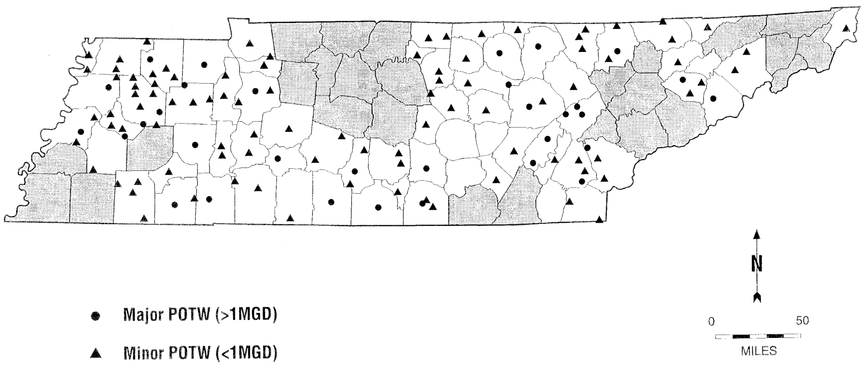

Figure 1: Communities of population < 10,000 with major and minor POTWs. MSAs are depicted in gray.

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2.2 Unsewered communities

Data for unsewered communities, fig. 2, in Tennessee were not readily available. Information on failing subsurface systems, nonexistent systems (*e.g.* outhouse) or health problems (*e.g.* outbreak of diarrhea) was not recorded on a statewide basis. Subsurface disposal problems are known by people experiencing them and sometimes by health officials. In Tennessee, TDEC has the responsibility of regulating and monitoring subsurface sewage disposal systems. Surveys of county environmentalists and regional health departments were conducted to supplement available information.

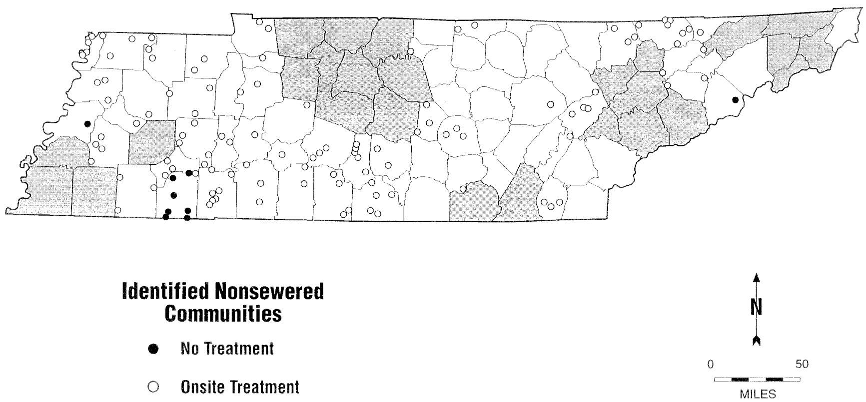

Figure 2: Unsewered communities with on-site treatment and no treatment. MSAs are depicted in gray.

3 Water quality data and aesthetic impacts

Using quarterly noncompliance reports for major POTWs in Tennessee, the project team found five parameters that they considered to be the best indicators of possible health, water quality and aesthetic effects. The parameters included five-day biochemical oxygen demand (BOD_5), fecal coliform, residual chlorine concentration, bypassing and heavy metals. A digital database of the information, linked by FIPS code, was created.

To explore health risk, water quality violations and aesthetic problems for minor POTWs in Tennessee, the project team examined National Pollutant Discharge Elimination System (NPDES) permit and Discharge Monitoring Report (DMR) information, maintained by TDEC. The same five parameters (BOD_5, fecal coliform, residual chlorine concentration, bypassing and heavy metals) used in evaluating major POTWs were used to evaluate minor POTWs.

Information for major POTWs (fig. 3), minor POTWs (fig. 4) and unsewered communities (fig. 5) was entered into digital databases and linked to the appropriate FIPS place code. Problems from the quarterly noncompliance reports for major and minor POTWs were rated as continuous or sporadic, depending on the length of time noncompliance was reported. Problems were considered continuous when the noncompliance was noted on two or more quarterly reports. Sporadic problems were any violations that existed for one quarter. Continuous problems were considered to be the most severe.

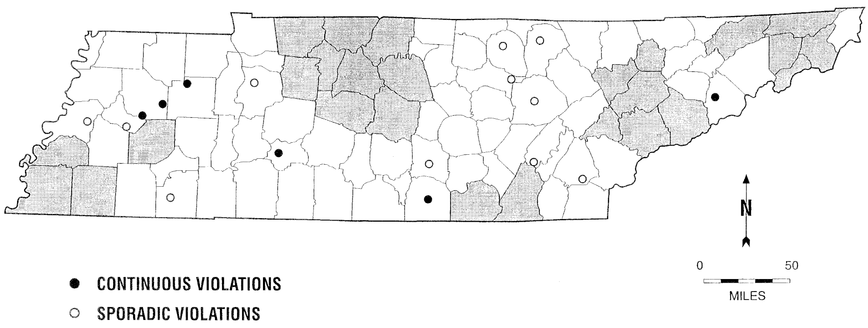

Figure 3: POTWs greater than 1 mgd with problems. MSAs are depicted in gray.

