Potential for Levels of Arsenic and Chromium in Drinking Water to Contribute to the Higher Cancer Rates Found in Eastern Kentucky as Compared to the Rest of the State

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Running head: Drinking water As and Cr contribution to cancer rates in KY

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Abstract: Cancer incidence and mortality rates have been and continue to be higher in Appalachia than in the rest of the United States, and Kentucky, in particular, have had some of the highest rates of any state. It has been proposed that elevated levels of heavy metals like arsenic (As) and chromium (Cr) in the drinking water and soil of Appalachia significantly contribute to the region's high cancer rates and that the areas that produce the most coal directly correspond to those with the highest cancer rates. Are metals, including Cr and the metalloid As, at levels in public drinking water that could result in risks to residents from drinking water from that source? Are levels elevated in private drinking water wells? Finally, are levels of As and Cr greater in eastern Kentucky drinking water public systems and private wells (groundwater) than other regions of the state? To address the questions, we gathered monitoring data over the past twelve years (2000- 2012) from the 519 permitted drinking water facilities statewide, including commercial bottled water facilities, and from 407 private drinking water wells and analyzed them for total arsenic and total chromium. Analytical results for both public and private drinking water indicate As and Cr were below MCLs in all samples and below the analytical detection limits in 97.5% of the samples. Available total cancer incidence rates, skin and colon- rectal incidence and mortality rates (2000-2009), were not significantly higher ($\alpha = 0.05$) in the Appalachian Region of Kentucky than other regions of the state. Total cancer mortality and lung-bronchus incidence and mortality rates were greater in Eastern Coal Field (Appalachia) than other regions of the state. However, no link could be made between cancer rates in Appalachia and As and Cr in the regional drinking water. In addition, no significant differences in cancer incidence were found between those areas with the greatest coal production as compared to those with the lowest production in either the Eastern or Western Coal Field regions.

INTRODUCTION

Cancer incidence and mortality rates have been and continue to be higher in Appalachia than in the rest of the United States, and Kentucky, in particular, have had some of the highest rates of any state [1-7]. For example, Kentucky had one of the highest invasive cancer incidence rates for all cancers (2002-2006) of any state at 511.2 per 100,000 people, and as compared to the entire U.S. rate of 472.9 per 100,000, both age-adjusted incidence rates [3]. Similarly, Kentucky had the highest cancer-induced death rate of any state during 2002-2006. The Commonwealth's mortality rate for all cancers was 219.3 deaths per 100,000 people (age-adjusted) as compared to 186.9 deaths per 100,000 people reported for the entire U.S. [3].

Although the Appalachian Regional Commission (ARC) [8] has defined and redefined the boundaries of Appalachia several times since it's inception as to what states and counties should be part of the region, currently 420 counties in 13 states are included. The ARC has further subdivided Appalachia into five sub-regions, having relatively homogenous characteristics of topography, demographics and economics. The Central Region encompasses portions of Tennessee, Virginia, West Virginia and Kentucky. Unfortunately, the Central Appalachian Region has some of the highest poverty and mortality rates in Appalachia [9, 2, 10, 6]. In eastern Kentucky, mortality rates for total cancer, lung cancer, and cervical cancer have been reported to be up to 36% greater than the overall Appalachian rates and up to 50% greater than corresponding U.S. rates [6].

Several investigators have proposed that elevated levels of heavy metals like arsenic and chromium in the drinking water and soil of Appalachia significantly contribute to the region's high incidence and mortality cancer rates, specifically lung and colorectal cancer rates [11-16]. The investigators have further indicated that high concentrations of arsenic in the region's coal beds and high levels of chromium and other heavy metals found in the region were to blame for the higher cancer rates; and that the counties that have the highest level of arsenic and chromium directly correspond to those with the highest cancer rates [14-16].

These assertions present several questions that the Kentucky Division of Water (DOW) must confront as an environmental and public health agency faced with the task of assuring that the citizens of Kentucky, including those living in eastern Kentucky, have clean drinking water available for consumption. Are metals, including chromium and the metalloid arsenic, at levels in public drinking water that could result in risks to residents from drinking water from that source? Are levels of the metal and metalloid elevated in private drinking water wells? Finally, are levels of arsenic and chromium greater in eastern Kentucky drinking water public systems and private wells (groundwater) than other regions of the state?

To address the questions, we gathered monitoring data from the 519 permitted drinking water facilities statewide ranging in size of as few as 6 people drinking from that source (e.g., Ken-Lake Trailer Park) to our largest drinking water system and its 730,611 customers (i.e., Louisville Water Company). Monitoring data was also evaluated from our commercial bottled water facilities (e.g., High-Bridge Spring Water). Assessed data included monitoring information (3,081 samples) from the past twelve years, January 2000 to January 2012. In addition, drinking water samples were collected from 407 wells (707 samples) and analyzed for total arsenic and total chromium. Although the DOW does not regulate private drinking water wells, the Division routinely samples individual drinking water wells for which a resident has concern; therefore, the wells DOW does sample potentially bias the sampling towards problem areas. The Kentucky Groundwater Database includes monitoring information on 33,987 wells statewide the vast majority of which are not used as a drinking water source. Only drinking water wells were used in this evaluation. Samples used in the groundwater evaluation dated from January 2000 to January 2012.

In an issue brief on Kentucky Drinking Water [17], it was noted that since 2000, the Commonwealth expanded public water service from approximately 37,000 miles of water main to 56,500 miles thereby increasing the percentage of the state's population of 4.3 million being served by a PWS. The percentage was indicated to have increased from 85% in 2000 to 95% in 2010. A more recent estimate [18], determined that the percentage may be as high as 97% of Kentuckians having public water service available for their use. Although having access to a potable public water supply does not assure that citizens will rely on that source, less than 5% or 215,000 residents statewide likely are without access to a PWS. Still areas, especially areas in rural eastern Kentucky, may be underserved and without ready access to public drinking water and the citizens in those areas must rely on groundwater wells, springs or cisterns as sources for their potable supply of drinking water.

