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Understanding Demographic Factors Influencing Open Burning Incidents in Kentucky

Major Ballard [1], Buddhi R. Gyawali [2,*], Shikha Acharya [2], Maheteme Gebremedhin [2], George Antonious [2] and Jeffrey Scott Blakeman [1]

[1] Kentucky Department for Environmental Protection, Frankfort Regional Office, Frankfort, KY 40601, USA; major.ballard@ky.gov (M.B.); jeffrey.blakeman@ky.gov (J.S.B.)
[2] College of Agriculture, Health, and Natural Resources, Kentucky State University, Frankfort, KY 40601, USA; shikha.acharya@kysu.edu (S.A.); maheteme.gebremedhin@kysu.edu (M.G.); george.antonious@kysu.edu (G.A.)
* Correspondence: buddhi.gyawali@kysu.edu; Tel.: +1-502-597-6029

Abstract: Open burning poses a significant threat to human health and the environment by releasing hazardous chemicals and exacerbating plastic pollution. Urgent action is required to address its pervasive impact and the substantial release of gaseous pollutants. Limited research has explored the demographic aspect of open burning behavior, with none specifically conducted in Kentucky. An analysis of open burning complaints reported to the Kentucky Division for Air Quality in 2015, 2019, and 2021 revealed no significant differences in reported incidents by month and county. Binary logistic regression analyses identified the urban vs rural divide as significant predictors of open burning incidents, while violations were influenced by both urban and rural factors and average household income. Unemployment rates and the percentage of individuals with less than a high school diploma did not significantly predict open burning violations. Targeted interventions at the state and local level, focusing on rural areas and economically disadvantaged communities, can effectively address and mitigate open burning issues.

Keywords: open burning; rural; socioeconomic factors; urban; violation; waste management

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1. Introduction

Open burning (OB), also known as backyard burning, is the intentional residential incineration of household waste, involving the combustion of paper, cardboard, food scraps, plastics, and yard trimmings in the outdoors, as a method of disposing of non-hazardous wastes such as residential municipal solid wastes or yard wastes [1]. It emits more pollutants per unit of fuel compared to controlled combustion sources [2]. These emissions are typically released near ground level, spread across large areas, and originate from non-point sources, rendering point source pollution control methods ineffective [2]. Such a practice presents a significant challenge to both human health and the environment's well-being [3]. The consequences are stark, with uncontrolled waste burning alone causing 4.2 million deaths in 2019, disproportionately impacting low- and middle-income countries [4]. Despite government-implemented waste collection services and laws, open burning remains a prevalent waste disposal method [5,6]. In the United States (U.S.), rural backyard burning is a significant waste management concern due to the presence of synthetic chemicals in household waste [7]. Urban-to-rural migration has increased the pressure to ban backyard burning; however, the rising costs of rural waste disposal have led to continued burning where it is still legal [7]. Urgent action is required to address this pervasive practice and its substantial release of gaseous pollutants [8].

Smoke from waste combustion releases a range of hazardous pollutants, such as particulate matter (PM), hydrogen cyanide, sulfur dioxide (SO_2), polycyclic aromatic hydrocarbons, benzene, lead, mercury, dioxin/furans, nitrogen oxides (NOx), and carbon monoxide (CO) [1,9,10]. The Clean Air Act mandates the Environmental Protection Agency (EPA) to regulate six principal pollutants, including those from waste combustion, which can cause respiratory problems and environmental damage. These emissions, alongside organic compounds like black and brown carbon, impact atmospheric quality, exacerbating climate change and posing serious health risks [11–16]. Household waste burning emits high concentrations of fine particulate matter, and exposure to it can lead to premature death, cardiovascular issues, asthma attacks, and respiratory illnesses [17–19].

Chemical pollutants from these fires can harm various organs such as the lungs, nervous system, kidneys, and liver [9], while dioxin/furan exposure can increase cancer risk [20,21]. Despite the limited research on the health impacts of backyard burning, it still highlights its negative effect on human health. By releasing pollutants at ground level, it increases the risk of inhalation and contaminating the food chain [22,23]. It reduces soil productivity by eradicating vital humus and disrupting the soil consistency, reducing crop yields, increasing fertilizer needs, and causing the successive nutrient loss [24]. Vulnerable groups, including children, the elderly, pregnant women, and low-income neighborhoods, are disproportionately affected by the impacts [25]. The EPA prioritizes research on sociodemographic factors to address air pollution disparities [26].

