Throwing the Baby Out with the Ashwater? Coal Combustion Residuals, Water Quality, and Fetal Health

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[1] The views expressed in this presentation do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency (EPA).

Motivation

Figure: The Buck Steam Station's Ash Pond near Dukeville, NC *(Source: Les Stone — Greenpeace)* ▸ Coal ash constituent compounds.

Contribution and Regulatory Relevance

- A puzzle: U.S. surface water regulations have an average benefit-cost ratio of 0.37 despite spending $1.9T since 1960 [Keiser, Kling, Shapiro (2019)].
- An important missing benefit: drinking water and human health.
- Steam Electric Effluent Limitation Guideline BCA does not quantify drinking water safety benefits.
    - Water systems are legally bound to comply with the SDWA.
    - Drinking water from systems in compliance does not pose an appreciable health risk.

Figure: Wastewater discharge location for the Barry Electric Generating Plant near Bucks, AL
(Source: Alabama Public Radio via EPA)

Research Questions

1. How does coal ash water pollution affect nearby surface waters?
2. How does coal ash water pollution affect drinking water quality?
3. Are there fetal health consequences of coal ash water pollution?
4. How much are homeowners willing to pay to avoid exposure to coal ash water pollution?

Research Questions: Overview of Findings

1. How does coal ash water pollution affect nearby surface waters?
    - Waters affected by coal ash are have substantially altered properties and more pollutants. Mixed evidence on whether these changes are driven by contemporaneous releases.
2. How does coal ash water pollution affect municipal water quality?
    - Municipal water systems sourcing from coal ash-affected waters have more health-based and MCL SDWA violations. They also have more lead and higher conductivity in years when more coal ash is released upstream.
3. Are there fetal health consequences of coal ash water pollution?
    - Compared to unexposed siblings, affected siblings are 1.2 ounces lighter, 1.7 PP more likely to have low birthweight, and 1.2 PP more likely to be preterm. Mixed evidence on whether these impacts are driven by contemporaneous releases.
4. How has this form of pollution affected home values?
    - Home sale prices within 1-mile of ash ponds declined by $37K after home well testing revealed unsafe drinking water.

Part I: Municipal Drinking Water Quality

Intuition of the Approach

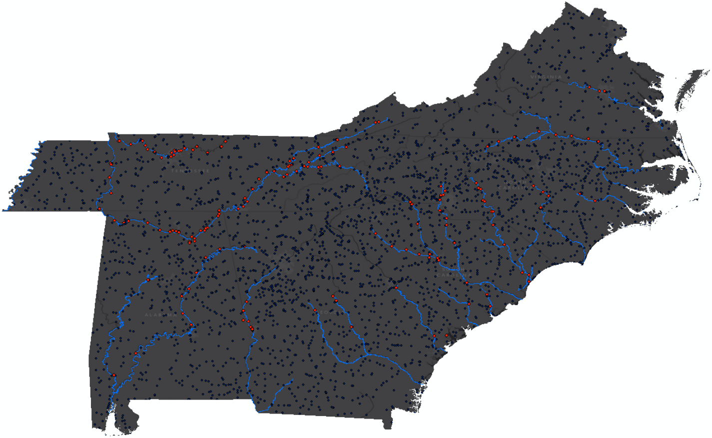


Figure: Water Systems Affected by Coal Ash Water Pollution (n=193)
Source: Southern Environmental Law Center ▸ Coal Sites and Downstream Rivers.

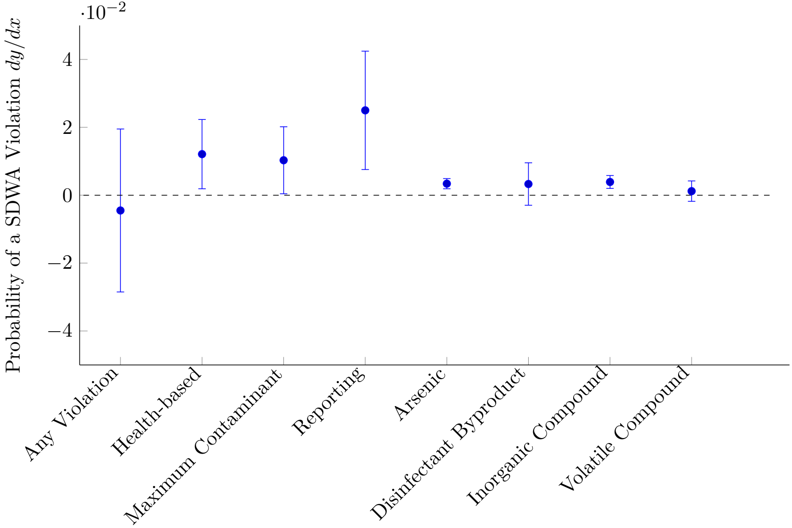
Empirical Strategy: SDWA Violations

Let Vio_{it} be a binary indicator for a SDWA violation for municipal water system i in year t.