Arsenic and chromium are naturally occurring elements found at low concentrations (mg/Kg, ug/L) in soils, stream sediments, rocks (including coal), water (including surface and groundwater), and in terrestrial and aquatic organisms. In a study on arsenic in groundwater [19], levels determined in each physiographic region in Kentucky (geologic regions) were compared to each other. Approximately 95% of all arsenic measurements (N= 4,402) were equal to or less than 0.010 mg/L (i.e., Maximum Contaminant Level, MCL). The median value for arsenic in each of the physiographic regions was 0.002 mg/L. Although the investigator evaluated data from all wells in the state (i.e., drinking and monitoring), he concluded that there were no widespread occurrences of high arsenic concentrations in groundwater in any physiographic region, including the Eastern Kentucky Coal Region (Central Appalachia). In a study focusing on arsenic in drinking water in Central Appalachia [9], resident self-collected samples were analyzed from one hundred and ninety-five wells in thirteen eastern Kentucky counties. Of those, only two were determined to have concentrations above 0.010 mg/L (i.e., one each in Floyd and Johnson County). Shiber also collected samples from 29 PWSs, nine springs and three bottled water systems, all samples were below the MCL and all but one spring (i.e., Floyd County at 0.002 mg/L) were below a detection limit of 0.001 mg/L.

In another study [20], soil samples were collected and analyzed for metals from more than sixty counties and five physiographic regions of Kentucky. Statewide, 539 surface soil samples were collected and analyzed for arsenic, mean levels were 8.9 $\pm$ 7.0 S.D. mg/Kg and median levels were 7.2 mg/Kg. Chromium levels averaged 20.5 $\pm$ 13.9 mg/Kg with a median level of 17.3 mg/Kg from the 771 samples analyzed. Although the highest concentrations for arsenic and chromium were detected in samples collected in the Bluegrass Region of Kentucky (i.e., 55.5 mg As /Kg and 168 mg Cr /Kg, collected from industrial sites), the authors determined that average and median surface soil concentrations were not appreciably different between the five regions.

In a study on concentrations of metals in rocks (specifically focusing on coal-producing areas) and sediments from the Central Appalachian Basin of Kentucky [21], arsenic and chromium levels were determined on samples collected from 25 of the 27 counties in the Eastern Coal Field Region. Arsenic in sediments ranged from <0.6 to 98 mg/Kg and chromium from <2.0 to 145 mg/Kg in the 1265 sediment samples collected in the Region. The leading coal producing counties [22] of Pike, Perry, Harlan, Letcher and Knott had some of the lowest levels of arsenic and chromium in sediments in the Eastern Coal Field. The authors indicated that transport of arsenic and presumably other metals such as chromium from coal and shale into the water were unlikely because they were absorbed on the prevalent iron oxyhydroxides present in the area soils and sediments.

The U.S. Environmental Protection Agency's and Kentucky Division of Water's MCL in public drinking water for total arsenic is 0.01 mg/L (10 μg/L) and total chromium is 0.10 mg/L (100 μg/L)[23]. The MCL includes a margin of safety to allow for possible sensitive individuals in the population. Although high doses of arsenic (e.g., 600 μg/L) in drinking water have been found to result in bladder, lung, colorectal and other cancers, skin cancer appears to be the more prevalent possible outcome of drinking water exposures approaching 10-50 μg/L [24], levels that are more characteristic of waters of the United States [25-27]. Skin cancer incidence is the effect for which the MCL was developed. Lung and colorectal cancers from arsenic exposures are generally associated with inhalation exposure rather than oral exposures. Total chromium (Cr) analysis includes Cr 0, III, IV, and VI, with Cr III, and to a less extent Cr VI, the most common valence forms of the element present in the environment, including rocks, coal, soils, sediments and water. Chromium III is an essential nutrient and exposure is not known to cause cancer from either the oral or inhalation exposure [28]. However, Cr VI is known to be carcinogenic from inhalation exposure and can result in lung and other respiratory track cancers. Chromium VI is not known to be carcinogenic from oral exposures (e.g., drinking water) [28, 29], but some evidence has been published indicating that it could be carcinogenic from drinking water exposures. An increased mortality from stomach cancers was reported in China where drinking water was highly contaminated by Cr VI [30]. This study has been reanalyzed by a number of investigators, some confirming the association and others finding no significant link between oral exposures to Cr VI and cancer [31-36]; adding to the uncertainty was the fact that the original paper was editorially retracted [30]. The possible link remains uncertain and awaits further investigation [28, 37].

METHODS

In evaluating the public drinking water systems to answer the questions posed, we pooled the information based on the general physiographic region considerations of Eastern Coal Fields, Western Coal Fields, Bluegrass, Mississippi Plateau, and Jackson Purchase (Figure 1). We are aware that the physiographic regions perhaps more definitely could be further divided into Inner and Outer Bluegrass, Knobs, Ohio River Floodplain, Eastern and Western Mississippi Plateau (Pennyrile) and Jackson Purchase resulting in seven instead of five regions. However, dividing the general regions chosen into smaller areas resulted in fewer than five drinking water facilities to evaluate for some of the physiographic regions and over forty for others. Our regionalization includes: 27 counties for the Eastern Coal Field (Bell, Boyd, Breathitt, Carter, Clay, Elliott, Floyd, Greenup, Harlan, Jackson, Johnson, Knott, Knox, Laurel, Lawrence, Lee, Leslie, Letcher, McCreary, Magoffin, Martin, Morgan, Owsley, Perry, Pike, Whitley, Wolfe); 10 counties from the Western Coal Fields (Butler, Crittenden, Daviess, Henderson, Hopkins, McLean, Muhlenberg, Ohio, Union, Webster); 44 counties from the Bluegrass Region (Anderson, Bath, Boone, Bourbon, Boyle, Bracken, Bullitt, Campbell, Carroll, Clark, Estill, Fayette, Fleming, Franklin, Gallatin, Garrard, Grant, Harrison, Henry, Jefferson, Jessamine, Kenton, Lewis, Lincoln, Madison, Mason, Menifee, Mercer, Montgomery, Nelson, Nicholas, Oldham, Owen, Pendleton, Powell, Rockcastle, Robertson, Rowan, Scott, Shelby, Spencer, Trimble, Washington, Woodford); 31 counties in the Mississippi Plateau (Adair, Allen, Barren, Breckinridge, Caldwell, Casey, Christian, Clinton, Cumberland, Edmonson, Grayson, Green, Hancock, Hardin, Hart, Larue, Livingston, Logan, Lyon, Marion, Meade, Metcalfe, Monroe, Pulaski, Russell, Simpson, Taylor, Todd, Trigg, Warren, Wayne); and 8 counties in the Jackson Purchase (Ballard, Calloway, Carlisle, Fulton, Graves, Hickman, McCracken, Marshall).