1.1. Open Burning Behavior

Solid Waste Management (SWM) is a complex system involving environmental, social, and economic considerations [27]. Positive practices like source separation, recyclables donation, selling recyclables, and using drop-off facilities, contrast negative behaviors like illegal dumping and backyard burning [17,28]. Individuals' attitudes toward SWM are shaped by intrinsic factors such as attitudes and motives, influenced by information access and persuasive communication, as well as extrinsic factors like infrastructure systems, policies, regulations, and community infrastructure [29,30]. These factors, contingent on geographical location and demographics, significantly impact residents' choices [31,32]. Given that the success of Municipal Solid Waste (MSW) management relies on the participation of all stakeholders, analyzing the social and economic factors of MSW management is both important and urgent [33].

Socioeconomic Dimension

Socioeconomic factors strongly influence waste management practices, particularly in incidents of open burning [5]. Individual behavior and financial considerations significantly impact household waste management behavior [34], while external factors such as situational–contextual, technological, and organizational aspects also play a role [29]. Social dimensions in waste management encompass vulnerability, public participation, attitudes, behavior, and policy considerations [33]. Economic and power disparities contribute to social vulnerability, particularly affecting marginalized communities [35]. Individual participation is influenced by awareness, attitude, and demographics, with social norms and networks positively impacting waste-sorting behavior [36]. Convenience is a key factor in waste management behavior [29], as financial constraints may prompt residents to resort to burning waste to avoid disposal costs [37]. Despite the awareness of the legal ban on waste burning, health risks associated with MSW burning may not be a priority for waste handlers and households facing other challenges [32].

Efficient MSW management requires a collaboration between social and infrastructural systems [38]. Addressing open burning involves shifts in mindsets, values, and power dynamics, alongside economic and technological progress [35] Informal restrictions by residents and neighborhood associations, coupled with an improved waste pickup infrastructure, can reduce MSW burning. Advocating for a ban on open burning while promoting sustainable waste management through recycling, reuse, composting, and energy recovery is crucial [39]. However, a study suggested that legalizing waste burning and utilizing dry plastic waste for water heating could potentially decrease emissions from open burning and enhance air quality [40].

Community programs, waste sorting education, and active public participation can foster a 'recycling culture' [29], and raise awareness about waste hazards for prevention. Collaborative efforts among local governments, academics, NGOs, and community leaders, along with strategic policies, are crucial for promoting pro-environmental behavior and reducing open burning rates [5]. The ease of understanding and the use of the system is pivotal to its adoption, as a perceived difficulty results in inconvenience [9]. However, the intervention's effectiveness can vary by location due to implementation issues [33]. Leveraging expert knowledge to identify affordable indigenous technologies and designing context-aware waste management mechanisms and policies, including regulations and incentives, are crucial for encouraging individual involvement and reducing open burning [17,39]. Tailored interventions based on regional characteristics for vulnerable populations require innovative dialogue and communication [35]. Addressing local socioeconomic factors, particularly in high-density areas, is crucial for successful MSW management [29].

1.2. Open Burning in Kentucky

The Kentucky Division for Air Quality (KY DAQ) reported receiving an annual range of 533 to 660 open burning complaints between 2013 and 2021, with 554 in 2015, 527 in 2019, and 557 in 2021. Actual violations ranged from 31% to 51% of reported complaints each year [41].

Open burning, defined by the KY DAQ (2023), involves unregulated combustion without approved burn chambers or chimneys. Burning prohibited items can result in fines of up to $25,000 per day per offense including household garbage, construction debris, wood materials, and waste from industries, businesses, schools, and farms. Open burning is only allowed within 150 feet of woodland areas during specified fire hazard seasons (1 October–15 December and 15 February–30 April) between 6 PM and 6 AM, with potential fines of $25,000 per day for violations (401 KAR 63:005). Kentucky's policy, 401 KAR 63:005, allows open burning for specific purposes under strict conditions. Restrictions are more stringent in non-compliant counties for pollutants like ozone (O_3) and PM, with a complete ban on open burning from May through September to maintain or achieve attainment status. Non-attainment counties include Boone, Boyd, Bullitt, Campbell, Jefferson, Kenton, Lawrence, and Oldham.