$$Pr(Vio_{it} = 1) = \Phi(\beta Ash_{it} + X_{it}\gamma' + \eta_i + \eta_t) \tag{1}$$

- **Data:** Safe Drinking Water Inventory System for AL, GA, NC, SC, TN & VA from 2000-2018. ▸ Summary Statistics
    - Ash_{it} is a binary measure of upstream releases within 25 miles, where this variable is set to zero if the water system is not sourcing from coal-ash affected waters.
    - X_{it} includes dummy variables for water system size category, water source type, system type, school water system, protected source-water, and water system age.
    - η_i and η_t are water-system and year random effects.
- Identification requires that $E(\epsilon_{ist}|Ash_{it}, X_{it}, \eta_i, \eta_t) = 0$ i.e. coal ash releases are exogenous conditional on water system characteristics and random effects.
▸ Regions with power plants do not have more water pollution.

Probability of a SDWA Violation



Rule Violations by Infraction Type

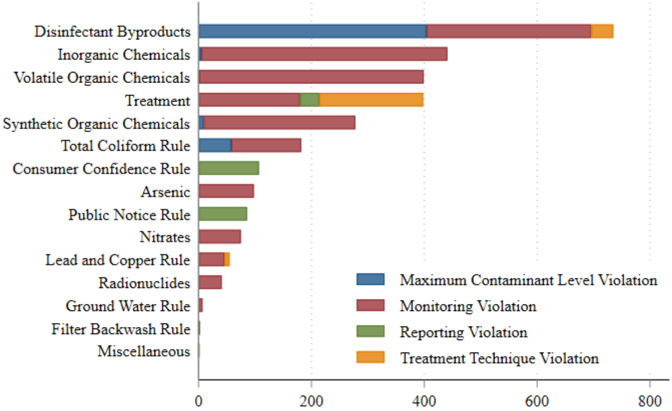
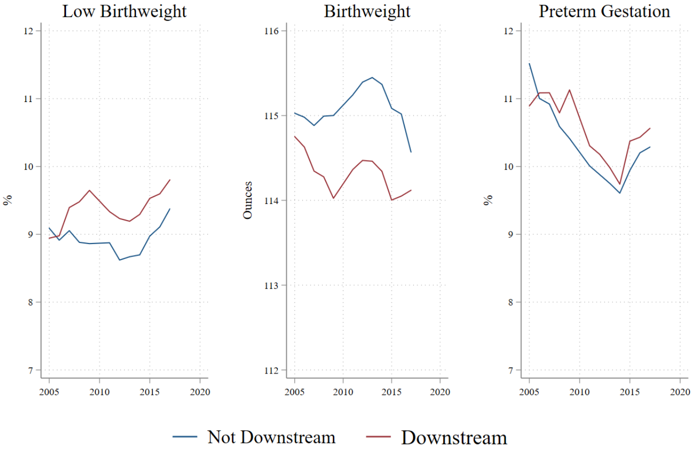


Figure: All Recorded SDWA Violations in Water Systems Potentially Affected by Coal Ash

▸ Rule Violations over Time ▸ Infraction Types over Time ▸ Violations by State

Part II: Fetal Health

Intuition of Fetal Health Analysis



▸ Water Service Zones in North Carolina

Sibling Comparison Model

Let y_{imt} represent birthweight in ounces, an indicator for low birthweight, or preterm gestation for child i born to mother m in time period t in zipcode z.

$$Health_{imtz} = \beta Ash_{it} + X'_{imt}\gamma + \eta_m + \eta_t + \eta_z + \epsilon_{imtz} \tag{2}$$

- **Data:** State Center for Health Statistics in North Carolina (2005-2017) and the Atmospheric Composition Analysis Group. Summary Statistics
  - Ash_{it} is a time-constant indicator for whether a municipal water system is ever affected by coal ash *or* a time-varying binary equal to one if the upstream pollution site is actively releasing in year t.
  - X_{imt} is a vector controlling for air pollution, mother characteristics, and birth characteristics such as birth order.
  - η_m is a mother fixed effect, η_t is a year–of–birth fixed effect, and η_z is a zip-code fixed effect.
- Identification requires that $E(\epsilon_{imt} | Ash_{it}, X_{imt}, \eta_m, \eta_t, \eta_z) = 0$ i.e. potential pollution exposure is exogenous conditional on mother fixed effects, zip-code fixed effects, and time-varying controls.

