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journal homepage: www.elsevier.com/puhe

Original Research

Shale gas development and cancer incidence in southwest Pennsylvania



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ARTICLE INFO

Article history:

Received 25 May 2016

Received in revised form

15 August 2016

Accepted 7 September 2016

Available online 26 October 2016

Keywords:

Unconventional shale development

Hydraulic fracturing

Cancer incidence

Cancer epidemiology

Environmental epidemiology

ABSTRACT

Objective: To what extent does unconventional gas development lead to an increase in cancer incidence in heavily drilled Southwest Pennsylvania?

Study design: Ecological study.

Methods: Data for urinary bladder, thyroid and leukaemia were abstracted from the Pennsylvania Cancer Registry (PCR). Cancer incidence among counties with high, moderate and minimal number of producing wells is compared before drilling activity and thereafter. Observed vs expected cases, standardized incidence ratio and 95% confidence intervals are presented. Data are presented by county, diagnosis and sex for the years 2000–2004, 2004–2008 and 2008–2012. The percent difference between the observed cases from 2000 to 2004 and 2008–2012 was calculated.

Results: The observed number of urinary bladder cases was higher than expected in both sexes in counties with shale gas activity. In counties with the fewest number of producing wells, the increase was essentially non-existent. The number of observed cases of thyroid cancer increased substantially among both sexes over the time period in all counties regardless of the number of wells drilled. The pattern for leukaemia was mixed among males and females and among the counties regardless of the extent of shale gas development activities.

Conclusion: Potential risk factors other than shale gas development must be taken into account to explain the higher than expected cancer cases in counties with and without shale gas wells before and during unconventional shale gas activity.

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Introduction

Unconventional oil and gas development has enhanced the ability to extract trapped gas from tight shale formations. The process, using hydraulic fracturing, requires injecting millions

of gallons of water combined with a mixture of chemicals (many of which are toxic) and proppants (usually sand or silica) into the drilled well under high pressure. With unconventional natural gas extraction, trapped gas is released along with flowback fluids consisting of the water and the chemicals used in hydraulic fracturing. In the USA, over the decades,

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<http://dx.doi.org/10.1016/j.puhe.2016.09.008>

38,000 oil and gas production wells in at least 25 states were hydraulically fractured, the majority of which are in Texas, Colorado, Pennsylvania and North Dakota.¹

Studies conducted in the USA have linked shale gas development to surface and ground water contamination,^{2–6} and a landmark 2015 Environmental Protection Agency (EPA) report on the impact of hydraulic fracturing estimated that almost 10 million people live within one mile of a fracked well and that hydraulic fracturing and associated activities not only have the potential to contaminate drinking water, ground water and other water resources but actually did in a number of places.⁷

Further, air pollutants, such as hydrogen sulphide, nitrogen oxides, volatile organic compounds (e.g. benzene and formaldehyde), particulate matter and ground level ozone are emitted or produced, are released during all phases of the drilling and extracting phases.^{8–11} Well venting, flaring and burning gas on release account for a large source of air emissions.¹² Truck traffic and diesel truck exhaust also contribute to airborne emissions of fugitive dust, fine particulate matter and high-benzene concentrations. Werner et al.¹³ comprehensively reviewed the strength of evidence focussing on the environmental health impacts of unconventional natural gas development (UGD), including the potential for harm to air, water, soil and climate change.

Finkel and Law¹⁴ and later Shonkoff et al.¹⁵ were the first to raise the issue of a paucity of well-designed epidemiologic studies on the public health impact of hydraulic fracturing. Anecdotal reports from areas with UGD found that adults and children living near drilling sites were presenting with symptoms such as skin rashes, dizziness, headaches, nausea, respiratory problems, eye and throat irritations, nosebleeds, anxiety. Other health conditions, many potentially serious, will take more time to develop (e.g. cancers; endocrine and reproduction systems disruptions). Hydraulic fracturing fluids contain endocrine disrupting chemicals that may adversely impact organs in the body years or decades after exposure.¹⁶

