# An interactive web-based GIS system for the space-time visualization of groundwater quality from private wells

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## Introduction

Private wells are crucial resources of drinking water for residents in rural areas. Although the quality of drinking water in the United States is considered to be one of the best in the world, waterborne diseases remain a concern in some regions (Whitacre, 2009). According to the United States Environmental Protection Agency (EPA), approximately 13 million households (45 million Americans) rely on unregulated private wells for drinking water, and private wells are generally move vulnerable than municipal water for exposure to various contaminants. Long-term exposure to contaminated water can cause health effects, for instance gastrointestinal illnesses, damage to the nervous system, liver complications and chronic diseases such as cancer (Smith et al., 1992). Health impacts are also governed by other factors, such as the type and concentration of contaminants in the water, the quantity of water consumed and the duration of exposure.

Gaston County is the 10th most populous county in North Carolina, and over 42% of households currently rely on unregulated private wells as their primary source of drinking water (Fig. 1). For these residents, the availability of safe groundwater, and the reliance on purification services provided by functioning ecosystems, is essential for wellbeing. However, the quality of groundwater has varied significantly across the County, and in many cases has been degraded by a range of contaminant sources, ranging from anthropogenic sources such as agricultural run-off, leach fields and coal ash ponds, to naturally-occurring trace elements such as arsenic. Exposure to contaminated groundwater poses a significant health risk to rural populations, especially children who drink more water per body weight and possess immature metabolic pathways.

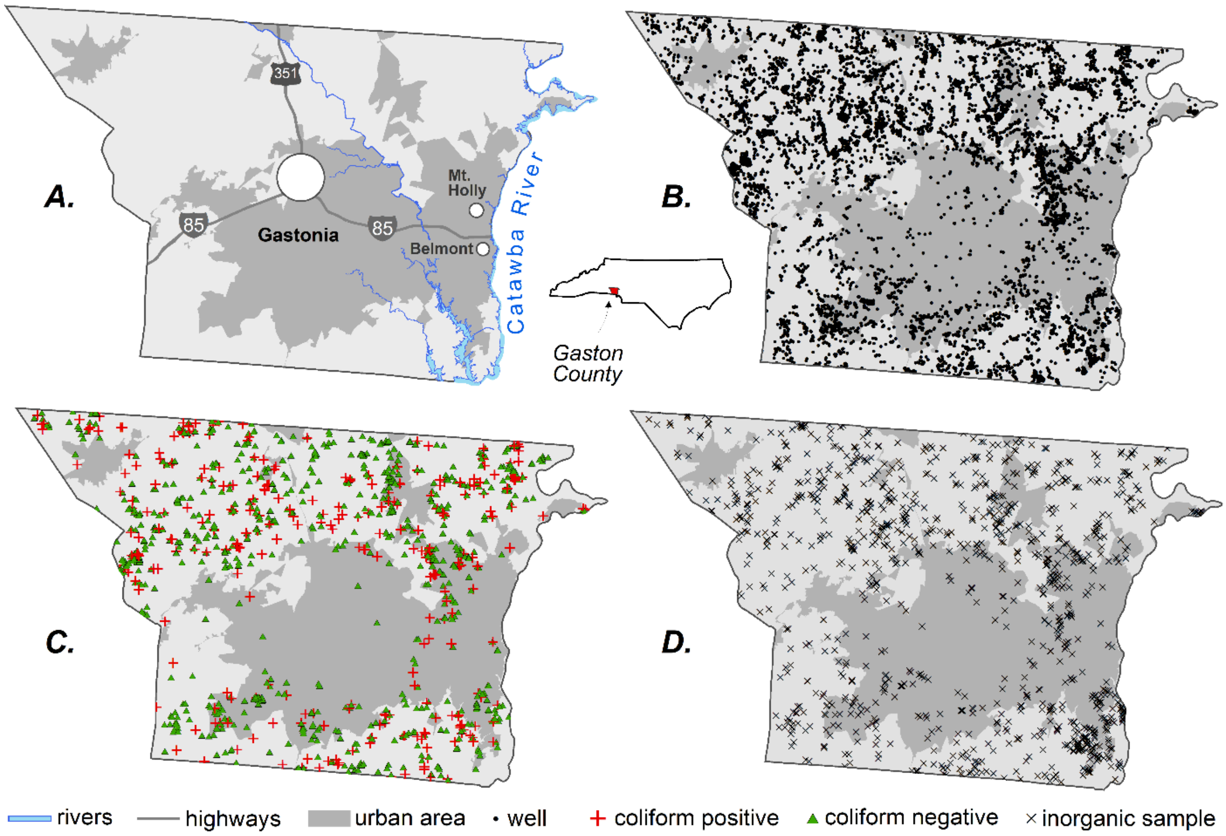


Figure 1: Study area. A: Gaston County; B: spatial distribution of geocoded wells; C: presence of total coliform; D: historical data on inorganic contaminants 2012-2017.

