FINDINGS BRIEF
August 2023

RURAL & MINORITY Health Research Center

Assessing Key Indicators of Rural versus Urban Water Quality

Daniel Kilpatrick, PhD; Jeremy Cothran, BS; Stella Self, PhD; Dwayne Porter, PhD; Peiyin Hung, PhD; Elizabeth Crouch, PhD; Nicholas Yell, MS; Jan M. Eberth, PhD

Abstract:

- This brief provides an overview of the need for improvements in national water quality monitoring data to examine rural-urban differences.
- Included is a review of salient water quality monitoring datasets and models in the United States.
- The lack of standardized data makes it challenging to protect the public from unsafe waters in a variety of settings.
- The creation of a database and model(s) to monitor and estimate water quality nationally, across both urban and rural contexts, is warranted.

INTRODUCTION

Water quality monitoring throughout the U.S. poses unique challenges particularly when attempting to compare localities or urban versus rural communities. According to the U.S. Environmental Protection Agency (EPA), water quality is determined by whether the standards for the waters of states, territories, and tribes are at their desired condition.[1] This includes whether known pollutants are beyond a certain threshold. It also includes whether the chemical, physical, and biological integrity of the water has been degraded. For example, if the oxygen concentration in the water is reduced this can be considered a negative impact to the water's overall quality.[2] The transport of pollutants (both small and large scale) in surface waters combined with groundwater access and use types across various types of geography create a voluminous number of locations that could be monitored in both urban and rural contexts.[3] Estimating water quality concentrations across ecological landscapes in the U.S. must accommodate this inherent variability; whereas, air quality dispersion modeling for long-range atmospheric transport has been demonstrated to overcome and/or avoid a number of these challenges.[4] Large-scale water quality models estimating concentrations for the entire U.S. population, including both rural and urban, are currently not available. Water quality models exist; however, they do not include a complete national assessment to compare urban-rural differences.

Polluted waters have a variety of public health implications. Events like the water crises in Jackson, MS and Flint, MI highlight how aging infrastructure and a changing climate can expose significant sections of the nation's population to unsafe water. In the summer of 2022, heavy rains led to flooding from the Pearl River in Jackson which damaged the city's water treatment services and ended up shuttering the city's ability to deliver drinking water to their residents.[5] The governor of Mississippi declared a state of emergency as some 180,000 people were left without adequate drinking water.[6] Around 99,000 residents in Flint were exposed to lead from their drinking water in 2015 after the city switched their source of water from Lake Huron to the Flint River.[7] The corrosivity of the river more readily dissolved the lead in the city's water pipes and delivered drinking water with concentrations well above safe levels. This prompted the governor of Michigan to declare a state of emergency.[8] An examination of water quality in rural areas cannot be overlooked considering the events in Flint and Jackson. Rural monitoring is needed because rural communities may lack funding to update their water infrastructure. Small water systems may not have adequate back-up systems in case of failure. Water has been diverted for use in larger areas in selected regions impacting farms, drinking water supplies, and water-powered electricity (e.g., Colorado River).[9-11]

The Safe Drinking Water Act (SDWA) was first adopted in 1974 to protect public health by regulating the nation's public drinking water supply.[12] It was amended both in 1986 and 1996 and includes protections from over 90 contaminants. Rural water systems, which often include well systems, come with their own challenges. Individual wells are not covered by the SDWA and many of these wells are dug instead of drilled. As shallow wells they are often contaminated by chemicals and bacteria.[9] Furthermore, testing does not occur routinely or in some cases at all.[13]

There has not yet been a comprehensive national examination of key indicators of rural versus urban water quality across the U.S. In this brief, we present a summary of the water quality monitoring data sources and models, identify the gaps that persist, and propose the salient categories and types of data that should be contained in a national water quality monitoring database to accurately describe rural water quality.

METHODS

A variety of water quality data sources and water pollution models were investigated for their urban and rural coverage across the U.S. Initial water pollutants were explored including lead, arsenic, and copper due to their significant public health implications.[14] Exposure to these pollutants can lead to certain cancers, cardiovascular and neurological diseases, and some reproductive effects.[14] The primary water quality dataset investigated was the Environmental Protection Agency's (EPA) Water Quality Portal (WQP).[15] The WQP is the nation's largest source for water quality monitoring data. According to the EPA, it contains over 380 million data records from 900 federal, state, tribal, and other partners. Data for the years 2000 to 2020 were downloaded and then plotted using QGIS, a free open-source geographic information system software.[16] Monitoring sites for each pollutant were plotted to assess national, urban, and rural coverage.