The byproducts of hydraulic fracturing, including benzene, fine particulate matter, and other nitrogen oxides, sulphur dioxide and ozone, have been shown to increase the risk of adverse birth outcomes and a variety of health problems among those living in near proximity to hydraulic fracturing activities.¹⁷ Recent empirical evidence shows an increase in adverse birth outcomes (e.g. preterm birth, low-birth weight) in areas with active drilling, especially among women living close to gas wells.^{18–20} Also documented is an increase in hospital utilization rates (admissions for cardiac and neurological conditions in particular) among those living in proximity to wells,²¹ and mental health problems have been shown to be associated with proximity to drilling sites.^{22,23}

While the accumulation of reports enumerating the potential for harm in the short-term are a matter of concern, the long-term effects of living in near proximity to unconventional drilling sites are not known as of this writing. Certainly, the potential for harm will vary by proximity to wells, length of time of exposure and route of exposure. Confounding factors would need to be taken into account as well to understand the extent of the relationship between health outcomes and UGD.

Purpose of study

Many states actively support unconventional natural gas development (e.g. Colorado, Louisiana, North Dakota, Pennsylvania, Texas, Wyoming). Pennsylvania, in particular, has embraced an aggressive policy of drilling and extracting natural gas from the Marcellus Shale, one of the largest shale plays in the USA. Drilling commenced in 2008, and as of May 1, 2015, 9134 unconventional wells have been drilled in Pennsylvania, notably in several counties in the southwest part of the State.²⁴

Anecdotal reports of elevated cancer rates in the heavily drilled southwest region of the state provided the impetus to investigate whether exposure to UGD activities impacts the development of cancers that are known to be associated with environmental exposure (e.g. bladder, leukaemia and thyroid cancers). To what extent were the observed number of cancer cases higher than expected in counties with the highest number of producing wells (Washington and Greene) compared to counties with little or no UGD (Fayette and Westmoreland) and to counties with a moderate amount of producing wells (Allegheny and Beaver). Data before UGD commenced (2000–2008) are compared to years during UGD (2009–2012). Key questions that we sought to answer include: to what extent was cancer incidence elevated prior to UGD? To what extent does UGD contribute to cancer development?

Methods

While genetics and lifestyle factors account for many cancers, occupational and environmental exposures also can be major risk factors. Three specific cancers were selected for inclusion in this study: bladder, leukaemia and thyroid. Bladder cancer, for example, is associated with exposure to arsenic in drinking water, and exposure to benzene, cadmium, aromatic amines, trichloroethylene solvents, silica and lead. Benzene, pesticides, reactive chemicals, dioxin solvents and non-ionizing radiation are linked to leukaemia. Radiation, pesticides and genetics are linked to thyroid cancer. However, cancer causation is complex and multi-factorial. UGD requires hundreds of different chemicals in the fracturing process, many of which have been shown to be carcinogenic.

Cancer incidence and mortality were abstracted from the Pennsylvania Department of Health (DOH) Bureau of Health Statistics and Research's Pennsylvania Cancer Registry (PCR).²⁵ The PCR includes the annual number of invasive cancer cases and cancer deaths by age, sex, race, primary site, as well as observed and expected cases by diagnosis. The observed number of cases is based on the number of primary tumours, not the number of individuals diagnosed with cancer. The PCR follows the SEER ICD-0 coding structure used to identify primary sites of cancers. Expected cases represent the total number of primary malignant tumours that would have been reported to the PCR if Pennsylvania's male and female populations had experienced the same age-specific rates of cancer incidence as those reported by the SEER program during the same time period.

The PCR includes the standardized incidence ratio (SIR), which is calculated by dividing the number of observed cases by the number of expected cases and multiplying the dividend by 100. A ratio greater than 100 indicates that there were more cases observed than expected. The 95% confidence interval for the SIR was calculated independently. The percent difference between the observed cases from 2000–2004 to 2008–2012 was calculated.

The following cancer sites were selected for analysis because epidemiologic evidence shows a moderate to strong relationship to environmental pollutants (e.g. chemical exposures): urinary bladder (invasive and in situ), leukaemia and thyroid. Other potential risk factors such as occupational exposures (e.g. diesel fumes, rubber byproducts, paint solvents), tobacco smoking, alcohol consumption, diet and genetic history could not be assessed in this ecologic study.

Based on anecdotal reports of 'high' cancer morbidity and mortality among residents in Washington County, we also include data at the township level. We acknowledge that there is a higher probability of chance variation in an observed number in rural counties with small populations, rather than a real change or difference. There is always the possibility that some events could have occurred by chance.

