Measuring the Environmental Health of Wisconsin's Counties

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ABSTRACT

Introduction: Environmental factors—such as air and water pollution, lead exposure in homes, or aspects of urban design—influence the health of a community. Monitoring these environmental health influences is a core function of public health, making it necessary to identify critical priorities and effectively target outreach and intervention efforts. This paper reviews the methods used to develop a summary measure of the environmental health of Wisconsin's 72 counties and the city of Milwaukee.

Methods: We collected publicly available data on 9 indicators of environmental health, divided into 3 constructs—air quality, water quality, and the built environment. We looked at how the counties ranked in each construct and then combined the estimates into a summary measure of environmental health. We ranked the summary measure from lowest to highest risk, with higher representing a worse physical environment.

Results: In 2007, Wisconsin regions with major metropolitan areas had the worst environmental health risk. In contrast, the 10 counties with the best environmental health were all located in rural areas of the state.

Conclusion: Publicly available data can be used to compare and contrast environmental health in Wisconsin's communities. Although the measures used to collect these data could be improved, the results can still be used in community health planning and improvement efforts.

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INTRODUCTION

The relationship between the physical environment and population health has long been documented.[1-3] In particular, individual contaminants found in the air, water, and residential dwellings are all attributes of the physical environment that lead to population exposures with negative health outcomes.[4-6] A growing body of literature also highlights the relationship between the built environment—particularly urban design—and health.[7] Environmental health includes all factors, both natural and human-made, that directly affect human health or the ecological balance necessary for long-term human health.[8]

Because of the relationship between environmental exposures and health outcomes, measuring and monitoring environmental health has long been a core function of public health. Environmental health influences are unique in that they require knowledge about the sources and distribution of hazards, potential for population exposures, and subsequent health effects. Further complicating matters, environmental and health agencies are often fragmented, and efforts to develop methods, data, and tools to assess the true impact of environmental factors are inadequate.[9-11]

In the Wisconsin County Health Rankings (Rankings), the University of Wisconsin Population Health Institute creates and ranks summary measures of population health outcomes. These are based on mortality and health-related quality of life, as well as health determinants, including summary measures of health care, health behaviors, socioeconomic factors, and the physical environment.[12] The goal of this paper is to review measures derived to assess the environmental health of communities in Wisconsin. The strengths and limitations of the existing physical environment measures are discussed, as well as future directions to improve assessment of the physical environment and its effect on health.

METHODS

Three constructs were developed to measure the health of a community's environment—air quality, water quality, and the built environment—in the 2007 Wisconsin County Health Rankings. The 9 physical environment indicators included in this report were selected based on their public availability for all 72 counties. Public availability refers to the ability to impute values for all counties from publicly available data, the frequency with which they are updated, and their known health effects.[13] Each construct contributes 33% to the overall summary measure. Table 1 lists the constructs and their indicators, as well as the weights each individual indicator contributes to the summary measure of the physical environment. For indicators with data available yearly, such as ozone and fine particulate matter, we averaged the 3 most recent years of data.

Air Quality

The air quality construct is measured with 4 indicators: cancer risk (cases per million); the respiratory hazard index, both from the US Environmental Protection Agency (EPA) and National Air Toxics Assessment (NATA); measures of fine particulate matter, defined as particulates smaller that 2.5 micrometers in diameter (<2.5 µm, $PM_{2.5}$); and ozone from the Bureau of Air Management, Wisconsin Department of National Resources (DNR). Several of the pollutants measured by NATA are known carcinogens that contribute to cancer incidence, including benzene, arsenic compounds, and carbon tetrachloride; noncarcinogenic pollutants include acrolein, chlorine, and formaldehyde. The pollutants measured in the respiratory hazard index, fine particulate matter, and ozone all contribute to decreased lung function, chronic bronchitis, asthma, and other adverse pulmonary effects.[3-4]