Fetal Health

	Birthweight (ozs)	Low Birthweight	Preterm Gestation
Downstream	-1.2411***	0.0171***	0.0126*
	(0.4127)	(0.0065)	(0.0020)
PM 2.5	-0.949***	0.0111***	0.0195***
	(0.0514)	(0.0007)	(0.0012)
Releases (binary)	0.4147***	-0.0029	-0.0043**
	(0.1241)	(0.0021)	(0.0020)
PM 2.5	-0.954***	0.0111***	0.0195***
	(0.0514)	(0.0007)	(0.0008)
Mother Fixed Effects	✓	✓	✓
Zipcode Fixed Effects	✓	✓	✓
Dep. Var. Mean	114.89	0.0903	0.1040
% Change from Mean	-1.0% / 0.3%	18% / -3%	12% / -4.0%
Observations	747,468	747,468	747,468

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered at the mother in parentheses.

Results among mothers with high school degree or less.

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▸ Results among mothers with high school degree or less.

Fetal Health Across Mover Types

	(1) Birthweight (ozs)	(2) Low Birthweight	(3) Preterm Gestation
In Movers (=1)	-1.8378***	0.0280***	0.0211**
	(0.4419)	(0.0069)	(0.0073)
Out Movers (=1)	0.5801	-0.0100	-0.0023
	(0.4342)	(0.0068)	(0.0072)
PM2.5	-0.9502***	0.0111***	0.0196***
	(0.051)	(0.0007)	(0.0008)
Mother Fixed Effects	✓	✓	✓
Zipcode Fixed Effects	✓	✓	✓
Dep. Var. Mean	114.89	0.0903	0.1040
Observations	747,468	747,468	747,468

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered at the mother in parentheses.

Cost of Low Birthweight Newborns

Hospitalization of LBW newborns costs an excess $15,000 (Russell et al. 2007). LBW newborns are twice as likely to qualify for special education services, costing roughly $44,000 more to educate than their peers (Petrou et al. 2000).

- Of 1.5m newborns from 2005-2018, 900,000 use municipal water and 1 in 22 use coal-ash affected municipal water → 1.7 PP increase in LBW → 700 increased cases of LBW.
- $10.7M in hospitalization fees.
- $2.8M in K-12 special education expenses.

Estimated annual benefits of the Steam Electric ELGs were $464M to $582M, while estimated annual costs were $493M.

Conclusion

- Municipal water systems potentially affected by coal ash water pollution are not more likely to be out of compliance with the SDWA, but they do have more health-based and MCL SDWA violations.
- Newborns potentially exposed to water systems sourcing from coal ash affected waters, in comparison to unexposed siblings, have lower birthweight and are more likely to be preterm. External costs could be at least $13M in NC. Mixed evidence on whether this is driven by contemporaneous releases.
- Homes near coal ash sites lost as much as 12% of their value, or $37,000, after state legislation led to home well testing. Total loss to home values is at least $20M.

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Thank you!
Questions/comments?

Appendix

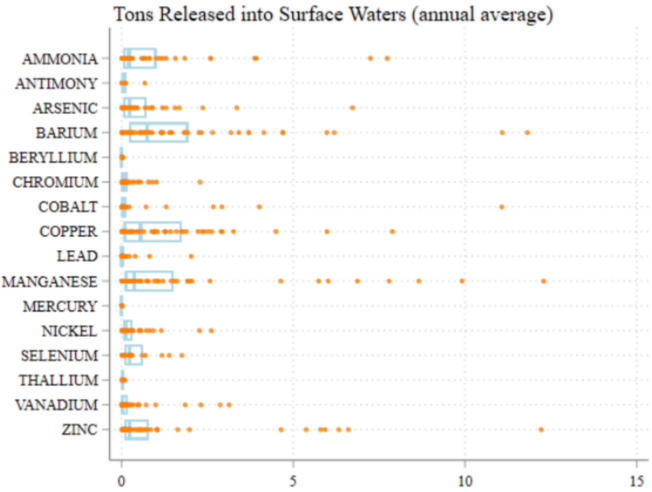


Figure: Toxic Releases Inventory (TRI) Coal Ash Surface Water Releases ▸ Go back.

