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The Use of GIS in Drinking Water Quality and Protection

Geographic Information Systems (GIS) have been used in the field of drinking water quality and protection for at least 16 years. A web search in Google Scholar revealed that the first paper containing both GIS and Drinking Water in the title was published in 1995. This article was published in the journal Epidemiology and was entitled “Use of a GIS in Drinking Water Epidemiology: Byproducts of Chlorination As A Risk Factor for Low Birth Weight”. There are seven results from 1996 to 2000, 13 from 2001 to 2005, and 26 from 2006 to 2011. If a Google Scholar search were a scientific study we could conclude that the use of GIS in drinking water has been doubling every five years and therefore increasing linearly.

Safe drinking water is one of the most vital resources on the earth and approximately one billion people do not have access to it. Drinking water can come in the form of groundwater or surface water, and its vulnerability to contamination is quite variable. In many cases it takes only a small amount of a contaminant to cause illness. Potential sources of contamination are numerous and protecting drinking water supplies from them involves many factors such as community planning, collaboration of stakeholders, and expertise on the various parameters contributing to susceptibility of the water supply. GIS has proven to be an extremely valuable tool in delineating and evaluating existing drinking water contamination issues as well as the susceptibility of drinking water to potential contamination.

GIS is used for drinking water quality and protection primarily by public health and natural resource agencies, emergency responders, researchers, consultants, and community decision-makers. The GIS tools that are used most include: Global Positioning System (GPS) units and differential correction software for georeferencing such important data points as wells, intakes, and potential contaminant sources; distance buffers to create wellhead protection area times-of-travel and setbacks; integration of shapefiles from groundwater modeling software such as MODFLOW; numerous vector and raster overlays such as digital line graphs, digital raster graphics, watersheds, soils, land use, and regulatory data; map layouts to clearly display the data; GIS-compatible statistics software; the Spatial Analyst extension to employ various interpolation tools such as kriging and Inverse Distance Weighting (IDW); and, web-enabled GIS and virtual globes. The next few paragraphs will discuss examples of how these GIS tools are used by researchers, public health agencies, and communities.

Many of the studies that use GIS in drinking water research, and are published in
peer-reviewed journals, analyze the distribution of waterborne illness and land use. Odoi et al. (2004) used a census sub-division overlay and spatial statistics software to determine if clusters of the waterborne disease giardiasis correlated with livestock density and/or manure application. Also studying agricultural practices, but with respect to the impact of chemical fertilizers on drinking water, Mandalos et al. (2007) used a GPS unit to georeference the sample sites, the IDW tool to interpolate between sample sites, and a Water Pollution Index (WPI) mathematical formula to determine the combined impact of the most common chemicals on the drinking water. Samadder and Subarea (2007) also used a census block overlay to determine how arsenic concentrations in drinking water vary spatially; populated the attribute table with arsenic concentrations, area, and population; and showed the spatial variation between the predicted and actual number of cancer deaths due to arsenic contamination. Overall, the most valuable GIS tools utilized by researchers appear to be GPS, overlays such as land use and census tracts, and geostatistical interpolation.

Much of the work in drinking water quality and protection is done at the government and community level and is not often published in journals, but is just as relevant. In the United States, the 1996 amendments to the Safe Drinking Water Act (SDWA) required states to provide all public drinking water systems with a Source Water Assessment (SWA). This SWA includes a report and maps showing the water source (well, spring, or surface water intake), the delineated area where the drinking water is coming from, an inventory of potential contaminant sources, and the water system’s susceptibility to contamination. The purpose of the SWA is to provide communities with a planning tool to assist with developing strategies to protect their drinking water. This SDWA requirement came during a time when GIS was becoming more widespread and user-friendly, and so GIS was a vital resource for creating these SWAs.

The states were required to develop the SWAs and provide them to the communities, but some large communities also have GIS staff and the resources to complete and/or modify their own SWAs. Developing SWAs often starts with collecting latitude and longitude locations of the water sources using GPS units. These GPS locations are imported into GIS, followed by base maps, delineated drinking water protection areas, potential contaminant source locations from pre-existing regulatory databases, and soil susceptibility overlays. GIS also enables the user to create time-of-travel zones, distance buffers, potential contaminant source point symbols, and labels directly in the software. States and communities are then able to create GIS map layouts with titles, keys, scale bars, etc. to easily display the information to communities for use in planning protection strategies. In addition, broader layers incorporating multiple communities, or even the entire state, can be created to share with stakeholders and aid in such decisions as emergency response and regulation prioritization.

I think the biggest shortcoming of GIS has been the learning curve and lack of accessibility to the layperson. As Miller (2007) eludes, there is a learning curve even for drinking water
professionals if they do not use it frequently and keep up with the technology changes. Jankowski (2009) describes how decision makers were more satisfied with a group decision-making meeting when the facilitator manipulated the data in GIS than when they had to use it themselves. I think this is starting to change with web-enabled GIS and I believe this is the future of GIS. Some examples of programs that are user-friendly and enable anyone to create and share maps are: ESRI’s ArcGIS online, a cloud-based online GIS; the state of Massachusetts’ OnLine ViewER “Oliver”, a mapping tool that uses open-source technology; and Google’s Fusion Tables, spreadsheets that will export latitude and longitude data directly onto a Google map. I believe this path that GIS is on will make it easier for people to understand the drinking water quality issues and to willingly participate in making drinking water protection decisions.