To determine the cancer and noncancer respiratory hazard risk due to air pollutants, NATA models exposure data for 33 air toxics considered most harmful to human health. The cancer risk measure estimates lifetime cancer risk attributable to these air toxics given a lifetime (approximately 70 years) of continuous exposure and is reported as the incidence of cancer per 1 million people. The respiratory hazard index measures the lifetime risk of non-cancer respiratory conditions also based on modeling of emissions data. If the hazard index is ≤1, no adverse health effects are expected. A hazard index >1 suggests a greater risk of respiratory conditions due to exposure to air pollutants. We used NATA's most current cancer risk and respiratory hazard index values (1999) for the 2007 Rankings.

Data on fine particulate matter and ozone are collected through the Wisconsin DNR's Air Monitoring Network in accordance with federal code established by the EPA.[14] As of March 2007, the DNR has 35 monitoring sites in 29 Wisconsin counties. Data for the 2006 Rankings are based on 3-year averages from 2003–2005. Average yearly values of fine particulate matter ($PM_{2.5}$), reported as µg/m^3, are based on data collected from sites in 18 Wisconsin counties. Each county was assigned an average yearly $PM_{2.5}$ value based on monitoring site results. For counties with more than 1 monitoring site, an average of the county site values was used; for counties without monitoring sites, an average value for counties in their region was used.

Ozone values, reported as parts per billion (ppb), are collected from sites in 29 Wisconsin counties; our data represent the 2004–2006 annual average design values. As with $PM_{2.5}$, ozone values for counties with more than 1 monitoring site are based on an average of the monitoring site values. To create the regions within Wisconsin, a boundary was drawn between counties exceeding the allowable limit for ozone (≥85 ppb), and those who were near the limit (75–84 ppb). Another boundary was drawn between the borderline counties (75–84 ppb) and those with a low risk of exceeding the limit (<75 ppb). These regions coincided with geographic location in the state, with the higher risk counties on the coast bordering Lake Michigan. Most counties without a monitoring site fell in the low risk group. Counties without measurements were assigned a value equal to the average of the counties within their region.

Water Quality

The water quality measure is comprised of 1 indicator: nitrate levels in water. Exposure to nitrates in drinking water is most notably associated with blue baby syndrome, but increasing studies suggest birth defects and cancer are among other potential negative health effects.[15-16] This indicator, created with 2006 data from the Bureau of Drinking Water and Groundwater, Wisconsin DNR, measures the percentage of the population on both private and municipal water supplies exposed to water with nitrate levels that exceed the EPA Preventive Action Limit (PAL) of 2 mg/L. Identification of wells exceeding the PAL allows intervention that ideally controls contamination before these water sources reach or exceed the Enforcement Standard (ES) of 10 mg/L.

The Built Environment

The last construct, the built environment, includes 4 measures. To provide a proxy for lead exposure, we include 2 indicators: percent of housing with increased

Table 1. Measures of the Physical Environment

Construct	Physical Environment Measures	Physical Environment Summary Measure Weight (%)
Air quality	Air quality cancer risk *Attributable risk of cancer due to inhalation of air pollutants (cases per million)*	8.3
	Air quality hazard index *Risk ratio for adverse, noncancer health effects due to inhalation of noncarcinogenic air pollutants*	8.3
	Fine particulate matter (<2.5 µg/m3)	8.3
	Ozone level (ppb)	8.3
Water quality	Nitrate levels in water *Percent of population exposed to water with nitrate levels >2 mg/L*	33.3
Built environment	Pre-1950s housing *Percent of housing stock built before 1950*	5.6
	Lead poisoned children *Percent of children tested positive for lead poisoning*	5.6
	Radon risk *Percent of homes tested with radon levels >10 pCi/L at the basement level*	11.1
	Commuting method: Driving alone *Percent of the labor force (age 16+) that reports driving alone to work*	11.1