Despite the existing regulations, open burning violations persist in Kentucky, highlighting a gap between policy and implementation. The lack of research in Kentucky emphasizes the need for a comprehensive study to identify the root causes, enabling the proposal of targeted interventions for improved compliance and air quality management in the state. Given the evident environmental and health impacts of open burning, compounded by prevalent violations and research gaps, there is an urgent need for this study [5]. While environmental knowledge's link to open burning is well-established, the social dimensions of MSW management lack sufficient attention [33]. Emerging environmental risks from open burning incidents and a dearth of research on backyard burning necessitate robust tools and frameworks for study [28].

This study aims to understand the causes of open burning, focusing on demographic factors like education, employment, household income, and residential characteristics. Specifically, it assesses factors associated with higher open burning violations in Kentucky, exploring associations between socioeconomic status, education, and geographic locations. The research seeks to understand the social nuances influencing open burning practices, informing policymakers on addressing barriers associated with violations and proposing solutions to mitigate both open burning practices and associated health risks.

2. Materials and Methods

2.1. Study Area

The study was conducted in Kentucky, a southeastern U.S. state covering 40,409 square miles, with a mean elevation of 750 feet. With a population of approximately 4.468 million people, Kentucky exhibits a diverse demographic makeup, including both urban and rural communities.

Urban counties, including Jefferson County (Louisville Metro), typically feature higher population density, industrial activities, and more robust waste management infrastructure. In contrast, rural counties often face unique challenges due to dispersed populations and limited resources. However, the Louisville Metro Air Pollution Control District, operating independently from the KY DAQ, utilizes different data collection methods, making it challenging for consistent comparisons with other Kentucky counties. Consequently, Jefferson County was omitted from this study and is intentionally excluded from the research analysis. See Figure 1.

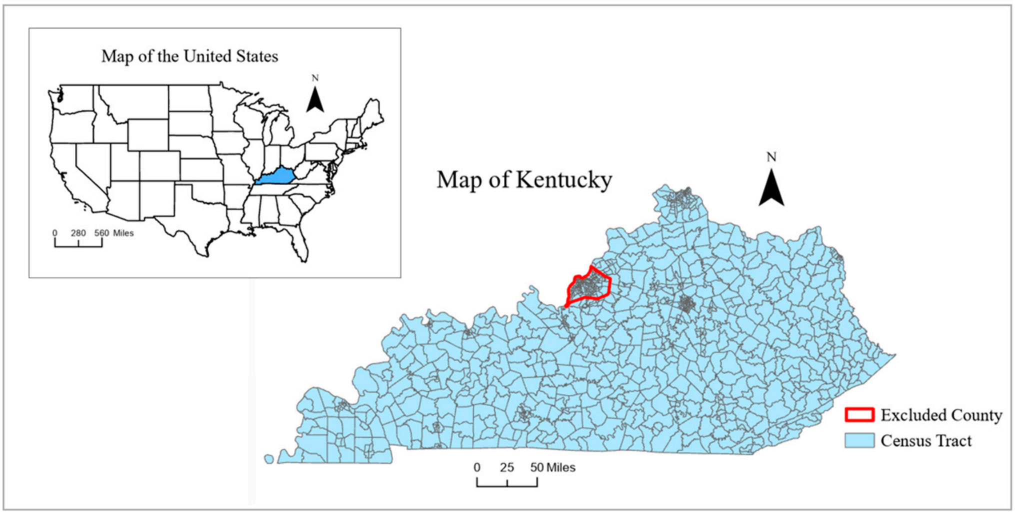

Figure 1. Study area showing the census tract of Kentucky.

2.2. Data Collection Protocol

2.2.1. Open Burning Incidents in 2019 and 2021

All open burning incidents reported to the KY DAQ during the calendar years 2019 and 2021 were included in this study. Each reported incident underwent an on-site investigation and compliance assessment by KY DAQ staff to be considered for inclusion. The subsequent investigation reports and compliance ratings were documented and stored in the Kentucky Department for Environmental Protection's TEMPO 360 (TEMPO) database. Permission to access and review the requested data was obtained after submitting an open records request to the KDEP—Kentucky Open Records Act office (KDEP KORA). All relevant information for open burning incidents in 2019 and 2021, including the date and time of the incident, complaint description, type of pollutant(s) released, impacted media, and the physical address of the alleged violation, was extracted, compiled, and organized in an Excel spreadsheet.