Metal monitoring information was evaluated from the DOW Public Drinking Water System (PWS) database using analytical data collected from all public drinking water systems and from commercial bottled water facilities in the state. Analytical laboratories utilized by drinking water systems to generate analytical results were certified by Commonwealth of Kentucky, Department for Environmental Protection Laboratory (i.e., NELAC Institute-NELAP, National Environmental Laboratory Accreditation Program, certified laboratory) and U.S. Environmental Protection Agency. Arsenic and chromium in water were analyzed following EPA approved procedures from Standard Methods for Examination of Water and Wastewater, 20th Edition [38] Method 3114 B for arsenic and Method 3113 B [39] for chromium in drinking water. The analytical detection limits were 0.01 mg/L for arsenic and chromium in 2000-2002 and 0.001 mg/L in 2003-2012. Method 3112 B for mercury [40] and Method 3120 B [41] were utilized for metal analysis of antimony, barium, beryllium, cadmium, selenium and thallium. The analytical detection limits were 0.003 mg/L for antimony, 0.002 mg/L for barium, 0.0002 mg/L for beryllium, 0.001 mg/L for cadmium, 0.0002 mg/L for mercury, 0.002 mg/L for selenium and 0.001 mg/L for thallium. Some facilities purchase all or a portion of their supplies from adjacent facilities, but all systems are required to provide monitoring information to the database. Each PWS system was evaluated separately even if they bought all their water from another source. A distinction was not made on source of the water that was treated, some systems treat surface water, others groundwater and some a combination of the two sources. A similar physiographic regional pooling of information was applied to evaluating the groundwater data to answer the questions posed. Groundwater analytical data was generated from the Kentucky Department for Environmental Protection Laboratory or from the state certified Kentucky Geological Survey Laboratory.

Arsenic and chromium levels were often below the standard detection limits (i.e., non-detection) for those two substances in the groundwater samples. Samples collected from each well over the 12 year period were averaged and that value used in the physiographic regional calculations. The actual concentration present in a below detection sample could be zero or any value up to the detection limit, but using a zero in the calculations or ½ the detection limit, as has been used with risk assessment data having some non-detections, potentially would skew the average in a region towards a low value, especially where sampling indicates many samples were non-detections; and calculating central tendency values (i.e., median) for the well data assuming that non-detected concentrations were at the detection limit could over-estimate the regional levels. As a consequence, simple descriptive statistics were used that utilized all the samples including less than values (e.g., median, mode), and number of samples, numbers of detections and number of detections above the particular standard of comparison for that parameter, such as MCL.

Summary statistics for cancer rate data consist of mean, standard deviation, and number of samples (i.e., counties). Project cancer rate data were evaluated using summary statistics, one-way ANOVA (analysis of variance), Levene's Test for Equality of Variance and pairwise t-test using SAS®.

RESULTS

Public Water Systems

Based on the monitoring data collect over the last twelve years (since 2000) from the 519 public drinking water systems across the state (Table 1), only one MCL violation was seen for any metal, including arsenic and chromium (i.e., antimony in a February 2003 sampling at one facility in Knox Co.). All samples were determined to be less than the standard analytical detection limit required to be used during a given year (i.e., 0.01 mg/L for arsenic and chromium in 2000-2002, and 0.001 mg/L in 2003-2012). The detection limit was below the MCLs for arsenic and chromium during both of these periods and for barium, beryllium, cadmium, mercury, selenium, thallium and antimony, except for the single sample from 2003 (It should be noted that in resampling of the facility, antimony was not detected.).

To address the first question posed above, DOW does not have any evidence that arsenic and chromium are at levels of concern anywhere in public water supplies across the state, and in fact, monitoring indicates that they are below currently accepted health effects levels (i.e., below MCLs, Table 1). As for the third question posed above, our monitoring data indicates that the Eastern Coal Field Region also did not have arsenic and chromium levels above other regions of the state (Table 1). Therefore, we would conclude that Eastern Coal Field public water systems are not uniquely, among other regions in the state, exposing their customers to toxic levels of arsenic and chromium, nor have the concentrations of metals present in eastern Kentucky public drinking water been of health concern (at least over the last twelve years evaluated), with the one exception noted in 2003 for antimony.

Domestic Drinking Water Wells

Central Tendency median and mode arsenic and chromium concentrations in sampled wells statewide and in each of the physiographic regions of Kentucky are given in Table 2. The median values were also compared to the standards (i.e., MCLs), and three other considerations, the number of wells with concentrations below the analytical detection limits, the number of wells with levels greater than 0.5 the MCLs and the number of wells with concentrations less than 0.5 the MCLs. Well data was pooled for the years 2000 to 2012. Drinking water wells in all six regions had median levels less than the MCLs (i.e., 0.01 mg As/L; 0.1 mg Cr/L) and 0.5 of the MCLs. Statewide, 97.5% of the 407 wells sampled had concentrations below the analytical detection limits for arsenic and chromium. However, arsenic was detected in 3.8% of the Eastern Coal Field Region (ECF) and 6.3% of the Western Coal Field Region (WCF) wells, and chromium was quantified above the detection limit in 4.7% of ECF and 6.3% of WCF wells.

Reported Cancer Incidence and Mortality Rates

As noted earlier, the total invasive cancer incidence rates and the cancer mortality rates are reported as being some of the highest for Kentucky as compared to Appalachia in general, Central Appalachia (subregion including Kentucky) and the United States [4, 5, 7]. A comparison between the cancer incidence and cancer mortality rates by Kentucky physiographic region is presented in Table 3. The state data is drawn from The Kentucky Cancer Registry for the years 2000-2009 [7] and the national data for the same years from the National Cancer Institute's Surveillance Epidemiology and End Result (SEER) program [5].

The physiographical regional, highest, total invasive cancer incidence rate was reported in the Bluegrass Region at 522.42 per 100,000 people (age-adjusted to 2000 census). The cancer incidence rate was higher in the Bluegrass than either the Eastern Coal Field or the Western Coal Field Regions. The mortality rate was greatest in the Eastern Coal Field Region, indicating that a greater proportion, as compared to the rest of the state, of the cancers that occurred in that region resulted in death.

Although the invasive cancer incidence rate for the Bluegrass Region was higher than the other regions, the question is was it significantly higher? A one-way ANOVA ($\alpha = 0.05$) and Levene's Test for Equality of Variance were used to compare the regions. A one-way ANOVA requires the assumptions of normally distributed data, independent samples from each group and variance homogeneity among groups. Levene's Test for Equality of Variance yielded a p-value of 0.1400. The p-value is greater than the reference probability value of 0.05, so there is insufficient evidence to conclude that the variances in cancer incidence rate for the five regions are significantly different. Thus, it is appropriate to use the ANOVA test. Since the p-value of 0.2873 is greater than the reference probability value of 0.05, we fail to reject the null hypothesis and conclude that the averages for cancer incidence rate between regions of Kentucky are not significantly different.