lead risk (pre-1950s housing stock), available from the 2000 US Decennial Census, and percent of children under age 6 that tested positive for lead poisoning in 2006, provided by the Wisconsin Department of Health and Family Services (DHFS). In severe cases, lead poisoning is associated with cognitive and behavioral problems in children;[17-18] among adults, lead poisoning is associated with fertility and neurological problems.[6] The federal Lead-Based Paint Poisoning Prevention Act was not passed until 1973, but the Rankings uses a measure of pre-1950s housing stock since manufacturers began voluntarily limiting the use of lead as an additive after 1950.[19] In reference to the lead poisoning indicator, it is important to note that the figure is not from a random sample of children and should be interpreted with caution. Children in the cities of Milwaukee and Racine are tested more thoroughly; children elsewhere are tested only if they are determined to be at high risk of lead exposure.[13] Furthermore, a child must have a blood lead level of at least 10 µg/dL to qualify as "poisoned,"[20] though blood lead levels of 5-10 µg/dL can also result in decreased cognitive ability among children.[21] Since the Rankings rely on publicly available data, children with lower (<10 µg/dL) but potentially significant blood lead levels are not included in the sample.

In 2007, we added 2 new indicators to the built environment construct: radon risk and method of commuting. Radon exposure is the second leading cause of lung cancer, and the risk increases at greater radon concentrations. According to the EPA, the risk of lung cancer with lifetime exposure (approximately 70 years) to radon levels of 4 pCi/L is 4 in 1000 people for never smokers, and 6 in 100 for current smokers. The radon risk indicator uses 2006 data from DHFS and represents the percent of homes screened that have radon levels greater than 10 pCi/L. We selected this indicator because radon concentrations that exceed 10 pCi/L at the basement level of a residence correlate to a level of at least 4 pCi/L in the upper levels of the home. The EPA, based on the National Academy of Sciences' 1999 report on the health risks of exposure to radon, recommends that radon concentrations in occupied spaces of a residence not exceed 4 pCi/L.[22] As with the indicator percent of children screening positive for lead poisoning, the radon measure is not from a random sample of homes and should be interpreted with caution.

The last indicator included is the method of commuting to work, which comes from the 2000 US Census. This indicator is calculated as the percent of the labor force, age 16 and over, that reports driving alone to work. We use this measure to assess the quality of the built environment, as the ability of community members to walk, bicycle, or use public transportation depends heavily on design factors. The advantages of alternative transportation for environmental health are clear: car emissions result in non-point source pollution of air and water and also contribute to an urban heat island effect. Alternative methods of commuting, including walking, bicycling, car-pooling, and public transportation result in reduced levels of air and water contamination; bicycling and walking also improve health through increased physical activity.[7]

Composite Scores and Ranks—Physical Environment Summary Measure

To rank Wisconsin's counties and the city of Milwaukee on the physical environment, we used a method to standardize each county's value so that we could combine them into a single summary measure. We first calculated Z-scores for each county and the city of Milwaukee on each of the 9 measures: Z-score=(measure – mean value for 72 counties)/(standard deviation of measure). Z-scores rescale all measures according to a normal (Z) distribution, allowing for the creation of composite scores across a range of measures.[23] Z-scores >3.0 and <–3.0 were truncated at 3.0 and –3.0, respectively, so outlier values did not overly influence the composite measure ranks. The Z-scores for each measure were adjusted by their weight listed in Table 1 and added to create a summary Z-score for the physical environment for each jurisdiction. Lower Z-scores ranked better and higher Z-scores ranked worse. If counties' Z-scores tied for a particular measure, they each received the same rank. Subsequent counties were ranked as if the tied counties were in order (eg, if 2 counties were ranked first, the county following the tie was ranked third, not second).[13]

For the purposes of this paper, we also ranked the counties on each construct of the physical environment summary measure: air quality, water quality, and the built environment. ArcGIS software (version 9) was used to map the counties' ranks by quartile for the physical environment summary measure and each construct.

