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EXECUTIVE SUMMARY

Purpose of the Report: Potential health consequences of environmental exposures from chemical manufacturing or industrial sites have not been well studied for rural populations. The current study examines whether chemical releases from facilities monitored through the Toxics Release Inventory (TRI) program were associated with population mortality rates and birth outcomes for both rural and urban populations. We also examined whether rural and urban areas characterized by poor socioeconomic status or higher percentages of racial minorities had greater TRI releases.

Methods: We used the TRI database, Centers for Disease Control and Prevention age-adjusted mortality data, National Center for Health Statistics birth data, and additional county level covariate data to conduct a national study at the county level of the association between amounts of on-site TRI air and water releases for the years 1988-2006 and several population health outcomes. These outcomes included age-adjusted mortality rates for the years 1999-2006 for cancer, respiratory, cardiovascular, and total causes, and birth outcomes for 2003 including low birth weight, preterm births and birth defects, after controlling for the effects of other risk variables. Rural counties are defined based on rural-urban continuum codes from the USDA: urban counties are metropolitan (codes 1-3) and rural counties are non-metropolitan (codes 4-9).

Results: There were significantly higher adjusted total mortality rates associated with greater air and water releases in both rural and urban counties. The strongest associations between TRI releases and rural mortality rates were found when eight or more prior years of TRI release data were used to study subsequent mortality, but significant effects were also found when releases and mortality were measured concurrently. Effects were found in rural areas for total, cardiovascular, and (marginally) cancer mortality outcomes. We also found that counties with higher percentages of African American populations had more non-zero releases, but did not find this for populations characterized by greater Native American populations, lower income levels or higher poverty. We did not find consistent evidence for higher TRI releases being related to poorer birth outcomes.

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Policy Implications: The results support the use of the TRI as a public reporting tool and demonstrate that greater amounts of air and water TRI releases are related to mortality outcomes for both rural and urban populations. Suggestions for reducing emissions, understanding human health impacts, and for improving rural health care are presented.

BACKGROUND

Research on environmental health hazards for rural populations has focused primarily on agricultural studies. For example, migrant populations exposed to pesticides [1] or persons exposed to Concentrated Animal Feeding Operations (CAFOs) [2, 3] are at risk for health problems resulting from such exposure. Populations that live in rural mining environments have also been shown to experience adverse health consequences from both the environmental and socioeconomic disadvantages prevalent in those regions.[4, 5] Like their urban counterparts, however, rural populations may also be at risk from other pollution sources such as those originating from land development, industry or power generation.[6]

One potential source of hazardous environmental exposure is from facilities that manufacture, process or use chemicals monitored through the Toxics Release Inventory (TRI) program. Chemical releases meeting certain criteria (see Methods for further detail) must be reported to the TRI program, including releases to air, water, or land of a planned or unplanned nature. The TRI program is designed to encourage pollution prevention and waste reduction by increasing public access and knowledge of environmental chemical releases.[7] Previous research on TRI sites and population health outcomes is limited, but includes findings suggesting that such sites pose health risks, especially with regard to air releases. Agarwal et al.[8] found significant associations between TRI air releases and infant mortality rates. Suarez et al.[9] found that mothers in Texas living near TRI sites with chemical air releases had an increased risk for children born with neural tube defects. Boeglin et al.[10] reported a significant association between TRI air releases of volatile organic compounds (VOCs) and the incidence of some types of cancers in an Indiana sample. A previous national study of TRI sites indicated that 16,574 such sites existed in rural counties, but found no association between the number of sites per square mile and population mortality rates;[6] however, the study only calculated the density of sites and did not consider the amounts of actual chemical releases from these sites.

In this study, we used the TRI database, Centers for Disease Control and Prevention (CDC) mortality data, and National Center for Health Statistics (NCHS) birth data to investigate the association between air and water chemical releases and age-adjusted mortality rates and birth outcomes nationally at the county level, with an emphasis on comparative effects that may be present for rural and urban counties. Mortality rates include all-cause, cancer, cardiovascular, and respiratory mortality. Birth outcomes include rates of low birth weight, preterm birth, and birth defects. We test the hypothesis that greater amounts of releases into air and water will be associated with poor health outcomes across all measures in both rural and urban counties, after controlling statistically for the effects of other risk variables. We also examine whether exposures may be greater for rural and urban populations defined by socioeconomic status or race.

METHODS

TRI database

The TRI database was established under the 1986 Emergency Planning and Community Right-to-Know Act (EPCRA).[7] EPCRA requires manufacturing facilities that have 10 or more full-time employees and manufacture or process over 25,000 pounds annually or otherwise use more than 10,000 pounds of any chemical specified on the TRI list to report annually their estimated releases and transfers of those chemicals to the U.S. Environmental Protection

Agency (EPA). Releases include unplanned spills and routine emissions of chemicals released directly to the air and land, injected into land, discharged to surface water, transferred to publicly owned sewage treatment plants, or transferred to other off-site locations for recycling and waste disposal. The list of reportable chemicals has changed over time, but as of 2010 it included 666 chemicals and chemical categories. For the current study we limit releases to on-site planned or unplanned releases to air or surface water.