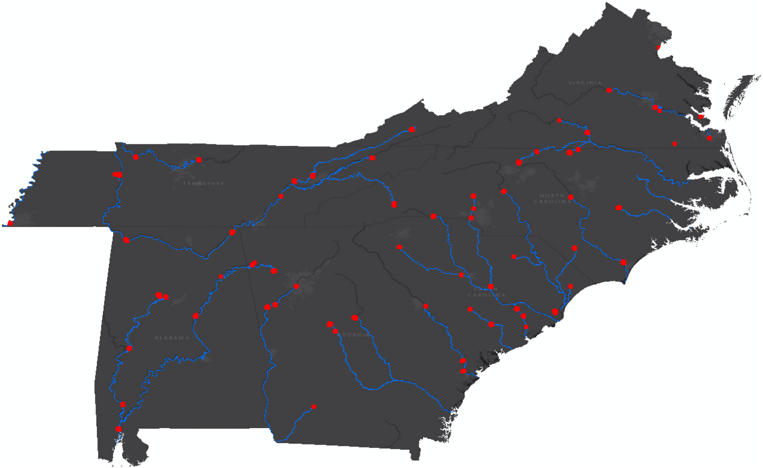
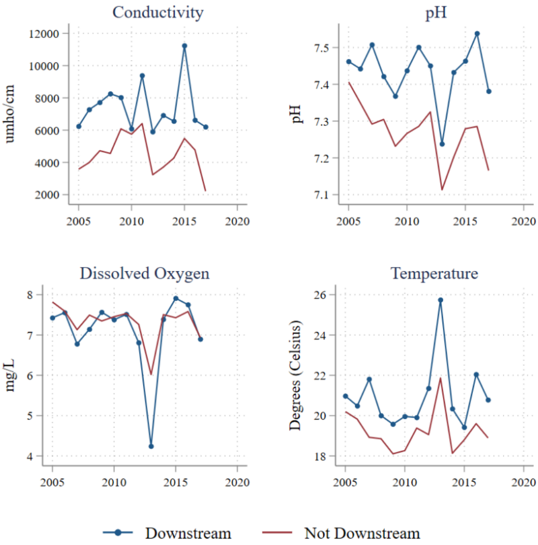


Figure: Toxic Releases Inventory (TRI) Coal Ash Sites and Downstream Water System Segments from the NHD Plus version 2.

Go back.

Surface Waters Properties (2005-2017)



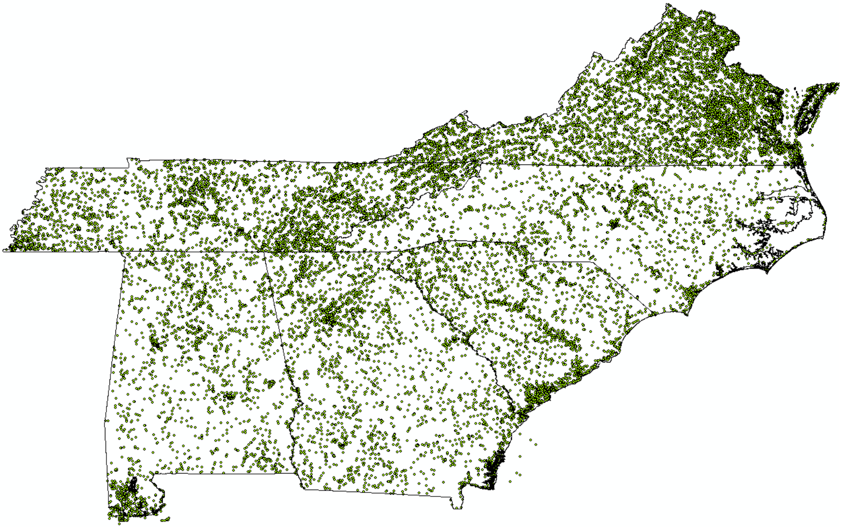


Figure: Freshwater Monitoring Locations in the Water Quality Portal (2005-2018)

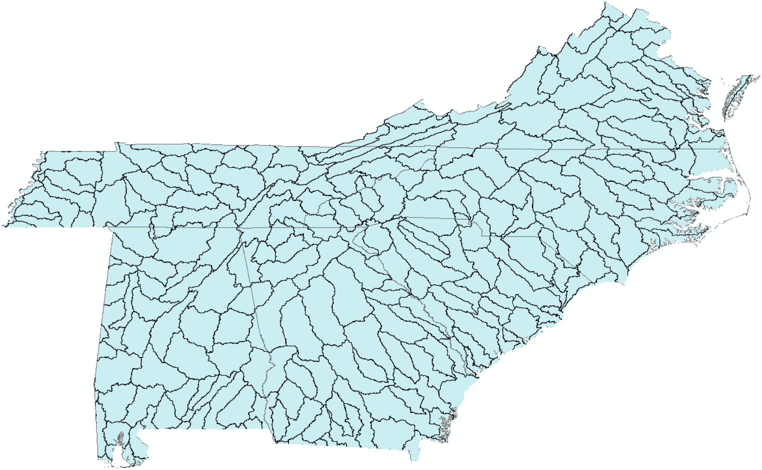


Figure: HUC-8 Hydrologic Unit Watershed Regions

Empirical Strategy: Surface Water Quality

Let y_{imwt} be the arsenic, chromium, conductivity, dissolved oxygen, lead, pH, selenium, or temperature detected at monitor i in month m, watershed w, and year t.