Surface water models were also explored during the investigation and are summarized in a 2018 assessment developed for the EPA's Water Modeling Workgroup (WMW).[17] The assessment listed 18 separate surface water modeling applications that support efforts such as assessing permit conditions for pollution discharge elimination systems, developing pollutant threshold planning, evaluating water quality policies, and carrying out additional water quality analyses.

An additional data source was investigated containing 303(d) Clean Water Act impaired waters[18] including data from states, territories, and authorized tribes. These data sources contained variables for 34 impairment types based on a single pollutant or a combination of pollutants.[19] The data source was downloaded and then plotted using QGIS to assess national, urban, and rural coverage.

RESULTS

Coverage of Water Sampling Sites

The following sub-section highlights the coverage of monitoring sites where water quality samples are collected across the U.S. A map of lead, arsenic, and copper monitoring sites for 2020 is included below in Figure 1. This map shows an abundance of monitoring sites in some areas (e.g., Florida) and sizable lack of monitoring sites in many other areas and states (e.g., Maine). Simple interpolations (i.e., imputing data for areas without monitoring sites) based on a map with such high levels of missingness would likely be invalid and unreliable. A national level water quality model like the EPA's Community Multiscale Air Quality (CMAQ) model[20] or National Air Toxics Assessment (NATA) model[21] would be a solution to overcome this level of missingness; however, none was not found during the investigation.