Measurements of exposure

We used the TRI database to extract total TRI on-site releases for the period of time 1988-2006. TRI data collection began in 1987 but we excluded 1987 releases because the dataset was still developmental and incomplete during its first year of operation. We included two measures of on-site releases, those occurring into surface water sources, and those occurring to the air including both fugitive and stack emissions. The Toxic Release Inventory dataset was provided by the EPA in the TRI Basic Data File Format. Per our request, the data was provided in state by state files for all available years. [11] State files were processed individually and both tabular and geographic datasets were developed and carefully checked for errors. Following this, we developed nationwide datasets by year. These datasets were used to derive future subsets of specific fields for more in depth analysis and also, of course, to create fields that aggregated years. Derivation of variables used in this analysis (on site releases into air or water) required the aggregation of several fields. We utilized the "TRI Basic Data File Format Documentation" as well as EPA personnel to ensure correct interpretation of the dataset.

For both air and water discharges, we calculated the release at the county level measured in pounds summed over the combined years. The amounts of both air and water releases were found to be non-normally distributed and therefore we conducted a natural logarithm transformation of the non-zero county-level release amounts for the analysis.

National Center for Health Statistics (NCHS) birth data

From the NCHS we obtained birth data on all live births occurring in the United States in 2003. As distinct from other datasets in this study, the NCHS data is a person-level dataset, with a record for each of the over 4 million births that year. Dependent variables of interest for the current study include whether the birth was preterm (<37 weeks), low weight (< 2500 grams), or had any of the 22 types of birth defects recorded in the dataset. Covariates of interest include mother's age, prenatal care, whether or not the mother reported either smoking or alcohol use during pregnancy, race/ethnicity (African American, Native American, or Hispanic, with non-Hispanic White as the referent), sex of the infant, mother's co-occurring diabetes, and mother's years of education. Mother's age was re-coded into <35 vs. 35 years or over. Prenatal care was re-coded into low (less than 8 visits) vs. high (9 or more visits.)

CDC mortality database

The Centers for Disease Control and Prevention (CDC) Wonder database contains age-adjusted county-level mortality data for the years 1999-2006 based on ICD-10 classifications.[12] For this study, mean mortality rates were found combined across years and age-adjusted using the standard 2000 US Census population. Mortality from all internal causes was included (mortality from accident or intentional injuries was excluded.)

We also analyzed mortality rates for all types of cancer, and for chronic or unspecified forms of cardiovascular and respiratory disease. Forms of cardiovascular disease included heart failure, chronic ischemic heart disease and others due to long term effects of cardiovascular disease such as stroke and heart attack. Forms of respiratory disease included chronic and unspecified disease such as asthma, emphysema, and bronchitis, but excluded known acute cases such as pneumonia. We retained classifications where the acute or chronic nature of the illness was unknown (e.g., "respiratory disorder, unspecified"). Acute forms of cardiovascular or respiratory diseases were excluded under the assumption that exposure effects occur at low dose levels over time and would be more likely to lead to the development of chronic disease or exacerbate existing chronic illness, rather than cause acute disease mortality.

Covariates and rural-urban classification

County attributes data were extracted from the 2005 Area Resource File to gather data on potential confounders, including proportions of the population who were African American, Native American, Asian American, and Hispanic (percent White was used as the referent in regression models), percent male population, percent population without a high school education, percent with college or higher education (percent with high school education was used as the referent in regression models), percent of the population below the federal poverty level, and the number of active, non-federal primary care doctors per 1,000 population. Most of these indicators were from the 2000 US Census although poverty rate was the average of the years 2000-2002. Prevalence of smoking for each county was obtained from Behavioral Risk Factor Surveillance System (BRFSS) data based on samples conducted in 2003 and 2006, supplemented with additional county estimates based on review of state public health department websites. Obesity rates for each county were taken from the US Department of Agriculture (USDA) Food Atlas,[13] which in turn is based on CDC BRFSS survey and US Census estimates for the years 2006-2008. Rural-urban continuum codes from the USDA were used to categorize counties into metropolitan (codes 1-3) or non-metropolitan (codes 4-9) areas.

Statistical analysis

Age-adjusted mortality rates were linked with TRI releases and covariates at the county level. The dataset included all 50 states and the District of Columbia. A descriptive summary of study variables was calculated. A set of exploratory multiple linear regression analyses were conducted to test temporal relationships between TRI discharges from 1988 to 2006 and mortality from 1999-2006: we tested whether associations between TRI discharges and mortality were dependent on the number of years that discharges were assessed, and whether they were dependent on discharges concurrent with or prior to the years covered by the mortality data.

Univariate and multivariate ordinary least squares linear regression analyses were used to determine the association of age-adjusted mortality rates with amounts of TRI on-site air and water releases. In the multivariate analyses, we adjusted for potential confounders indicated above. We assessed these associations separately for both metropolitan and non-metropolitan counties. The terms "rural" and "non-metropolitan" are used interchangeably in this study.

The dichotomous measures of birth outcomes were examined using logistic regression controlling for the covariates noted above in the birth data. For this analysis, because births were limited to the year 2003, we limited TRI discharges to those occurring in 2002 and 2003 to approximate releases that were occurring during pregnancy.

We used linear models to test whether the percent of minority populations (percent African American, Native American, and Hispanic), percent poverty, lower per capita income, and lower percent with college education, were higher in counties with higher levels of TRI discharges. We conducted these tests for all counties and separately for rural and urban counties. For this analysis we combined air and water discharges into a measure of total TRI discharges.