Results

Of the 67 counties in Pennsylvania, there are 30 overwhelmingly rural counties that sit atop the Marcellus Shale. [Table 1](#) presents a profile of the counties included in this study. The principle products and/or industry in these counties include coal mining (e.g. the Klondike and Pittsburgh coalfields), agriculture, manufacturing (e.g. fabricated metals and electric machinery) and shale gas development.

[Table 2](#) shows the trend in incidence of urinary bladder cancer by county, sex and year grouping. The SIR in each year grouping for all Pennsylvania was above 100 indicating that there were more observed cases than expected. There was a 10% increase in the number of observed cases from 2000 to 2012. In every county and for each of the year groupings, the SIR was above 100 among males and females (with the exception of 2000–2004 in Greene County and 2004–2008 in Westmoreland County where there were fewer number of observed cases of urinary bladder cancer than expected in

females). In all of the counties for each of the year groupings, the observed number of cases exceeds the expected in each of the year groupings among males. The increase in the number of observed cases from 2000 to 2012 was notably higher among males in the heavily drilled Washington County (+20.2%), but in heavily drilled Greene County there was a 20% decline in observed cases. The numbers are quite small, which could distort the findings. In moderately drilled Westmoreland County, there was a 19.9% increase in the number of observed cases. In the counties with the fewest number of drilled wells, there was an insignificant change in the number of observed cases over the time period.

Among females, in heavily drilled Washington County, there was a 5.3% increase in the number of observed cases and a 7.7% increase in Greene County. In moderately drilled Fayette County, there was a 22.5% decline in the number of observed cases from 2000 to 2012; however, in Westmoreland County there was a 44.4% increase over this time period. In Allegheny and Beaver Counties, there was a 3.2% decrease and a 4.4% increase in the number of observed cases, respectively. Bladder cancer is generally more prevalent among males, which may be a factor in explaining the differences between the sexes.

[Table 3](#) shows the trend in incidence of thyroid cancer by county, sex and year grouping. The SIR for each year grouping exceeds 100 for the state of Pennsylvania, and there was a huge 91.2% increase in the number of observed cases from 2000 to 2012. The data show that the number of thyroid cancer cases over the time period has been higher than expected, especially among males. While the numbers are small (as apparent by the 95% confidence interval range), the number of observed cases in males and females in all counties almost always exceeded the number of expected cases from 2004 to 2012 regardless of shale gas development activity in the specific county.

Among males in Washington County, there is a 92.9% increase in the number of observed cases of thyroid cancer from 2000 to 2012. The numbers in Greene County are too small to draw any conclusions. In Fayette and Westmoreland counties, there was a 231.3% and 160% increase in the number of observed thyroid cases from 2000 to 2012, respectively. In Allegheny and Beaver Counties, where there has been relatively little unconventional drilling activity, there is a 105.9% and 68.2% increase in the number of observed cases over the time period, respectively.

Table 1 – Demographic profile by county.

Demographic characteristics	Allegheny	Beaver	Fayette	Greene	Washington	Westmoreland
Population: (2014 est)	123,125	169,392	134,086	37,843	208,187	359,320
Population: (as of 2010)	122,348	170,539	136,607	38,686	207,820	365,169
% Change	0.6%	–0.7%	–1.8%	–2.2%	0.2%	–1.6%
< 5 years of age (as of 2014)	5.3%	5.1%	5.0%	4.9%	5.0%	4.6%
>64 years of age (as of 2014)	17.4%	19.7%	19.4%	17.1%	18.9%	20.7%
% White (as of 2014)	81.0%	91.1%	93.1%	94.7%	94.0%	95.1%
Persons in poverty (as of 2014)	12.9%	11.3%	19.2%	16.3%	10.9%	10.7%
Number of unconventional active wells, 2015	63	30	257	870	1146	251

Source: <http://quickfacts.census.gov/qfd/states/42000.html>

Source: <http://stateimpact.npr.org/pennsylvania/drilling/counties>

Table 2 – Urinary bladder cancer incidence by county 2000–2012.