Upon submission of an open burning complaint to KY DAQ, an on-site investigation is mandated within five workdays. Post-investigation, the inspector produces a report detailing observations and assigns a compliance rating. Compliance ratings include no violations observed, impending violation trends observed, violations documented, notice of violation (NOV), and letter of warning (LOW). The inspector then sends the appropriate report to the property involved.

For open burning violations, remedial measures typically include ceasing prohibited open burning, cleaning up debris at the burning site, proper disposal of debris at a landfill or transfer station, and submitting disposal receipts to the inspector. Following the completion of remedial measures, a follow-up investigation is conducted to ensure compliance. If the violations are successfully abated, a sufficiency letter is sent to the responsible party, and the case is closed. High-priority open burning violations or repeat offenders are referred to KDEP's Division of Enforcement, where a conference is held with the responsible party. In such cases, a remedial contract (agreed order) and/or civil penalty (fine) may be issued. Non-co-operative cases are further referred to the Office of Legal Services, where formal legal action may be pursued against the responsible party.

2.2.2. KY DAQ Open Burning Incidents in 2015

A KY DEP KORA-approved dataset for open burning complaints from 1 January 2015, through 31 December 2015, was assessed through a secondary source [41]. The data collection process for KY DAQ Open Burning Violations in 2015 mirrored that of the incidents documented for 2019 and 2021.

2.2.3. American Community Survey Income and Poverty Data, 2020

The American Community Survey (ACS) Income and Poverty Data for the year 2020 were downloaded from the Social Explorer website at the census-tract level, representing the most recent income data available for the study. This dataset was subsequently imported into ArcGIS and used as the base map layer in ArcGIS Pro to merge all other data. The measures that were used in this study at the census-tract level included average household income, unemployment rate, no high school diploma, and counties with populations (equal to or greater than 50,000 as urban, and less than 50,000 as rural).

2.3. Data Analysis

The analysis was conducted at the census-tract level, with two dependent variables: (1) a binary measure indicating the presence of open burning incidents reported in 2019 or 2021 (0 = no, 1 = at least one open burning complaint reported); and (2) a binary measure of open burning violations documented, indicating notice of violation (NOV), low-level violation (LOW), or violations documented (0 = no, 1 = at least one open burning complaint reported).

The dependent variables were derived using the *summarize within* tool in ArcGIS Pro, which generated counts of open burning incidents and violations at the census-tract level, resulting in two binary measures. The independent variables included three ACS measures: average household income, unemployment rate, and the percentage of the population with no high school diploma, obtained from ACS data. Moreover, there was an additional measure indicating whether a census tract was categorized as urban or rural.

2.3.1. ANOVA Tests

To assess significant differences between KY DAQ open burning incidents reported in 2015, 2019, and 2021, two ANOVA analyses were conducted. To verify whether the 2019 and 2021 data were representative of an average year for the DAQ, three years of data were compared to assess for any irregularities between the years. The first ANOVA compared the monthly mean of reported open burning incidents over the three years, and the second ANOVA compared the mean of open burning incidents by county across the same period.

After confirming that there were no significant differences among the three years, two binary logistic regressions were performed using a combined dataset for 2019 and 2021 open burning incidents in R Studio 3.4.1. The first logistic regression evaluated the effects of independent variables, predicting the presence of reported open burning incidents and violations within a census tract. The second logistic regression model used the same independent variables.

2.3.2. Logistic Regression Analysis

Binary logistic regression was utilized to explore the relationship between burning incidents, violations, and sociodemographic factors. Linear regression is not suitable for binary dependent variables due to the nature of response values and error terms [42]. In this study, a binary logit model was specified to predict factors influencing open burning incidents and violations in both 2019 and 2021, with sociodemographic variables serving as explanatory factors. The same model and analysis were used for both OB incidents and violations, where P_i is the probability of the presence of open burning violations (0 = no, 1 = at least one open burning complaint reported) and P_{ia} is the probability of the open burning violation (0 = no, 1 = at least one open burning violation).