As with incidence rate, the total cancer mortality rate (per 100,000, age adjusted to the 2000 census) in Kentucky from 2000-2008 (only years available) appear greater in one region, the Eastern Coal Field, than in the other regions of the state. Levene's Test for Equality of Variance yields a p-value of 0.9057. The p-value is greater than the reference probability value of 0.05, so there is insufficient evidence to conclude that the variances in cancer mortality rate for the five regions are significantly different. The ANOVA results for cancer mortality rate regional comparison determined a p-value of <0.0001 which is less than the reference probability value of 0.05; we reject the null hypothesis and conclude that at least one mean for cancer mortality rate between regions of Kentucky differs significantly from the others. The regional pairs with significantly different means, at a significance level of $\alpha = 0.05$, are those where zero was not contained in the 95% confidence interval. A pairwise t-test of these comparisons was performed to determine those significantly different ($\alpha = 0.05$). From that comparison, we conclude that the cancer mortality rate in the Eastern Coal Field region is significantly higher than those in the other four regions. We can also conclude that the cancer mortality rate in the Jackson Purchase region is significantly lower than those in the other four regions.

A similar regional statistical comparison (i.e., one-way ANOVA ($\alpha = 0.05$) and Levene's Test for Equality of Variance, pairwise t-test at $\alpha = 0.05$) was made with lung and bronchus invasive cancer incidence and mortality data from the Kentucky Cancer Registry for the years 2000-2009 [7] and is presented in Table 4. National data for the same years from the National Cancer Institute's Surveillance Epidemiology and End Result (SEER) program [5] are also given as a point of reference. Lung and bronchus cancer incidence and mortality rates (per 100,000, age-adjusted to the 2000 census) were significantly higher in the Eastern Coal Field and Western Coal Field as compared to the other three regions.

Colon and rectum invasive cancer incidence and mortality data (per 100,000 age-adjusted to the 2000 census) from the Kentucky Cancer Registry for the years 2000 -2009 [7] and the National data [5] are shown in Table 5. A statistical comparison with one-way ANOVA ($\alpha = 0.05$), Levene's Test for Equality of Variance, and pairwise t-test ($\alpha = 0.05$) was performed to determine if the incidence and mortality were significantly different ($p=0.05$) between the regions. The colon and rectum cancer incidence rates were not significantly different between the physiographic regions with the exception that the Bluegrass was significantly higher than the Mississippi Plateau region. Cancer mortality colon and rectum rates were significantly lower (p=0.05) in the Western Coal Field than the Eastern Coal Field and Bluegrass regions, all other comparisons indicated no significant differences. For some of the counties included in the data sets, the incidence and mortality cases were too few to assure that the age-adjusted rates per 100,000 were reasonable normalizations. However, the calculated rates were included in the regional evaluation and may have contributed to the significance determination between the regions.

The response for which the arsenic MCL was developed was skin cancer incidence [21]. National data from SEER [5] indicate an average invasive cancer incidence rate of 20.882 (per 100,000 age-adjusted to the 2000 census) for melanoma in the US, a rate higher than either the Eastern Coal Field (18.859) or the Western Coal Field (19.195) reported in the Kentucky Cancer Registry for those years, 2000 -2009 [7]. The three non-coal producing regions had incidence rates higher than either coal region (i.e., Jackson Purchase at 24.784, Bluegrass at 23.277, Mississippi Plateau at 21.263).

Coal Production and Cancer Incidence

A comparison of coal production [22] and invasive total cancer incidence, lung and bronchus cancer incidence, and colon and rectum incidence rates for the years 2000-2009 (per 100,000 age-adjusted to the 2000 census, Kentucky Cancer Registry 2012) for the six highest coal producing counties and the six lowest coal producing counties in the Eastern and Western Coal Fields are shown in Table 6. Only one county was part of the grouping for the highest and lowest coal production from the Western Coal Field. Although coal production varies from year to year in a given county and coal has been mined from all the counties in the Eastern and

Western Coal Fields at various times in the past, since 2000 those counties listed as high or low have remained generally the same. A statistical comparison with one-way ANOVA ($\alpha = 0.05$), Levene's Test for Equality of Variance, and pairwise t-test ($\alpha = 0.05$) was performed to determine if the incidence rates were significantly different (p=0.05) between the high coal producing and low coal production counties. Although the top six coal producing counties averaged 18,618,225 tons as compared to 977 tons for the lower six coal fields producing counties, invasive total cancer incidence, lung and bronchus incidence, and colon and rectum incidence rates were not significantly different (p=0.05) between the two groups. Coal production did not appear to be a predictive tool for evaluating the incidence of cancer in a county.

In published studies in which drinking water arsenic levels were similar to those from this study (i.e., 0.010 mg/L), no increased incidence or mortality for lung, bladder, kidney, liver, prostate and colorectal cancer were found [42-47]. Levels determined from Kentucky's PWSs across the state and within all physiographic regions were potentially less than 0.010 mg/L (e.g., below a detection limit of 0.001 mg/L). Groundwater arsenic results for each physiographic region were similarly much less than the 0.010 mg/L. Although these results do not preclude arsenic as a causative agent of cancer in the Central Appalachian Region of Kentucky, we have no indication that arsenic in drinking water is significantly contributing to cancer causation in the region.

Conclusions

In this evaluation, three questions were posed about arsenic and chromium levels in drinking water in Kentucky and their relationship to cancer incidence and mortality. First, are metals, including chromium and arsenic, at levels in public drinking water systems that could result in risks to residents from drinking water from that source? Secondly, are concentrations of arsenic and chromium elevated in groundwater wells used as a drinking water source? Finally, are levels of total arsenic and total chromium greater in eastern Kentucky (Eastern Coal Field) or Western Coal Field drinking water systems and private drinking water wells than other regions of the state?

Based on the routine monitoring data collect over the last twelve years (since 2000) from the 519 public drinking water systems across the state (Table 1), only one MCL violation was seen for any metal, including arsenic and chromium (i.e., antimony on one sampling period, February 2003, at one facility in Knox Co.). Since facility monitoring for health-based effects levels were not found, our conclusion is that resident's health statewide has not been detrimentally effected by metals in their finished drinking water over the last tweleve years, including the potential for developing cancer. Cancer certainly may have a latency period before it is manifested subsequent to exposure, but information from the last twelve years does not indicate that metals received in public drinking water are contributing to the cancer incidence in Kentucky.

