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FACTORS ASSOCIATED WITH RESPIRATORY SYMPTOMATOLOGY IN A POPULATION LIVING NEAR AN OPEN CAST COAL MINE IN LA GUAJIRA, COLOMBIA

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Abstract: *Objective:* To determine factors associated with respiratory disease symptoms in communities living near an open cast coal mine in northern Colombia.
Methods: A survey was applied three times a year, during rainy and dry seasons, inquiring about health conditions and the homes' internal and external environment. People classified as having symptoms of respiratory disease if they fell into at least one of three respiratory symptomatology groups. All other persons were classified as having no symptoms of respiratory disease. Fixed effects logistic models were estimated to determine which factors influence the probability of respiratory symptomatology.
Results: Children with a history of asthma or pneumonia and adults who live in inadequate housing, cook with wood, smoke, or have a history of pneumonia or hypertension are more likely to have symptoms of respiratory disease. In this study, the concentration of particulate matter and proximity to the mining operation do not have a significant influence on this probability; however, this may be due to the remoteness of some air quality monitoring stations from homes and other sources of contamination in the area.
Conclusions: In addition to outdoor air pollution, other factors are associated with respiratory symptoms in the population living near the open cast coal mine. Indoor air pollution, physical characteristics of the dwellings, lifestyles, and having a history of disease increase the risk of respiratory symptoms. For future studies, we recommend having air quality monitoring stations as close as possible to the homes, identifying other potential sources of contamination in the area, and carrying out objective medical evaluations of the respiratory health conditions of the population.
Keywords: Opencast coal mine; Respiratory diseases; Air pollution; Risk factors; Colombia.

INTRODUCTION

Air quality is a critical factor for human health since as the inhalation of pollutants can adversely affect the respiratory and cardiovascular systems. Exposure to air pollution can cause a wide range of health problems, ranging from minor irritations to serious chronic diseases. Common air pollutants include fine particulate matter (PM2.5), ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide, and volatile organic compounds. These pollutants can have negative health effects, including respiratory problems such as asthma, bronchitis and emphysema, cardiovascular disease, lung cancer, and neurological effects.

In addition, pollutants can disproportionately impact specific populations, such as children, older adults, and people with pre-existing health conditions. Long-term exposure to air pollution can also reduce life expectancy (MANISALIDIS *et al.*, 2020).

In Colombia, mining exploitation processes generate debates about the benefits to the economy, its effects on air quality, and the respiratory health of the populations living near the extraction site. Consequently, investigating the possible association between air quality in areas surrounding coal mines and the respiratory health of those living in these areas is of academic and political interest. The mining industry is one of the sectors that contributes the most to the Colombian economy. According to the Ministry of Mines and Energies, between 2009 and 2013, coal production grew by an average of 3.28% (UNIDAD DE PLANEACIÓN MINERO ENERGÉTICA, 2014).

One of the largest opencast coal mines in the world is in the central area of the department of La Guajira in northeastern Colombia and generates 38.9% of coal production in Colombia. Indigenous people

living under precarious conditions primarily inhabit the region where extraction occurs. Most roads are unpaved, and many houses cook with firewood, a risk factor for chronic lung disease.

A study looked at the particulate matter's effect on children's respiratory health. This study took a population exposed and unexposed to opencast coal mining and found that the children's past and present respiratory health was similar. Nonetheless, the visits to the family doctor for respiratory conditions were higher in the communities exposed to the open cast mine during the study period (PLESS-MULLOLI *et al.*, 2000).

Respiratory diseases are associated with lifestyles, biological conditions, and access to healthcare services (ACADEMIA NACIONAL DE MEDICINA, 2015). Although there is some evidence of the correlation between air quality and respiratory health, it continues to be a relevant subject of study, considering that particulate matter comes from a variety of polluting sources (roads, household conditions, and business emissions) and that the disease burden depends on factors such as intensity, frequency, and time of exposure to pollution (PALACIOS; KATALINA, 2019). Most of the air pollutants that emerge from opencast mining are total suspended particulate matter (TSP) with an aerodynamic diameter of less than 10 $\mu g/m^3$ (PM_{10}) (HUERTAS, José I. *et al.*, 2012; HUERTAS, José I.; HUERTAS; SOLÍS, 2012) Dust from blasting and transporting materials have been identified as the main source of TSP and PM_{10} particulate matter emissions in opencast mining operations (HUERTAS, Jose I.; CAMACHO; HUERTAS, 2011).

It is essential to know if there is an association between living near opencast coal mining and the respiratory health of children and adults, as high concentrations of particulate matter (TSP and PM_{10}) have been associated with asthma and allergies, among other diseases (GUARNIERI; BALMES, 2014; SIMOES OLMO *et al.*, 2011). Asthma is a common disease that affects children and adults of all ages. According to findings of the International Study of Asthma and Allergies in Childhood (ISAAC), its average prevalence in Latin America is 13%, ranging between 9% and 13% in Colombia (GIL TORRES, 2015).

On the other hand, the combustion of fuels, the burning of waste, and forest fires raise $PM_{2.5}$ particulate matter emissions (ECHEVERRI LONDOÑO; VASCO; JAIME, 2008; HARRISON *et al.*, 2012; OLAYA-OCHOA; OVALLE MUNOZ; URBANO LEÓN, 2017; ROJAS; GALVIS, 2005). $PM_{2.5}$ has been identified as a metric more closely associated with adverse health effects than PM_{10} (HARRISON *et al.*, 2012).

An environmental aspect of pressing concern in mining operations is the study of particulate matter generation and its effects on neighboring communities. Consequently, a growing field of research on the respiratory health of communities living near these operations could inform public policy and establish environmental regulations that minimize risk factors and reduce certain diseases.

This present study sought to identify the factors associated with respiratory symptoms in the communities living near an opencast coal mining in the north of Colombia.

METHODOLOGY

This research is a non-experimental analytical cohort study with a longitudinal follow-up period of one and a half years that included rainy and dry seasons to control for the possible influence of climate conditions on respiratory symptoms. Three visits were made: the first in April 2019 (dry season), the second in November 2019 (rainy season), and the third in March 2020 (dry season).

PARTICIPANTS AND DATA COLLECTION

To indirectly measure the association of mining operations with the presence of respiratory symptoms, exposed and non-exposed communities were defined by adapting criteria used in previous studies (FERNÁNDEZ-NAVARRO *et al.*, 2012; HOWEL; PLESS-MULLOLI; DARNELL, 2001). A community was considered exposed if its distance to the mining operation was 3 km or less and non-exposed if the distance was greater than 3 km. The exposed communities were Campoalegre, El Pilar and San Francisco, and the non-exposed communities were Brisas de Rancheria, El Cerro, El Rodeo, Guayacanal and Pozohondo (Figure 1).