$$Y_{imwt} = \beta Ash_{it} + X_{it}\gamma' + \eta_i + \eta_{wm} + \eta_{wt} + \epsilon_{imwt}$$

- **Data:** Water Quality Portal and Toxic Releases Inventory from 2005-2018.
  - Ash_{it} is a binary (time-varying and time-invariant) or continuous measure of upstream releases within 25 miles.
  - X_{it} includes dummy indicators for sample medium type, abnormal weather event, hydrologic condition type, and if the analyte was not detected.
  - η_i is a monitor fixed effect. Monitor Locations
  - η_{wm} is a watershed–by–month fixed effect Watershed Regions
  - η_{wt} is a watershed–by–year fixed effect.
- Identification requires that $E(\epsilon_{imwt}|Ash_{it}, \eta_i, \eta_{wm}, \eta_{wt}) = 0$ i.e. coal ash releases are exogenous conditional on monitor, watershed, and temporal fixed effects.

Summary Statistics (2005-2018)

	Within 25 Miles Downstream		Not Within 25 Miles Downstream	
Arsenic (mg/l)	0.3958	(1.8176)	0.7785	(6.877)
Chromium (mg/l)	1.9103	(8.9721)	2.7691	(15.1431)
Conductivity (us/cm)	8994.3	(14089.9)	5030.7	(11422.4)
Dissolved Oxygen (mg/l)	5.073	(2.688)	7.393	(24.506)
Lead (mg/l)	1.0357	(4.8987)	3.6671	(50.27)
PH	7.32	(0.605)	7.27	(0.753)
Selenium (mg/l)	0.1218	(0.7242)	0.1115	(0.5329)
Temperature (c)	24.310	(7.598)	19.639	(12.640)
Monitor Observations	748,988		4,848,838	
Monitors	2,064		122,163	

Mean values reported, standard errors in parentheses.

Results: Surface Water Quality

	Downstream	Releases Binary	Annual Tons Released
Inorganic Compounds			
Arsenic	0.0863**	0.0576	0.0021
Dep. Var. Mean = 0.4596	(0.0373)	(0.0366)	(0.0022)
Observations	[36,715]	[36,715]	[36,715]
Chromium	0.1538	-0.0313	-0.0018*
Dep. Var. Mean = 1.627	(0.3353)	(0.0757)	(0.0007)
Observations	[57,089]	[57,089]	[57,089]
Lead	0.1730	0.4992	-0.0124***
Dep. Var. Mean = 1.516	(0.1662)	(0.3538)	(0.0020)
Observations	[61,731]	[61,731]	[61,731]
Selenium	0.0190***	0.0179***	0.0008*
Dep. Var. Mean = 0.0536	(0.0066)	(0.0020)	(0.0005)
Observations	[28,928]	[28,928]	[28,928]
Monitor FEs		✓	✓
Watershed-Year FEs	✓	✓	✓
Watershed-Month FEs	✓	✓	✓

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered at the monitor and watershed in parentheses. Note average non-zero upstream releases is 15.5 tons.

Results: Surface Water Quality

	Downstream	Releases Binary	Annual Tons Released
Properties			
Conductivity	1567.42	-333.19**	1.050
Dep. Var. Mean = 5279.45	(1932.85)	(147.58)	(3.077)
Observations	[1,119,939]	[1,119,939]	[1,119,939]
Dissolved Oxygen	-0.6367**	0.0237	-0.0006
Dep. Var. Mean = 6.982	(0.2491)	(0.0362)	(0.0011)
Observations	[1,097,515]	[1,097,515]	[1,097,515]
pH	0.1948***	0.0464**	0.0007
Dep. Var. Mean = 7.28	(0.1384)	(0.0174)	(0.0011)
Observations	[1,227,668]	[1,227,668]	[1,227,668]
Temperature	1.0293***	-0.0435	-0.0009*
Dep. Var. Mean = 20.275	(0.0407)	(0.0407)	(0.0006)
Observations	[1,240,357]	[1,240,357]	[1,240,357]
Monitor FEs		✓	✓
Watershed-Year FEs	✓	✓	✓
Watershed-Month FEs	✓	✓	✓

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered at the monitor and watershed in parentheses. Note average non-zero upstream releases is 15.5 tons.