In an evaluation of the private drinking water data collected over the last twelve years, wells in all six regions had median concentrations that were less than the MCLs (i.e., 0.01 mg As/L; 0.1 mg Cr/L) and 0.5 of the respective MCLs. Statewide, 97.5% of the 407 wells sampled had concentrations below the analytical detection limits for both arsenic and chromium. Arsenic was detected in 3.8% of the Eastern Coal Field Region (ECF) and 6.3% of the Western Coal Field Region (WCF) wells, and chromium was found above the detection limit in 4.7% of ECF and 6.3% of WCF wells. However, no information was generated to indicate that concentrations were at a level of concern (above MCLs).

Total arsenic and chromium levels in public drinking water systems and in private drinking water wells does not appear to be elevated in the Eastern Coal Field Region or the Western Coal Field Region as compared to the rest of the state, including the more metropolitian Bluegrass Region. Although the current study did not evluate exposures prior to 2000, residents in the Appalachian portion of Kentucky (Eastern Coal Field) are not differentially receiving greater exposure to concentrations of the carcinogens arsenic and chromium in their drinking water than other parts of the Commonwealth.

Although the greater total cancer incidence rate found in the Bluegrass Region as compared to other regions of the state may reflect the relatively higher arsenic levels noted in Bluegrass soils, none of the regions had a significantly higher cancer incidence than that found in the other regions.

Total cancer mortality was significantly greater (p=0.05) in the Eastern Coal Field Region than the other four regions, and the cancer mortality rate was significantly lower (p=0.05) in the Jackson Purchase Region than the other four regions However, arsenic and chromium monitoring data from PWSs and private drinking water wells statewide were below their respective MCLs. Therefore, the greater cancer mortality in Eastern Kentucky does not appear to be related to drinking water exposure, at least based on the data collected over the last 12 years.

Lung and bronchus invasive cancer incidence and mortality rates were significantly greater in the Eastern Coal Field Region as compared to the other four regions of the state. However, arsenic and chromium regional median levels in PWSs and private wells collected in the Eastern Coal Field were considerably below the MCLs and levels identified from the literature that could result in lung and broncial cancer.

The colon and rectum invasive cancer incidence and mortality rates were not significantly different (p=0.05) between the regions with the possible exception of a greater incidence in the Bluegrass Region as compared to the Western Coal Field, which may have resulted from the small number of cases of colon and rectal cancer seen in some of the counties in those regions.

A comparison of coal production and invasive total cancer, lung and bronchus cancer, and colon and rectum cancer incidence rates indicated that coal production was not a predictive tool for evaluating the incidence of cancer for a county. The cancer incidence was not significantly higher in the high coal producing counties as compared to those that produced relatively very little coal.

Although cancer incidence and mortality rates are elevated in Kentucky as compared to much of the rest of the U.S., data collected during this study does not support the contention that the cancer rates are due to elevated concentrations of arsenic and chromium in drinking water. As a public agency concerned with the health and well-being of its citizens, DOW will continue to work with public water systems to facilitate extension of access to public facility-treated water to all areas of the Commonwealth, ensure drinking water standards are reached at the public facilities, monitor private wells to inform users of possible problems, and look for any environmental factors that may be contributing to the chronicled cancer incidence and mortality rates in the state.

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REFERENCES

1. Lengerich, E.J., Tucker, T.C., Powell, R.K., Coisher, P., Lehman, E., Ward, A.J., Siedlecki, J.C., and Wyatt, S.W. 2005. Cancer incidence in Kentucky, Pennsylvania, and West Virginia: Disparities in Appalachia. J Rural Health, winter, 21:39-47.

2. Wingo, P.A., Tucker, T.C., Jamison, P.M., Martin, H., McLaughlin, C., Bayakly, R., Bolick-Aldrich, S., Colsher, P., Indian, R., Knight, K., Neloms, R., and Richards, T.B. 2007. Cancer in Appalachia, 2001-2003. Cancer, 112:181-192.

3. Jemal, A., Siegel, R., Xu, J., and Ward, E. 2010. Cancer Statistics, 2010. CA Cancer J Clinicol, 60:277-300.

4. American Cancer Society. 2011. Cancer Facts and Figures 2011. American Cancer Society, Atlanta, GA.

5. National Cancer Institute (NCI). 2012. Surveillance, Epidemiology, and End Results Program (SEER). http://www.seer.cancer.gov.

6. Borak, J., Salipante-Zaidel, C., Slade, M.D., and Fields, C.A. 2012. Mortality disparities in Appalachia: Reassessment of Major Risk Factors. J. Occup Environ Med, 54:146-156.

7. Kentucky Cancer Registry (KCR). 2012. The population-based central cancer registry for the Commonwealth of Kentucky. http://www.cancer-rates.info/ky/index.php.

8. Appalachian Regional Commission (ARC). 2011. The Appalachian Region, Washington, DC, Appalachian Regional Commission. 2011. http://www.arc.gov/applachian_region.

9. Shiber, J.G. 2005. Arsenic in domestic well water and health in Central Appalachia, USA. Water, Air and Soil Pollut, 160:327-341.

10. Hendryx, M., and Ahern, M.M. 2009. Mortality in Appalachian in coal mining regions: The value of statistical life lost. Pub Health Reports, 124:541-550.

11. Appalachian Community Cancer Network. 2009. The Cancer Burden in Appalachia. National Cancer Institute, The Appalachian Community Cancer Network, Kentucky, Ohio, Pennsylvania, M. Dignan, E. Paskett, and E. Lengerich Investigators.

12. Appalachian Community Cancer Network. 2010. Addressing the Cancer Burden in Appalachian Communities. National Cancer Institute, The Appalachian Community Cancer Network, Kentucky, Ohio, Pennsylvania, M. Dignan, E. Paskett, and E. Lengerich Investigators.

13. Hendryx, M. 2009. Mortality from heart, respiratory, and kidney disease in coal mining areas of Appalachia. Int. Archives Occupational Environmental Health 82:243-249.

14. Johnson, N., Shelton, B.J., Hopenhayn, C., Tucker, T.T., Unrine, J.M., Huang, B., Christian, W.J., Zhang, Z., Shi, X., and Li, L. 2011. Concentrations of arsenic, chromium, and nickel in toenail samples from Appalachian Kentucky residents. J. Environmental Pathology, Toxicology and Oncology 30(3):213-223.

15. Legislative Research Committee (LRC). 2011. Doctor say environment might contribute to cancer rates, LRC eNews, http://www.lrc.ky.gov/pubinfo/release.htm.

16. Kentucky House Republican Caucus (KHRC). 2011. Doctor say environment might contribute to cancer rates, 11/3/2011 http://www.kentuckyhouserepublicans.org/index.cfm/article_83.htm.