Annotated Bibliography


This paper’s introduction gave a more thorough overview on how GIS has been used in groundwater studies throughout the years than any other paper in this bibliography, which was a surprise given the abstract’s emphasis on the study conducted in Konya City, Turkey. It also was very clearly written and had basic maps that brought the reader step by step through the ultimate conclusion of showing groundwater quality differences in Konya City. The authors started by showing and explaining how a GIS map of simplified geology, monitoring points, and groundwater flow direction was created by digitizing in a UTM projection, how the wells were located with a GPS unit, and how the well data was entered into an attribute table. The paper read like an Introduction to GIS in Environmental Science course until it became slightly more complex by explaining normal distributions, transformations, and global trends in reference to kriging. The results were clearly shown on maps as the spatial distribution of nitrate concentrations, hardness, pH, chloride, sulfate, and electrical conductivity. The authors concluded their paper by examining the advantages and disadvantages of kriging and correlating groundwater quality with land use.


The author of this paper discusses whether participatory GIS (PGIS) can be a tool for more effective public participation, particularly for making community-scale natural resource decisions. After giving a thorough overview of PGIS and the “participation ladder”, two studies are used to make this determination. The first study addresses the difficulty in getting
the public to participate in voluntary drinking water protection programs in their community and the second explored whether hands-on access to GIS helps stakeholders make decisions in group meetings. A fault of this paper is that the findings of both studies were not expressed very clearly by the author; however, his conclusions, first that participation can affect outcomes and result in collaboration and empowerment, and second that a balance must be maintained between encouraging participants to take ownership and use creativity while still providing experts to offer technical assistance with the technology, are intuitive and helpful to anyone looking to improve participation in environmental decision making using GIS.


In this study, the authors correlated areas of intensive agricultural practices in the Evros region of northern Greece with contamination of the groundwater drinking water supply. Tap water was sampled for the fertilizer chemicals nitrates, nitrites, ammonium, phosphate, and sulfate at 64 locations once a month from May to September 2006. A Magellan GPS unit was used to locate the sample sites and ArcGIS 9.2 was used to perform spatiotemporal analysis on chemical data and intensity of agricultural practices. Two additional tools were used with GIS to perform the analysis: 1. The ‘Inverse Distance Weighted’ (IDW) algorithmic method was used to interpolate data between the sample points, and 2. A ‘water pollution index’ (WPI) mathematical formula was used to incorporate the European Commission’s drinking water standards in determining the combined impact of the most common chemicals nitrate, phosphate, and sulphate on the drinking water. Although this paper did a good job at showing how GIS can be used to show correlation between agriculture and drinking water quality, it was missing some key research explanations. Some examples are: the figure showing the “areas of high agricultural importance” did not have a key to explain the different colors; the reason for sampling only the summer season is not explained; potential limitations with sampling only the summer season for one year is not included; and, a new concept, ‘Nitrate Vulnerable Zones’ (NVZ) was introduced in the Conclusions section.


Through case studies and references to other researchers this paper illustrates the growth of GIS use at the Whatcom County Health Department’s (WHCD) Drinking Water Program in Bellingham, Washington; some common pitfalls; and the benefits of collaboration between researchers and public health professionals. The first case study is a good example of how GIS positions are often first created when a need suddenly arises; in this case, by citizen concern about a leukemia cluster which ultimately was investigated by spatially organizing leukemia, water quality, and well log data. Case studies two and three summarize how wellhead
protection areas and well locations are integrated in GIS and used to determine whether a fuel truck spill will affect water bodies and wells. The author discusses several pitfalls of using GIS in a small local health department, but suggests that GIS technology can reach its full potential in environmental health if there is collaboration between GIS users and researchers from a variety of fields and that increases in training programs, conferences, and web-enabled GIS is making collaboration easier. This paper was unique in how it interweaved case studies and findings from papers written by other public health and GIS experts, and this style demonstrated the author’s point very well.


The authors of this study used GIS and the spatial scan statistic software SaTScan to determine if they could correlate clusters of giardiasis with cattle density, livestock density, and/or intensity of animal manure use on agricultural land in Ontario, Canada. ArcView GIS 3.2 was used to show, analyze, and interpret the different variables spatially according to census sub-divisions. The authors concluded that although there are “hot-spots” of giardiasis they do not significantly correlate with cattle or livestock density or manure use. However, although the conclusion was that there was no correlation, the authors did a good job in pointing out that public health professionals can use GIS and spatial scan statistics to narrow down disease surveillance to statistically significant disease clusters. They can then focus their resources to perform more thorough investigations of what is or is not the cause of the cluster.


In this paper, the authors studied the distribution of arsenic in the drinking water, and its associated cancer mortality, in the Murshidabad district of West Bengal, India. They introduced the topic well by giving a thorough review of arsenic in the area, the differing theories on the source of the arsenic, and the health affects of arsenic ingestion. GIS was used to show how arsenic concentrations vary spatially in six administrative blocks and the authors were clear about the assumptions they had to make, including having to use the average arsenic concentration to estimate exposure since the residents drink from different wells throughout the day, and the need to use well-established studies from other countries to predict cancer risk because of the lack of death reports available in this area. GIS was important to the conclusion they reached because by comparing the spatial variation of the actual arsenicosis data they did have and their theoretical risk estimates, they were able to conclude that their locations matched well; however, their numbers were different because the number of expected cases is based on lifelong exposure.
Other references (not included in Annotated Bibliography)