Environment health agencies play an important role in educating well owners, especially those lived in the area with high risk of groundwater contamination. Based on findings from our ongoing CDC-funded "Healthy Wells" project, only a fraction of these households regularly test their drinking water, placing them at risk. Further, few public health regulatory instruments are available to inform well users as to the quality of their water. Needed are tools that 1) educate well users as to the best practices to manage their water, and 2) provide timely information and analyses to both individuals and County health officials to support decision-making, specifically by presenting them information on the spatial and temporal variation of those contaminants.

## Space-time visualization

Since Ilägcrstrand (1970) first introduced the concept of space-time cube, it has been widely applied into interactive visualization systems, such as social interaction across space and time (Bach et al., 2014). The space dynamic in temporal is one clear character in the studies of groundwater quality or other environment health concerns, and space-time cubes are implements in the three-dimensional (3D) in many environment health studies (Desjardins et al., 2019; Lu & Fang, 2015). Dübel et al. (2014) claimed that combing 2D and 3D presentation for spatial data shows a better performance than solely using either one presentation. Lee et al. (2010) introduced a tool set combined trends table and 3D maps to provide spatiotemporal trend information for the water quality of a river, while authors did not mention the interactivity of 3D maps.

For educational purposes, the methods discussed in the papers mentioned above could be challenging for well owners to understand. Thus, developing an accessible, easy-understanding and interactive visualization system could assistant residents to better understand the current level of contamination in their area and monitor the risk of over time.

In this study, we introduce a web-based interactive space-time visualization of groundwater quality from private wells from 2011 to 2017 in Gaston County, United States (US). This visualization combines animated maps in two-dimensional (2D) and space-time cube in 3D both in interactive way to visualize the contamination threshold for areas at high risk of certain contaminant.

## Data

In this study, we used a wells dataset of 1,235 private wells with inorganic contaminants information collected from 2011 to 2017 in Gaston County, North Carolina, US. Those contaminants included arsenic, chromium, copper, fluoride, lead, mercury, nitrate, nitrite among other, and arsenic is selected as the main contaminant to illustrate the web-based interactive space-time visualization of groundwater quality.

## Method

We develop visualization solutions to map the space-time variation in groundwater quality. Specifically, we develop animated map and space-time cube to present outline changes of the area at high risk of contamination in both temporal and spatial scale.

### *Threshold boundaries*

We use the concept of threshold boundaries to visualize the groundwater quality. Threshold boundaries stands for the boundary of area in where contaminant level is equal to maximum contaminant level (MCL) for drinking water quality according to US Environmental Protection Agency (EPA). In other words, the area within threshold boundaries have a high risk for contamination. The main visual contents in both animated map and space-time cube are threshold boundaries of arsenic contamination from 2011 to 2017.

To generate threshold boundaries from wells as points data, a GIS workflow (see Figure 2) is applied. 1) Wells in each time interval are selected. We current use a cumulate time range for seven years. For example, the first-time range is the whole year of 2011 and the second-time range is from the first day of 2011 to the last day of 2012. Thus, there are seven time ranges for this study, and wells in the last time range are equal to all the wells in this dataset. However, we will use a finer temporal resolution, such as monthly or three-month, for the study. This abovementioned yearly time range is only used to illustrate our design for this abstract. 2) Using selected wells, we conduct a spatial interpolation of arsenic. Inverse distance weighting (IDW) is chosen as the spatial interpolation method. Although the result of interpolation could be different using other interpolation techniques, the comparison among those methods is not the focus of this study. 3) The raster is clipped by the county boundary, as the result of interpolation is a raster in a rectangle range of all the selected wells. 4) The contour lines are generated based on arsenic level from the clipped raster result. 5) Only the contour lines equal to MCL are selected as threshold boundaries.

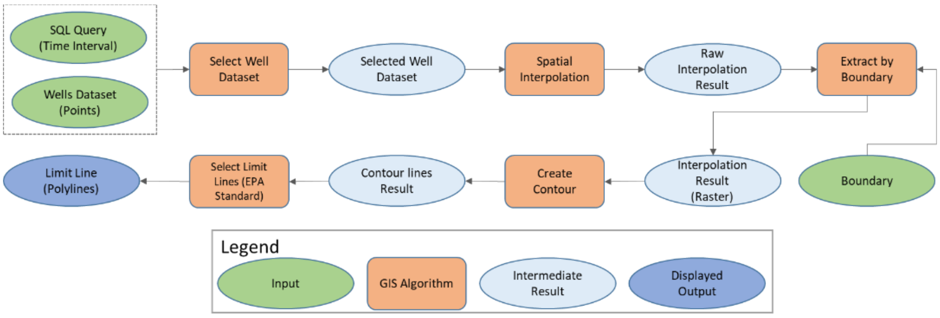


Figure 2: The workflow to generate threshold boundaries.