17. American Society of Civil Engineers (ASCE). 2011. Kentucky Drinking Water. Issue Brief, February 17, 2011, Kentucky Infrastructure Authority, Heitzman, G., Anderson, R., Cooper, S., and Roney, J.

18. Anderson, R. and Bunch, B. 2012. Population Served by Water and Sewer Systems. Kentucky Infrastructure Authority: http://kia.ky.gov/wris/, 4/12/2012.

19. Fisher, R.S. 2002. Groundwater quality in Kentucky: Arsenic. Kentucky Geological Survey, Series 12, Information Circular 5, 4 p.

20. Winner, E.J., Purdy, J.W., Martin, J.D., and Westerman, A.G. 2005. Development of Generic Background Values for Inorganic Elements in Kentucky Soils. Natural Resources and Environmental Protection Cabinet, Department for Environmental Protection, 401 KAR 100:030.

21. Tuttle, M.L.W., Goldhaber, M.B., Ruppert, L.F., and Hower, J.C. 2002. Arsenic in rocks and stream sediments of the Central Appalachian Basin, Kentucky. U.S. Department of Interior, U.S. Geological Survey, Open-File Report 02-28, Denver, Co.

22. Kentucky Office of Mine Safety and Licensing. 2006. Annual Report, KY Coal Facts-County Production. http://www.coaleducation.org/KY_Coal_Facts/production/county_production.htm.

21. U.S. Environmental Protection Agency (EPA). 2011. Drinking Water Standards and Health Advisories, 2011 Edition, Office of Water, EPA, Washington, DC. EPA 820-R-11-002.

23. U.S. Environmental Protection Agency (EPA). 2012. Integrated Risk Information Systems (IRIS), Toxicological Review of Inorganic Arsenic. http://www.epa.gov/iris/subst/0278.htm.

24. Welch, A.H., Westjohn, D.B., Helsel, D.R., and Wanty, R.B. 2000. Arsenic in ground water of the United States: Occurrence and geochemistry. Ground Water, 38:589-604.

25. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry (ATSDR). 2007. Toxicological Profile for Arsenic. ATSDR, Division of Toxicology and Environmental Medicine, Atlanta, GA.

26. Ayotte, J.D., Gronberg, J.A., and Apodaca, L.E. 2011. Trace Elements and Radon in Groundwater Across the United States, 1992-2003. Scientific Investigations Report 2011-5059, U.S. Department of Interior, U.S. Geological Survey, Reston, VA.

27. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry (ATSDR). 2008. Toxicological Profile for Chromium (Draft). ATSDR, Division of Toxicology and Environmental Medicine, Atlanta, GA.

28. U.S. Environmental Protection Agency (EPA). 2012. Integrated Risk Information Systems (IRIS), Toxicological Review of Inorganic Chromium. http://www.epa.gov/iris/subst/0278.htm.

29. Zhang, J.D., and Li, X.L. 1997. Cancer mortality in a Chinese population exposed to Hexavalent chromium in water. J Occup Environ Med, 39:315-319.

30. Beaumont, J.J., Sedman, R.M., Reynolds, S.D., Sherman, C.D., Li, L.H., Howd, R.A., Sandy, M.S., Zeise, L., and Alexeeff, G.V. 2008. Cancer mortality in a Chinese population exposed to Hexavalent chromium in drinking water. Epidemiology, 19:12-23.

31. Kerger, B.D., Butler, W.J., Paustenbach, D.J., Zhang, J., and Li, S. 2009. Cancer mortality in Chinese populations surrounding an alloy plant with chromium smelting operations. J Toxicol and Environ Health Part A, 72:329-344.

32. Kerger, B.D., Butler, W.J., Ye, T., and Li, S. 2009. Chromium(VI) ingestion and cancer. Epidemiology, 20:627.

33. Paustenbach, D.J. 2009. On the chromium reanalysis. Epidemiology, 20:625-626.

34. Smith, A.H. 2009. Author response on chromium reanalysis. Epidemiology, 20:626.

35. Beaumont, J.J., Sedman, R.M., Sandy, M.S., Zeise, L., and Reynolds, S.D. 2009. Author response on chromium reanalysis. Epidemiology, 20(4): 628.

36. Zhitkovich, A. 2011. Chromium in drinking water: sources, metabolism, and cancer risks. Chem Res Toxicol, 24:1617-1629.

37. Chen, C.-J., Chen, C.W., Wu, M.-M., and Kuo, T.-J. 1992. Cancer potential in liver, lung, bladder, and kidney due to ingested inorganic arsenic in drinking water. Br J Cancer, 66:888-892.

38. Standard Methods for the Examination of Water and Wastewater, 20th Edition (Standard Methods). 1998a. Method 3114 B, Manual hydride generation/ atomic absorption spectrometry method, p. 3-32 to 3-35 in L. S. Clesceri, A. E. Greenberg and A. D. Eaton (eds.), APHA, AWWA, WEF, United Book Press, Inc., Baltimore, MD.

39. Standard Methods for the Examination of Water and Wastewater, 20th Edition (Standard Methods). 1998b. Method 3113 B, Electrothermal atomic absorption spectrometry method, p. 3-26 to 3-31 in L. S. Clesceri, A. E. Greenberg and A. D. Eaton (eds.), APHA, AWWA, WEF, United Book Press, Inc., Baltimore, MD.

40. Standard Methods for the Examination of Water and Wastewater, 20th Edition (Standard Methods). 1998c. Method 3112 B, Method by cold-vapor atomic absorption spectrometry, p. 3-22 to 3-24 in L. S. Clesceri, A. E. Greenberg and A. D. Eaton (eds.), APHA, AWWA, WEF, United Book Press, Inc., Baltimore, MD.

41. Standard Methods for the Examination of Water and Wastewater, 20th Edition (Standard Methods). 1998d. Method 3120 B, Individually coupled plasma (ICP) method, p. 3-38 to 3-43 in L. S. Clesceri, A. E. Greenberg and A. D. Eaton (eds.), APHA, AWWA, WEF, United Book Press, Inc., Baltimore, MD.

42. Guo, H.-R., and Tseng, Y.-C. 2000. Arsenic in drinking water and bladder cancer: comparison between studies based on cancer registry and death certificates. Environ Geochem and Health, 22:83-91.

43. Steinmaus, C., Yuan, Y., Bates, M.N., and Smith, A.H. 2003. Case-control study of bladder cancer and drinking water arsenic in the Western United States. Am J Epidemiol, 158:1193-1201.

44. Lamm, S.H., Engel, A., Penn, C.A., Chen, R., and Feinleib, M. 2006. Arsenic risk confounder in Southwest Taiwan data set. Environ Health Perspect, 114:1077-1082.