Statistical Analysis Software (SAS) version 9.1 and ESRI Arc GIS were used for analyses.

RESULTS

Table 1 presents sociodemographic characteristics of the study population, and summarizes air and water discharges. In rural counties, the mean county-level air chemical discharge totaled over 2.6 million pounds for the combined years 1988-1998, and mean county-level water discharges totaled more than half a million pounds. In urban counties, the mean discharges totaled more than 12 million pounds to air and over one million pounds to water. Figures 1 and 2 show the distribution of TRI air and water release quantities across rural-urban counties.

Table 1: Descriptive summary of study variables for rural, urban, and combined counties. Figures are means and standard deviations in parentheses.

	Rural	***Urban***	***Combined***
N of counties	2,049	1,093	3,142
Annual age-adjusted mortality rate per 100,000 for 1999-2006	813.7 (133.5)	812.3 (105.1)	813.2 (124.4)
Smoking rate	22.1 (4.1)	21.2 (4.7)	21.8 (4.3)
Obesity rate	28.6 (3.6)	27.7 (3.6)	28.3 (3.6)
Percent male population	49.9 (2.0)	49.6 (1.4)	49.8 (1.8)
Active primary care doctors per 1,000	1.00 (0.94)	1.90 (1.83)	1.32 (1.39)
Poverty rate	14.9 (5.7)	11.2 (4.5)	13.6 (5.6)
Percent African American	7.9 (14.9)	10.9 (13.8)	8.9 (14.6)
Percent Native American	2.6 (9.2)	0.8 (2.1)	1.9 (7.6)
Percent Hispanic	6.3 (12.8)	6.9 (11.3)	6.5 (12.3)
Percent Asian American	0.5 (1.6)	1.7 (3.0)	0.9 (2.3)
Percent without high school education	24.1 (9.0)	19.8 (7.6)	22.6 (8.8)
Percent with college education or higher	14.4 (5.7)	20.5 (9.4)	16.5 (7.8)
County total air releases 1988-1998 in 1000 pounds	2617.1 (7582.0)	12005.4 (29638.6)	5883.0 (19049.5)
Log of county total air releases 1988-1998 in pounds	3.81 (3.36)	6.46 (3.11)	10.4 (6.4)
County total water releases 1988-1998 in 1000 pounds	535.5 (15545.8)	1097.7 (8217.7)	731.1 (13458.2)
Log of county total water releases 1988-1998 in pounds	0.88 (1.94)	6.93 (5.61)	4.60 (5.44)

Figure 1: TRI Air Releases 1988-1998

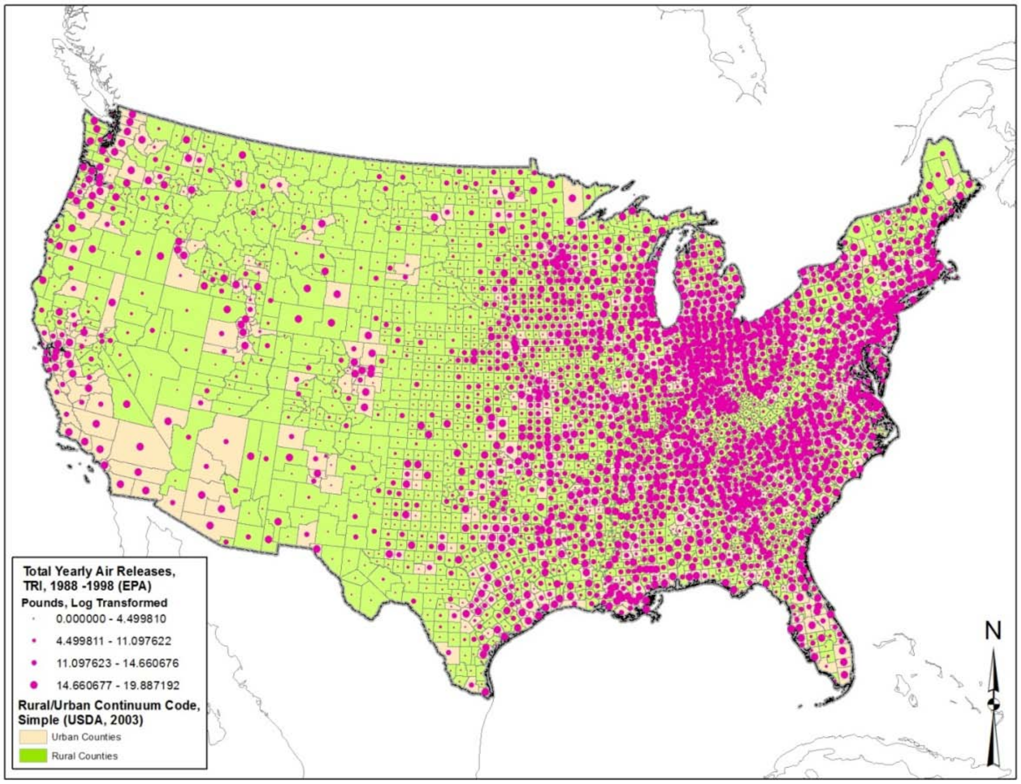
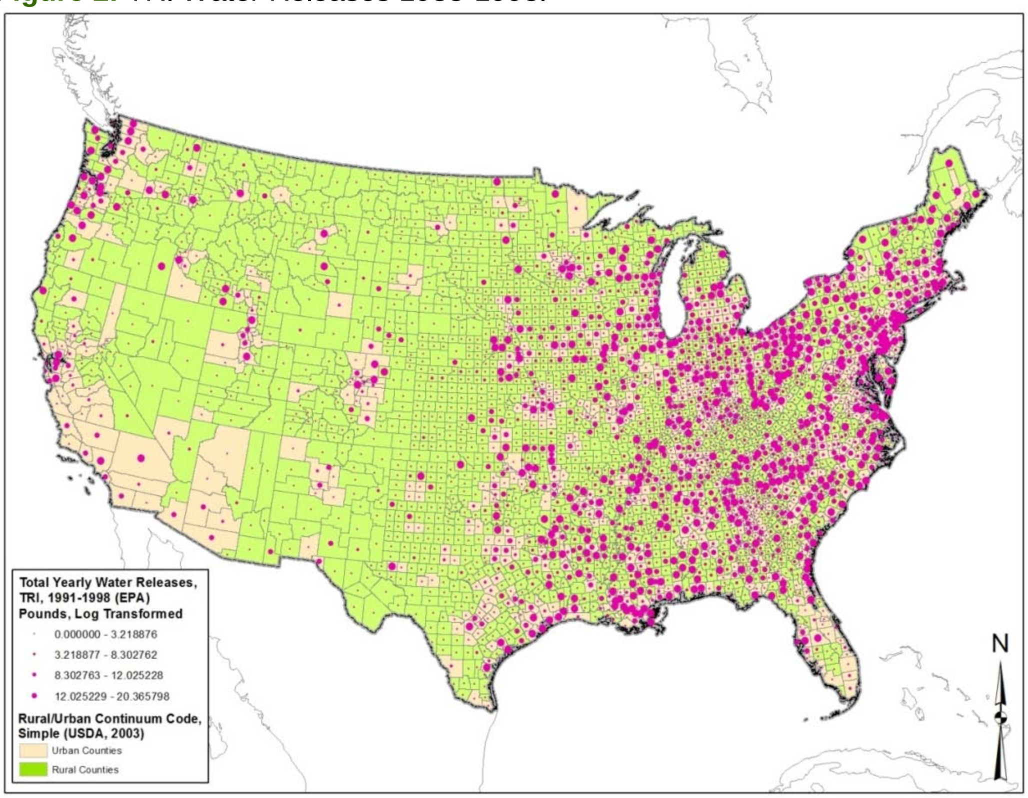


