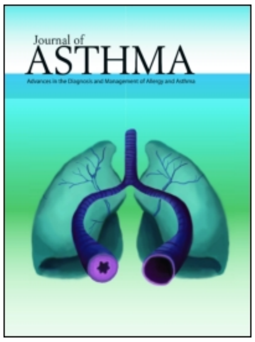

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Journal of Asthma

ISSN: 0277-0903 (Print) 1532-4303 (Online) Journal homepage: https://www.tandfonline.com/loi/ijas20

EXHIBIT D2

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To cite this article: Christine Rutlen, Mohammed Orloff, Joseph Bates & Austin Porter (2020): Crop burning and the prevalence of asthma and COPD emergency department treatments in a rural Arkansas county, Journal of Asthma, DOI: 10.1080/02770903.2019.1708096

To link to this article: https://doi.org/10.1080/02770903.2019.1708096

Accepted author version posted online: 20 Dec 2019.
Published online: 06 Jan 2020.

JOURNAL OF ASTHMA
https://doi.org/10.1080/02770903.2019.1708096

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Crop burning and the prevalence of asthma and COPD emergency department treatments in a rural Arkansas county

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ABSTRACT

Objective: To evaluate the impact of crop burning on the prevalence of asthma and COPD emergency department (ED) treatments in a rural Arkansas county.
Methods: Administrative datasets listing ED treatments for asthma and COPD obtained from the Arkansas Hospital Discharge Dataset System for the calendar years 2014–2016 were used in this semi-ecological study. Primary diagnosis codes (ICD-9: 490–496 and ICD-10: J40–J47) were used to identify patients who were diagnosed with asthma and COPD. Patients with a reported county of residence in Craighead County were determined as case county residents and those in Sebastian County were control county residents. Month of visit was used to determine seasonal variation. PM 2.5 air quality data were obtained from the EPA AQS Data Mart.
Results: Between 2014 through 2016, there were a combined total of 2,536 ED treatments due to asthma and 8,530 due to COPD in Craighead and Sebastian counties. The odds of being treated in the ED during the fall months for asthma and COPD are associated with a 20.9% increase and 16.9% increase respectively in Craighead County as compared to Sebastian Country after adjusting for potential confounders ($p = 0.04$, $p = 0.003$). PM 2.5 concentrations were higher in Craighead County than Sebastian County during the fall season ($p = 0.005$).
Conclusion: Fall ED treatments for asthma and COPD were higher in Craighead County, Arkansas compared to Sebastian County, Arkansas for the years 2014–2016. PM 2.5 levels were also higher in Craighead County in the fall during these years. These differences may be attributable to crop burning.

ARTICLE HISTORY
Received 24 May 2019
Revised 17 December 2019
Accepted 17 December 2019

KEYWORDS
Asthma; COPD; crop burning; particulate matter

Introduction

Crop burning is a common agricultural practice throughout the Southeast that quickly removes residual plant material waste after the fall and spring harvests of crops (1). While effective, crop burning releases significant amounts of air pollutants that may represent a public health concern (2–8). In eastern Arkansas, anecdotal evidence from the local medical community suggests that crop burning may contribute to respiratory disease (W. Skaug, oral communication, January, 2019). Currently, crop burning is not regulated in the state (9).

Multiple pollutants are released from crop burning that may contribute to respiratory disease. Crop burning is a source of many criteria air pollutants regulated by the EPA, including carbon monoxide, nitrous oxide species, sulfur dioxide, and particulate matter less than 10 micrometers (PM 10) and less than 2.5 micrometers (PM 2.5) (10,11). PM 10 and PM 2.5 both pose health risks, but PM 2.5 is considered a greater risk due to its smaller size (12). A causal relationship has been established between PM 2.5 and respiratory disease, and PM 2.5 is a proven Group 1 human carcinogen (13). In a case-crossover study of all Medicare recipients from 2000 to 2012, deaths were more likely to occur on days with increased PM 2.5 and ozone concentrations (14). The authors calculated that every $10\,\mu g/m^3$ increase in PM 2.5 was associated with an increase of 1.42 deaths per 1 million persons.

Associations between crop burning and respiratory disease have been found in multiple countries. These associations include worsened respiratory symptoms among patients with obstructive lung disease during an episode of crop burning in Canada (2), increased risk of hospitalization for asthma with an increase in the amount of rice crops burned in California (3), decreased pulmonary function after crop burning in Iran (6) and India (5,7), an increase in asthma hospital admissions with an increase in total suspended particles during sugar cane burning in Brazil (4), increases in acute respiratory infections in areas with

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significant crop burning in India (8), and increases of respiratory illness among those living in areas proximal to sugar cane burning on days when greater amounts of acreage was burned (15).