The area had five air quality monitoring stations: Fonseca, Campoalegre, Barrancas, Pozohondo, and Provincial. All the stations captured $PM_{2.5}$ and PM_{10} measurements except the Fonseca station, which did not capture $PM_{2.5}$ measurements. Figure 1 shows the communities and air quality monitoring stations involved in the study.

The concentrations of particulate matter were collected every third day in the months of each period at the air monitoring stations, and the Inverse Distance Weighted (IDW) interpolation was carried out by QGIS 3.10 software to assign the average concentration of PM_{10} and $PM_{2.5}$ to the nearest home. Figure 1 shows the level of $PM_{2.5}$ and PM_{10} obtained in the three visits carried out in the study, considering the annual AQG (Air Quality Guideline) proposed by the World Health Organization in 2021 (WORLD HEALTH ORGANIZATION, 2021).

During the dry season (Apr/2019 and Mar/2020), the concentration of PM_{10} was between 31 and 50 μg/m^3, below the maximum level of particulate matter allowed in Colombia (MINISTERIO DE AMBIENTE Y DESARROLLO SOSTENIBLE, 2017), except near the Campoalegre station, which captured levels above 50 μg/m^3 for the Campo Alegre community. The concentration of $PM_{2.5}$ was between 16 and 25 μg/m^3, within the maximum allowable limits, both in exposed and unexposed areas (Figure 1). During the rainy season (Nov/2019), particulate matter levels were reduced to 21-30 μg/m^3 PM_{10} and 11-15 μg/m^3 $PM_{2.5}$.

The distance from communities to the nearest air monitoring station was highly variable, ranging from 0.06 to 12.4 km. The farthest communities were: Brisas de Rancheria, 12.4 km from Pozohondo station and 2.3 km from the Fonseca station; El Cerro, 4.7 km from the Pozohondo station; San Francisco, 3.5 km from the Provincial station; and Guayacanal, 2.8 km from the Pozohondo station.

The minimum sample size for exposed and non-exposed households was calculated using the Epidat 4.2 software, considering the following criteria: estimated prevalence for Chronic Obstructive Pulmonary Disease (COPD) of 8.9% (CABALLERO *et al.*, 2008), strength of the test at 82%, confidence level of 90%, equal group sizes, and relative risks of 2 or more statistically significant. The sample size was 324 households; 340 households were enrolled at the first visit and 323 remained until the end of the study.

The survey was applied face-to-face by interviewers who lived in the area and spoke the participants' mother tongue, Wayuunaiki. Children 12 years or younger and adults 45 years or older were surveyed in each household. Data collection previously required the informed consent of adults and the assent of children. The average duration of application per household with four people was about 102 minutes, and the information was digitized in the Kobotoolbox app during the visit.

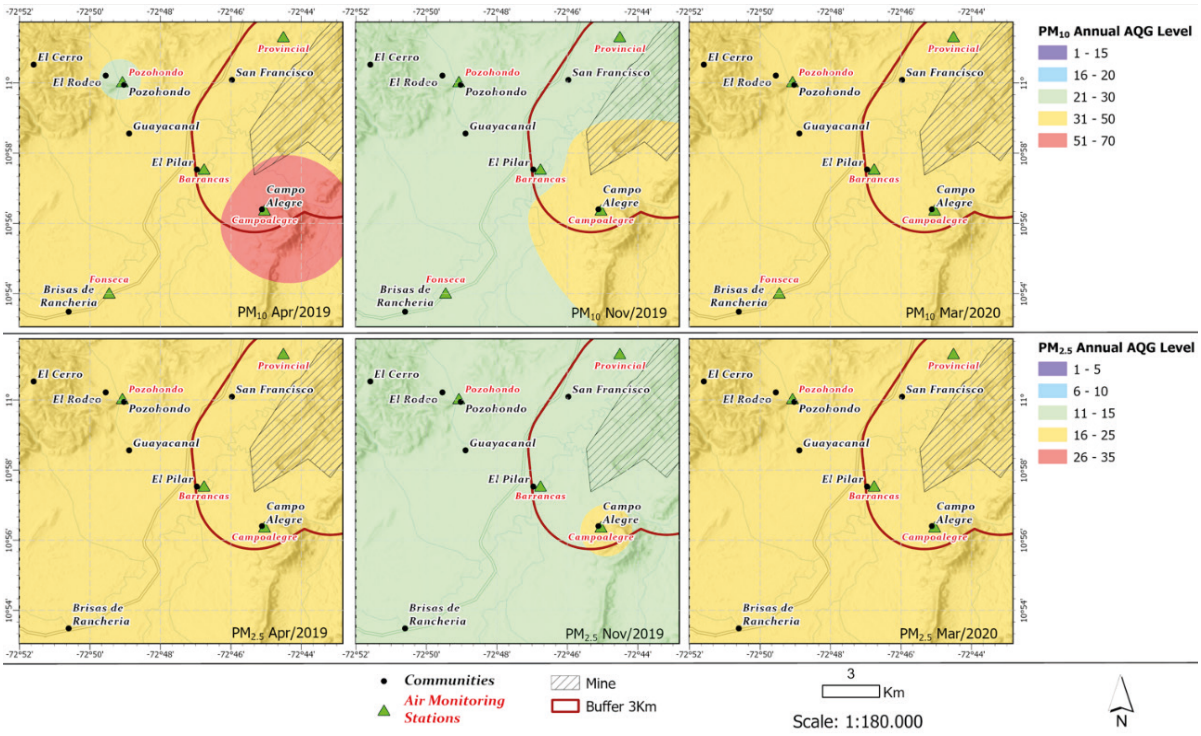

Figure 1. PM_{10} and $PM_{2.5}$ according to AQG level in communities and air monitoring stations.

Category	Risk Condition
Population characteristics	No health insurance
	History of asthma treated in the year prior to the survey
	History of pneumonia or bronchitis treated in the year prior to the survey
	History of malnutrition treated in the year prior to the survey[a]
	History of delayed motor and language development treated in the year prior to the survey[a]
	History of hypertension treated in the year prior to the survey[b]
	History of diabetes treated in the year prior to the survey[b]
	Current or former smoker[b]
External environment	Increased average concentration of PM_{10} via the IDW method
	Increased average concentration of $PM_{2.5}$ via the IDW method
	Exposed (living up to 3.8 km of the mining operations)
	Living near unpaved roads, roads with constant volume of traffic or heavy transport like trucks, buses or trains
	Living near garbage dumps or garbage burnings
	Living near brick kilns or quarries
	Garbage burning for disposal

Category	Risk Condition
Indoor environment	Presence of moisture in walls, floor or ceiling of the house
	Presence of mold or fungus in any surface of the house
	Inadequate ventilation in the house: Little or no air exchange between the indoor and external environment.
	Indoor smokers: presence of smokers in the house in the last 7 days
	Cooking with wood or charcoal
	Pets indoors: presence of pets inside the house
	Critical overcrowding: more than three persons per room (excluding kitchen, bathroom and garage)
	Inadequate housing: Physical characteristics of households considered unsuitable for human habitation. In urban areas, households with wall material made of zinc, fabric, canvas, cardboard, cans, waste, plastic or dirt floors. In rural areas, households with wall material of plastered wattle and daub, unplastered wattle and daub or rough wood, board, plank, and dirt floors.
	Inadequate services: lack of access to basic sanitary and hygiene living conditions. In urban areas, households that lack toilets or an aqueduct that is supplied with water from rivers, springs, water tanks or rainwater. In rural areas, households that lack toilets and aqueducts and are supplied with water from rivers, springs or rainwater.