Figure 2: TRI Water Releases 1988-1998.



The five highest quantity chemical releases to air were for methanol, toluene, ammonia, xylene, and acetone. The five highest quantity chemical releases to water were for sodium sulfate, phosphoric acid, nitrate compounds, ammonia, and ammonium sulfate solution. Other releases to air and/or water included many chemicals known to be harmful to human health including arsenic, cyanide, benzenes, cadmium, mercury, polycyclic aromatic hydrocarbons, and others, including hundreds of compounds in various chemical classifications.

Results of exploratory temporal analysis.

A multiple regression analysis with covariates was conducted using TRI discharge amounts in rural counties for the eight years 1999-2006 as the primary independent variable, and age-adjusted mortality rates for the same years 1999-2006 as the dependent variable. The results showed significant associations between mortality rates and air and water discharges in rural areas with p values ranging from $p<.02$ to $p<.002$. In contrast, effects for TRI air discharges in the eight years prior to the years of mortality data (1991-1998) were significant in all tests at slightly stronger levels, $p<.02$ to $p<.0001$, and did not improve by adding additional earlier years of TRI discharge data. However, to use the greatest amount of prior discharge data we included TRI discharges for the years 1988 through 1998 for the final linear regression models presented in the next section (and the results shown in Table 1), and used mortality rates for the eight-year period 1999-2006. Measuring discharges in one period of time and mortality outcomes later in time allows us to estimate associations between earlier discharges and subsequent illness development.

Final model results for urban and rural areas.

Final linear regression results for total mortality for rural and urban areas, and overall, are presented in Table 2. A higher quantity of both water and air discharges was significantly related to higher total age-adjusted mortality rates in both rural and urban settings, and in the combined rural-urban analysis. The effects appear to be strongest for air releases in rural areas, but were significant for all tests. Figure 3 shows the age-adjusted mortality rate distribution across the country.