Empirical Strategy: Analyte Levels

Let y_{imst} be the level of arsenic, conductivity, haloacetic acids, lead, pH, or trihalomethanes observed in municipal water system i, state-year st, and month m

$$y_{imst} = \beta Ash_{it} + X_{it}\gamma' + \eta_i + \eta_{st} + \eta_m + \epsilon_{imst} \tag{3}$$

- **Data:** Municipal Water Quality Monitoring Tests for NC, SC, GA, AL, & VA from 2005-2018. ▸ Summary Statistics
  - Ash_{it} is a binary or continuous measure of upstream releases within 25 miles, where these variables are set to zero if the water system is not sourcing from coal-ash affected waters.
  - X_{it} includes dummies for facility type, system size, system age, and if the analyte was not detected.
  - η_i is a water-system fixed effect.
  - η_m is a month fixed effect.
  - η_{st} is a state–by–year fixed effect.
- Identification requires that $E(\epsilon_{imst}|Ash_{it}, X_{it}, \eta_i, \eta_m, \eta_{st}) = 0$ i.e. coal ash releases are exogenous conditional on water system characteristics, state, and temporal fixed effects.
  ▸ Regions with power plants do not have more water pollution.

State Regulatory Monitoring Tests (2005-2017)

	Downstream		Not Downstream	
Arsenic (mg/l)	0.00002	(0.0005)	0.0020	(0.4723)
Conductivity (us/cm)	183.44	(264.4)	299.10	(1012.6)
Lead (mg/l)	0.0017	(0.0309)	0.0058	(2.423)
Haloacetic Acids (mg/l)	0.0246	(0.0150)	0.0228	(0.4034)
PH	7.796	(.6041)	7.725	(0.6806)
Trihalomethanes (mg/l)	0.0417	(0.0219)	0.0359	(0.4431)
Water System Samples	162,790		1,185,225	
Water System Years	42,722		491,892	
Water Systems	193		3,839	

Go back

Safe Drinking Water Inventory System Violations (2000-2018)

	Downstream		Not Downstream	
Total Violations	10.396	(14.781)	7.996	(28.322)
Health-Based Violations	2.734	(4.145)	0.7357	(2.9364)
Annual Violation Rate	0.1670	(0.3730)	0.1285	(0.3347)
Health-based Violation Rate	0.0698	(0.2549)	0.0225	(0.1482)
Maximum Contaminant Level	0.0511	(0.2201)	0.0197	(0.1390)
Monitoring Violation	0.0901	(0.2864)	0.0935	(0.2912)
Reporting Violation Rate	0.0344	(0.1822)	0.0371	(0.1890)
Treatement Technique	0.0219	(0.1463)	0.0029	(0.0542)
Arsenic	0.0047	(0.0683)	0.0014	(0.0374)
Consumer Confidence Rule	0.0279	(0.2092)	0.0218	(0.2185)
Disinfectant Byproducts	0.1771	(0.7811)	0.0308	(0.3496)
Inorganic Compounds	0.0477	(0.7468)	0.0165	(0.4333)
Lead and Copper	0.0109	(0.1287)	0.0163	(0.1911)
Public Notice	0.0224	(0.2824)	0.0603	(0.6036)
Volatile Organic Chemicals	0.0711	(1.3958)	0.0688	(1.6584)
Water System Samples	162,790		1,185,225	
Water System Years	42,722		491,892	
Water Systems	193		3,839	

Go back

Municipal Water Quality: Analyte Levels

	Downstream	Releases Binary	Annual Tons Released
Inorganic Compounds			
Arsenic	-0.0058	0.0084	0.0007
Dep. Var. Mean= 0.0027	(0.0075)	(0.0123)	(0.0009)
Observations	[46,729]	[46,729]	[46,729]
Lead	0.0081	-0.0033	0.0035***
Dep. Var. Mean= 0.0070	(0.0089)	(0.014)	(0.0003)
Observations	[364,643]	[364,643]	[364,643]
Properties			
Conductivity	-120.43	45.99**	3.37***
Dep. Var. Mean = 291.00	(75.03)	(19.10)	(1.08)
Observations	[29,697]	[29,697]	([29,697]
pH	-0.3765**	-0.0172***	0.0070**
Dep. Var. Mean= 7.76	(0.0427)	(0.0001)	(0.0008)
Observations	[71,059]	[71,059]	[71,059]
Water System		✓	✓
State-by-Year	✓	✓	✓
Month	✓	✓	✓
Watershed	✓		

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered at the water system and state in parentheses. All models include state-by-year fixed effects and month fixed effects.

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Dep. Var. Mean= 0.0070	(0.0089)	(0.014)	(0.0003)
Observations	[364,643]	[364,643]	[364,643]
Properties			
Conductivity	-120.43	45.99**	3.37***
Dep. Var. Mean = 291.00	(75.03)	(19.10)	(1.08)
Observations	[29,697]	[29,697]	([29,697]
pH	-0.3765**	-0.0172***	0.0070**
Dep. Var. Mean= 7.76	(0.0427)	(0.0001)	(0.0008)
Observations	[71,059]	[71,059]	[71,059]
Water System		✓	✓
State-by-Year	✓	✓	✓
Month	✓	✓	✓
Watershed	✓		

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered at the water system and state in parentheses. All models include state-by-year fixed effects and month fixed effects.