Table 1. Risk conditions that may be associated with symptoms of respiratory disease.

[a] For children aged 12 years or younger

[b] For adults aged 45 years or older

Environment	Risk factor	Total (n=323)	Exposed (n=161)	Non- exposed (n=162)	p-value
		n (%)	n (%)	n (%)	
Indoor	Cooking with wood or charcoal	126 (39.0)	57 (35.4)	69 (42.6)	0.185
	Inadequate housing	85 (26.3)	34 (21.1)	51 (31.5)	0.034*
	Pets indoors	78 (24.1)	33 (20.5)	45 (27.8)	0.126
	Indoor smokers	46 (14.2)	22 (13.7)	24 (14.8)	0.767
	Critical overcrowding	41 (12.7)	21 (13.0)	20 (12.3)	0.851
	Inadequate ventilation	40 (12.4)	19 (11.8)	21 (13.0)	0.751
	Inadequate services	31 (9.6)	1 (0.6)	30 (18.5)	0.000*
	Moisture in walls, floors or ceiling	10 (3.1)	4 (2.5)	6 (3.7)	0.527
	Surfaces with mold/fungus	8 (2.5)	3 (1.9)	5 (3.1)	0.480
External	Near unpaved roads or heavy traffic	207 (64.1)	96 (59.6)	111 (68.5)	0.096
	Garbage burning for disposal	124 (38.4)	42 (26.1)	82 (50.6)	0.000*
	Near garbage dumps or garbage burnings	75 (23.2)	31 (19.3)	44 (27.2)	0.093
	Near brick kilns or quarries	6 (1.9)	6 (3.7)	0 (0.0)	0.013*

Table 2. Time-invariant environmental characteristics (indoor and external) of exposed and non-exposed households.

* Statistically significant difference between exposed and non-exposed households (p-value<0.05).

IDENTIFICATION OF PEOPLE WITH RESPIRATORY DISEASE SYMPTOMS

Based on the symptoms of respiratory diseases reported by Goldman and Schafer (GOLDMAN; SCHAFER, 2020) three major groups of respiratory disease symptoms were defined:

1. Persistent cough in the last six months, with phlegm (yellow, brown, reddish or green) and frequent expectoration.
2. Shortness of breath with wheezing that required treatment, or use of oxygen or inhalers as treatment to improve breathing.
3. Having ever felt chest pressure, weight on the chest or chest pain, and nasal flaring, sinking of the skin between the ribs when breathing, increased respiratory rate, painful breathing, persistent fever, fatigue, night sweats, feeling weak, blue skin color or unexplained weight loss.

A person was considered to "have respiratory disease symptoms" when he or she met the above criteria established in at least one of the three symptomatic groups. All other persons were classified as "having no respiratory symptoms".

STATISTICAL ANALYSIS

Table 1 presents the individual variables and the internal and external environment of the households considered for the analysis, specifying the risk condition for having respiratory symptoms.

The analysis accounted for 323 households (161 exposed and 162 non-exposed) and 592 people who participated in all three visits (338 children aged 12 years or younger and 254 adults aged 45 years or older). We built a panel database to visualize the behavior of individuals over time (TORRES-REYNA, 2007) and to estimate random effects logistic models, suitable when panel data and binary response variables are available. These models allow the inclusion of random effects that explain the existing variability in the study individuals due to repeated measurements, consider time-invariant and time-variant explanatory variables, and admit correlation of observations (BARTELS, [*s. d.*]).

The results of this model include the Odds Ratios (ORs) and the intraclass correlation coefficient *rho* that takes values between zero and one (HEDEKER; GIBBONS, 2006). A coefficient significantly different from zero ($p<0.05$ to reject the null hypothesis, H_0: *rho=0*) indicates the percentage of variance of the dependent variable not explained by the independent variables considered in the model, which is due to the repeated measures.

For each age group, two multivariate models were generated, separated by the two air pollution measures recorded ($PM_{2.5}$ and PM_{10}) due to the high linear correlation existing between them (HO *et al.*, 2003; WANG *et al.*, 2006). Variables statistically significant at the bivariate level ($p<0.05$), and without high correlation with the other explanatory variables, were included in the multivariate regression models. In all models, the exposure variable was incorporated, even if it had not been significant in the bivariate models, because it was considered a factor that could influence the respiratory condition of individuals. The estimation was performed using the Stata statistical software package Stata/IC version 13.

RESULTS

TIME-INVARIANT AND TIME-VARYING RISK CONDITIONS

The percentage of households was determined according to time-invariant indoor and external environmental characteristics. The results show that the homes are frequently located near roads with traffic and dust (64%). 38-39% of households cook with firewood and burn garbage to

dispose of it, and approximately one in four households live in inadequate housing, allow pets in the house, or live near garbage dumps or garbage burners. Significant differences by exposure group resulted in only four of the 13 factors considered (Table 2).

Table 3 shows the percentage of people according to characteristics that changed between the three visits, indicating those in which the relative weights differ significantly between exposed and non-exposed.

For $PM_{2.5}$ and PM_{10} concentrations, the average values during the rainy season were lower than the dry season, yielding consistently and significantly higher values in the exposed group throughout the three visits (Table 3). The largest differences according to exposure, greater than 11 $\mu g/m^3$, occurred in the concentrations of PM_{10} collected on the first visit, going from approximately 45 in the exposed group to 34 in the non-exposed group.

Compared to the dry season findings, during the rainy season, there was an increase in the percentage of children and adults with self-reported symptoms related to respiratory diseases, suggesting that this perception is not directly related to the particulate matter but rather to the weather conditions.

The absence of healthcare coverage in children tended to decrease over time, going from 5.0% to 3.3%, while in adults it increased from 2.0% to 4.3%.

Regarding having a history of respiratory diseases, the prevalence of asthma and pneumonia increased between study collection periods and tended to be higher in children versus adults.

Similarly, the percentage of children with a history of delayed motor or language development or a history of malnutrition between the first and third visits increased 1.5 and 3.0 percentage points, respectively. Among adults, the prevalence of diabetes and hypertension increased between the first and third visits, from 4.7% to 7.1% and from 26.0% to 29.1%, respectively.