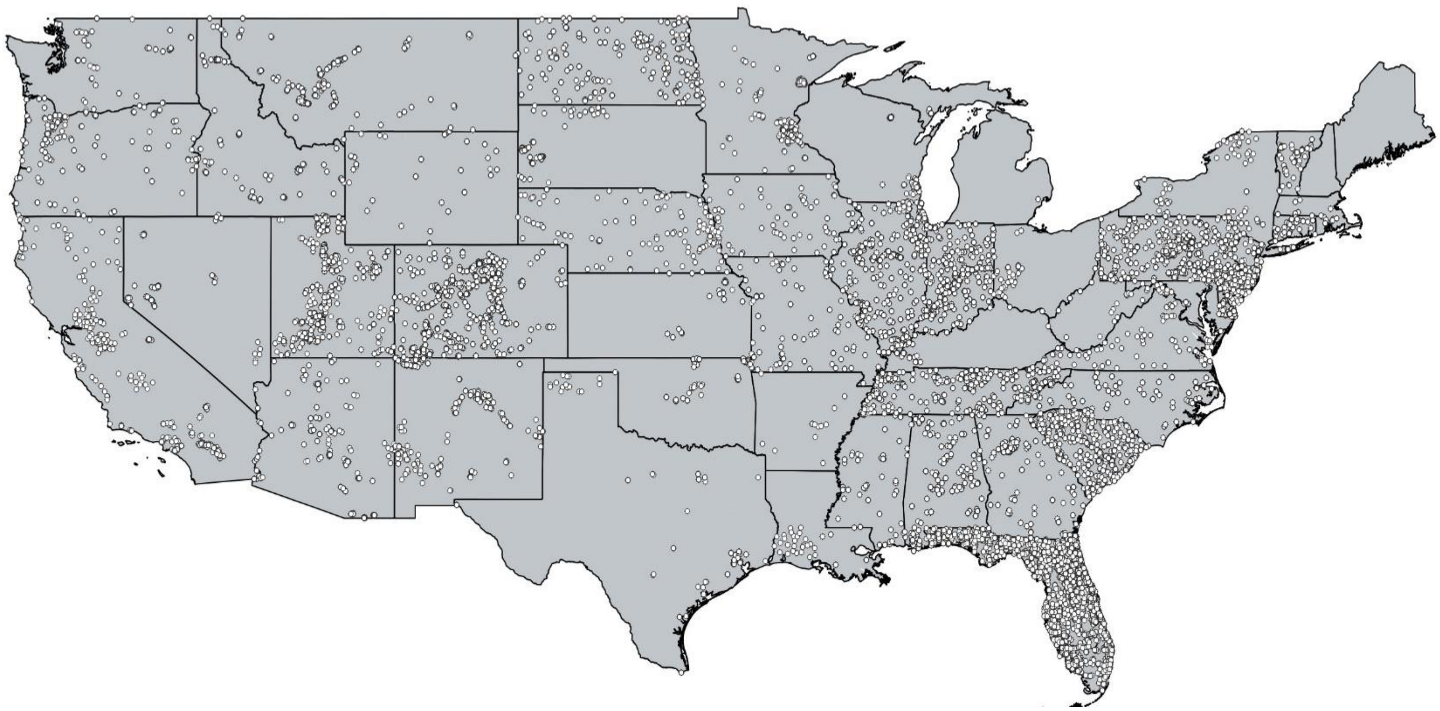
Coverage of Water Models

To assess water quality where data is unavailable, models can provide valid estimates for potential harmful exposures. This sub-section provides a brief overview of the EPA's WMW and their 2018 report carried out to evaluate the coverage of surface water models in the U.S. The EPA's Water Modeling

Workgroup received a report in 2018 assessing the utility of known surface water models and their status.[17] Each of these models was reviewed for application in the current investigation. None of the models had the capability to provide a national-level assessment of relevant pollutants for public health. One model, the BASINS model, had the capability for comparing across several states within a large watershed. This was the largest geographic coverage possible. A national level comparison was not possible. No models assessed had a similar national coverage to air models such as CMAQ or NATA.

It is also important to note that the assessed models were of surface water and did not include groundwater. National groundwater modeling programs were observed in other countries (e.g., England, Wales, and Denmark); however, none were observed in the U.S.[22-23] The geographic variability and size of the U.S. may create barriers for national groundwater modeling.

Figure 1. Water Quality Portal Monitoring Sites for Lead, Copper, and Arsenic, 2020