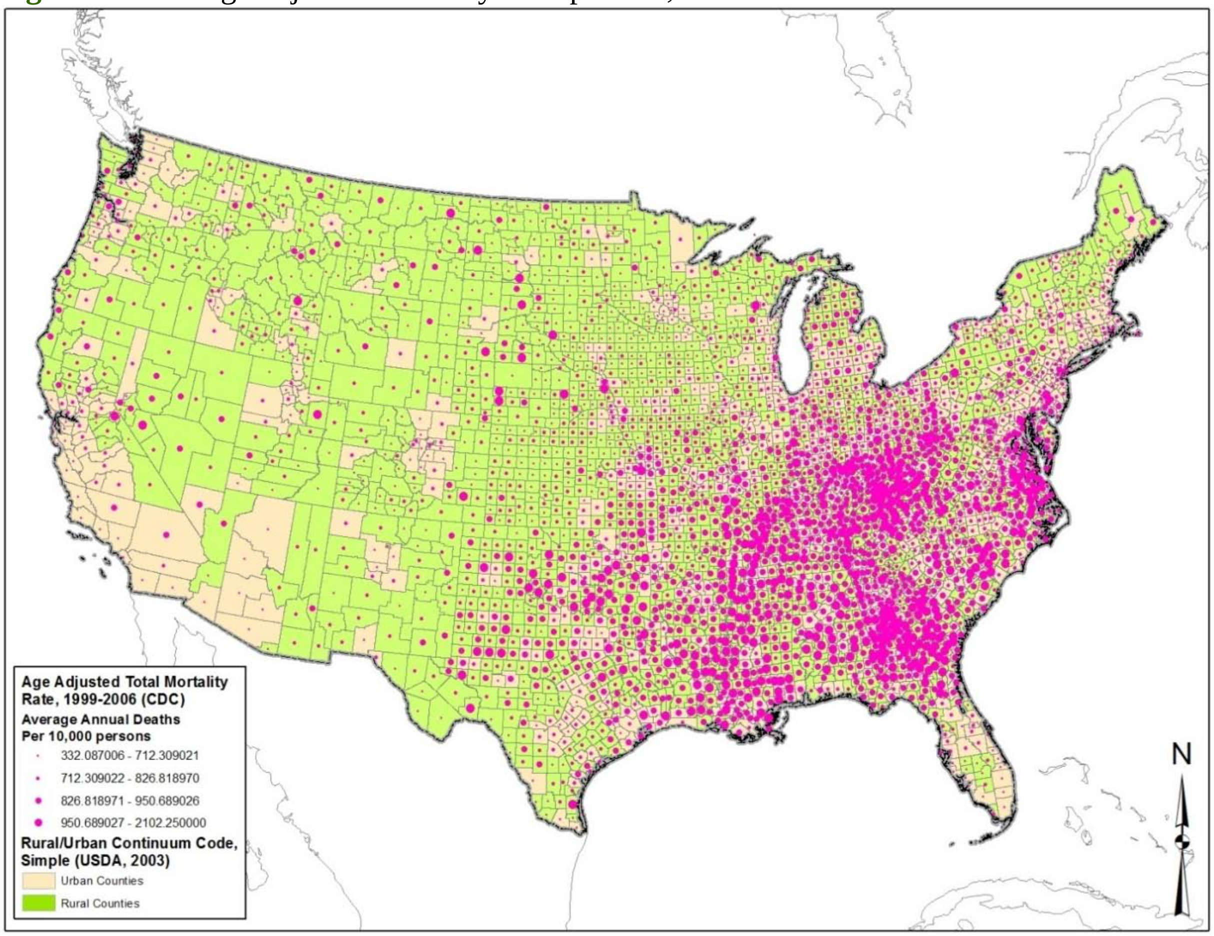
Table 2: Results of multiple linear regression analyses on total internal-cause age-adjusted mortality rates 1999-2006 for rural, urban, and combined counties.

Variable	Rural [1]	Urban [1]	Combined [1]
Adjusted R-square	.47	.60	.50
Smoking rate	3.88 (0.64) [5]	3.02 (0.54) [5]	3.76 (0.45) [5]
Obesity rate	3.85 (0.92) [5]	5.11 (0.89) [5]	4.38 (0.68) [5]
Percent male population	-1.36 (1.12)	3.42 (1.52) [2]	-0.13 (0.90)
Active primary care doctors per 1,000	7.02 (2.63) [3]	0.56 (1.57)	3.10 (1.52) [2]
Poverty rate	3.84 (0.66) [5]	4.58 (0.78) [5]	3.69 (0.51) [5]
Percent African American	1.06 (0.22) [5]	1.44 (0.20) [5]	1.17 (0.16) [5]
Percent Native American	1.08 (0.27) [5]	-1.20 (1.00)	0.95 (0.24) [5]
Percent Hispanic	-1.39 (0.21) [5]	-2.42 (0.24) [5]	-1.71 (0.16) [5]
Percent Asian American	1.49 (1.37)	-0.78 (0.81)	-0.30 (0.79)
Percent without high school education	4.54 (0.48) [5]	3.16 (0.54) [5]	4.38 (0.36) [5]
Percent with college education or higher	-1.64 (0.59) [3]	-0.87 (0.45)	-1.11 (0.38) [3]
Metropolitan county (yes/no)	--	--	30.53 (3.93) [5]

Log of air releases 1991-1998 in pounds	1.95 (0.43) [5]	1.14 (0.53) [2]	1.68 (0.33) [5]
Log of water releases 1991-1998 in pounds	1.21 (0.54) [2]	1.28 (0.47) [3]	1.23 (0.38) [3]

1) Cell values are unstandardized regression coefficients with standard errors in parentheses.
2) p<.05; 3) p<.01; 4) p<.001; 5) p<.0001

Figure 3: Total age-adjusted mortality rates per 100,000.



Effects of covariates operated as expected – higher mortality rates were associated with such risk factors as smoking, obesity, poverty, low education, and some racial minority variables. In the combined model, higher mortality rates were found in urban counties relative to rural.