Arkansas was estimated to have the fourth-highest amount of crop acres burned in the US and the fifth-highest amount of PM 2.5 released from crop burning for the year 2014 (11), but the health impacts of this burning have not been considered. Crop burning in Arkansas is almost entirely located in the eastern part of the state along the Mississippi River Delta. This distribution has been detected using satellite data (16), and it aligns with data from the USDA Cropscape indicating that the large majority of crops in Arkansas are located almost entirely in the Mississippi River Delta (17). Crop burning occurs twice a year, first in the late spring and early summer and then again in the fall (1). Crop burning in the fall occurs much more frequently than in the spring.

Asthma and COPD exacerbations also follow a seasonal pattern. In children, exacerbations peak in the fall months, and in older populations, exacerbations shift from peaking in the fall months to peaking in the winter months (18). This period overlaps with fall crop burning, confounding study of the issue.

Another potential confounder is racial disparities in Arkansas. The counties in the Mississippi River Delta have a larger percentage of African-Americans (AA) compared to many other counties in the state (19). AA have higher rates of asthma than whites, estimated at 11.6% vs 8.3% respectively, and also have a higher death rate due to asthma, 23.3 vs 8.2 deaths per million (20).

This study hypothesized that markers of respiratory disease were higher during the fall months in the Mississippi River Delta, due to crop burning with the associated PM 2.5 increase, when compared to another part of the state where crop burning is almost absent. To investigate the possible impact on ED treatments resulting from increased concentrations of PM 2.5 particulates that occur during crop burning, we evaluated two Arkansas counties of comparable population. One county had little crop burning while the other had extensive crop burning.

Methods

Craighead County (Craighead), located in the Mississippi River Delta, was chosen as the case county of interest. According to the County Extension Agent for Craighead County, there are approximately 76 000 acres of rice planted each year in the county and it is estimated that one-third to one-half of the acres are burned annually after harvest (B. Thiesse, oral communication, November 2019).Farmers begin burning the stubble in late-August and burning may last until early-November (B. Thiesse, oral communication, November 2019). The point in time when each farmer chooses to burn varies and may be dependent upon weather conditions and the harvest schedule (B. Thiesse, oral communication, November 2019). Sebastian County (Sebastian), resting on the western border of the state which no crop burning, was chosen as the control county. According to the Arkansas Division of Agriculture and the County Extension Agent for Sebastian County, there are very few row crops and rice is not grown in this or any of the surrounding counties (M. Fryer, oral communication, November 2019; C. Fenton, oral communication, November 2019).

Due to the seasonal nature of crop burning and asthma and COPD exacerbations, ED treatments were analyzed by season. Seasonality was determined by the month of ED treatment using the monthly guidelines outlined by Trenberth (21). Winter months are December, January, and February; Spring months are March, April, and May; Summer months are June, July, and August; and Fall months are September, October, and November.

Racial demographics differ between the counties. The respective AA populations for the case and control county are 13.8% and 6.6%, respectively (19). Other demographics between the counties are similar as indicated by the U.S. Census Bureau. The respective populations for the case and control counties were estimated at 102 884 and 127 351 for 2016. The case and control county each have one sizeable city, Jonesboro and Fort Smith, with estimated respective populations of 72 638 and 87 712 for 2016. Both counties have the same percentage of adult smokers, 26.2% (22), higher than the state average of 23.6% (23).

A retrospective review of patients treated in the ED of Arkansas-based hospitals from 2014 through 2016 was performed using data obtained from the Arkansas Department of Health's Hospital Discharge Data System. This is an administrative dataset containing de-identified patient-level records from all EDs in the state. Patient demographics, date of treatment, primary cause of ED treatment, and county of residence were obtained. Individual patient ED treatment data was used to summarize asthma- and COPD-related ED treatments. County of residence was used to classify patients who live in the case or control county.

Primary International Classification of Diseases (ICD) Ninth and Tenth Edition codes were used to identify patients who were treated for asthma and

COPD. Asthma-related ED visits were classified using a primary ICD-9 or ICD-10 diagnosis code of 493 or J45, respectively. COPD-related ED treatments were identified using 490–496 (ICD-9) and J40–J47 (ICD-10) diagnosis codes.