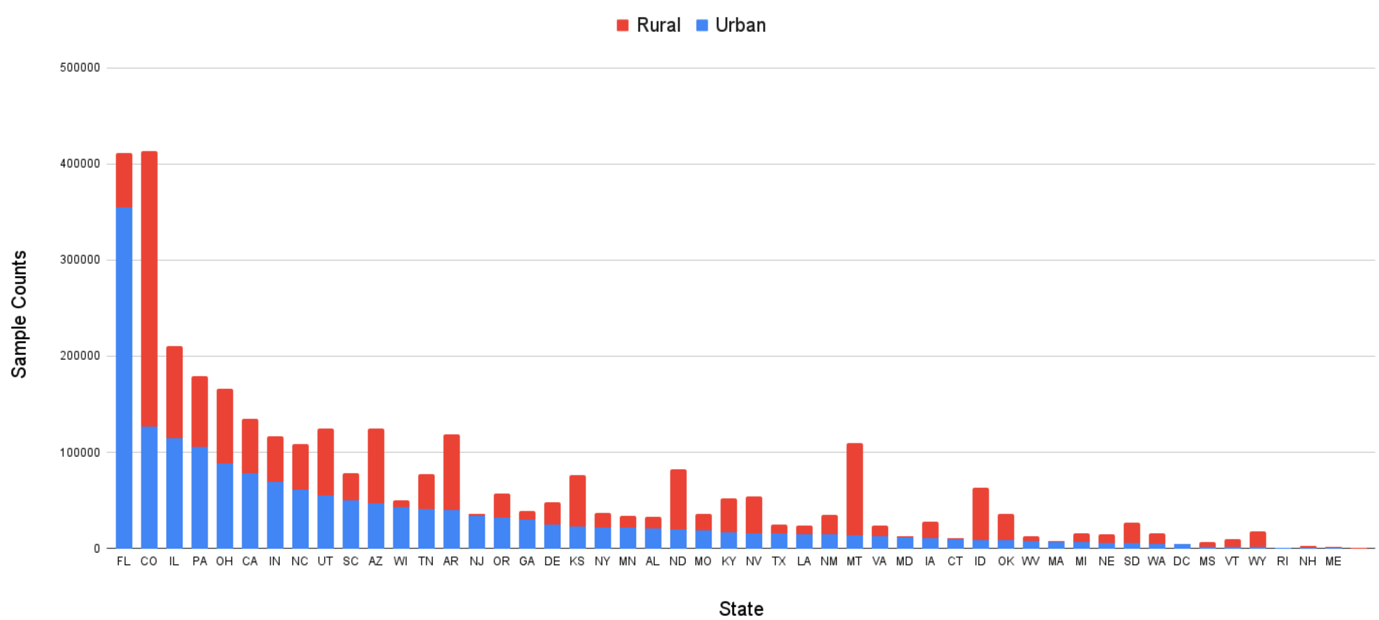
Coverage of Clean Water Act Data

To assess the coverage of an alternative source to what the EPA provides in the WQP, a data source was found by investigating impaired waters according to the Clean Water Act. Maps of the ESRI 2015 303(d) dataset (included in the appendix, Appendices A through C). Similar to the figure above, these maps show an abundance of coverage (e.g., Florida) and a sizable lack of coverage in many other areas and states (e.g., Maine). However, what is unique about these maps is they are more than individual sampling sites. These maps indicate areas and lines of impaired waters in addition to points for where water quality samples were collected. This data file includes aggregated data from multiple state sampling initiatives. These initiatives vary in sampling/targeting methods (e.g., non-targeted analysis vs. targeted analysis), scope (e.g., percentage and type of public water system), detection limits, sample location, reporting limits, quantification methods, reported data elements, and even what data are reported (e.g., some states choosing only to report detections while other states report all test results). Because of these significant differences in how states are collecting data, the information in this file should not be compared across state boundaries. EPA intends to continue adding data from more states as it becomes available.[18]

Rural and Urban Water Data Coverage

This final sub-section provides an overview of a rural-urban comparison of WQP data. Again, the WQP is EPA's effort to provide a clearinghouse of all water data, both surface and groundwater, collected nationally. This was assumed to be the gold standard of data to assess both urban and rural coverage of sampling sites. Figure 2 below represents the urban and rural sample counts of water quality by state between 2000 to 2020 according to the WQP. The number of samples and whether more or less of these were urban or rural depended on the state. Similar to the figures above, select states had a high number of counts while others did not. Additionally, there was a high degree of variability between urban and rural counts per state and generalizations, other than coverage, were not assessed.

Figure 2. Urban and Rural Counts of Water Quality Samples, 2000-2020, WQP



DISCUSSION

This brief provides an overview of the need for improvements in national water quality monitoring data to examine rural-urban differences. After reviewing an exhaustive list of water quality monitoring datasets and models, the creation of a national water quality model across both urban and rural contexts is warranted. Such a model would have to overcome the challenges of the various potential sources of pollution for both surface water and groundwater, the inherent variability of pollutant transport through the nation's surface waters, and the variability in groundwater access, maintenance, and use.

Water quality monitoring datasets provided by the EPA offer available data and, in turn, make them publicly available online but do not standardize the data in a format or vocabulary that would facilitate broader regional or national analysis. Additionally, 303(d) Impaired Waters datasets vary in spatial formats at the state-level with varying density between point, line, and area as well as broad 'metals other than mercury' descriptions for pollutants as an example. This creates barriers to data access. Also, datasets are not presented in a way that allows for comparability. This is largely due to the way in which water quality data is collected. A systematic and standardized methodology to collect data across states and regions was not found during the investigation. This further necessitates a national water modeling initiative comparable to what is available for air pollution.

Water pollution exposure varies according to its source (i.e., surface water or groundwater), route of exposure (drinking, showering, recreation, etc.), as well as topographical, meteorological, ecological, agricultural, and industrial influences and inputs. Thus, water quality data is linked to its source and its potential route of exposure. For example, drinking water quality is routinely monitored in Community Water Systems (CWSs). However, CWS reports are provided for local review and not formatted for aggregated reporting or comparison at a wider regional or national level. CWS reports also do not reflect potential harmful infrastructure exposures (lead, etc.) between a treatment facility and household consumption or households served by wells.[24]

The lack of standardized data makes it challenging to protect the public from unsafe waters in a variety of settings. As surveillance is a core function of public health, the water quality data currently collected is inadequate to monitor potential harmful exposures across the nation especially as water infrastructure ages, population increases, and climate change continues. Several states in the present investigation were identified as having a plethora of water quality data (e.g., Florida). As a peninsular state, Florida is surrounded by water and has significant surface waters including the Everglades. Its aquifer levels are closer to the surface relative to many other states.[25] With an added focus on governance and water-related policies (e.g., Florida's five regional Water Management Districts), the role that water plays in Florida contributes to the availability of water monitoring data and makes a positive contribution to the essential services of public health especially those related to assessment, policy development, and assurance.[26-27]

One of the recent studies carried out to assess urban and rural comparisons of polluted waters in the U.S. was Strosnider et al. in 2017.[24] The dataset used contained 26 states' worth of data leaving almost half of the country unassessed. The study used data from Community Water Systems (CWSs) from the CDCs' Environmental Public Health Tracking (EPHT) network as their data source which has little to no well data. From a statistical perspective, this was an adequate sample size to assess urban and rural differences for states where data was available. However, the challenge remains for those jurisdictions and for those respective populations where water quality monitoring data is non-existent. This adds to the importance for greater coverage of water data in the rural sector of the U.S.