Tables 3-5 have final results for cancer, respiratory and cardiovascular outcomes, respectively. For cancer (Table 3), the only significant effect was for water discharges in urban counties. However, the effects of air discharges in rural areas was marginally significant (p<.09). In other research that we are currently developing, we are finding that *lung* cancer incidence and mortality are related to higher levels of TRI air and water discharges, but these findings will be reported separately.[14-15]

Table 3: Results of multiple linear regression analyses on age-adjusted cancer mortality rates 1999-2006 for rural, urban, and combined counties.

Variable	Rural [1]	Urban [1]	Combined [1]
Adjusted R-square	.22	.42	.24
Smoking rate	0.92 (0.24) [5]	0.89 (0.15) [5]	0.89 (0.16) [5]
Obesity rate	0.15 (0.34)	0.63 (0.24) 3	0.32 (0.24)
Percent male population	-1.20 (0.42) [3]	0.16 (0.41)	-1.01 (0.32) [3]
Active primary care doctors per 1,000	4.63 (0.98) [5]	0.85 (0.43) [2]	2.29 (0.54) [5]
Poverty rate	1.55 (0.25) [5]	0.38 (0.21)	1.19 (0.18) [5]
Percent African American	0.11 (0.08)	0.28 (0.05) [5]	0.15 (0.06) [3]
Percent Native American	0.16 (0.10)	-0.41 (0.27)	0.15 (0.06)
Percent Hispanic	-0.67 (0.08) [5]	-0.63 (0.07) [5]	-0.70 (0.06) [5]
Percent Asian American	-1.88 (0.51) [4]	-0.14 (0.22)	-0.72 (0.28) [2]
Percent without high school education	0.21 (0.18)	0.55 (0.15) [4]	0.44 (0.13) [4]
Percent with college education or higher	-1.22 (0.22) [5]	-0.31 (0.12) [2]	-0.63 (0.14) [5]
Metropolitan county (yes/no)	--	--	9.44 (1.40) [5]
Log of air releases 1991-1998 in pounds	0.25 (0.16)	-0.01 (0.14)	0.23 (0.12)
Log of water releases 1991-1998 in pounds	0.22 (0.20)	0.28 (0.13) [5]	0.22 (0.14)

1) Cell values are unstandardized regression coefficients with standard errors in parentheses.
2) p<.05; 3) p<.01; 4) p<.001; 5) p<.0001

Table 4: Results of multiple linear regression analyses on age-adjusted non-acute respiratory disease mortality rates 1999-2006 for rural, urban, and combined counties.

Variable	Rural 1	Urban 1	Combined 1
Adjusted R-square	.10	.25	.11
Smoking rate	0.34 (0.17) 2	0.29 (0.10) 3	0.33 (0.11) 3
Obesity rate	-0.07 (0.29)	0.24 (0.16)	0.04 (0.17)
Percent male population	0.63 (0.29) 2	0.64 (0.29) 2	0.62 (0.22) 3
Active primary care doctors per 1,000	3.95 (0.68) 5	0.13 (0.29)	1.53 (0.37) 5
Poverty rate	1.26 (0.17) 5	0.74 (0.15) 5	1.07 (0.13) 5
Percent African American	-0.27 (0.06) 5	-0.18 (0.04) 5	-0.25 (0.04) 5
Percent Native American	-0.23 (0.07) 3	-0.02 (0.18)	-0.23 (0.06) 4
Percent Hispanic	-0.31 (0.06) 5	-0.24 (0.04) 5	-0.31 (0.04) 5
Percent Asian American	-0.62 (0.35)	-0.22 (0.15)	-0.40 (0.19) 2
Percent without high school education	0.02 (0.13)	-0.04 (0.10)	0.06 (0.09)
Percent with college education or higher	-0.69 (0.15) 5	-0.33 (0.08) 5	-0.46 (0.09) 5
Metropolitan county (yes/no)	--	--	5.40 (0.97) 5
Log of air releases 1991-1998 in pounds	0.18 (0.11)	-0.21 (0.10) 2	0.12 (0.08)

Log of water releases 1991-1998 in pounds	-0.11 (0.14)	0.008 (0.09)	-0.10 (0.09)

1) Cell values are unstandardized regression coefficients with standard errors in parentheses.
2) p<.05; 3) p<.01; 4) p<.001; 5) p<.0001

Table 5: Results of multiple linear regression analyses on age-adjusted non-acute cardiovascular disease mortality rates 1999-2006 for rural, urban, and combined counties.