County		Males				Females			
		Observed	Expected	SIR	95% CI	Observed	Expected	SIR	95% CI
Allegheny	2000–2004	1547	1257	123.1+	117, 129.2	589	481	122.5+	112.6, 132.4
	2004–2008	1555	1244	125.0 +	118.8, 131.2	561	460	122.0 +	111.9, 132.1
	2008–2012	1588	1254	126.7+	120.5, 132.9	570	445	128.1+	117.6, 138.6
	% difference	2.70%				–3.20%			
Beaver	2000–2004	273	193	141.8+	125, 158.6	90	69	131.2+	104.1, 158.3
	2004–2008	242	194	124.6 +	108.9, 140.3	106	67	157.2 +	127.3, 187.1
	2008–2012	273	196	139.0+	122.5, 155.5	94	66	142.0+	102.2, 181.8
	% difference	0%				4.40%			
Fayette	2000–2004	201	151	133.0+	114.6, 151.4	80	57	140.9+	109.9, 171.9
	2004–2008	214	153	139.6 +	120.9, 158.3	57	55	103.0	26.7, 110.6
	2008–2012	223	153	145.8+	126.6, 165	62	52	118.9	89.3, 148.5
	% difference	10.90%				–22.50%			
Greene	2000–2004	50	37	134.3	97.1, 171.5	13	13	99.4	45.3, 153.5
	2004–2008	52	39	135.0 +	36.7, 172.2	13	13	101.8	46.4, 157.2
	2008–2012	40	39	101.8	70.2, 133.4	14	12	113.3	53.9, 172.7
	% difference	–20.00%				7.70%			
Washington	2000–2004	243	211	115.2+	14.5, 130.8	94	76	122.9	98.1, 147.7
	2004–2008	283	215	131.6 +	15.3, 148.4	101	75	135.0 +	108.5, 161.5
	2008–2012	292	227	128.6+	14.7, 145.7	99	76	130.7+	104.8, 156.6
	% difference	20.20%				5.30%			
Westmoreland	2000–2004	452	396	114.0+	10.5, 135.3	144	142	101.4	84.8, 118
	2004–2008	532	404	131.7 +	126, 137.4	137	139	98.4	81.9, 114.9
	2008–2012	542	426	127.3+	116.6, 138	208	141	147.1+	127.1, 167.1
	% difference	20.00%				44.40%			
All PA	2000–2004	13,496	11,280	119.6+	117.6, 121.6	4917	4120	119.3+	116, 122.6
	2004–2008	14,149	11,620	121.8 +	119.8, 123.8	4831	4060	119.0 +	115.6, 122.4
	2008–2012	14,843	12,290	120.8+	118.9, 122.7	4941	4117	120.0+	116.7, 123.4
	% difference	10.00%				0.50%			

CI, confidence interval; SIR, standardized incidence ratio.
% difference between 2000–2004 and 2008–2012.

Among females, Westmoreland County shows the largest increase in the number of observed cases during this time period (+187.6%), followed by Fayette County (+138.5%) and Allegheny County (+108.2%). The numbers for Greene County are too small to make any meaningful determination. Given the higher than expected number of cases in both males and females in the counties in the years before unconventional drilling, other factors must be taken into account to explain this finding.

Table 4 shows the trend in incidence of leukaemia by county, sex and year grouping. Compared to thyroid and urinary bladder cancers, the data for leukaemia present a different picture. For all of Pennsylvania, the SIR for each year grouping was less than 100, and there was a modest 18.9% increase in the number of observed cases from 2000 to 2012. For each county, as evident by the SIR, for the most part there are fewer observed cases than expected in males and females over the years. The percent increase from 2000 to 2012 is comparatively minimal, and in many instances, there fewer observed cases than expected during this time period in each of the counties and in males and females, regardless of county well status.

The data show that the observed number of urinary bladder cases were higher than expected in males and females in southwest Pennsylvania prior to shale gas development; however, in counties with the fewest number of producing wells (Allegheny and Beaver) the increase from

2000–2004 to 2008–2012 was essentially non-existent. In the counties where drilling was more intense, the percent increase among males was the highest in Washington and Westmoreland Counties and in Westmoreland and Fayette Counties among females. The number of observed cases of thyroid cancer increased substantially among males and females over the time period in all counties (excluding Greene County because of the small number of cases). The pattern for leukaemia was much more mixed among males and females and among the counties regardless of the extent of shale gas development activities.