According to Ingram (2010), environmental economists have devoted less attention to water quality than air quality.[28] This is significant for water pollution-related policies for several reasons. Outdoor air pollution has a direct impact on public health. Economists can quantify a value to this and subsequently compare to regulation costs. Ingram contrasts this with the benefits of controlling water pollution which are rooted in improving recreational use of surface waters and protecting ecosystem health. Additionally, economists have been able to implement market-based approaches for air quality with efforts like tradable permits and emissions taxes.[28] This has been challenging to apply to the water pollution context as quantifying cost-effective policies have been explored in theory but not in practice. Finally, Ingram suggests that the most beneficial environmental intervention for water quality has to do with the treatment of drinking water and sanitation. However, for many industrialized nations, improvements to drinking water and sanitation were implemented long before environmental economics existed as a field. As a result, there was little demand for such investigations. It is important to note that this may be true presently to some degree; however, as the nation's drinking water and sewer infrastructure ages, crises like Flint, MI and Jackson, MS may become more frequent. Additionally, the science in the U.S. need not only consider domestic implications. Science must be willing to contribute for the sake of low- and middle-income countries (LMICs) where such investigations could be beneficial.

The 1969 National Environmental Policy Act (NEPA) indicates the president of the United States shall present an annual report to Congress on the status of the environment.[29] This is to include the aquatic environments (marine, estuarine, and fresh water) as well as urban and rural terrestrial spaces among other sectors (e.g., air quality). Additionally, this report shall include current and foreseeable trends in the quality, management, and utilization of these sections of the environment. Finally, this report shall indicate remedies for any deficiencies of any programs or activities for the environment and its conservation. Thus, the NEPA policy implications are clear. Presently, monitoring water quality for the entire nation is lacking and a remedy for this deficiency should be developed for NEPA compliance.

Existing data is insufficient to produce national estimates of water quality or to compare water quality in rural versus urban areas.

Existing data is insufficient to produce national estimates of water quality or to compare water quality in rural versus urban areas. Water quality can vary dramatically over short distances particularly when water is drawn from different wells. Most states do not report water quality at a sufficiently fine geographic scale to permit reliable spatial estimation of water quality. Furthermore, data is not reported at a representative sample of urban and rural locations but is skewed towards areas with known or suspected high levels of pollution (e.g., mining areas).