Variable	Rural 1	Urban 1	Combined 1
Adjusted R-square	.44	.54	.45
Smoking rate	2.07 (0.36) 5	1.08 (0.29) 4	1.62 (0.25) 5
Obesity rate	2.19 (0.53) 5	2.83 (0.48) 5	2.47 (0.38) 5
Percent male population	-2.72 (0.63) 5	1.73 (0.82) 2	-1.96 (0.51) 5
Active primary care doctors per 1,000	2.45 (1.50)	-1.62 (0.85)	-0.47 (0.86)
Poverty rate	3.04 (0.38) 5	2.11 (0.42) 5	2.70 (0.29) 5
Percent African American	0.61 (0.12) 5	0.53 (0.11) 5	0.54 (0.09) 5
Percent Native American	-0.16 (0.16)	-1.20 (0.54) 2	-0.25 (0.13)
Percent Hispanic	-0.82 (0.12) 5	-1.00 (0.13) 5	-0.94 (0.09) 5
Percent Asian American	-2.13 (0.78) 3	0.91 (0.44) 2	-0.12 (0.45)
Percent without high school education	1.20 (0.27) 5	1.58 (0.29) 5	1.59 (0.20) 5
Percent with college education or higher	-1.75 (0.33) 5	-0.63 (0.25) 2	-0.93 (0.21) 5
Metropolitan county (yes/no)	--	--	11.46 (2.23) 5
Log of air releases 1991-1998 in pounds	1.22 (0.24) 5	0.32 (0.29)	1.11 (0.19) 5
Log of water releases 1991-1998 in pounds	0.39 (0.31)	0.43 (0.25)	0.31 (0.22)

1) Cell values are unstandardized regression coefficients with standard errors in parentheses.
2) p<.05; 3) p<.01; 4) p<.001; 5) p<.0001

For respiratory mortality outcomes (Table 4), we found no significant effects. There was one negative association between higher air discharges and lower mortality rates in urban areas, but this likely represents a spurious statistical artifact.

For cardiovascular outcomes (Table 5), greater TRI air discharges were significantly associated with higher mortality rates in rural areas and in the combined analysis; in urban areas the effect of greater air discharges was marginally significant (p<.07). The effect for greater water discharges in rural areas was also marginally significant (p<.09).

TRI discharges and birth outcomes

There were a total of 2,995,803 live births in 2003 with complete data on all variables of interest. (The total number of live births was 3,908,133 but missing data on one or more variables reduced the sample by almost 1 million cases.) The results of the logistic regression analyses found an inconsistent pattern or positive, negative, and null associations between higher TRI discharges to air or water, and greater risk for any of the three birth outcomes (preterm delivery, low birth weight, or birth defects) for rural, urban, or combined areas (results not shown). We attribute this pattern to the very large sample size, such that even small and probably chance variation results in significant findings even at p values < .0001. Because of this pattern we decided not to further analyze or attempt to interpret the results of this analysis.

TRI discharges by race and socioeconomic variables

Contrary to expectations, we found that, with one notable exception, higher TRI discharges were associated with populations with higher income, more college education, and lower poverty rates (Table 6). The exception was that rural areas with more college educated populations had lower TRI discharge amounts. We also found that areas with higher percentages of Native American populations had lower TRI discharges. This was the case for both rural and urban areas. We did find, however, that both rural and urban areas with higher percentages of African American populations had greater TRI discharges per county. These results only show bivariate associations and are not adjusted for other covariates.

Table 6: Results of linear regression analyses on effects of race/ethnicity and socioeconomic indicators on total of air and water TRI discharges in log tons for 1991-1998, for rural, urban, and combined counties.

Variable	Rural 1	Urban 1	Combined 1
Percent African American	0.15 (0.01) 5	0.07 (0.02) 4	0.15 (0.01) 5
Percent Native American	-0.17 (0.02) 5	-0.28 (0.14) 2	-0.22 (0.02) 5
	-0.13 (0.02) 5	-0.001 (0.03)	-0.08 (0.02) 5
Percent with college education or higher	-0.17 (0.04) 5	0.17 (0.03) 5	0.20 (0.02) 5
Poverty rate	-0.19 (0.04) 5	-0.10 (0.06)	-0.35 (0.03) 5
Per capita income 2000-2002	.0002 (.00005) 4	.0003 (.00004) 5	.0004 (.00003) 5

1) Cell values are unstandardized regression coefficients with standard errors in parentheses.
2) p<.05; 3) p<.01; 4) p<.001; 5) p<.0001

Discussion

In rural areas, population all-cause mortality rates were sensitive to the amounts of TRI chemical discharges through both on-site air and water release routes. The effects were present at the strongest levels when eight or more years of prior discharge data were included, but were also significant when discharges and mortality were measured concurrently. The significance level was greater for the measure of air release compared to water release. In urban areas, higher amounts of both water and air chemical releases in the years prior to the mortality data time period were also associated with higher adjusted mortality rates. A previous analysis that counted only TRI sites per square mile[6] did not find a significant relationship between this measure and mortality outcomes, suggesting that the quantities of chemicals released are important over and above potential geographic or population confounds associated with the location of TRI facilities. The distribution of releases shown in Figure 1 indicates that release quantities are higher in the eastern half of the country, and are concentrated in portions of the Midwest (e.g., Ohio and Indiana), Northeast, and South.

Analyses conducted for more specific disease groups showed less strong effects. This may be because the exposure effects are small within disease categories and require cumulative effects across categories to become more apparent. The specific categories of disease that we examined do not include all causes (excluded forms include kidney disease and diabetes, for example). On the other hand, it is also possible that we would find stronger effects if we examined even more specific forms of illness that are related more clearly to exposure effects. In the case of cancer, for example, we have conducted additional analyses showing that both incidence and mortality from lung cancer are related to higher TRI discharges in rural areas.[14-15]

Although we focused on TRI discharges for an eleven-year period prior to the years of mortality data, the results were only slightly different, and the TRI effects remained significant when measuring TRI discharges over the same time as the mortality data. It may be the case that both short-term and long term discharges can impact health outcomes, as has been found in other research on effects of environmental pollutants.[16-18] It may also be the case that earlier discharges at the county-level serve as a proxy for concurrent discharges, or vice versa; that is, that counties with higher or lower discharges tend to be stable in that regard over time, such that we cannot extract effects specific to short- or long-term exposure. Or it may be that unmeasured confounds correlated with both TRI discharges and mortality outcomes influence the observed associations. Additional research is necessary to better identify the potential temporal relationships between TRI exposures and population-level morbidity and mortality outcomes.