For P_i, the presence of open burning incidents reported in 2019 or 2021, the logistic regression equation can be written as:

$$P_i = E\left(Y = \frac{1}{X}\right) = \beta_0 + \beta_1 X_1 \quad (1)$$

In this equation, P_i is the probability that Y equals 1 when there is the presence of open burning incidents and zero (0) if there are none for given values of X_i (i = 1,2,3. . .n). X_i represents the explanatory variables. β_0 represents the intercept, and β_i represents the coefficients to be estimated.

$$P_i = E\left(Y = \frac{1}{X_1}\right) = \frac{1}{1 + e^{-(\beta_0 + \sum \beta_1 X_1)}} \quad (2)$$

For simplification, Equation (2) could be written as:

$$P_i = \frac{1}{1 + e^{-Z_i}} \quad (3)$$

$Z_i = \beta_0 + \sum\beta_i X_i$. Z_i is a linear combination of ($\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_n X_n$) and ranges from $-\infty$ to $+\infty$; P_i ranges between 0 and 1. If P_i in Equation (3) represented the probability of open burning incidents occurring, then $(1 - P_i)$ represented the probability otherwise, so that:

$$1 - P_i = \frac{1}{1 + e^{-Z_i}} \quad (4)$$

Combining Equations (3) and (4), the new equation is shown as:

$$\frac{P_i}{1 - P_i} = \frac{1 + e^{Z_i}}{1 + e^{-Z_i}} = e^{Z_i} \quad (5)$$

$\frac{P_i}{1-P_i}$ represents the log odds in favor of the occurrence of open burning incidents, which was the ratio of the probability of the presence or absence of open burning incidents. By taking the natural log of Equation (5), the results would be the following equation (where L was the natural log of the odds of OB occurrence, also called the logit—the logistic regression model is that the natural log of the odds equals the constant (β_0) plus the product of the estimated coefficients β_i and X_i). For estimation purposes, we write Equation (5) as:

$$L_i = \mathrm{In}\left(\frac{P_i}{1 - P_i}\right) = \beta_0 + \sum \beta_i X_i + e_i \quad (6)$$

The explanatory variables: It is hypothesized that a set of explanatory variables influences the open burning behavior. Prior to designing suitable models to identify the factors influencing open burning incidents and violations, a comprehensive literature review was conducted. Previous research on solid waste management behavior consistently highlighted income, education, location, and employment status as key factors. Studies using logistic regression analysis indicated that income predominantly influenced waste generation and households' willingness to minimize waste [43–45]; while education positively correlated with recycling behavior [44–48]. Location significantly influenced attitudes toward waste separation and recycling, [49,50] and employment rate also showed patterns in waste behavior [51]. Additionally, structural factors such as the presence of waste management facilities, influenced by urban vs rural settings, were observed [47,52].

$X_1 ... X_4$ are factors that influence open burning incidents occurrence and are defined as X_1 for average household income (represents the mean income of households), X_2 for the unemployment rate (indicates the percentage of the workforce that is unemployed within a census tract), X_3 for the percentage of the population with no high school diploma, and X_4 for the urban/rural indicator. This study categorizes counties based on population size; counties of 50,000 or more population are coded as Urban (1) and those with less than 50,000 as Rural (2). These variables provide insights into urbanization, economic prosperity, employment conditions, and educational attainment, offering a comprehensive perspective on the diverse factors influencing open burning patterns.

3. Results

A total of 1638 open burning incidents were reported to KY DAQ in 2015, 2019, and 2021 (554 in 2015, 527 in 2019, and 557 in 2021). An ANOVA test revealed no significant differences in monthly incidents between these years. The monthly average was 45.5 (SD = 12.93), and the means for each year were as follows—2015: Mean = 46.2 and SD = 12.7; 2019: Mean = 43.9 and SD = 15.5; 2021: Mean = 46.4 and SD = 11.3. The Kruskal–Wallis test also showed no significant differences in incidents by county. Thus, 2019 and 2021 are not anomalies and represent average years for KY DAQ.

3.1. Descriptive Statistics

Table 1 shows the descriptive statistics for demographic data, including urban vs rural areas, household income, unemployment rate, and no high school diploma. Urban vs rural had a mean of 1.55 and a standard deviation of 0.50. Household income had a mean of $71,873 with a standard deviation of $30,379. The unemployment rate demonstrated a mean of 5.89 with a standard deviation of 5.46. Moreover, the percentage of individuals without a high school diploma had a mean of 14.07 and a standard deviation of 8.45.

Table 1. Descriptive statistics of variables.