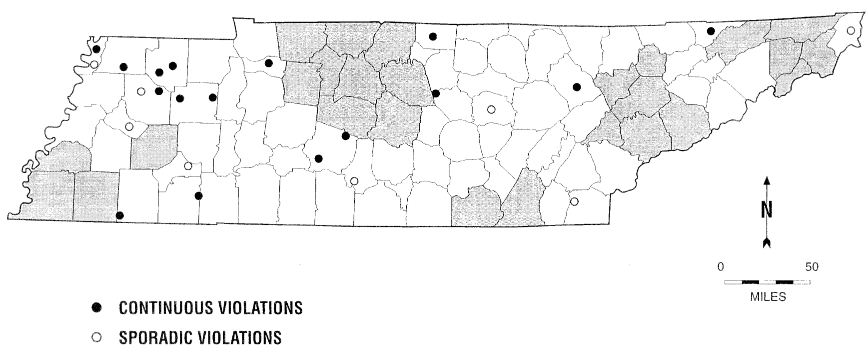

Figure 4: POTWs less than 1 mgd with problems. MSAs are depicted in gray.

For minor POTWs, violations were again rated as continuous or sporadic, depending on the length of time violations were reported. Continuous violations were recorded when six or more monthly DMRs contained noncompliance for any of the five parameters. Any of these violations that existed for less than six monthly DMRs were considered to be sporadic.

Communities with direct discharge, such as sewage running into ditches or streams, were considered to be nontreatment. Some areas of a single community can have on-site treatment but have enough of a direct discharge problem to be considered a nontreatment community. Problems in nonsewered Tennessee communities were ranked as either those posing a serious health threat (odour, sewage surfacing, sewage running into ditches or streams, sewage backing up, inability to site a drainfield, insects, hepatitis A or *E. coli* in wells, digestive disturbances and groundwater contamination) or those posing a less serious health threat (gray water discharge and slow-flushing commodes).

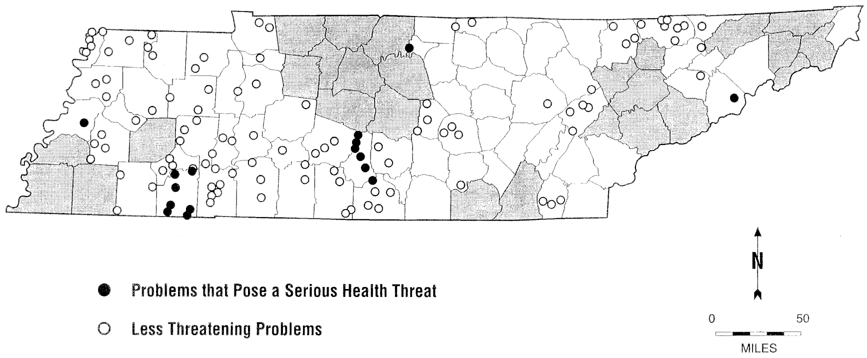

Figure 5: Identified unsewered communities with problems. MSAs are depicted in gray.

4 Potential waterborne diseases

Potential waterborne-disease rates were obtained from a database available electronically through the Tennessee Department of Health. The data included age, race, sex, city, county, disease code, disease name, date and reporting facility. A subset of diseases occurring in Tennessee was targeted as being of interest to this study due to the potential for waterborne transmission: campylobacteriosis, giardiasis, hepatitis A, legionellosis, malaria, shigellosis and typhoid.

The public health database consists of the epidemiological data supplied by the Tennessee Department of Health Surveillance Program to the Centers for Disease Control on a weekly, cumulative basis. The database was supplied in an ASCII format and processed using the Statistical Analysis System (SAS)® software. The adjusted subset of health data was combined by city name with the FIPS code database to interface with the GIS for georeferencing. A "disease frequency" parameter was calculated by summing the number of incidences of any of the target diseases occurring in that city/town (by FIPS codes). The disease frequency was divided by population and multiplied by 10,000 to produce a weighted integer value indicating the per capita incidence of targeted diseases. The output was generated by SAS® in a format suitable for interfacing with ArcInfo® GIS software to visualize the information on a state map. The disease frequency was plotted by the GIS software on a map of Tennessee as a function of FIPS code location, fig. 6. Data for information lacking a FIPS code were added manually to the Tennessee map.

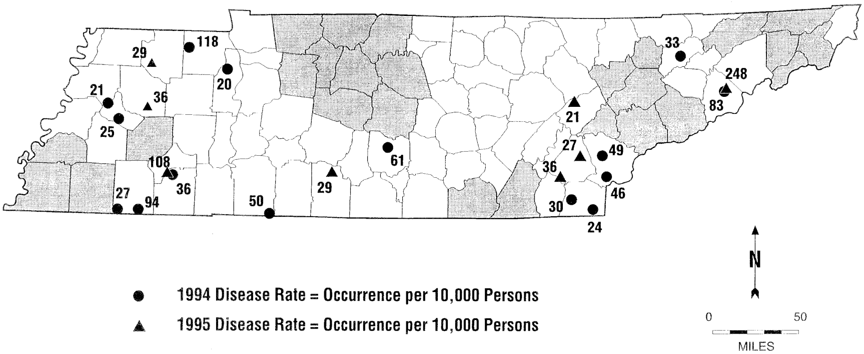

Figure 6: Rate for potential waterborne diseases. MSAs are depicted in gray.

5 Georeferencing

ArcView® software was used to georeference data and identify communities that experienced frequent combinations of health and environmental problems. By overlaying the data from the major POTWs, minor POTWs, nonsewered and health databases using a GIS approach, the project team identified Tennessee communities with the highest ranking problems. Two control communities, one sewered and one unsewered, were also readily identified by the GIS method developed. The control communities had no known health, water quality or aesthetic problems arising from inadequate wastewater treatment. The selected communities were considered for further sociological investigation [3].

6 Conclusions

State and local decision makers need a process to determine small communities at risk from inadequate wastewater treatment. The GIS approach enables decision makers to establish a fair and equitable approach to allocating diminishing funds available for remediation strategies in small communities. The use of GIS in this manner is demonstrated for the state of Tennessee, yet the method discussed here is applicable broadly nationwide.

Acknowledgement

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