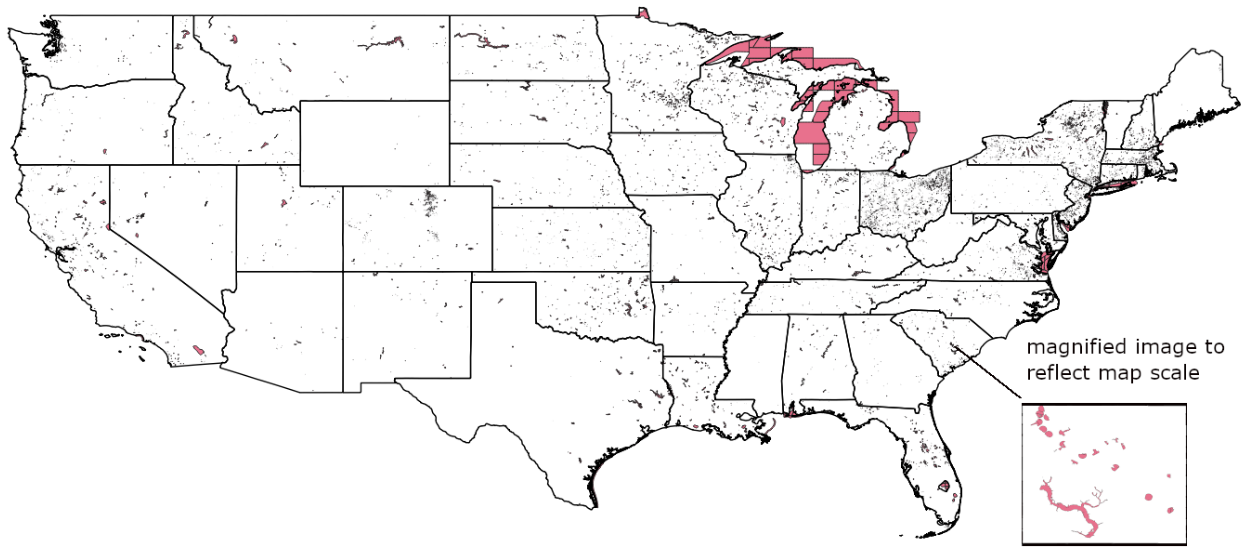
RECOMMENDATIONS

In summary, there is a dearth of consistent and uniformly available data for water quality monitoring in contrast to air quality data over space. Air quality models like the EPA's CMAQ and NATA systems address a variety of pollutants with varying scales and create a "One-Atmosphere" perspective that incorporates the work of the scientific community.[20] Such large scale models take the varying amounts of air quality data available, apply them over the entirety of the U.S., and estimate levels of pollutant exposure in places where that data is unavailable or unmonitored. Thus, a single space is created for air monitoring, and this estimate is applied across the nation. A similar approach is warranted for water quality in which the varying amounts of monitored data are pulled into a single space so water quality data can be modeled and validly estimated for places where monitoring does not occur. This "One-Hydrosphere" approach would combine the scientific community's contributions for surface and groundwater pollutants and subsequently estimate for unmonitored areas through a model or models. Further research and funding for a CMAQ-like national model in the water sector should be pursued.

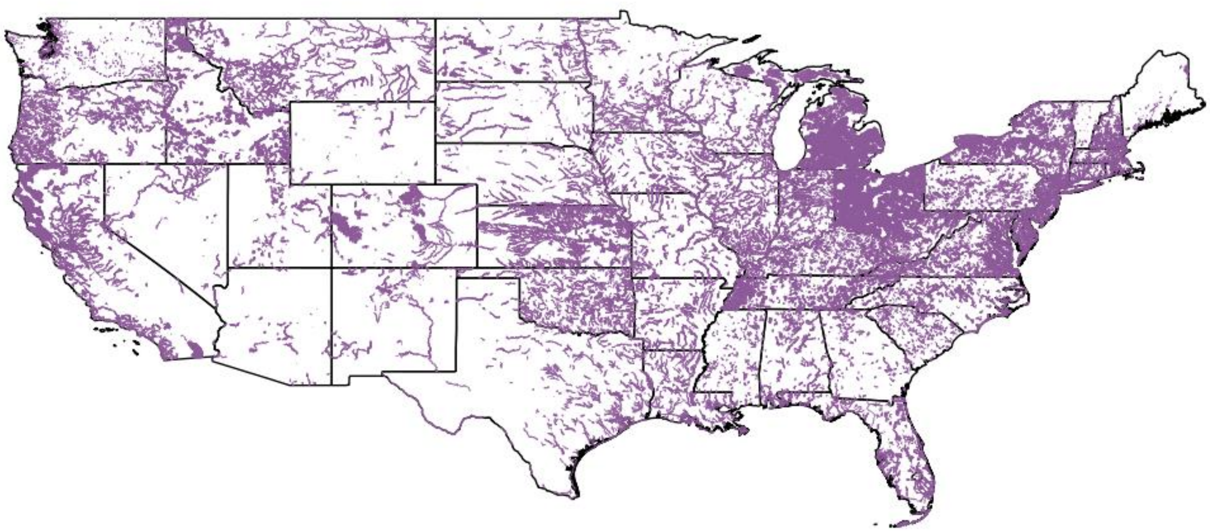
To produce national estimates of water quality and/or assess differences in water quality between urban and rural areas, data must be routinely collected at a fine scale of *representative* geographic locations. The spatial resolution of this scale need not be the same in all areas. Large areas served by a single water source may need only a couple sampling points while smaller areas served by multiple water sources (e.g., wells) will need sufficient sampling to capture the variation in water quality attributable to the different sources. Statistical corrections for oversampling of highly polluted areas may be applied provided these sites can be differentiated from representative sites.