Variables	M	Standard Deviation (SD)	Minimum	Maximum
Urban vs. rural	1.55	0.50	1	2
Household income	71,873	30,379	15,593	293,758
Unemployment rate %	5.89	5.46	0.00	100.00
No high school diploma %	14.07	8.45	0.00	54.57

3.2. Binary Logistic Regression

The logistic regression presented in Table 2 showed that the urban/rural variable significantly predicted open burning incidents ($\beta = 0.884$, SE = 0.130, $p < 0.001$), indicating that rural counties had an increased odds of open burning incidents in comparison to urban counties. However, average household income ($\beta = 0.282$, SE = 0.233, $p = 0.226$), unemployment rate ($\beta = 0.010$, SE = 0.015, $p = 0.502$), and the percentage of individuals with less than a high school diploma ($\beta = 0.003$, SE = 0.010, $p = 0.762$) were not found to be significant predictors of open burning incidents.

Table 2. Logistic regression for open burning incidents (P_i).

Variables	Estimate	Std. Error	Z Value	*p* Value
Urban vs. rural	0.88	0.13	6.81	0.000 ***
Average household income	0.28	0.23	1.21	0.226
Unemployment, %	0.01	0.02	0.67	0.502
No high school diploma, %	0.003	0.01	0.30	0.762

*** $p < 0.001$.

In reference to open burning violations, the logistic regression model outlined in Table 3 demonstrated that both the urban/rural variable ($\beta = 0.980$, SE = 0.143, $p < 0.001$)

and average household income (β = 0.628, SE = 0.253, p = 0.013) were significant predictors. An increase in the urban/rural factor and higher average household income were associated with increased odds of open burning violations. Conversely, the unemployment rate (β = 0.000, SE = 0.016, p = 0.991) and the percentage of individuals with less than a high school diploma (β = 0.018, SE = 0.011, p = 0.090) did not attain statistical significance. The Akaike Information Criterion (AIC), serving as a measure of model fit, for both models was 1446, indicating a reasonable fit for the logistic regression models.

Table 3. Logistic regression for open burning violations (P_{ia}).

Variables	Estimate	Std. Error	Z Value	*p* Value
Urban vs. rural	0.98	0.14	6.84	0.000 ***
Average household income	0.63	0.25	2.48	0.0130 *
Unemployment, %	0.00	0.02	0.01	0.991
No high school diploma, %	0.02	0.01	1.70	0.090

*** $p < 0.001$, * $p < 0.05$.

Figure 2 shows the distribution of open burning incidents reported to the Kentucky DAQ in 2019 and 2021. Concentrations of incidents (1 or more) are represented in orange, indicating the intensity and geographical spread of open burning. Regions with no reported incidents are in green. Jefferson County, marked in black, was excluded from the study, and grey areas indicate missing data. The map illustrates the scattered open burning incidents without a discernible pattern.