Relating to cigarette smoking, the number of former smokers increased from 15% to 24.8% adults between visits 1 and 3, and the number of adult smokers remained relatively constant over time with significant differences between exposed and non-exposed population.

RELATIONSHIP BETWEEN RISK FACTORS AND RESPIRATORY HEALTH

The multivariate logistic regression models with fixed effects were estimated considering the presence of respiratory disease symptoms as the dependent variable and considering as independent variables those significant in the bivariate models. Figure 2 shows the ORs and confidence intervals for the independent variables considered in each model, together with the significance of the intraclass correlation coefficient *rho*.

The intraclass correlation coefficient was significantly different from zero ($p<0.05$), indicating that in 15% of the models for population aged 12 years or younger, and 20.5% in the models for population aged 45 years or older, the variance of the dependent variable not explained by the independent variables was due to the repeated measures.

The risk of having respiratory disease symptoms among children with a history of asthma or pneumonia with treatment in the past year is 2.7 (95% CI: 1.2, 6.0) and 3.3 (95% CI: 1.8, 6.1) times as high as the risk of having the outcome among those without these preexisting health conditions, respectively. Other characteristics such as living in the area exposed to the mining operation and not having adequate ventilation in the home have no significant influence on the presence of respiratory disease symptoms in children.

Among adults, the results indicate that the

Age group	Risk factor	Visit 1 (dry season)	Visit 2 (rainy season)	Visit 3 (dry season)
		n (%)	n (%)	n (%)
Children 12 years old and younger (n=338)	Concentration of $PM_{2.5}$ [a]	19.4 (1.7)*	12.2 (0.8)*	17.5 (0.4)*
	Concentration of PM_{10} [a]	39.7 (6.3)*	27.8 (2.6)*	39.7 (2.1)*
	Respiratory disease symptoms	83 (24.6)	127 (37.6)	121 (35.8)
	Pneumonia or bronchitis with treatment	21 (6.2)	23 (6.8)	28 (8.3)
	No health insurance	17 (5.0)*	14 (4.1)	11 (3.3)
	Asthma with treatment	12 (3.6)	12 (3.6)	15 (4.4)
	Delayed development with treatment	5 (1.5)	8 (2.4)	10 (3.0)
	Malnutrition with treatment	2 (0.6)	4 (1.2)	12 (3.6)
Adults 45 years old and older (n=254)	Concentration of $PM_{2.5}$ [a]	19.2 (1.8)*	12.2 (1.0)*	17.4 (0.3)
	Concentration of PM_{10} [a]	39.3 (6.7)*	27.8 (2.9)*	39.3 (1.8)*
	Respiratory disease symptoms	78 (30.7)	113 (44.5)	98 (38.6)
	Hypertension with treatment	66 (26.0)	69 (27.2)	74 (29.1)
	Former smoker	38 (15.0)	51 (20.1)	63 (24.8)
	Smoker	25 (9.8)*	27 (10.6)*	25 (9.8)*
	Diabetes with treatment	12 (4.7)	16 (6.3)	18 (7.1)
	Pneumonia or bronchitis with treatment	12 (4.7)	13 (5.1)	14 (5.5)
	No health insurance	5 (2.0)	8 (3.1)	11 (4.3)
	Asthma with treatment	3 (1.2)	3 (1.2)	5 (2.0)

Table 3. Time-varying characteristics by age group and visit.

[a] Values for concentration of particulate matter ($PM_{2.5}$ and PM_{10}) are the mean and standard deviation in parenthesis, in units of $\mu g/m^3$.

* Statistically significant difference between exposed and non-exposed households (p-Value<0.05).

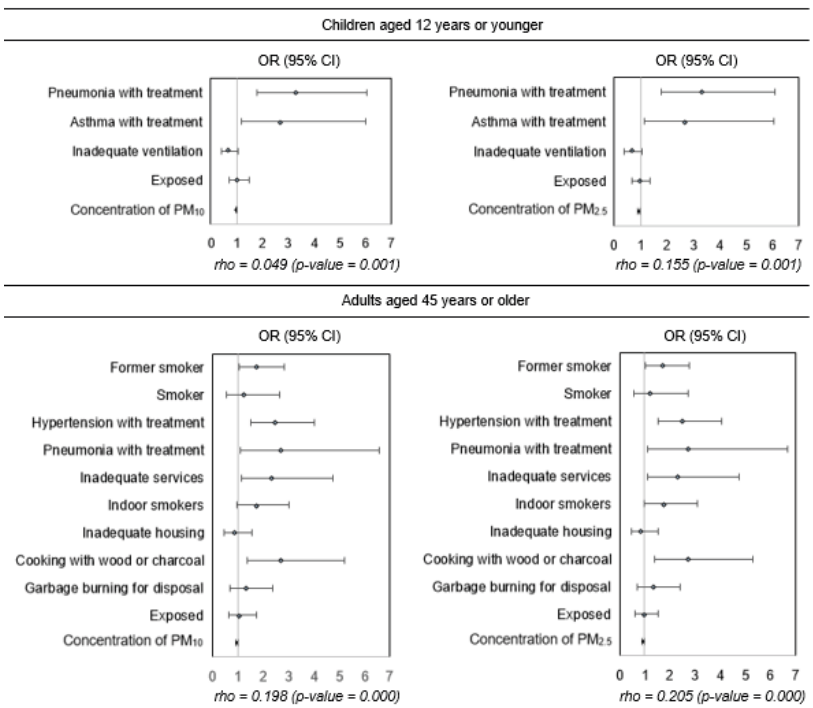

Figure 2. Multivariate logistic models. Adjusted ORs and 95% CIs of factors associated with respiratory diseases symptoms.

risk of having respiratory symptoms when cooking with firewood, wood, or charcoal or if living in a dwelling with inadequate services is 2.7 (95% CI: 1.4, 5.2) and 2.3 (95% CI: 1.1, 4.7) times as high as the risk of having the outcome among those cooking without solid fuels or not in those living conditions, respectively. The risk of having the health outcome among former smokers is 1.7 (95% CI: 1.1, 2.8) times as high as those who have never smoked. For preexisting conditions, the risk of having respiratory symptoms among adults with a history of pneumonia or hypertension is 2.7 (95% CI: 1.1, 6.6) and 2.5 (95% CI: 1.5, 4.0) times as high as those who have no history of these diseases, respectively. The other variables, including exposure, do not significantly explain the probability of an adult having respiratory disease symptoms.

For both children and adults, the influence of particulate matter concentrations $PM_{2.5}$ and PM_{10} on the risk of having symptoms of respiratory diseases is low.

DISCUSSION

This longitudinal cohort study, conducted in some communities living near opencast coal mining, identified the factors associated with symptoms of respiratory disease in two population groups (children aged 12 years or younger and adults aged 45 years or older).