EPA PM 2.5 data were obtained from the EPA's Air Quality Data Mart website. These data were available as 24-h average concentrations collected every three days. The monitor closest to Craighead was located in the neighboring county of Jackson and is approximately 30 miles from the largest city in Craighead, Jonesboro. The monitor closest to Sebastian was located in the neighboring county and state, Sequoyah County, Oklahoma and was approximately 8 miles from the largest city in Sebastian, Fort Smith.

This research was submitted to the institutional review board and was determined to not be human subject research.

Statistical analysis

A bivariate analysis was used to test variable differences such as age, gender, and seasonality of ED treatment between the patients who lived in the case county compared to those who lived in the control county. A chi-square analysis was used to determine these differences along with corresponding odds ratios. Logistic regression analyses were performed to control for demographic variables such as age, gender, and race along with county of residence. The regression equation is set out in Table 3. Statistical significance was set at $\alpha = 0.05$. Data analysis was performed using SAS version 9.4 (SAS Institute, Cary, NC).

Aggregate data were used to reduce daily and weekly variability in ED treatments and air quality data. Data from multiple years were combined and stratified by seasons. The use of aggregate data reduced the potential variations in weather that would impact the dispersion of particulate matter. In addition, crop burning is not coordinated among farmers and therefore air quality data has large variation that is best represented by seasonal analysis.

Results

ED treatments for asthma and COPD

Table 1 shows the study population demographics. For the calendar years 2014–2016, 2,536 individuals visited an ED for an asthma-related complaint and 8,530 individuals visited for a COPD-related complaint in Craighead and Sebastian. The mean ages were 24.8 and 37.5, respectively. Of those visits for asthma, most occurred in the fall and were 28.4% of all visits. For COPD, most visits occurred in the winter (28.4%), followed by spring (26.7%), and fall (25.4%). For both asthma and COPD, the least number of visits occurred in the summer (20.3% and 19.6%, respectively).

Table 1. Demographics of patient encounters, 2014–2016.

	Asthma-related ED treatments	COPD-related ED treatments
Demographics of patient encounters		
Number of ED treatments	2,536	8,530
Age mean (median)	24.8 (21.5)	37.5 (37.0)
Age Groups, N (%)		
0–18 years	1,118 (44.1%)	1,958 (23.0%)
19–64 years	1,326 (52.3%)	5,505 (64.5%)
65+ years	92 (3.6%)	1,067 (12.5%)
Male, N (%)	1,234 (48.7%)	3,851 (45.2%)
Race, N (%)		
AA	953 (37.6%)	2,007 (23.5%)
White	1,451 (57.2%)	6,197 (72.7%)
Other	132 (5.2%)	326 (3.8%)
Season, N (%)		
Fall	721 (28.4%)	2,164 (25.4%)
Spring	712 (28.1%)	2,276 (26.7%)
Summer	515 (20.3%)	1,671 (19.6%)
Winter	588 (23.2%)	2,419 (28.4%)

Source: Arkansas Hospital Discharge Dataset, Arkansas Department of Health.

Table 2 shows the stratification of the population for each county for asthma-related ED treatments. For AA, residency in Craighead was associated with a 230% increased likelihood of ED treatment compared to Sebastian ($p < 0.0001$). For whites, residency in Craighead was associated with a 54% decreased likelihood of ED treatments compared to Sebastian ($p < 0.0001$). In the fall season, residency in Craighead was associated with a 28% increased likelihood of ED treatments compared to Sebastian ($p = 0.005$). No other season exhibited a significant difference among ED treatments.

Table 3 shows the stratification of the study population for each county for COPD-related ED treatments. For AA, residency in Craighead was associated with a 176% increased likelihood of ED treatment compared to Sebastian ($p < 0.0001$). For whites, residency in Craighead was associated with a 47% decreased likelihood of ED treatment compared to Sebastian County ($p < 0.0001$). In the fall season, residency in Craighead was associated with a 24% increased likelihood of ED treatment compared to Sebastian ($p < 0.0001$). In the spring season, residency in Craighead was associated with a 10% decreased likelihood of ED treatment compared to Sebastian ($p = 0.04$).

Table 4 presents the logistic regression model for ED treatments due to asthma in the fall months. Residency in Craighead was associated with a 21% increased likelihood for an ED treatment due to asthma in the fall when controlling for gender, age and race (95% CI 1.01–1.45, $p = 0.04$). It was also

Table 2. Demographics of patient encounters stratified by county for asthma emergency department treatment, 2014–2016.