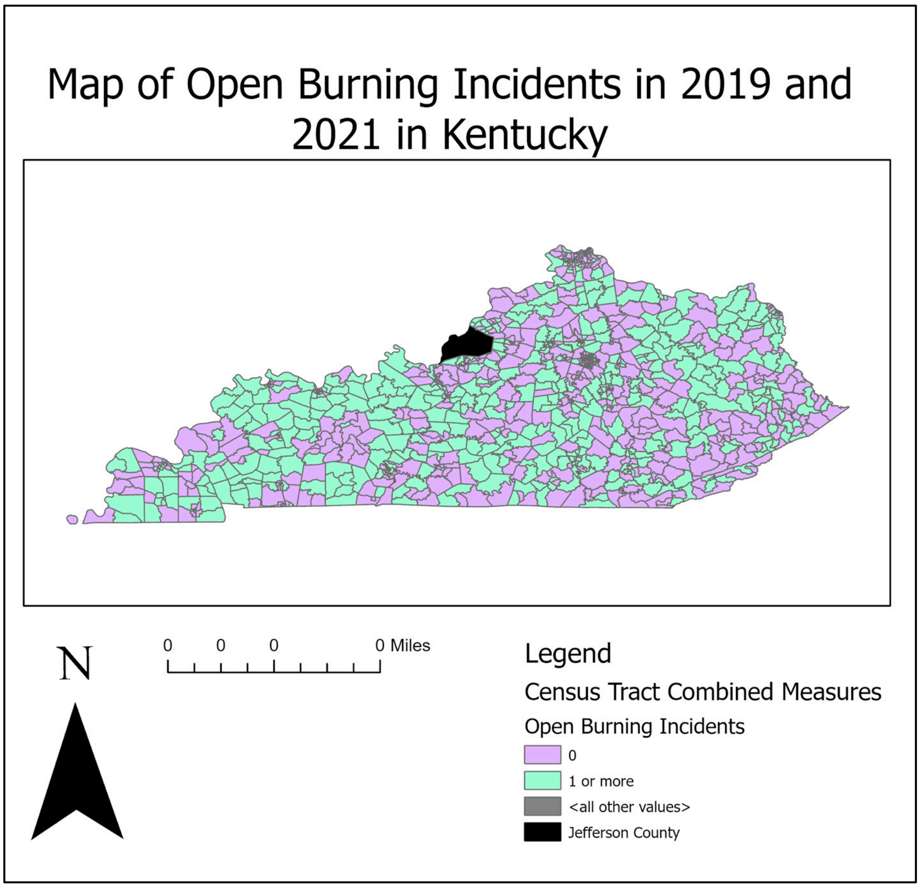

Figure 2. Open burning incidents in Kentucky.

Similarly, Figure 3 shows the distribution of open burning violations in Kentucky DAQ in 2019 and 2021. Concentrations of incidents (1 or more) are represented in orange.

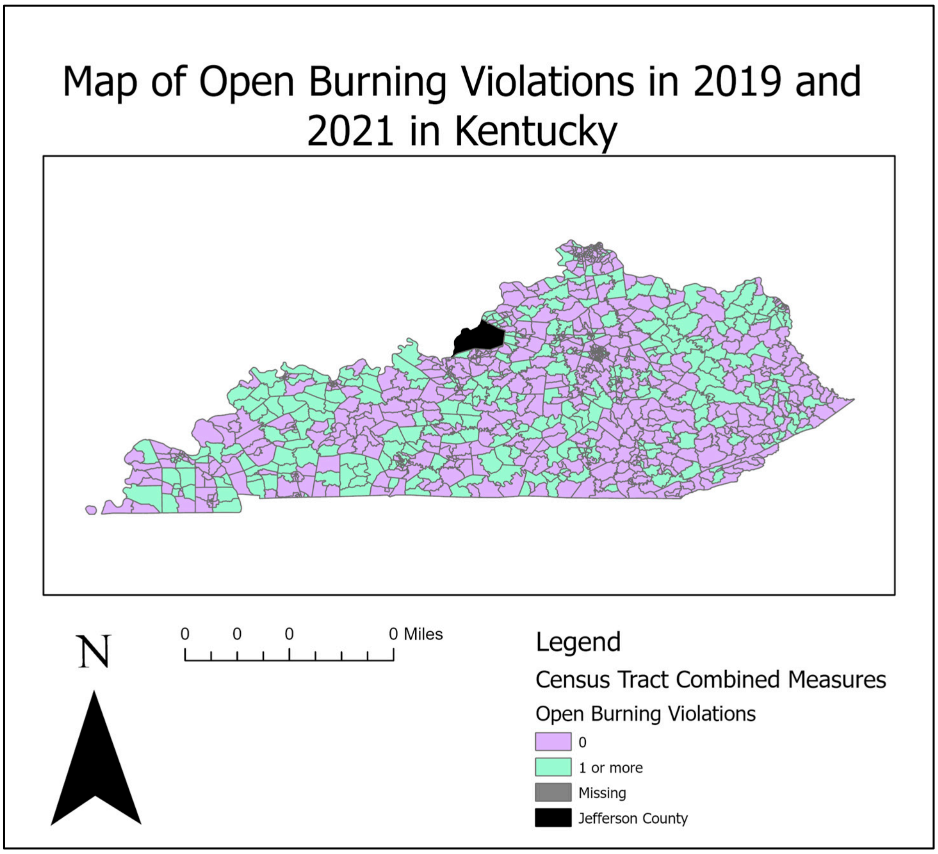

Figure 3. Open burning violations in Kentucky.

Figure 4 represents urban and rural census tracts in Kentucky. Green indicates urban areas (counties with population > 50,000), and red represents rural areas (counties with population < 50,000). The map highlights a high concentration of rural areas.