Municipal Water Quality: Analyte Levels (*contd.*)

	Downstream	Releases Binary	Annual Tons Released
Disinfectant Byproducts			
Haloacetic Acids (HAA5)	-0.0026*	-0.0032	-0.0001
Dep. Var. Mean= 0.0220	(0.0010)	(0.0047)	(0.0001)
Observations	[249,467]	[249,467]	[249,467]
Trihalomethanes (TTHM)	0.0007	-0.0099	-0.0003
Dep. Var. Mean= 0.0362	(0.0030)	(0.0088)	(0.0002)
Observations	[249,132]	[249,132]	[249,132]
Water System		✓	✓
State-by-Year	✓	✓	✓
Month	✓	✓	✓
Watershed	✓		

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Rule Violations over Time

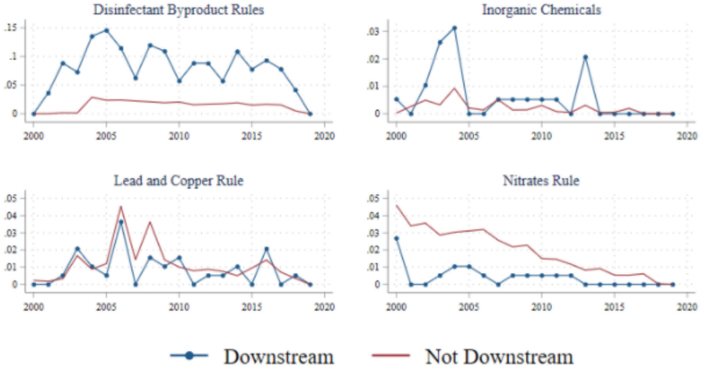

Figure: SDWA Violations by Type of Rule Go back.

Infraction Types over Time

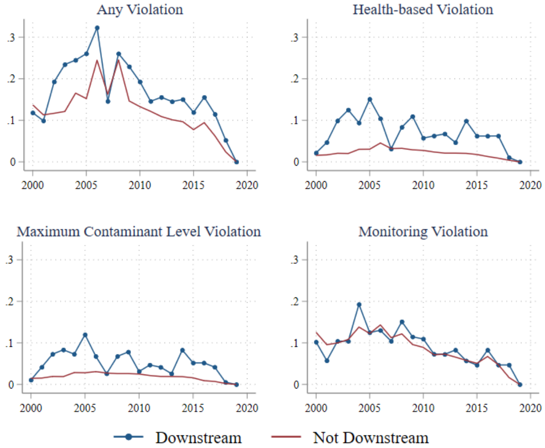

Figure: SDWA Violations by Type of Infraction

Go back.

Violations by State

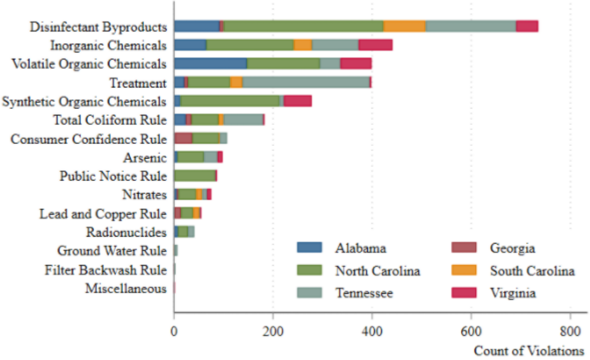

Figure: SDWA Violations by Rule across States ▸ Go back.

Municipal Water Service Zones

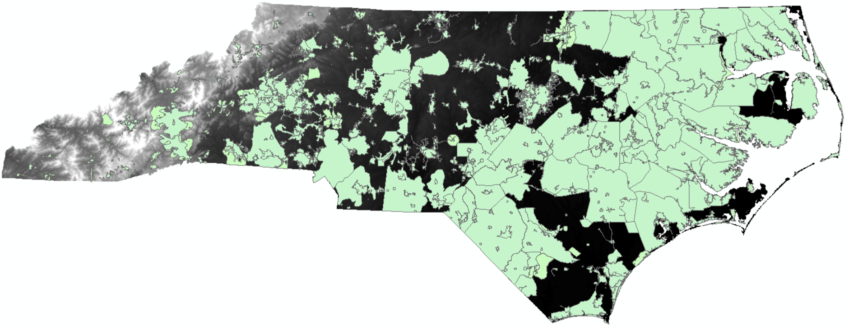

Figure: Municipal Water Service Zones (n = 1765) covering 77% of 5.4M unique residential addresses. Go back.