The results showed that children with a history of asthma or pneumonia had a higher risk of respiratory symptomatology than those without this history. This risk was higher in adults with the following risk factors: having a history and treatment of pneumonia or hypertension, living in a house with inadequate services, being a former smoker, or cooking with wood or charcoal.

Some studies have found that the respiratory health of people can be affected by certain conditions in the households, such as the presence of mold/moisture, floor/wall material and smokers in the household (ANWAR *et al.*, 2021; QUIROZ *et al.*, 2013; ZHUGE *et al.*, 2020)

Likewise, it has been shown that some recurrent practices such as cooking with wood or charcoal (GIODA; PONCE DE LEON, 2017; WOOLLEY *et al.*, 2021, 2020) or burning garbage (DEPARTMENT OF ENVIRONMENTAL QUALITY, 2019; KHAWAJA, 2017)" affect the respiratory health of the population, especially young children, pregnant women, elderly, and people with respiratory diseases such as asthma.

On the other hand, a weak association resulted between $PM_{2.5}$ and PM_{10} particulate matter concentrations and respiratory disease symptoms in children and adults, in contrast to what previous research has found.

Authors have shown that increased particulate matter concentrations are associated with increased mortality from respiratory and cardiovascular diseases (ATKINSON *et al.*, 2014; FAJERSZTAJN *et al.*, 2017; GRISALES-ROMERO *et al.*, 2021; LI *et al.*, 2022; POPE III *et al.*, 2002; ZANOBETTI; SCHWARTZ, 2009) more visits to the emergency room for respiratory diseases in children and young adolescents and for cardiovascular diseases in adults (FERREIRA BRAGA *et al.*, 2007; WU *et al.*, 2021) and higher prevalence of rhinitis or asthma especially in children and adolescents (BRANDT *et al.*, 2015; LIU *et al.*, 2019; MCCONNELL *et al.*, 1999) Exposure to different sources and types of air pollutants has effects on the respiratory system, both acute (increased symptoms, emergency room visits, hospitalizations and deaths) and chronic (increased incidence of asthma, COPD and lung cancer) (SANTOS *et al.*, 2021).

The findings from this research showed no significant association between exposure to the mining operation and the risk of respiratory symptomatology. However,

other studies have proven that there is an increased risk of respiratory diseases due to proximity to different sources of pollution, such as opencast coal mines (HOWEL; PLESS-MULLOLI; DARNELL, 2001; PLESS-MULLOLI *et al.*, 2000; PLESS-MULLOLI; HOWEL; PRINCE, 2001), opencast gold and copper mining operations (HERRERA *et al.*, 2018, 2016), power plants, quarries and oil refineries (LOYO-BERRÍOS *et al.*, 2007), and timber industries (MARCHETTI *et al.*, 2014; RAVA *et al.*, 2012).

Few studies have been conducted in Colombia on the factors affecting respiratory health in communities near opencast coal mining operations (ARREGOCÉS *et al.*, 2018; QUIROZ *et al.*, 2013). The present research provides evidence of the association between self-reported respiratory disease symptoms in the population near the opencast coal mining and indoor and external environmental factors, frequent practices (cigarette smoking or cooking with firewood), and having a history of respiratory or chronic diseases.

MAIN LIMITATIONS

The distance defined for the variable "exposure" might not objectively characterize mining operations as a source of pollutant emissions.

The population environmentally exposed to mining operations includes communities living in the immediate vicinity, but could extend much further due to the transport of contaminants to more distant locations, and this, in turn, could under or over-estimate the effect on respiratory health (STEPHENS; AHERN, 2001). Obtaining data from air quality monitoring station filters that characterize the particulate matter (i.e., specifying the pollutant source) would allow for a more objective assessment.

On the other hand, air quality monitoring stations were not located equidistant from all households. Although some stations were located close to the homes, others were far away, and this could have influenced the average concentration of PM_{10} and $PM_{2.5}$ assigned to the corresponding households.

Finally, the assessment of respiratory conditions and their risk factors were identified by inquiring about the population's perception through surveys applied at the individual level (self-reported) and not through an objective assessment of the respiratory condition based on clinical examinations and a presumptive diagnosis.

CONCLUSIONS

The results presented in this study provide evidence of the main factors that could influence the respiratory health of people living near coal mining operations in Colombia. Some studies have shown the association between respiratory condition and air quality, but this is the first study that considers and identifies several factors that are also associated with the presence of respiratory symptomatology.

The concentration of particulate matter produced in the open cast coal mining process is one of the many factors that can affect people's respiratory conditions. In addition to this factor, this study evaluated indoor environmental conditions and personal characteristics associated with respiratory symptoms. Frequent practices of household members, such as smoking or cooking with firewood, wood, or charcoal, increase the probability of having respiratory problems, as does living in a house with inadequate services. The likelihood of respiratory symptomatology also increases when the person has a history of respiratory/chronic illness with ongoing treatment to manage their health condition.

The effect of particulate matter levels on respiratory health could be impacted by two factors: (1) some air quality monitoring

stations were distant from the homes and thus may not be accurately representing the actual exposure to the surrounding air quality; and (2) there may be other sources of $PM_{2.5}$ and PM_{10} emissions in the area. For future studies of this type, it is suggested to ensure monitoring stations are closer to the homes and to control and measure other external sources of pollution that could generate respiratory symptomatology.

Likewise, to guarantee an objective measurement of the respiratory condition of people, it is recommended that an expert physician carry out a clinical assessment.

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REFERENCES

ACADEMIA NACIONAL DE MEDICINA. **La contaminación del aire y los problemas respiratorios**. Revista de la Facultad de Medicina UNAM (México), vol. 58, no. 5, p. 44–47, Oct. 2015.

ANWAR, Naiela; KIRYCHUK, Shelley; KARUNANAYAKE, Chandima P.; RAMSDEN, Vivian; THOMPSON, Brooke; RUSSELL, Eric; MCMULLIN, Kathleen; RENNIE, Donna; SEESEEQUASIS, Jeremy; FENTON, Mark; ABONYI, Sylvia; PAHWA, Punam; DOSMAN, James. **Associations between Housing Factors and Respiratory Symptoms in Two Saskatchewan First Nations Communities**. International Journal of Environmental Research and Public Health, vol. 18, no. 7, p. 3744, Jan. 2021. https://doi.org/10.3390/ijerph18073744.

ARREGOCÉS, Heli A.; ROJANO, Roberto; ANGULO, Luis; RESTREPO, Gloria. **Intake Fraction of PM_{10} from Coal Mine Emissions in the North of Colombia**. Journal of Environmental and Public Health, vol. 2018, p. e8532463, 29 Jul. 2018. https://doi.org/10.1155/2018/8532463.