APPENDICES

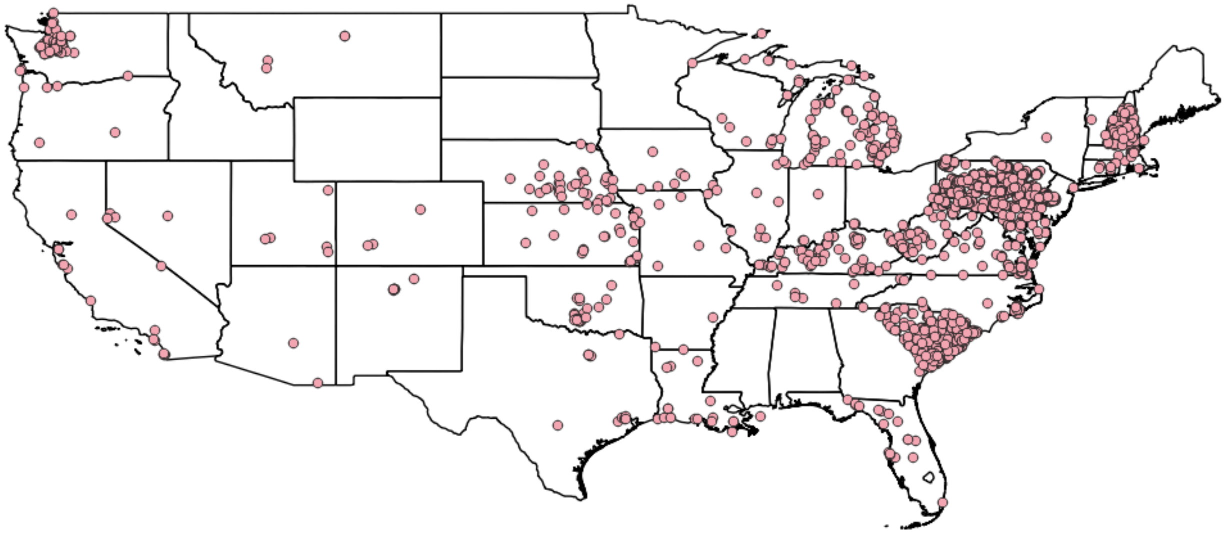
Appendix A. 303(d) Clean Water Act Impaired Water Areas*



Appendix B. 303(d) Clean Water Act Impaired Water Lines*



Appendix C. 303(d) Clean Water Act Impaired Water Points*



*Note: Impaired waters according to the EPA are those with relevance to the Clean Water Act and are the pollutants that have reached Total Maximum Daily Loads (TMDLs) that are allowed in a waterbody and serve as the starting point or planning tool for restoring water quality.

RHRC Rural Health Research & Policy Centers
Funded by the Federal Office of Rural Health Policy
www.ruralhealthresearch.org

RURAL & MINORITY Health Research Center

Funding: This project was supported by the Health Resources and Services Administration (HRSA) of the U.S. Department of Health and Human Services (HHS) under grant number #U1CRH45498, Rural Health Research Grant Program Cooperative Agreement. This information or content and conclusions are those of the authors and should not be construed as the official position or policy of, nor should any endorsements be inferred by HRSA, HHS or the U.S. Government.

For more information about the Rural and Minority Health Research Center, contact the Director Dr. Elizabeth Crouch (crouchel@mailbox.sc.edu) or Deputy Director Dr. Peiyin Hung (hungp@mailbox.sc.edu).

Suggested citation: Kilpatrick D, Cothran J, Self S, Porter D, Hung P, Crouch E, Yell N, Eberth JM. Assessing Key Indicators of Rural versus Urban Water Quality Brief, Rural & Minority Health Research Center, Columbia, SC. 2023.
[View Policy Brief]