45. Marshall, G., Ferreccio, C., Yuan, Y., Bates, M.N., Steinmaus, C., Selvin, S., Liaw, J., and Smith, A.H. 2007. Fifty-year study of lung and bladder cancer mortality in Chile related to arsenic in drinking water. J Nat Cancer Inst, 99:920-928.

46. Baastrup, R., Sorensen, M., Balstrom, T., Frederksen, K., Larsen, C.L., Tjonneland, A., Overvad, K., and Raaschou-Nielsen, O. 2008. Arsenic in drinking-water and risk for cancer in Denmark. Environ Health Perspect, 116:231-237.

47. Dauphine, D.C., Ferreccio, C., Gunter, S., Hammond, S.K., Balmes, J., Smith, A.H., and Steinmaus, C. 2011. Lung function in adults following in utero and childhood exposure to arsenic in drinking water: preliminary findings. Int Arch Occup Environ Health, 84:591-600.

List of Figures and Tables

Figure 1. The Physiographic Region Division used in Evaluating Public Water Supplies and the Number of Facilities per County

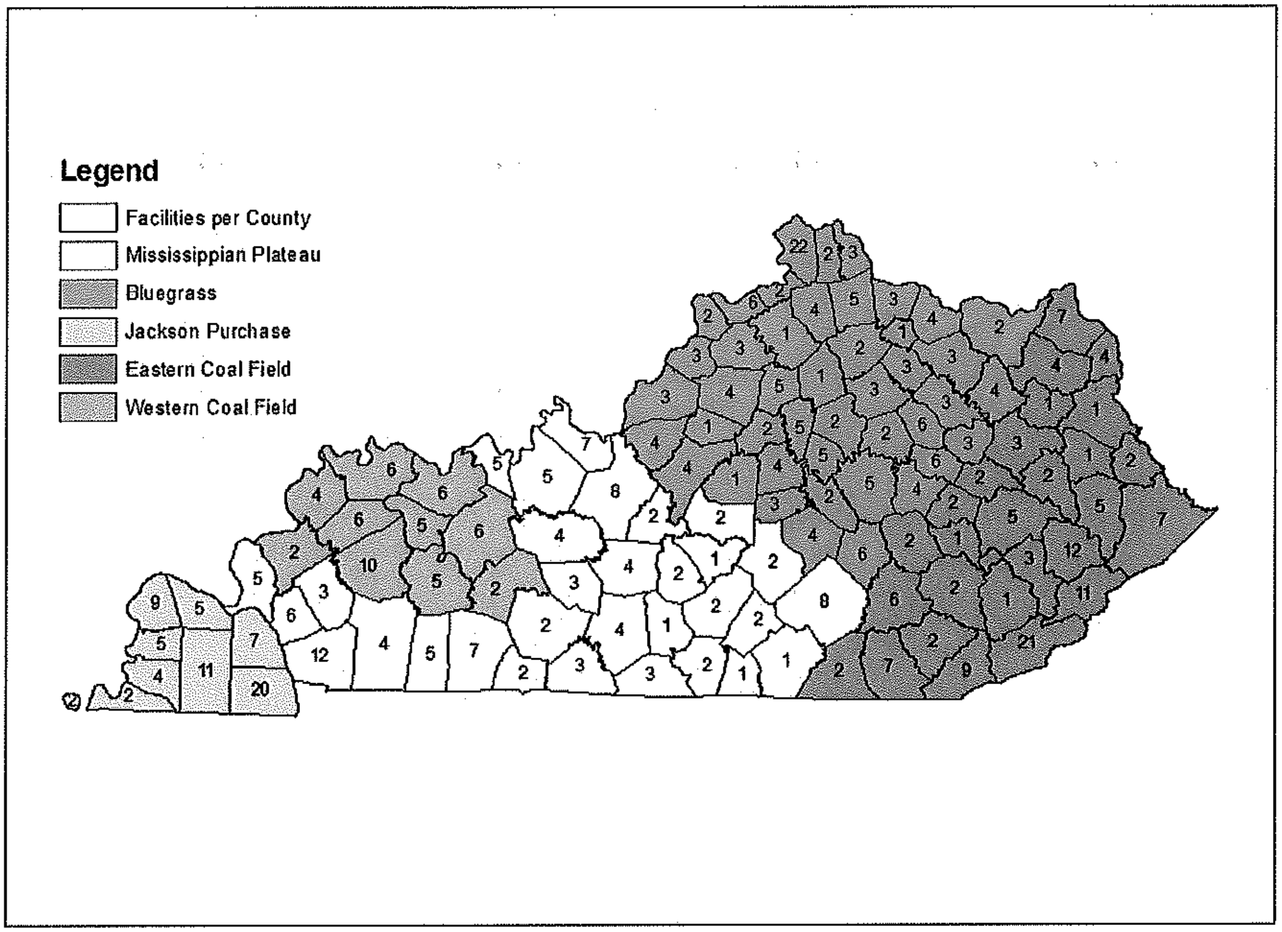

Table 1. Arsenic (As) and chromium (Cr) Maximum Contaminant Level (MCL) determinations in public drinking water systems by physiographic regions of Kentucky, 2000-2012[a]

Physiographic Region	Number of Systems	Number of As samples	As samples above MCL[b]	Number of Cr samples	Cr samples above MCL[b]
Eastern Coal Field	143	794	0	789	0
Western Coal Field	40	360	0	339	0
Bluegrass	148	776	0	776	0
Mississippi Plateau	126	789	0	744	0
Jackson Purchase	62	362	0	362	0

[a] The U.S. Environmental Protection Agency's and Kentucky Division of Water's MCL is 0.01 mg/L for As and 0.1 mg/L for Cr.

[b] All samples were less than the analytical detection limit used during a given year, 0.01 mg/L for As and Cr in 2000-2002 and 0.001 mg/L in 2002-2012.

Table 2. A comparison of arsenic (As) and chromium (Cr) levels in domestic drinking water wells by physiographic region in Kentucky, 2000-2012

Physiographic Region	Number of Wells[a]	Median Level	Mode Level	Wells below detection[b]	Wells ≤ 0.5 MCL	Wells ≥ 0.5 MCL	Wells > MCL
Arsenic (mg/L) [Maximum Contaminant Level (MCL) = 0.01 mg/L]							
Eastern Coal Field	234	<0.0010	<0.0005	225	9	0	0
Western Coal Field	16	<0.0035	<0.0050	15	1	0	0
Bluegrass	13	<0.0010	<0.0020	13	0	0	0
Mississippi Plateau	33	<0.0015	<0.0020	32	1	0	0
Jackson Purchase	111	<0.0008	<0.0005	111	0	0	0
Chromium (mg/L) [Maximum Contaminant Level (MCL) = 0.10 mg/L]							
Eastern Coal Field	234	<0.0005	<0.0005	223	11	0	0
Western Coal Field	16	<0.0010	<0.0200	15	1	0	0
Bluegrass	13	<0.0010	<0.0010	13	0	0	0
Mississippi Plateau	33	<0.0010	<0.0010	32	1	0	0
Jackson Purchase	111	<0.0010	<0.0100	108	3	0	0

[a] Several samples were collected from the individual wells over the 12 years and the average concentrations used to calculate the median and mode.