ATKINSON, Richard; KANG, Sujin; ANDERSON, Ross; MILLS, Inga; WALTON, Heather. **Epidemiological time series studies of PM2.5 and daily mortality and hospital admissions: a systematic review and meta-analysis**. Thorax, vol. 69, no. 7, p. 660–665, 2014. https://doi.org/10.1136/thoraxjnl-2013-204492.

BARTELS, Brandon L. **BEYOND "FIXED VERSUS RANDOM EFFECTS": A FRAMEWORK FOR IMPROVING SUBSTANTIVE AND STATISTICAL ANALYSIS OF PANEL, TIME-SERIES CROSS-SECTIONAL, AND MULTILEVEL DATA**. [*S. l.*: *s. n.*], [*s. d.*].

BRANDT, Eric B.; BIAGINI MYERS, Jocelyn M.; RYAN, Patrick H.; KHURANA HERSHEY, Gurjit K. **Air pollution and allergic diseases**. Current Opinion in Pediatrics, vol. 27, no. 6, p. 724, Dec. 2015. https://doi.org/10.1097/MOP.0000000000000286.

CABALLERO, Andrés; TORRES-DUQUE, Carlos A.; JARAMILLO, Claudia; BOLÍVAR, Fabio; SANABRIA, Fernando; OSORIO, Patricia; ORDUZ, Carlos; GUEVARA, Diana P.; MALDONADO, Darío. **Prevalence of COPD in five Colombian cities situated at low, medium, and high altitude (PREPOCOL study)**. Chest, vol. 133, no. 2, p. 343–349, Feb. 2008. https://doi.org/10.1378/chest.07-1361.

DEPARTMENT OF ENVIRONMENTAL QUALITY. **Burning Household Waste - State of Oregon Fact Sheet**. [*S. l.*: *s. n.*], 29 May 2019.

ECHEVERRI LONDOÑO, CARLOS ALBERTO; VASCO, Maya; JAIME, Gabriel. **Relación entre las partículas finas (PM2.5) y respirables (PM10) en la ciudad de Medellín**. Revista Ingenierías Universidad De Medellín, vol. 7, no. 12, p. 23-42, 1 Jan. 2008.

FAJERSZTAJN, Laís; SALDIVA, Paulo; AMADOR PEREIRA, Luiz Alberto; LEITE, Victor Figueiredo; BUEHLER, Anna Maria. **Short-term effects of fine particulate matter pollution on daily health events in Latin America: a systematic review and meta-analysis**. International Journal of Public Health, vol. 62, no. 7, p. 729–738, Sep. 2017. https://doi.org/10.1007/s00038-017-0960-y.

FERNÁNDEZ-NAVARRO, Pablo; GARCÍA-PÉREZ, Javier; RAMIS, Rebeca; BOLDO, Elena; LÓPEZ-ABENTE, Gonzalo. **Proximity to mining industry and cancer mortality**. The Science of the Total Environment, vol. 435–436, p. 66–73, 1 Oct. 2012. https://doi.org/10.1016/j.scitotenv.2012.07.019.

FERREIRA BRAGA, Alfésio Luís; AMADOR PEREIRA, Luiz Alberto; PROCÓPIO, Marly; AFONSO DE ANDRÉ, Paulo; SALDIVA, Paulo Hilário do Nascimento. **Associação entre poluição atmosférica e doenças respiratórias e cardiovasculares na cidade de Itabira, Minas Gerais, Brasil**. Cadernos de Saúde Pública, vol. 23, p. S570–S578, 2007. https://doi.org/10.1590/S0102-311X2007001600017.

GIL TORRES, Pablo Ramón. **Epidemiología del asma en Colombia**. Revista Colombiana de Neumología, vol. 27, no. 3, p. undefined-undefined, 2015. https://doi.org/10.30789/rcneumologia.v27.n3.2015.78.

GIODA, Adriana; PONCE DE LEON, Antonio. **Burning firewood and charcoal indoors: Air pollution and health risks**. [*S. l.*]: Sindigás, PUC-RJ, and UERJ, Mar. 2017.

GOLDMAN, Lee; SCHAFER, Andrew I. **Goldman-Cecil Medicine, 2-Volume Set**. [*S. l.*: *s. n.*], 2020. Available at: https://www.us.elsevierhealth.com/goldman-cecil-medicine-2-volume-set-9780323532662.html. Accessed on: 8 Aug. 2023.

GRISALES-ROMERO, Hugo; PIÑEROS-JIMÉNEZ, Juan Gabriel; NIETO, Emmanuel; PORRAS-CATAÑO, Sandra; MONTEALEGRE, Nora; GONZÁLEZ, Difariney; OSPINA, Dorian. **Local attributable burden disease to PM2.5 ambient air pollution in Medellín, Colombia, 2010–2016**. F1000Research, vol. 10, p. 428, 28 May 2021. https://doi.org/10.12688/f1000research.52025.1.

GUARNIERI, Michael; BALMES, John R. **Outdoor air pollution and asthma**. Lancet (London, England), vol. 383, no. 9928, p. 1581–1592, 3 May 2014. https://doi.org/10.1016/S0140-6736(14)60617-6.

HARRISON, Roy; LAXEN, Duncan; MOORCROFT, Stephen; LAXEN, Kieran. **Processes affecting concentrations of fine particulate matter (PM2.5) in the UK atmosphere**. Atmospheric Environment, vol. 46, p. 115–124, 1 Jan. 2012. https://doi.org/10.1016/j.atmosenv.2011.10.028.

HEDEKER, Donald; GIBBONS, Robert D. (Eds.). **Longitudinal Data Analysis**. 0 ed. [*S. l.*]: John Wiley & Sons, Inc., 2006. DOI 10.1201/9781420011579. Available at: https://www.taylorfrancis.com/books/9781420011579. Accessed on: 8 Aug. 2023.

HERRERA, Ronald; BERGER, Ursula; VON EHRENSTEIN, Ondine S.; DÍAZ, Iván; HUBER, Stella; MORAGA MUÑOZ, Daniel; RADON, Katja. **Estimating the Causal Impact of Proximity to Gold and Copper Mines on Respiratory Diseases in Chilean Children: An Application of Targeted Maximum Likelihood Estimation**. International Journal of Environmental Research and Public Health, vol. 15, no. 1, p. 39, Jan. 2018. https://doi.org/10.3390/ijerph15010039.

HERRERA, Ronald; RADON, Katja; VON EHRENSTEIN, Ondine S.; CIFUENTES, Stella; MORAGA MUÑOZ, Daniel; BERGER, Ursula. **Proximity to mining industry and respiratory diseases in children in a community in Northern Chile: A cross-sectional study**. Environmental Health, vol. 15, no. 1, p. 66, 7 Jun. 2016. https://doi.org/10.1186/s12940-016-0149-5.