### *Animated map*

In this visualization, generated threshold boundaries are published as web feature service (WFS), and the interface of the visualization is web-based using ArcGIS JavaScript API 4.14. Although there are only seven threshold boundaries for yearly interval at this stage, presenting all of them at the same time still could be a confusion. Furthermore, we will have more threshold boundaries because of short time interval, such as monthly, to make the transit of boundary smooth. It is impossible to present hundreds of different threshold boundaries within a small area at the same time. To alleviate this issue, an animation approach is developed. When the animation is active by clicking the “play” button, only the current stamp and the first past stamp are highlighted at once, and other past stamps are dark coloured close to background colour which can provide information without causing confusion for the reader. A dot, as the current stamp, along with a straight line, as the timeline, indicate the current stamp in the whole timeline. The legend for coloured year is also shown in the map. Users also can drag the dot to any time stamp in the timeline, and they can hover on the threshold boundary to show the time stamp.

### *Space-time cube*

In the visualization of space-time cube, threshold boundaries along with a space-time cube are shown in both the planar and vertical in the 3D map. In that way, it looks like that threshold boundaries from the vertical are projected to the two-dimensional plane, which can help reader to understand their relative location. A space-time cube above certain height of the plane is used to create a clear vision for the temporal axis as well as the maximum boundary of the change extend, and it can be any space that are suitable for the change area. All the layers are published as web scene and ArcGIS JavaScript API 4.14 are used to generate the interface. Users can rotate, pan, and zoom to interact with the content in any perception. The hollowed threshold boundaries and transparent cubes do not hide any information in the 3D map (Tominski et al., 2005).

## Results

In this section, we use an example of yearly threshold boundaries to illustrate the result, while a further study with increased time interval (such as threshold boundaries in monthly) will presented. There are two parts of this visualization: animated map and space-time cube. Both two parts have the basic function of web-based map including zoom, pan, and identify. In animated map, threshold boundaries are changed in the time sequence as Figure 3 shown, and users can start or stop the animation. In the example shown in the Figure 3, threshold boundaries of the current stamp (2014) is highlighted in blue, and the colour of first past stamp (2013) is bright purple while other past stamps (2011-2012) are coloured as dark purple. In space-time cube as shown in Figure 4, threshold boundaries are shown both in the planar and vertical. Users can rotate the map to view the difference among those lines at any perception. Threshold boundaries in space-time cube visualize the transit of outline in temporal, and the projection of threshold boundaries in the planar can be used to identify the location relation in spatial.