[b] The detection limit was 0.001 mg/L for arsenic and chromium.

Table 3. Average invasive cancer incidence rates and cancer mortality rates per 100,000 people (age-adjusted) in the physiographic regions of Kentucky, 2000-2009[a]

Physiographic Region	N[b]	Incidence ± SD	Significance[c] $\alpha = 0.05$	Mortality ± SD	Significance[c] at $\alpha = 0.05$
Eastern Coal Field	27	520.359±68.465	ns	243.704±19.655	*
Western Coal Field	10	504.549±16.477	ns	223.381±17.897	ns
Bluegrass	44	522.415±27.565	ns	217.213±21.609	ns
Mississippi	31	504.377±27.385	ns	213.688±14.781	ns
Jackson Purchase	8	502.640±19.585	ns	189.846±18.538	*
Statewide	120	522.900		217.640	
National[d]		479.421		187.384	

[a] Based on data from Kentucky Cancer Registry for years 2000-2009 for cancer incidence rate and 2000-2008 for mortality rate.

[b] Number of counties included in each physiographic region or in state.

[c] Cancer incidence rate was not significant different among the physiographic regions ($\alpha = 0.05$); the cancer mortality rate in Eastern Coal Field was significantly ($\alpha = 0.05$) higher than the other four regions, and cancer mortality in the Jackson Purchase was significantly ($\alpha = 0.05$) lower than the other four regions.

[d] National data was from National Cancer Institute SEER data base for years 2000-2009 for cancer incidence rate and 2000-2008 for cancer mortality rate.

Table 4. Lung and bronchus average invasive cancer incidence rates and cancer mortality rates per 100,000 people (age-adjusted) in the physiographic regions of Kentucky, 2000-2009[a]

Physiographic Region	N[b]	Incidence ± SD	Significance[c] $\alpha = 0.05$	Mortality ± SD	Significance[c] at $\alpha = 0.05$
Eastern Coal Field	27	117.276±21.187	*	94.155±12.453	*
Western Coal Field	10	108.095± 07.688	*	83.082±09.930	*
Bluegrass	44	99.913±11.975	ns	75.299±11.695	ns
Mississippi Plateau	31	99.561±11.523	ns	75.325±08.669	ns
Jackson Purchase	8	96.111±06.685	ns	70.103±07.191	ns
Statewide	120	101.330		77.324	
National[d]		62.294		53.177	

[a] Based on data from Kentucky Cancer Registry for years 2000-2009 for cancer incidence rate and 2000-2008 for cancer mortality rate.

[b] Number of counties included in each physiographic region or statewide.

[c] Lung and bronchus cancer incidence and mortality rates were significantly greater in the Eastern Coal Field and Western Coal Field than the other physiographic regions ($\alpha = 0.05$).

[d] National data was from National Cancer Institute SEER data base for years 2000-2009 for incidence rate and 2000-2008 for cancer mortality rate.

Table 5. Colon and rectal average invasive cancer incidence rates and cancer mortality rates per 100,000 people (age-adjusted) in the physiographic regions of Kentucky, 2000-2009[a]

Physiographic Region	N[b]	Incidence ± SD	Significance[c] $\alpha = 0.05$	Mortality ± SD	Significance[c] at $\alpha = 0.05$
Eastern Coal Field	27	59.635±11.096	ns	21.613±04.345	ns
Western Coal Field	10	55.702± 05.486	ns	19.086±02.310	*
Bluegrass	44	59.718±06.077	*	22.309±04.365	ns
Mississippi Plateau	31	56.056±07.964	ns	20.864±03.920	ns
Jackson Purchase	8	57.846±07.154	ns	18.835±05.125	ns
Statewide	120	57.960		21.350	
National[d]		48.813		18.377	

[a] Based on data from Kentucky Cancer Registry for years 2000-2009 for cancer incidence rate and 2000-2008 for cancer mortality rate .

[b] Number of counties included in each physiographic region or statewide.

[c] Colon and rectal cancer incidence rates were not significantly different among the five physiographic regions ($\alpha = 0.05$), except that the Bluegrass was significantly ($\alpha = 0.05$) higher than the Mississippi Plateau. Colon and rectal cancer mortality rates were significantly lower ($\alpha = 0.05$) in the Western Coal as compared to the Eastern Coal and Bluegrass physiographic regions.

[d] National data was from National Cancer Institute SEER data base for years 2000-2009 for cancer incidence rate and 2000-2008 for cancer mortality rate.

Table 6. Comparison of invasive cancer incidence rates per 100,000 people (age-adjusted) for Kentucky (2000-2009) and the counties with the highest and lowest coal production in tons[a]

County	Production	Total cancer[b]	Lung and bronchus[b]	Colon and rectum[b]
Pike	27,417,850	538.36	118.83	68.17
Perry	13,491,646	551.67	150.16	63.11
Harlan	11,220,209	521.35	126.88	58.74
Knott	10,575,583	503.38	124.91	53.83
Hopkins	10,229,026	521.21	107.52	56.92
Letcher	8,775,038	532.60	125.89	70.49
	Mean±SD	528.10±16.64[c]	125.70±13.99[c]	61.88±6.55[c]
Boyd	0	569.11	105.58	67.76
McCreary	0	530.88	138.28	52.34
Greenup	900	508.84	91.89	56.89
Wolfe	1,164	648.09	145.10	84.41
Butler	1,166	505.69	110.34	49.04
Carter	2,633	592.80	116.18	78.86
	Mean±SD	559.24 ±55.36	117.90±20.22	64.88±14.54

[a] An average of the coal production data reported by Kentucky Office of Mine Safety for 2000-2009.

[b] Invasive cancer incidence information was taken from the Kentucky Cancer Registry (2012).

[c] Total, lung and bronchus, and colon and rectum cancer incidence rates were not significantly different ($\alpha = 0.05$) between the six largest coal producing counties and the six lowest coal producing counties in the coal field regions.