	Craighead	Sebastian	Unadjusted OR	*p-value**
Demographics of patient encounters				
Number of treatments, N (%)	1,113 (43.9%)	1,423 (56.1%)		
Age (mean, median)	23.5 (21.0)	25.8 (22.0)		*0.04*
Age Groups, N (%)				
0–18 years	497 (44.7%)	621 (43.6%)	1.04	*0.61*
19–64 years	589 (52.9%)	737 (51.8%)	1.05	*0.57*
65+ years	27 (2.4%)	65 (4.5%)	0.52	*0.004*
Male, N (%)	552 (49.6%)	682 (47.9%)	1.07	*0.40*
Race, N (%)				
AA	589 (52.9%)	364 (25.6%)	3.27	*<0.0001*
White	520 (46.7%)	931 (65.4%)	0.46	*<0.0001*
Other	4 (0.4%)	128 (9.0%)		*<0.0001*
Season, N (%)				
Fall	348 (31.3%)	373 (26.2%)	1.28	*0.005*
Spring	298 (26.8%)	414 (29.1%)	0.89	*0.20*
Summer	211 (19.0%)	304 (21.4%)	0.73	*0.14*
Winter	256 (23.0%)	332 (23.3%)	0.98	*0.85*

*Differences among variables between Craighead and Sebastian counties using Chi-square or t-test.
Source: Arkansas Hospital Discharge Dataset, Arkansas Department of Health.

Table 3. Demographics of patient encounters stratified by county for COPD ED treatments, 2014–2016.

	Craighead	Sebastian	Unadjusted OR	*p-value**
Demographics of patient encounters				
Number of ED treatments, N (%)	3,426 (40.2%)	5,104 (59.8%)		
Age (mean, median)	35.9 (34.0)	38.5 (39.0)		*<0.0001*
Age Groups, N (%)				
0–18 years	815 (23.8%)	1,143 (22.4%)	1.04	*0.13*
19–64 years	2,221 (64.8%)	3,284 (64.3%)	1.02	*0.65*
65+ years	390 (11.4%)	677 (13.3%)	0.84	*0.01*
Male, N (%)	1,527 (44.6%)	2,324 (45.5%)	0.96	*0.38*
Race, N (%)				
AA	1,186 (34.6%)	821 (16.1%)	2.76	*<0.0001*
White	2,227 (65.0%)	3,970 (77.8%)	0.53	*<0.0001*
Other	13 (0.4%)	313 (6.1%)	0.06	*<0.0001*
Season, N (%)				
Fall	952 (27.8%)	1,212 (23.8%)	1.24	*<0.0001*
Spring	873 (25.5%)	1,403 (27.5%)	0.90	*0.04*
Summer	641 (18.7%)	1,030 (20.2%)	0.91	*0.09*
Winter	960 (28.0%)	1,459 (28.6%)	0.97	*0.57*

*Differences among variables between Craighead and Sebastian counties using Chi-square or t-test.
Source: Arkansas Hospital Discharge Dataset, Arkansas Department of Health.

Table 4. Adjusted models for ED treatments during the fall months, 2014–2016.

	Asthma		COPD	
Variables	Adjusted OR (95%CI)	*p-value*	Adjusted OR (95%CI)	*p-value*
Male (ref: Female)	1.01 (0.84, 1.26)	*0.94*	0.95 (0.86, 1.05)	*0.35*
Age groups				
0–18 years (ref: 19–64 years)	1.06 (0.88, 1.26)	*0.56*	1.06 (0.94, 1.19)	*0.38*
65+ years (ref: 19–64 years)	0.67 (0.39, 1.13)	*0.13*	0.74 (0.63, 0.87)	*0.0003*
AA (ref: White)	1.19 (0.98, 1.44)	*0.07*	1.19 (1.06, 1.34)	*0.003*
Other race (ref: White)	0.97 (0.64, 1.48)	*0.89*	0.74 (0.56, 0.99)	*0.04*
Craighead (ref: Sebastian)	1.21 (1.01, 1.45)	*0.04*	1.17 (1.06, 1.29)	*0.003*

Regression equation: number of visits = $\beta0 + \beta1$.gender + $\beta2$.age + $\beta3$.race + $\beta4$.county.
Source: Arkansas Hospital Discharge Dataset, Arkansas Department of Health.

associated with a 17% increased likelihood for an ED treatment due to COPD in the fall when controlling for the same variables (95% CI 1.06–1.29, $p = 0.003$).