Focus on Washington County townships

County-level data may mask activity at the small area level (e.g. township level). We focused on Washington County townships primarily because this county, as compared to the neighbouring counties, embraced shale gas development early on and has the most number of active producing unconventional wells. Fig. 1 shows the location of active, producing unconventional wells in Washington County as of 2015. Each well pad contains multiple wells.

Data were grouped by years before shale gas development (2000–2007) and during shale gas development (2008–2012). Table 5 shows the number of cases of urinary bladder and thyroid cancers and leukaemia by selected townships from 2000 to 2012. Townships with 20 or more observed cases of

Table 3 – Thyroid cancer incidence by county 2000–2012.

County		Males				Females			
		Observed	Expected	SIR	95% CI	Observed	Expected	SIR	95% CI
Allegheny	2000–2004	186	147	126.3+	108.2, 144.5	646	461	140.3+	129.5, 151.1
	2004–2008	284	186	153.1+	135.2, 170.9	1074	591	181.9+	171.0, 192.8
	2008–2012	383	230	166.8+	150.1, 183.5	1345	728	184.8+	174.9, 194.7
	% difference	105.90%				108.20%			
Beaver	2000–2004	22	22	100.2		115	65	176.3+	
	2004–2008	39	28	139	58.3, 142.1	145	85	169.8+	144.1, 208.54
	2008–2012	37	34	108.2	95.3, 182.7	131	104	126.2+	142.2, 197.4
	% difference	68.20%				13.90%			
Fayette	2000–2004	16	18	90.6	72.2, 159.5	52	53	98.2	94.9, 146.5
	2004–2008	27	23	115.8	137.2, 283.4	84	70	120.7	138.5, 160.7
	2008–2012	53	28	187.8+		124	83	149.6+	
	% difference	231.30%				138.50%			
Greene	2000–2004	2	5	–		9	13	–	
	2004–2008	6	7	–		26	17	148.8	91.6, 206.0
	2008–2012	13	8	166.1	159, 173.2	4	6		
	% difference	550.00%				–55.60%			
Washington	2000–2004	28	25	113		84	73	114.5	
	2004–2008	42	33	129.1	71.1, 154.9	129	97	132.4+	89.8, 139.2
	2008–2012	54	41	130.6	90.1, 168.1	163	123	132.3+	109.6, 155.23
	% difference	92.90%				94.00%			
Westmoreland	2000–2004	45	46	97.7	95.8, 165.4	133	134	99.1	112.0, 152.6
	2004–2008	73	60	121.6		206	176	116.8+	
	2008–2012	117	75	155.3+	69.1, 126.3	325	220	147.7+	82.3, 115.9
	% difference	160.00%				187.60%			
All PA	2000–2004	1752	1415	123.8+	93.7, 149.5	5969	4295	139.0+	100.9, 132.8
	2004–2008	2341	1857	126.1+	127.2, 183.4	7950	5706	139.3+	131.7, 163.8
	2008–2012	3350	2372	141.3+		10,237	7260	141.0+	
	% difference	91.20%				71.50%			

CI, confidence interval; SIR, standardized incidence ratio.
% difference between 2000–2004 and 2008–2012.

urinary bladder and thyroid cancers, and 15 or more leukaemia cases, are included in the Table. Given the small number of observed cases, one must interpret the data with caution.

Cecil and North Strabane townships showed the largest percent increase in urinary bladder cancer from 2000–2007 to 2008 to 2012, 141.7% and 81.3%, respectively. Three townships (Monogahela City, North Franklin and Washington City) showed a decrease in the number of urinary bladder cases over the time period. Regarding thyroid cancer, South Strabane and Peters Townships showed a substantial increase in the number of cases between the time periods (157.1% and 153.8%, respectively), whereas North Strabane, Washington City and Cecil Townships showed a decrease in the number of cases. Every township showed an increase in the number of leukaemia cases from 2000 to 2012. Of note is the 220% increase in the number of cases reported for Washington City; a 120% increase in South Strabane Township and a 100% increase in Peters Township.