RESULTS

Major metropolitan statistical areas in the state had the worst measures of environmental health. In contrast, the rural areas of Wisconsin had the best environmental health, with northern counties such as Bayfield, Menominee, Sawyer, Vilas, and Iron ranking in the top 10 counties overall for the physical environment. Similar clustering occurs with ranks for the constructs of air, water, and lead risk.

For air quality, counties in the eastern part of the state generally revealed worse measures of air quality, with counties in the southeastern part of the state comprising the counties with the lowest air quality. In contrast, the northeastern region has the best air quality in the state.

For water quality, the counties in the central and south central parts of the state had the worst quality, whereas counties distributed along the northern and eastern borders of Wisconsin had the best water quality.

Finally, counties clustered in the southeast and central region of the state had the worst measures of the built environment, with the notable exceptions of Florence and Douglas counties (Table 2, Figure 1).

DISCUSSION

The Wisconsin County Health Rankings have reported measures of environmental health since they were first released in 2003. The physical environment summary measure, in particular, has undergone significant revisions since the first edition of the Rankings. In the 2003 edition, the only measure of the physical environment included was the percent of children who tested positive for lead poisoning. Physical environment measures were expanded significantly in 2004, and in 2006 included multiple indicators over 3 constructs: air quality, water quality, and lead risk. Finally, in 2007, we created a new construct, the built environment, by adding 2 new indicators—radon and commuting method—to our lead risk measures.

This study demonstrates that publicly available data can be used to measure the health of the environment of Wisconsin's communities, and that environmental health risk varies across the state. According to our summary measure, counties in southern and southeastern Wisconsin have worse measures of environmental health. Although rural areas have better measures of environmental health, they commonly have lower socioeconomic status, worse health care access, and worse health behaviors. These confounders affect the relationship between current health outcomes and physical environment.

A complication of measuring environmental health is that the effects of environmental exposures on overall health may not result in poor health outcomes immediately, but may evolve over years or even decades. The logic model on which the Rankings are based derives from a framework described by Kindig and Stoddard to portray the relationships among policies and interventions, patterns of health determinants, and health outcomes.[24] In our formulation, a county's rank in health determinants theoretically represents its future health outcomes. A complication of this approach is that the latency between environmental exposures and their effects on health vary greatly or are unknown. Within the physical environment measures, this problem is acute. Though estimates are available for the latency period for negative health effects from individual contaminants, each of our measured pollutants have multiple health effects and different thresholds and latencies for those effects. The NATA measure for cancer risk and its noncancer respiratory hazard index exem-

Table 2. Rankings of Wisconsin's 72 Counties and the City of Milwaukee on Physical Environment Measures

County	Air Quality	Water Quality	Built Environment	Physical Environment Summary
Adams	29	57	6	28
Ashland	2	15	9	6
Barron	27	42	26	23
Bayfield	7	1	3	1
Brown	67	11	42	39
Buffalo	10	41	37	25
Burnett	13	22	8	9
Calumet	52	65	50	69
Chippewa	41	69	52	65
Clark	15	64	19	36
Columbia	53	50	49	55
Crawford	19	59	24	32
Dane	64	72	14	72
Dodge	51	21	71	42
Door	58	52	36	58
Douglas	49	1	43	20
Dunn	35	53	31	35
Eau Claire	54	37	44	40
Florence	3	1	56	16
Fond du Lac	60	32	59	52
Forest	8	30	4	11
Grant	44	40	35	29
Green	50	43	55	46
Green Lake	28	49	46	34
Iowa	14	46	48	30
Iron	5	1	10	5
Jackson	23	36	23	19
Jefferson	55	28	65	51
Juneau	31	34	15	17
Kenosha	71	9	61	59
Kewaunee	56	26	40	37
La Crosse	47	71	38	67
Lafayette	9	29	47	21
Langlade	26	48	64	44
Lincoln	39	63	62	63
Manitowoc	61	27	53	45
Marathon	48	54	73	68
Marinette	33	14	32	14
Marquette	30	58	2	27
Menominee	11	1	5	3
Milwaukee (city)	72	1	29	49
Milwaukee (county)	72	1	54	61
Monroe	38	68	20	48
Oconto	21	19	12	10
Oneida	37	20	22	13
Outagamie	63	1	60	43
Ozaukee	69	33	39	53
Pepin	22	38	27	22
Pierce	40	55	30	38
Polk	32	44	28	26
Portage	42	73	45	71
Price	4	16	16	8
Racine	70	18	67	62
Richland	25	45	18	24
Rock	66	70	69	73
Rusk	17	25	17	12
Sauk	43	66	34	54
Sawyer	12	12	1	2
Shawano	36	56	51	47
Sheboygan	68	24	63	57
St. Croix	46	67	41	56
Taylor	6	31	21	15
Trempealeau	24	51	33	31
Vernon	18	39	13	18
Vilas	1	17	7	4
Walworth	57	23	58	41
Washburn	16	10	11	7
Washington	59	47	70	70
Waukesha	65	35	66	66
Waupaca	34	61	72	64
Waushara	20	60	25	33
Winnebago	62	13	68	50
Wood	45	62	57	60