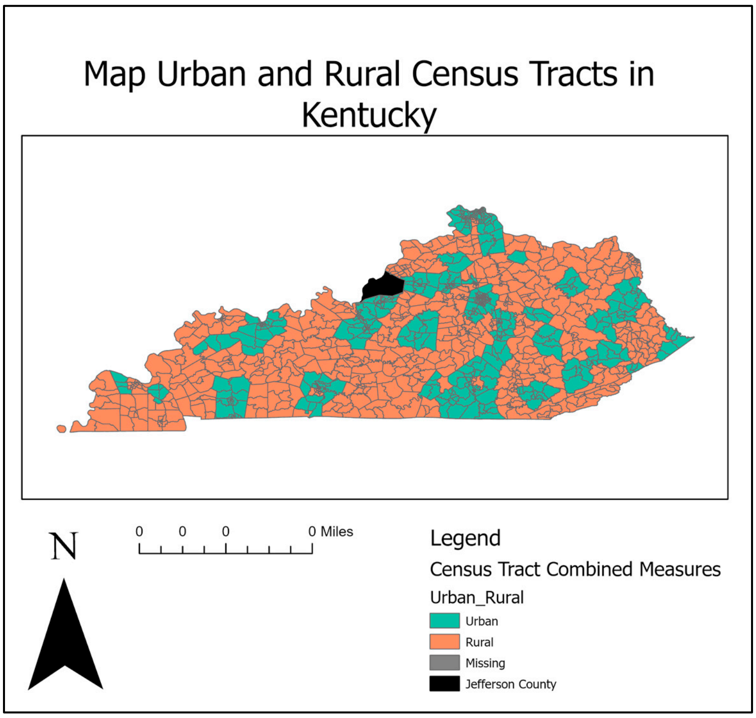

Figure 4. Urban and rural census tracts in Kentucky.

4. Discussion

The results of the study suggest that the rural census tracts significantly contribute to open burning incidents and violations, with average household income showing a positive correlation with such violations. However, factors such as unemployment and education showed no significant influence on those incidents. Despite the limited research on the socio-economic dimensions of open burning, the results were also compared with studies on general waste management behaviors.

Although education emerged as an influencing factor in open burning behavior in some studies [5,53], others suggested that satisfaction with waste management services and household distance from the city center influence negative behaviors [28]. Geographic locations were found to be a significant predictor for positive waste management behaviors [28]. In rural areas, 91% of the waste was disposed of through open burning due to a lack of waste collection services [12]. Conversely, metropolitan city residents were more affected by emissions from open burning [10]. Rural and peri-urban areas were major contributors to open burning incidents despite government waste collection services in Indonesia [5]. Geographical barriers significantly influenced municipal solid waste disposal [54]. Different waste management strategies were recommended for urban and rural areas [55]. Globally, solid waste generation rates in Turkey were related to the unemployment rate; however, the significance diminished at the local scale [56].

Similar to our results, income emerged as a predictor for positive waste management behaviors in several studies [28]. It was found that the average waste generation rate depended on income levels, with a 35% increase for high-income residents [57]. Low-income households recycled more compared to high-income households [58], while premature mortalities dominated by waste burning were reported in socioeconomically lower-status neighborhoods [59]. Economic recessions, impacting the unemployment rate, resulted in reduced waste generation [60]. A study in Poland associated higher waste quantity among working-age women with increased waste generation rates, particularly among unemployed women [51]. However, our study found no significant impact of the unemployment rate on open-burning behavior.

5. Conclusions

The analysis of open burning incidents and violations in Kentucky highlights the key societal factors influencing these prohibited activities. Understanding these factors enables policymakers to develop targeted strategies for mitigation and sustainable alternatives. The binary logistic regression highlighted the significance of societal and geographic variables, particularly the urban vs rural factor, indicating a higher likelihood of open burning in rural areas. This underscores the need for focused interventions, such as town hall meetings with state regulators, in rural regions.

The importance of equity in environmental policymaking is emphasized, suggesting solutions like subsidized trash collection, financial assistance for recycling, and awareness campaigns. Identifying influential factors allows for evidence-based interventions, leading to stricter regulations, enforcement, and public outreach. These efforts aim to reduce open burning, mitigate environmental pollution, and enhance human health outcomes in Kentucky. A comprehensive, locally tailored approach that combines policy interventions and awareness campaigns will promote responsible waste management and contribute to a healthier, more sustainable environment.

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