Overall, Peters and South Strabane Townships showed increases in the three cancers of interest over the time period. Cecil, North Strabane and Washington City Townships had a mixed record; e.g., urinary bladder was especially high in Cecil Township but thyroid and leukaemia cancers either declined or increased modestly. Geographically, the townships with the comparatively larger number of cancer cases are adjacent to each other in the north central part of the county. However,

as Fig. 1 shows the location of unconventional wells is primarily in the western portion of the county with a smaller concentration located in the southern part of the county. The wells are not proximate to the townships with elevated cancer cases. For example, Cross Creek, West Middletown, Hopewell, Mount Pleasant and Independence Townships are located in areas with the highest concentration of producing wells but have comparatively fewer cancer cases than townships in areas with few producing wells.

Discussion

It is important to note that Southwestern Pennsylvania is comprised of an ageing, rural, generally poor population. Township population is small, which makes it difficult to draw statistical conclusions. Trying to link shale gas development to higher than expected morbidity is complicated because shale gas development did not begin in earnest in the region until 2008, and the PCR data are available only through 2012. The data show, however, that the number of observed cancer cases exceeds the number of expected cases for each of the counties and for males and females even before shale gas development commenced.

Cancers generally take years to manifest, which make the findings from this study all the more concerning. Given the lead time in the diagnosis of chronic diseases, townships with

Table 4 – Leukaemia Incidence by County 2000–2012.

County		Males				Females			
		Observed	Expected	SIR	95% CI	Observed	Expected	SIR	95% CI
Allegheny	2000–2004	490	540	90.7-	82.7, 98.7	388	451	85.9-	77.4, 94.5
	2004–2008	487	536	90.9-	82.9, 98.9	425	449	94.6	85.6, 103.6
	2008–2012	559	590	94.8	86.9, 98.6	478	475	100.7	91.7, 109.7
	% difference	14.10%				23.20%			
Beaver	2000–2004	74	82	90.7	70.0, 111.4	63	64	98.5-	74.2, 122.8
	2004–2008	73	82	88.7	68.3, 109.1	48	65	75.1-	53.9, 96.3
	2008–2012	91	91	100.3	79.7, 120.9	64	70	91.9	69.4, 114.2
	% difference	23.00%				1.60%			
Fayette	2000–2004	60	65	92.7	69.3, 116.1	66	53	124.7	94.5, 154.9
	2004–2008	55	66	83.4	61.4, 105.4	51	54	95.3	69.1, 121.5
	2008–2012	47	72	65.5-	46.9, 84.1	31	55	56.3-	19.8, 61.9
	% difference	–21.70%				–53.00%			
Greene	2000–2004	19	17	114.7	63.1, 166.3	17	12	136.8	71.7, 201.9
	2004–2008	18	17	105	56.5, 153.5	21	13	166.8	95.4, 238.2
	2008–2012	21	19	100.3	57.4, 143.2	7	7		
	% difference	10.50%				–58.80%			
Washington	2000–2004	101	90	111.8	89.9, 133.7	84	72	117.3	92.2, 142.4
	2004–2008	92	93	99.4	79.1, 119.7	88	73	120.5	95.3, 145.7
	2008–2012	100	106	94	75.6, 112.4	79	80	98.2	76.5, 119.9
	% difference	1.00%				–5.90%			
Westmoreland	2000–2004	149	168	88.5	74.3, 102.7	120	132	90.9	74.6, 107.2
	2004–2008	163	172	95	80.4, 109.6	132	134	98.3	81.5, 115.1
	2008–2012	170	197	86.4-	73.4, 99.4	130	148	87.7	72.6, 102.8
	% difference	14.10%				8.30%			
All PA	2000–2004	4833	4962	97.4	94.7, 100.1	3741	3952	94.7-	91.7, 97.7
	2004–2008	5049	5129	98.4	95.7, 101.1	3874	4063	95.3-	92.3, 98.3
	2008–2012	5747	5902	97.4-	94.9, 99.9	4426	4487	98.6	95.7, 101.5
	% difference	18.90%				18.30%			

CI, confidence interval; SIR, standardized incidence ratio.
% difference between 2000–2004 and 2008–2012.

substantial shale gas activities could be posed to see a large increase in cancer incidence, not to mention other cardiovascular, respiratory, neurological, endocrine and reproductive conditions, over the next few years.

While there was a steady increase (and in some cases a substantial increase) in cancers from 2000 to 2012, clearly risk factors other than, or in addition to, shale gas development activities must be taken into account. To what extent is exposure to shale gas activities synergistic with past exposure to other risk factors for cancer and other diseases? The region has a long history of industry (e.g. coal mining and steel mills) that is associated with elevated morbidity and mortality.