plify this problem—by combining multiple toxins that result in a variety of conditions, it is nearly impossible to identify what the effect of improving these measures would be on overall health outcomes in the short term. Furthermore, acute exposures to nitrates are associated with blue baby syndrome among young infants, but long-term exposure at low levels may also affect cancer in adults. These disparate outcomes and exposure scenarios are not equally correlated with broad population health determinants.

Limitations exist in the quality of these data, and should be acknowledged when interpreting the results. For instance, the NATA data are based on modeling of emissions, and new estimates are only available periodically. The ozone and $PM_{2.5}$ measures are particularly problematic because of the dearth of air quality monitors in the northern and western regions of the state. Our measures for counties such as Chippewa, Sawyer, and Eau Claire, for example, are based on ozone and $PM_{2.5}$ values from neighboring or even noncontiguous counties. Similarly, though nitrate data are routinely collected for municipal water supplies, testing for private wells is inconsistent. Because Wisconsin is largely a rural state and private well use is common, our

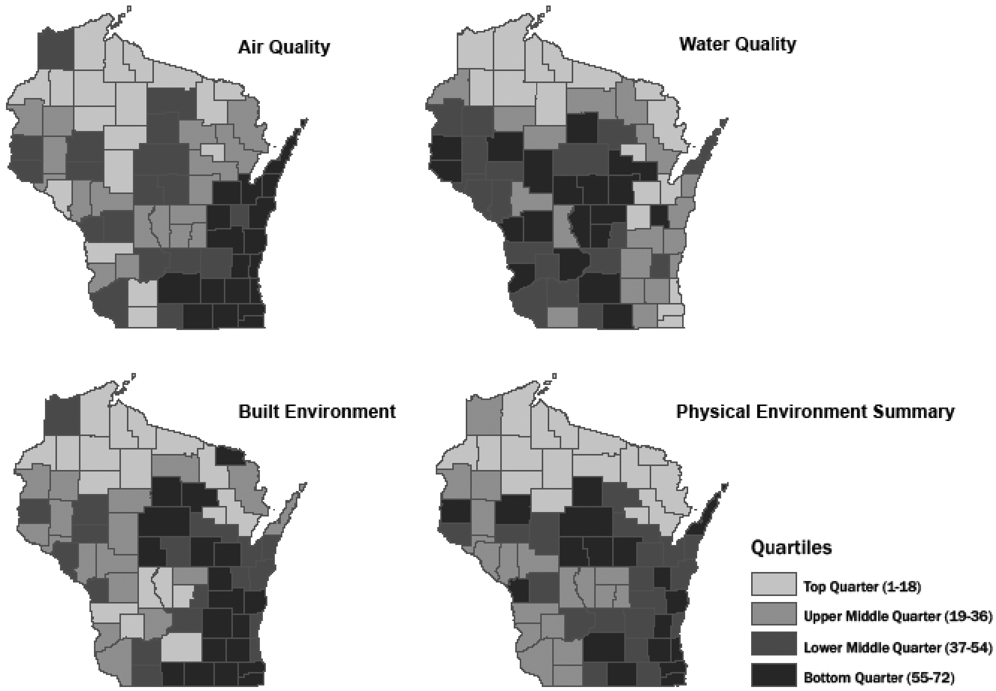

Figure 1. Air quality, water quality, the built environment, and the summary measure of the physical environment, by quartile. These maps represent the ranking of Wisconsin's 72 counties in the 3 physical environment constructs, and for the physical environment summary measure. Once ranked, the counties were divided into quartiles, with the top quartile (ranks 1-18, shaded in light gray) representing better environmental quality and the bottom quartile (ranks 55-72, shaded in black), representing worse environmental quality.

estimates of exposure to nitrates in drinking water in excess of 2 mg/L may not be accurate, and contaminants of primary health concern in more urban areas are not captured with the measure. Two measures, the percent of children testing positive for lead poisoning and the percent of homes with radon levels >10 pCi/L, do not represent random samples. As a result, these indicators may penalize counties that have high-quality screening programs.

Clearly, the availability of good quality and timely public data affect the validity of our environmental health measure. However, the use of publicly available data underscores our focus on applied research that can directly inform policy. The Rankings are intended to serve as a model for local public health agencies mandated to perform community health assessments; reliance on non-public data sources for which we could better control data quality and timeliness would prevent local agencies from using our method as a template. The constraints we face in developing a summary measure of physical environment therefore mirror those faced by local public health agencies. These constraints point to the need for improved data collection on environmental health measures for the purposes of public health assessment, research, and policy development.