EPA pm 2.5

Table 5 shows the average concentration of PM 2.5 by season for the years 2014–2016. Fall was the only season that showed a statistically significant difference in PM 2.5 concentrations between case and control counties, 10.179 μg/m3 vs 8.157 μg/m3, respectively ($p = 0.005$).

Discussion

Crop burning releases multiple air pollutants into the atmosphere that may trigger asthma and COPD

Table 5. Average PM 2.5 concentrations by season, 2014–2016.

	Jackson Co, AR*	Sequoyah Co, OK**	*p-value*
Winter	7.484	8.141	*0.29*
Spring	7.016	7.14	*0.84*
Summer	10.075	10.462	*0.57*
Fall	10.179	8.157	*0.005*

*PM 2.5 monitor closest to Craighead County.
**PM 2.5 monitor closest to Sebastian County.
Source: Air Quality Data Mart, Environmental Protection Agency.

exacerbations. This report offers evidence supporting such a conclusion. Asthma- and COPD-related ED treatments were 28% and 24% more likely to occur in Craighead than in Sebastian, respectively. When adjusting for demographics, fall asthma- and COPD-related ED treatments were 21% and 17% more likely to occur in Craighead than in Sebastian, respectively. In addition, PM 2.5 were significantly higher in Craighead than in Sebastian during the fall months, supporting the thesis that the worsened air quality during the fall months may contribute to respiratory disease in Craighead.

AA were more likely to visit the ED for both asthma and COPD in Craighead compared to Sebastian. As Craighead has a higher percentage of AA, these data align with known racial differences in asthma that demonstrate higher rates among AA (20). When controlling for demographics, there was no statistically significant difference found among AA between counties for fall asthma-related ED treatments. However, AA were more likely to be treated in the ED in the fall for COPD when adjusted for demographics. The difference in COPD treatments among AA residing in the counties studied may be due to multiple reasons. Both counties have similar rates of uninsured individuals, 11% vs 13% respectively, but there may be large racial differences among those uninsured that are unknown (22). Occupational exposures may also differ by race, but these data were not available.

The largest limitation to this study is the ability to adequately estimate the number of agricultural fires and their contributions to PM 2.5 air pollution. We relied upon agricultural data and published research to establish that crop burning occurs in the Mississippi River Delta during the fall and is largely absent from the rest of the state. However, this information does not adequately assess the extent of the exposure. A significant difference was found between the air quality measurements for the case and control counties. Limitations exist in using these data to estimate the contributions of crop burning. PM 2.5 data were collected every three days during this time period and represents 24-h averages. The data do not show peak values that would indicate any major burning events. In addition, the location of the monitor may not have been able to assess crop burning in Craighead. As described in the methods section, the monitor sites were not located in either Craighead or Sebastian County. Nonetheless, Jackson County has a large number of crops that are likely burned in the fall and would be measured by the EPA monitors (17). In Butte County, California, researchers analyzed ozone, CO, and PM 10 measurements over a ten year period and did not find an association with rice burning (3). However, the researchers did find a dose-response association between burning of rice fields and asthma hospitalizations, noting a poor correlation between air quality measurements and assessment of rice burning. Other pollutants released from crop burning that may contribute to asthma and COPD morbidity include nitrous oxide species, sulfur dioxide, and PM 10. The EPA monitors for these pollutants are not in proximity to either Craighead or Sebastian and therefore these measurements were not used.

Another limitation to this study is the limited population size, given that crop burning occurs in multiple counties and the surrounding counties may also be affected. Future studies should include more counties along the Mississippi River Delta region. Other limitations include the overlap of ICD codes for asthma and COPD, indicating that some of the asthma patients could have been counted in both analyses. However, there is often overlap in the diagnosis of COPD and asthma, so this classification may have been appropriate for some of the patients (24). A final limitation is the use of only ED data. Given that asthma and COPD exacerbations are often treated in outpatient settings, the ED data may be most representative of severe exacerbations and less so of mild and moderate exacerbations. Hospital admission data were also obtained, but this information was not included in this study as the number of admissions were too low.

Conclusion

Asthma- and COPD-related ED treatments were more likely to occur during the fall in Craighead County, Arkansas than in Sebastian County, Arkansas. EPA PM 2.5 concentrations were also elevated during this period and may be attributable to crop burning. This report adds to a small body of literature evaluating the possible health effects from crop burning.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper. The intent of this policy is not to prevent authors with these relationships from publishing work, but rather to adopt transparency such that readers can make objective judgments on conclusions drawn. The views expressed in this paper are not necessarily those of the Arkansas Department of Health.

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