HO, K. F; LEE, S. C; CHAN, Chak K; YU, Jimmy C; CHOW, Judith C; YAO, X. H. **Characterization of chemical species in PM2.5 and PM10 aerosols in Hong Kong**. Atmospheric Environment, vol. 37, no. 1, p. 31–39, 1 Jan. 2003. https://doi.org/10.1016/S1352-2310(02)00804-X.

HOWEL, Denise; PLESS-MULLOLI, Tanja; DARNELL, Ross. **Consultations of children living near open-cast coal mines**. Environmental Health Perspectives, vol. 109, no. 6, p. 567–571, Jun. 2001. https://doi.org/10.1289/ehp.01109567.

HUERTAS, Jose I.; CAMACHO, Dumar A.; HUERTAS, Maria E. **Standardized emissions inventory methodology for open-pit mining areas**. Environmental Science and Pollution Research International, vol. 19, no. 7, p. 2784–2794, Aug. 2011. https://doi.org/10.1007/s11356-012-0778-3.

HUERTAS, José I.; HUERTAS, María E.; IZQUIERDO, Sebastián; GONZÁLEZ, Enrique D. **Air quality impact assessment of multiple open pit coal mines in northern Colombia**. Journal of Environmental Management, vol. 93, no. 1, p. 121–129, Jan. 2012. https://doi.org/10.1016/j.jenvman.2011.08.007.

HUERTAS, José I.; HUERTAS, María E.; SOLÍS, Dora A. **Characterization of airborne particles in an open pit mining region**. The Science of the Total Environment, vol. 423, p. 39–46, 15 Apr. 2012. https://doi.org/10.1016/j.scitotenv.2012.01.065.

KHAWAJA, Bassam. **"As If You're Inhaling Your Death."** Human Rights Watch, 1 Dec. 2017. Available at: https://www.hrw.org/report/2017/12/01/if-youre-inhaling-your-death/health-risks-burning-waste-lebanon. Accessed on: 8 Aug. 2023.

LI, Haomin; DENG, Wenying; SMALL, Raphael; SCHWARTZ, Joel; LIU, Jeremiah; SHI, Liuhua. **Health effects of air pollutant mixtures on overall mortality among the elderly population using Bayesian kernel machine regression (BKMR)**. Chemosphere, vol. 286, p. 131566, Jan. 2022. https://doi.org/10.1016/j.chemosphere.2021.131566.

LIU, Yuewei; PAN, Jingju; ZHANG, Hai; SHI, Chunxiang; LI, Guo; PENG, Zhe; MA, Jixuan; ZHOU, Yun; ZHANG, Lan. **Short-Term Exposure to Ambient Air Pollution and Asthma Mortality**. American Journal of Respiratory and Critical Care Medicine, vol. 200, no. 1, p. 24–32, Jul. 2019. https://doi.org/10.1164/rccm.201810-1823OC.

LOYO-BERRÍOS, Nilsa I.; IRIZARRY, Rafael; HENNESSEY, Joseph G.; TAO, Xuguang Grant; MATANOSKI, Genevieve. **Air Pollution Sources and Childhood Asthma Attacks in Cataño, Puerto Rico**. American Journal of Epidemiology, vol. 165, no. 8, p. 927–935, 15 Apr. 2007. https://doi.org/10.1093/aje/kwk088.

MANISALIDIS, Ioannis; STAVROPOULOU, Elisavet; STAVROPOULOS, Agathangelos; BEZIRTZOGLOU, Eugenia. **Environmental and Health Impacts of Air Pollution: A Review**. Frontiers in Public Health, vol. 8, p. 14, 20 Feb. 2020. https://doi.org/10.3389/fpubh.2020.00014.

MARCHETTI, Pierpaolo; MARCON, Alessandro; PESCE, Giancarlo; PAOLO, Girardi; GUARDA, Linda; PIRONI, Vanda; FRACASSO, Maria Enrica; RICCI, Paolo; DE MARCO, Roberto. **Children living near chipboard and wood industries are at an increased risk of hospitalization for respiratory diseases: a prospective study**. International Journal of Hygiene and Environmental Health, vol. 217, no. 1, p. 95–101, Jan. 2014. https://doi.org/10.1016/j.ijheh.2013.03.015.

MCCONNELL, R.; BERHANE, K.; GILLILAND, F.; LONDON, S. J.; VORA, H.; AVOL, E.; GAUDERMAN, W. J.; MARGOLIS, H. G.; LURMANN, F.; THOMAS, D. C.; PETERS, J. M. **Air pollution and bronchitic symptoms in Southern California children with asthma**. Environmental Health Perspectives, vol. 107, no. 9, p. 757–760, Sep. 1999. https://doi.org/10.1289/ehp.99107757.

MINISTERIO DE AMBIENTE Y DESARROLLO SOSTENIBLE. **Resolución 2254 de 2017**. 1 Nov. 2017. Ministerio de Ambiente y Desarrollo Sostenible. Available at: https://www.minambiente.gov.co/documento-normativa/resolucion-2254-de-2017/. Accessed on: 8 Aug. 2023.

OLAYA-OCHOA, Javier; OVALLE MUNOZ, Diana Paola; URBANO LEÓN, Cristhian Leonardo. **Acerca de la estimación de la fracción PM2.5/PM10**. DYNA, vol. 84, no. 203, p. 343–348, 1 Oct. 2017. https://doi.org/10.15446/dyna.v84n203.65228.

PALACIOS, Medina; KATALINA, Edna. **La contaminación del aire, un problema de todos**. Revista de la Facultad de Medicina, vol. 67, no. 2, p. 189–191, 1 Apr. 2019. https://doi.org/10.15446/revfacmed.v67n2.82160.

PLESS-MULLOLI, Tanja; HOWEL, Denise; KING, Andrew; STONE, Ian; MEREFIELD, John; BESSELL, Jan; DARNELL, Ross. **Living near opencast coal mining sites and children's respiratory health**. Occupational and Environmental Medicine, vol. 57, no. 3, p. 145–151, Mar. 2000. https://doi.org/10.1136/oem.57.3.145.

PLESS-MULLOLI, Tanja; HOWEL, Denise; PRINCE, Helen. **Prevalence of asthma and other respiratory symptoms in children living near and away from opencast coal mining sites**. International Journal of Epidemiology, vol. 30, no. 3, p. 556–563, 1 Jun. 2001. https://doi.org/10.1093/ije/30.3.556.

POPE III, C. Arden; BURNETT, Richard T.; THUN, Michael J.; CALLE, Eugenia E.; KREWSKI, Daniel; ITO, Kazuhiko; THURSTON, George D. **Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution**. JAMA, vol. 287, no. 9, p. 1132–1141, 6 Mar. 2002. https://doi.org/10.1001/jama.287.9.1132.