Canonsburg Township located in heavily drilled Washington County, for example, was home to a major uranium milling facility for decades prior to 1957. At one time Canonsburg was known as ‘the most radioactive town in America’.²⁶ Uranium-238 decays to form radium-226. Long-term exposure to uranium-238 (half-life of 4.5 billion years) and radium-226 (half-life of 1600 years) increases the risk of bone and lung cancer, tumours of the lymphatic and haematopoietic tissues, leukaemia and lymphoma. The Canonsburg mill site was designated in the 1978 Uranium Mill Tailings Radiation Control Act as eligible for federal funds for clean-up. Also, Canonsburg is situated along Chartiers Creek, a tributary of the Ohio River, that is highly polluted from acid mine drainage, agricultural and industrial runoff

and sewer overflow. It remains one of the most polluted watersheds in Pennsylvania.²⁷

Canonsburg is located adjacent to Cecil, North Strabane Charters and Peters Townships, which have higher than expected cancer rates; yet, none of these townships are located in areas with substantial drilling activity (see Fig. 1).

Allegheny County, which has few producing wells, is home to the Clairton Coke Works Plant, the largest coke manufacturing facility in the USA. Significant quantities of fugitive dust from pet coke storage and handling operations raises the risk of heart and lung disease primarily from the inhalation of particles that are 10 µm in diameter or smaller. These particles, once inhaled, generally pass through the throat and nose and enter the lungs causing damage to tissues.²⁸

In heavily drilled Greene County, high concentrations of bromides and radionuclides were found in Ten Mile Creek, a stream that snakes through Greene and Washington Counties passing through areas of shale gas development. Ten Mile Creek feeds into the Monongahela River, the source of drinking water for hundreds of thousands of people in western Pennsylvania. Exposure to bromine can severely impact the thyroid gland²⁹ and has been linked to an increased risk of preterm delivery.³⁰ Bromides are found in fracking wastewater. Illegal dumping of fracking waste into streams and ponds has occurred in the county.³¹ Also in Greene County, the Hatfield's Ferry power plant, recently closed, was a major

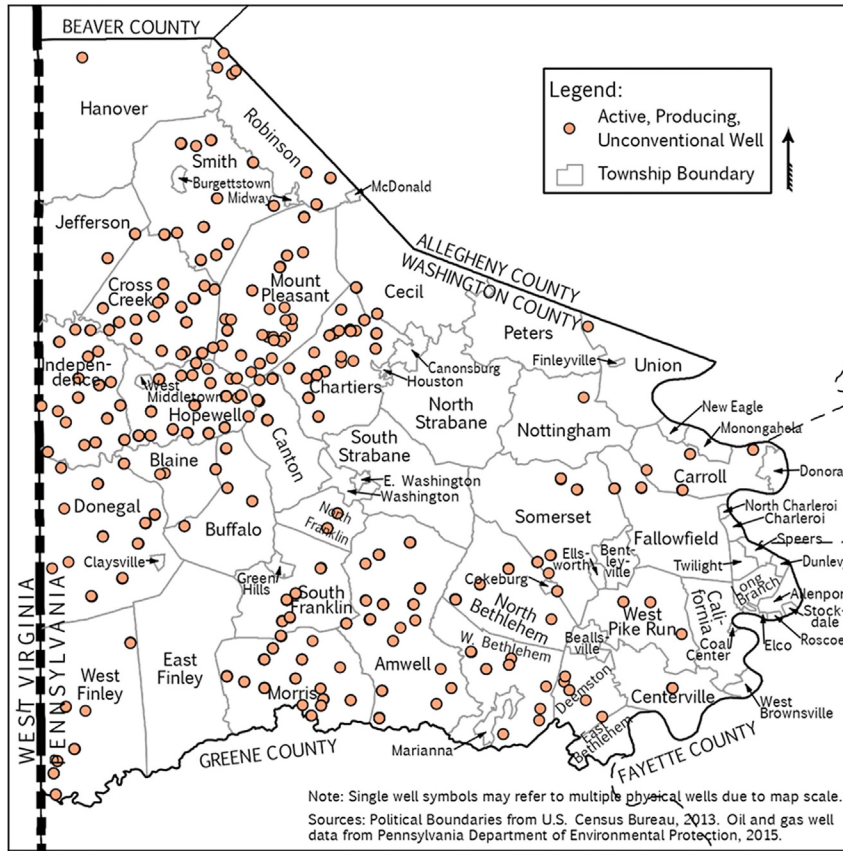


Fig. 1

Table 5 – Selected cancers by township by year, Washington county.