Summary Statistics (2005-2017)

	Ever Served by Affected Municipal Water System		Never Served by Affected Municipal Water System	
Mother Characteristics (2005-2017)				
Age	27.58	(5.99)	27.54	(6.01)
Asian	0.042	(0.201)	0.031	(0.173)
Black	0.303	(0.459)	0.212	(0.409)
Hispanic	0.161	(0.367)	0.155	(0.362)
White	0.552	(0.497)	0.656	(0.478)
Married	0.567	(0.495)	0.604	(0.489)
HS diploma or Less	0.424	(0.494)	0.443	(0.496)
Prenatal Visits	11.86	(4.27)	12.20	(4.23)
Tobacco	0.089	(0.286)	0.104	(0.305)
Birth Characteristics (2005-2017)				
Ounces	114.32	(21.82)	115.08	(21.84)
Low Birthweight (2500 grams)	0.094	(0.291)	0.089	(0.285)
Preterm Gestation (37 weeks)	0.106	(0.307)	0.103	(0.304)
Congenital Anomalies	0.005	(0.069)	0.003	(0.053)
Female	0.489	(0.499)	0.488	(0.499)
Movers	0.150	(0.357)	0.098	(0.298)
PM 2.5 Mean	10.49	(2.29)	9.97	(2.28)
PM 2.5 Max	16.32	(4.84)	15.97	(5.03)
Birth Observations	356,868		1,101,204	
Unique Mothers	241,188		779,974	

Mean values reported, standard errors in parentheses. Go back.

Fetal Health of Mothers with Less Education

	Birthweight (ozs)	Low Birthweight	Preterm Gestation
Downstream	-2.2118***	0.0286***	0.0255**
	(0.6251)	(0.0107)	(0.0109)
PM 2.5	-1.001**	0.0126***	0.0230***
	(0.0794)	(0.0012)	(0.0012)
Mother Fixed Effects	✓	✓	✓
Zipcode Fixed Effects	✓	✓	✓
Dep. Var. Mean	114.89	0.0903	0.1040
% Change from Mean	-1.9%	31%	25%
Observations	303,110	303,110	303,110

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered at the mother in parentheses.

Go back.

Summary Statistics (2000-2019)

	Homes Within 5 Miles of an Ash Pond		Homes Not Within 5 Miles of an Ash Pond	
Average Sale Value (thousands)	228.1	(201.2)	192.7	(163.1)
Avg. No. Sales	1.537	(0.938)	1.590	(0.985)
Lotsize (thousands sq ft.)	50.6	(351.5)	110.6	(1,080.0)
Bedrooms	2.797	(1.289)	2.678	(1.615)
Baths	1.811	(0.999)	1.753	(1.231)
Home Sales	37,224		248,743	
Unique Homes	24,699		157,000	

Mean values reported, standard errors in parentheses. Go back

The Dan River Spill of 2014

Figure: The Dan River Steam Station Ash Pond Post-Failure
Source: EPA Region IV Pollution Report via Wikipedia.

Empirical Strategy: Home Sales

Let y_{it} be the sale price for home i in year t, where all prices are converted to 2014 dollars.

$$y_{it} = \delta treat_i * post_t + \lambda post_t + \eta_i + \eta_t + \epsilon_{it} \tag{4}$$

- **Data:** CoreLogic Configurable Data Reports 2005-2019 & County Tax Assessors. Summary Statistics
  - $treat_i$ is an indicator for homes within a 1, 2.5, or 5 mile buffer region surrounding a coal ash pond.
  - $post_t$ is a dummy equal to one if the sale occurred after 2014.
  - η_i is a house fixed effect.
  - η_t is a year fixed effect.
- Identification requires that $E(\epsilon_{it}|treat_i, post_t, \eta_i, \eta_t) = 0$ i.e. the timing of the Dan River spill and well-testing is exogenous conditional on house and year fixed effects.

Results: Home Sales

Distance Cutoff	1 Mile	2.5 Miles	5 Miles
Near*Post	-37,333.5***	-16,090.1***	-12,673.9***
	(12,591.3)	(2,784.1)	(2,229.5)
Mean Sale Price	320,307.6	259,978.8	248,597.3
% Change	-11.6	-6.1	-4.8
Δ Total House Value	-19.9M	-79.6M	-228.7M
House and Year FEs	✓	✓	✓
Affected Home Sales	308	2,238	8,377

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors clustered at the county in parentheses.

Do Counties with Coal Ash Have More Water Pollution?

	(1) Tons of Surface Water Pollution	(2) Tons of Impounded Pollution
Coal Plant County (=1)	18.45 (33.57)	177.19 (140.82)
State Fixed Effects	✓	✓
Year Fixed Effects	✓	✓
Dep. Var. Mean	74.18	101.23
Observations	6,406	6,406

Standard errors in parentheses. Go back