QUIROZ, Leonardo; HERNÁNDEZ-FLÓREZ, Luis J.; AGUDELO CALDERÓN, Carlos A.; MEDINA, Katalina; ROBLEDO-MARTÍNEZ, Rocío; OSORIO-GARCÍA, Samuel David. **Enfermedad y síntomas respiratorios en niños de cinco municipios carboníferos del Cesar, Colombia**. Revista de Salud Pública, vol. 15, no. 1, p. 66–79, 1 Jan. 2013. .

RAVA, Marta; CRAINICIANU, Ciprian; MARCON, Alessandro; CAZZOLETTI, Lucia; PIRONI, Vanda; SILOCCHI, Caterina; RICCI, Paolo; DE MARCO, Roberto. **Proximity to wood industries and respiratory symptoms in children: A sensitivity analysis**. Environment International, vol. 38, no. 1, p. 37–44, 1 Jan. 2012. https://doi.org/10.1016/j.envint.2011.07.011.

ROJAS, Nestor Y.; GALVIS, B. **Relación entre PM2.5 y PM10 en la ciudad de Bogotá. 2005**. DOI 10.16924/RIUA.V0I22.371. Available at: https://www.semanticscholar.org/paper/Relaci%C3%B3n-entre-PM2.5-y-PM10-en-la-ciudad-de-Bogot%C3%A1-Rojas-Galvis/78d043b474935488a8d5752bd73b544f9562641f. Accessed on: 8 Aug. 2023.

SANTOS,Ubiratan de Paula; ARBEX, Marcos Abdo; FERREIRA BRAGA, Alfésio Luis; MIZUTANI, Rafael Futoshi; CANÇADO, José Eduardo Delfini; TERRA-FILHO, Mário; CHATKIN, José Miguel. **Environmental air pollution: respiratory effects**. vol. 47, no. 1, p. e20200267–e20200267, 2021. https://doi.org/10.36416/1806-3756/e20200267.

SIMOES OLMO, Neide Regina; SALDIVA, Paulo Hilário do Nascimento; FERREIRA BRAGA, Alfésio Luís; LIN, Chin An; SANTOS, Ubiratan de Paula; AMADOR PEREIRA, Luiz Alberto. **A review of low-level air pollution and adverse effects on human health: implications for epidemiological studies and public policy**. Clinics (Sao Paulo, Brazil), vol. 66, no. 4, p. 681–690, 2011. https://doi.org/10.1590/s1807-59322011000400025.

STEPHENS, Carolyn; AHERN, Mike. **Worker and Community Health Impacts Related to Mining Operations Internationally - A Rapid Review of the Literature**. Mining, Minerals and Sustainable Development, vol. No. 25, Nov. 2001.

TORRES-REYNA, Oscar. **Panel Data Analysis Fixed and Random Effects using Stata (v. 6.0)**. [*S. l.*: *s. n.*], Dec. 2007. Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.princeton.edu/~otorres/Panel101.pdf

UNIDAD DE PLANEACIÓN MINERO ENERGÉTICA, Ministerio de Minas y Energía. **Indicadores de la Minería en Colombia**. Preliminary version. [*S. l.*: *s. n.*], 2014. Available at: http://www1.upme.gov.co/simco/Cifras-Sectoriales/EstudiosPublicaciones/Indicadores_de_la_mineria_en_Colombia.pdf.

WANG, Xinhua; BI, Xinhui; SHENG, Guoying; FU, Jiamo. **Chemical Composition and Sources of PM10 and PM2.5 Aerosols in Guangzhou, China**. Environmental Monitoring and Assessment, vol. 119, no. 1–3, p. 425–439, 31 Jul. 2006. https://doi.org/10.1007/s10661-005-9034-3.

WOOLLEY, Katherine E.; BAGAMBE, Tusubira; SINGH, Ajit; AVIS, William R.; KABERA, Telesphore; WELDETINSAE, Abel; MARIGA, Shelton T.; KIRENGA, Bruce; POPE, Francis D.; THOMAS, G. Neil; BARTINGTON, Suzanne E. **Investigating the Association between Wood and Charcoal Domestic Cooking, Respiratory Symptoms and Acute Respiratory Infections among Children Aged Under 5 Years in Uganda: A Cross-Sectional Analysis of the 2016 Demographic and Health Survey**. International Journal of Environmental Research and Public Health, vol. 17, no. 11, p. 3974, 4 Jun. 2020. https://doi.org/10.3390/ijerph17113974.

WOOLLEY, Katherine E.; BARTINGTON SUZANNE E.; KABERA, Telesphore; LAO, Xiang-Qian; POPE, Francis D.; GREENFIELD, Sheila M.; PRICE, Malcolm J.; THOMAS, G. Neil. **Comparison of Respiratory Health Impacts Associated with Wood and Charcoal Biomass Fuels: A Population-Based Analysis of 475,000 Children from 30 Low- and Middle-Income Countries.** International journal of environmental research and public health, vol. 18, no. 17, 3 Sep. 2021. DOI 10.3390/ijerph18179305. Available at: https://pubmed.ncbi.nlm.nih.gov/34501907/. Accessed on: 8 Aug. 2023.

WORLD HEALTH ORGANIZATION. **WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide**. 22 Sep. 2021. Available at: https://www.who.int/publications-detail-redirect/9789240034228. Accessed on: 8 Aug. 2023.

WU, Yihan; JIN, Tingting; HE, Wen; LIU, Lijuan; LI, Hongjin; LIU, Cong; ZHOU, Yufeng; HONG, Jianguo; CAO, Lanfang; LU, Yanming; DONG, Xiaoyan; XIA, Min; DING, Bo; QIAN, Liling; WANG, Libo; ZHOU, Wenhao; GUI, Yonghao; ZHANG, Xiaobo; CHEN, Renjie. A**ssociations of fine particulate matter and constituents with pediatric emergency room visits for respiratory diseases in Shanghai, China**. International Journal of Hygiene and Environmental Health, vol. 236, p. 113805, 1 Jul. 2021. https://doi.org/10.1016/j.ijheh.2021.113805.

ZANOBETTI, Antonella; SCHWARTZ, Joel. **The Effect of Fine and Coarse Particulate Air Pollution on Mortality: A National Analysis**. Environmental Health Perspectives, vol. 117, no. 6, p. 898–903, Jun. 2009. https://doi.org/10.1289/ehp.0800108.

ZHUGE, Yang; QIAN, Hua; ZHENG, Xiaohong; HUANG, Chen; ZHANG, Yinping; LI, Baizhan; ZHAO, Zhuohui; DENG, Qihong; YANG, Xu; SUN, Yuexia; ZHANG, Xin; SUNDELL, Jan. **Effects of parental smoking and indoor tobacco smoke exposure on respiratory outcomes in children**. Scientific reports, vol. 10, no. 1, p. 4311, 1 Mar. 2020. https://doi.org/10.1038/s41598-020-60700-4.