REFERENCES

1. Standards for Water Body Health. Environmental Protection Agency. Retrieved online from: https://www.epa.gov/standards-water-body-health
2. Dissolved Oxygen and Water. United States Geological Survey. Retrieved online from: https://www.usgs.gov/special-topics/water-science-school/science/dissolved-oxygen-and-water
3. Jan F, Min-Allah N, Düştegör D. IoT Based Smart Water Quality Monitoring: Recent Techniques, Trends and Challenges for Domestic Applications. Water. 2021; 13(13):1729. https://doi.org/10.3390/w13131729
4. Environmental Protection Agency. 2003. Revision to the guideline on air quality models. Adoption of a Preferred Long-Range Transport Model and Other Revisions, 68 (7), 1840–18482.
5. Nwanai-Enwerem JC, Casey JA. Naming civic health in environmental justice discourse: The Jackson water
6. Harris B, Li DK. Mississippi governor declares state of emergency with end of Jackson water crisis nowhere in sight. 2022; Retrieved online from: https://www.nbcnews.com/news/us-news/mississippi-governor-declares-state-emergency-end-jackson-water-crisis-rcna45470
7. Flint Lead Exposure Registry. Centers for Disease Control and Prevention. Retrieved online from: https://www.cdc.gov/nceh/lead/programs/flint-registry.htm
8. Bellinger DC. Lead contamination in Flint—an abject failure to protect public health. New England Journal of Medicine. 2016 Mar 24;374(12):1101-3.
9. Fuller T. Rural water supplies and water-quality issues. Healthy Housing Reference Manual. 2006:1-2.
10. Baird, G.M. (2010), A game plan for aging water infrastructure. Journal - American Water Works Association, 102: 74-82. https://doi.org/10.1002/j.1551-8833.2010.tb10092.x
11. Salehabadi, H, Tarboton, D, Udall, B, Wheeler, K, Schmidt, J. An Assessment of Potential Severe Droughts in the Colorado River Basin, JAWRA Journal of the American Water Resources Association, (2022). https://doi.org/10.1111/1752-1688.13061
12. Overview of the Safe Drinking Water Act. Environmental Protection Agency. Retrieved online from: https://www.epa.gov/sdwa/overview-safe-drinking-water-act
13. Fox MA, Nachman KE, Anderson B, Lam J, Resnick B. Meeting the public health challenge of protecting private wells: Proceedings and recommendations from an expert panel workshop. Science of the Total Environment. 2016 Jun 1;554:113-8.
14. Calderon, R. L. "The epidemiology of chemical contaminants of drinking water." Food and chemical toxicology 38 (2000): S13-S20.
15. Environmental Protection Agency. 2022. Water Quality Data, Water Quality Portal. Retrieved online from: https://www.epa.gov/waterdata/water-quality-data
16. QGIS. A Free and Open Source Geographic Information System. Retrieved online from: https://qgis.org/en/site/
17. Environmental Protection Agency. 2018. Assessment of Surface Water Model Maintenance and Support Status. Retrieved online from: Assessment of Surface Water Model Maintenance and Support Status (epa.gov)

18. EPA. Clean Water Act Section 303(d): Impaired Waters and Total Maximum Daily Loads (TMDLs). Retrieved online from: https://www.epa.gov/tmdl

19. ESRI. 2022. USA Polluted Waters. Retrieved online from: https://www.arcgis.com/home/item.html?id=dfc9008829a6487db7e3050045c163fe

20. Byun, D., and Schere, K. L. (March 1, 2006). "Review of the Governing Equations, Computational Algorithms, and Other Components of the Models-3 Community Multiscale Air Quality (CMAQ) Modeling System." ASME. Appl. Mech. Rev. March 2006; 59(2): 51–77. https://doi.org/10.1115/1.2128636

21. EPA. National Air Toxics Assessment. Retrieved online from: https://www.epa.gov/national-air-toxics-assessment

22. Whiteman MI, Seymour KJ, Van Wonderen JJ, Maginness CH, Hulme PJ, Grout MW, Farrell RP. Start, development and status of the regulator-led national groundwater resources modelling programme in England and Wales. Geological Society, London, Special Publications. 2012;364(1):19-37.

23. Henriksen HJ, Troldborg L, Nyegaard P, Sonnenborg TO, Refsgaard JC, Madsen B. Methodology for construction, calibration and validation of a national hydrological model for Denmark. Journal of Hydrology. 2003 Sep 1;280(1-4):52-71.

24. Strosnider H, Kennedy C, Monti M, Yip F. Rural and Urban Differences in Air Quality, 2008-2012, and Community Drinking Water Quality, 2010-2015 - United States. MMWR Surveill Summ. 2017 Jun 23;66(13):1-10. doi: 10.15585/mmwr.ss6613a1. PMID: 28640797; PMCID: PMC5829865.

25. Haag, K., Miller, R., Bradner, L., McCulloch, D. (1997). Water Quality Assessment of South Florida. U.S. Geological Survey. Water-Resources Investigations Report 96-4177.

26. Public Health National Center for Innovations. 10 Essential Public Health Services. Retrieved online from: https://phnci.org/uploads/resource-files/EPHS-English.pdf

27. Kirchhoff, C. J., and L. Dilling (2016), The role of U.S. states in facilitating effective water governance under stress and change, Water Resour. Res., 52, doi:10.1002/2015WR018431.

28. Olstead, S. The Economics of Water Quality. Review of Environmental Economics and Policy, volume 4, issue 1, winter 2010, pp. 44–62 doi:10.1093/reep/rep016

29. National Environmental Policy Act. 1969. Retrieved online from: https://www.fsa.usda.gov/Internet/FSA_File/nepa_statute.pdf