The limitations of the physical environment summary measure in terms of data quality and availability do not undermine its usefulness in the policy arena. One goal of the measure is to show where disparities are in environmental health risk in order to inform policy designed to address these disparities. We have also intended the Rankings to highlight well-performing counties as models for counties with poorer environmental health. While the Rankings send a strong message that resources need to be committed to improve the health of poorer, rural counties, our summary measure of the physical environment also gives rural counties the opportunity to demonstrate their strengths.

Improving the Summary Measure of the Physical Environment

Though we believe our physical environment measures for the 2007 Rankings are vitally important constructs to consider, we continue to look for ways to improve the validity, accuracy, and utility of the physical environment summary measure.

The physical environment summary's most limited measure is water quality, which is comprised only of nitrates exposure data. Expanded water quality measures could possibly include results from the Women Infants and Children (WIC) program that tests well water quality in homes with newborns, the number of boil water orders per county, or expanded measures of chemical or bacteria contaminants in municipal water supplies. Unfortunately, as with nitrate data, most of these measures require assumptions to impute values for counties with limited or no data. However, an expansion of the measures we use to assess water quality would better represent the multiple exposures and health risks that result from compromised water supplies.

Though we have begun to measure the built environment in the 2007 edition of the Rankings, we intend to expand our indicators in the future. As noted earlier, the design of the built environment can significantly affect air and water quality as well as personal health behaviors.[7] Percent of municipalities in a county with sidewalk coverage or bike paths and trails, parks and green space per capita, or the percent of local zoning boards that include a public health representative are measures that could be relatively easy to incorporate in future editions of the Rankings.

CONCLUSION

Despite its limitations, the physical environment summary measure in the Wisconsin County Health Rankings has great utility for providing information in a concise format about the health of Wisconsin's communities. Increasing use of these measures by public health professionals will continue to drive revisions in the methods and demonstrate the need for additional data and improved access to data by those who can use the information to make community improvements. We see strong potential for monitoring the quality of the natural and built environments in Wisconsin with hopes of influencing policies that promote more healthful, sustainable communities.

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