Cancers by township	2000–2007	2008–2012	Total	
Urinary bladder				
Canonsburg	14	14	28	0.00%
Canton	12	18	30	50.00%
Carroll	6	20	26	233.00%
Cecil	12	29	41	141.70%
Chartiers	12	14	26	16.70%
Fallowfield	9	14	23	55.60%
Monongahela City	12	9	21	–25.00%
North Franklin	14	8	22	–42.90%
North Strabane	16	29	45	81.30%
Peters	20	29	49	45.00%
South Strabane	21	22	43	4.80%
Washington City	19	12	31	–36.80%
Total county	296	390	686	31.70%
Thyroid				
Cecil	11	9	20	–18.20%
North Strabane	12	8	20	–33.30%
Peters	13	33	46	153.80%
South Strabane	7	18	25	157.10%
Washington City	12	9	21	–25.00%
Total county	131	216	347	64.90%
Leukaemia				
Cecil	5	12	17	8.30%
North Strabane	7	9	16	28.60%
Peters	7	14	21	100.00%
South Strabane	5	11	16	120.00%
Washington City	5	16	21	220.00%
Total county	123	177	300	43.90%

source of air and water pollution. There is documented ground water contamination due to coal ash waste.³² Fly ash is known to contain heavy metals including arsenic and lead.

As the above illustrates, there are multiple sources of potentially toxic, harmful exposures in southwest Pennsylvania, many dating back decades. Shale gas development is a relative newcomer to the region, but there could be a synergistic effect of shale gas activities with past toxic exposures. This link must be more fully explored.

Data limitations include small population counts in these rural counties and townships, and a small number of events, which raises the risk of chance variation. Further, the short period of time between the onset of drilling and the development of cancer must be taken into account. What this study tries to do is illustrate that other potentially confounding factors must be taken into account before one can state with statistical certainty that UGD is the ‘cause’ of an increased risk of cancer.

Conclusion

As the above illustrates, pollution from industry is not new in southwest Pennsylvania. Multiple sources of air and water pollution, past and present, serve to raise the risk of disease among those living in the area. Given the decades-long exposure to highly toxic pollutants, it perhaps is not surprising that even in counties with minimal shale gas activities there are higher than expected rates of cancer, heart and respiratory diseases and other medical conditions. Data from

the PCR show that there were higher than expected cancer rates long before unconventional shale gas activity began in the region. To what extent are the higher than expected cases seen in 2008–2012 a result of exposure to the potentially harmful byproducts of past industrial activity? To shale gas development? To some combination thereof? To what extent do demographic and lifestyle factors contribute to the higher number of observed cancer cases? Given the long lead time for many cancers to develop, the results presented here may be just the tip of the iceberg.

Ecological studies such as this one cannot determine causality, cannot link exposure to risk factors to disease, nor can they take into account confounding factors such as lifestyle, genetics, poverty, age. They can, however, raise ‘red flags’ to warn of higher than expected morbidity and mortality and should provide the impetus for observational studies such as case-control and cohort studies. Given that shale gas continues to be extracted in many parts of the region, there must be a concerted effort to monitor health indicators on a county and township level in order to better understand what the future holds for individuals living in southwestern Pennsylvania, especially for those living in counties that have been heavily drilled. Clearly, further research should be conducted to better understand the relationship between health and UGD.

Author statements

Acknowledgements

The authors thank Maritza Montalvo for preparing the Tables, and Eliza Czolowski for preparing the well location map for Washington County. They also thank Jake Hays for his insightful suggestions and recommendations. The authors thank Sejal Shah and Anastasia Vinar for compiling the data.

Ethical approval

None sought.

Funding

No grant funding was sought for this study and because the data are abstracted from the Pennsylvania's Department of Health Division of Health Informatics public database, no IRB approval was deemed not necessary.

Competing interests

None declared.

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