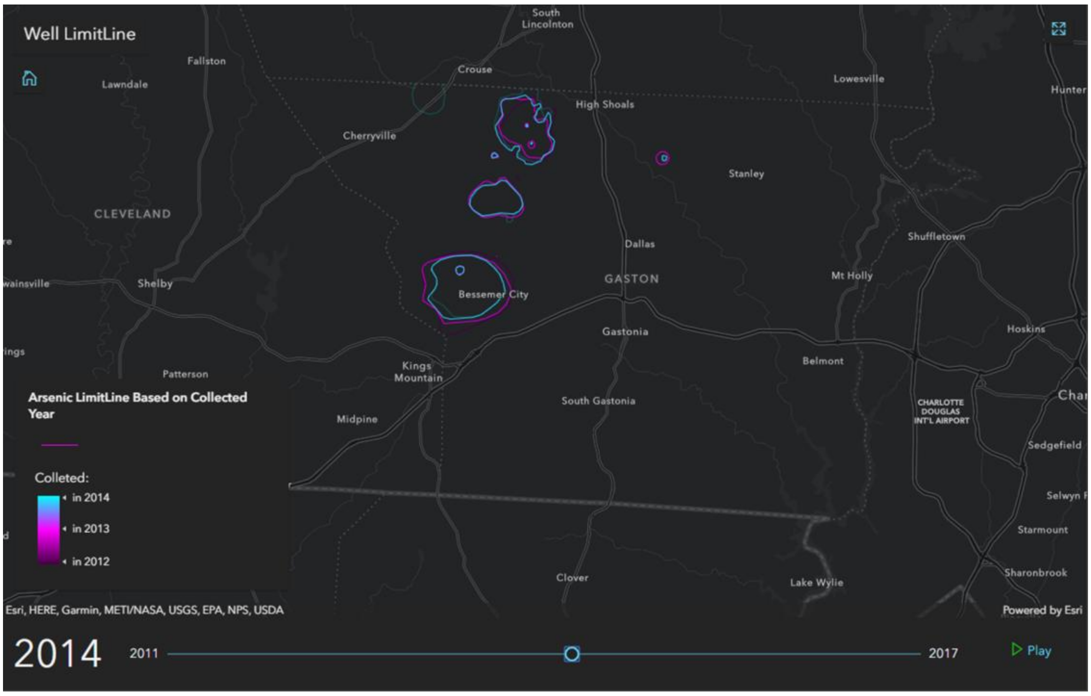


Figure 3: The Screenshot of the visualization of animated 2D map at the time stamp of 2014.

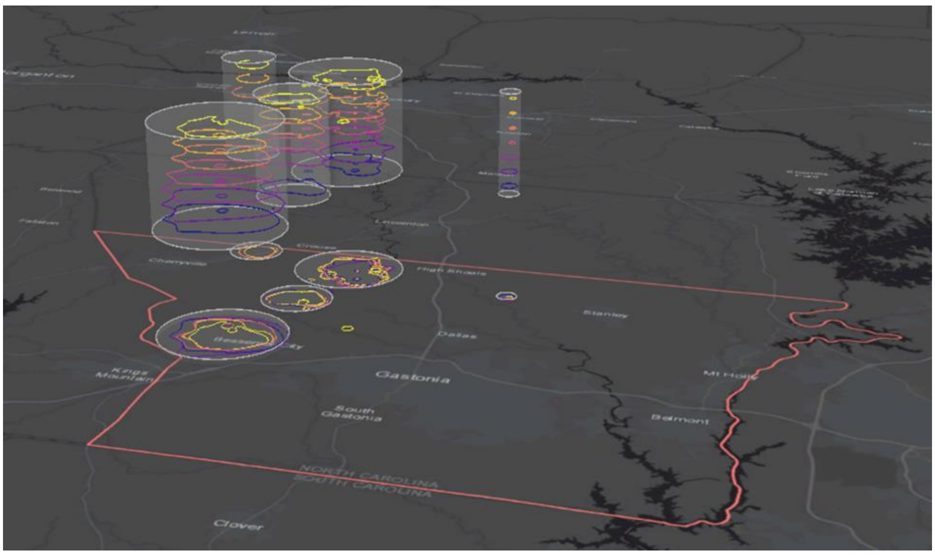

Figure 4: The Screenshot of the visualization of 3D space-time cubes.

## Discussion and Conclusion

Our web-based interactive space-time visualization of groundwater quality is accessible and straightforward for wells owners to monitor the contamination status around their wells. This visualization also can be applied to educate the general public to other environment health concerns, such as air pollution. However, threshold boundaries require to be generated and published as WFS. Future study will implement web processing service to generate real-time threshold boundaries with new data from environment health agencies or well owners themselves.


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## References


Bach, Dragicevic, Archambault, Hurter, & Carpendale. (2014). *A review of temporal data visualizations based on space-time cube operations*.

Desjardins, Hohl, Griffith, & Delmelle. (2019). A space–time parallel framework for fine-scale visualization of pollen levels across the Eastern United States. *Cartography and Geographic Information Science, 46*(5), 428-440.

Dübel, Röhlig, Schumann, & Trapp. (2014). *2D and 3D presentation of spatial data: A systematic review.* Paper presented at the 2014 IEEE VIS International Workshop on 3DVis (3DVis).

Ilägcrstrand. (1970). *What about people in regional science?* Paper presented at the Papers of the Regional Science Association.

Lee, Bhang, & Park. (2010). Effective visualization for the spatiotemporal trend analysis of the water quality in the Nakdong River of Korea. *Ecological Informatics, 5*(4), 281-292.

Lu, & Fang. (2015). Examining personal air pollution exposure, intake, and health danger cube using time geography and 3D geovisualization. *ISPRS International Journal of Geo-Information, 4*(1), 32-46.

Smith, Hopenhayn-Rich, Bates, Goeden, Hertz-Picciotto, Duggan, . . . Smith. (1992). Cancer risks from arsenic in drinking water. *Environmental health perspectives, 97*, 259-267.

Tominski, Schulze-Wollgast, & Schumann. (2005). *3d information visualization for time dependent data on maps.* Paper presented at the Ninth International Conference on Information Visualisation (IV'05).

Whitacre. (2009). *Reviews of environmental contamination and toxicology* (Vol. 202): Springer.