Counties with higher percentages of African American populations had significantly higher TRI discharge amounts, in both rural and urban counties. The association between African American populations and TRI discharges may be a result of sub-county residential proximity to more localized industrial facilities, or may be the result of higher exposure to releases in occupational settings among African Americans, although our data cannot answer this question. This possibility is supported by prior research showing that sources of pollution are often located in or near poor working-class communities and disadvantaged groups, which may result in African American populations being at increased risk for exposure to environmental hazards compared to other groups.[19-22]

However, we also note that education, income, and poverty levels were not worse in association with TRI releases, suggesting that economic opportunities may be higher in areas where TRI activity takes place. It is possible that relationships between pollutant discharges and socioeconomic indicators are nonlinear. An interesting finding that operated in opposite direction to this general pattern was that rural areas with more highly college educated populations had lower TRI discharge amounts; why this would be the case is unclear, but may reflect unique features of more educated rural communities, perhaps related to the presence of colleges or universities, or other specialized economies requiring educated workforces that consist of non-industrial activity.

The negative association between Native American populations and TRI discharges may reflect those areas that have larger Native American populations, which tend to be in less populated, more rural areas of the West where relatively little industrial activity takes place.

We found significant effects between TRI discharge amounts and birth outcomes, but those effects appeared to represent chance variation in the outcomes due to the very large sample sizes. It may be that the general TRI release measure was too crude relative to examining release of specific chemicals known to have impacts on reproductive outcomes. The timing between discharges and pregnancy exposures was imprecise. Only one year of birth outcomes was studied. Birth certificate data on such factors as the rates of birth defects and risk behaviors are known to be underestimated.[23] Despite the fact that TRI discharges at local levels have been linked to poor reproductive outcomes,[8-9] TRI discharges at the general county population level may require different sampling and analytic strategies to identify whether or not effects are present.

Limitations of the study include those imposed by the ecological study design. We have county-level aggregate data and not individual-level data on exposures, covariates and outcomes (although we do have individual-level data on birth outcomes and covariates). However, as noted above, there was an important effect of the amount of chemical release compared to the non-significant finding when only the TRI locations were considered, suggesting that amounts of discharges are important over the effect of the facilities' locations relative to other population risks. An additional limitation is that we measured exposure in tons grouped across all chemicals, but the toxicity effects of tons are not equal across chemicals. Weighting systems have been proposed [24] but the chemical listings are incomplete and the systems are not well validated against population health outcomes. Future research can investigate water and air TRI discharges in rural areas specific to chemical and to health outcome.

Conclusions and Policy Implications

The results support the use of the TRI as a public reporting tool and demonstrate that higher quantities of chemical releases from TRI sites were related to mortality outcomes for both rural and urban populations. The effects for rural populations were most apparent for all-cause mortality and for air releases, although significant effects were present for water releases in rural areas as well.

Although the TRI is designed to reduce pollution discharges and thereby improve environmental health, the results suggest that additional efforts are needed to realize this goal. These efforts can include improved safety practices to reduce accidental discharges. Policies that encourage alternative manufacturing or disposal practices may also be beneficial. These might include policies encouraging the discovery and use of alternative chemicals with less toxic properties. Other possibilities include disposal practices that involve capture and storage or treatment of chemicals prior to air or water release, so that the amounts released are reduced or rendered benign. In some cases industrial waste recycling may be possible: chemicals that are treated as waste in one process may be valuable as inputs in another process through recycling or capture and sale of a chemical.

The precautionary principle in environmental science[25] states that policies that protect human health in the face of uncertain risk are appropriate. The logic behind this position is similar to the medical dictum to “do no harm.” That is, even though cause and effect relationships are not fully established scientifically, preventive actions to reduce human exposures to potential environmental agents are appropriate. This principle can be used in support of efforts to understand and reduce human exposures. Understanding those exposures requires further research into the actual exposures that people experience; the TRI documents releases but does not attempt to determine what people are exposed to, and research to make these connections explicit would be valuable. Reducing exposures may require attention to issues such as environmental justice: African American populations were disproportionately exposed to higher TRI release levels. Reducing exposures may be advanced by improved zoning practices to distance industrial facilities from residential areas, and by efforts described above to reduce the amounts and types of releases.

Finally, persons interested in rural health care delivery can be cognizant of the fact that industrial chemical emissions are not limited to metropolitan areas and may affect rural populations throughout the United States as well. Rural health care providers can make more fully informed diagnostic and treatment decisions for particular patients when they are aware of potential environmental exposures that their patients face. Providers may thus wish to be aware of TRI facilities as well as other potential environmental problems in their practice area.

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Additional Information

See the Full Report that corresponds to this Brief for more detailed methods and findings from this study at: http://wvrhrc.hsc.wvu.edu/projects/2010/hendryx/