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Air chemical particles and pollution quality association with mental health: A case for depression and anxiety among Iranian university students in Iranian cities with lower air quality

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ABSTRACT

Air pollution is one of the greatest public health threats worldwide. All substances appear in excessive quantities in the atmosphere, such as particulate matter, nitrogen oxides, or sulfur oxides, maybe its ingredients. Depending on their size and nature, these compounds may cause a greater risk of suffering from respiratory or cardiovascular diseases for exposed people, as well as exacerbation and increased mortality due to these illnesses. Smaller particles may penetrate the brain's blood barrier and thus affect the central nervous system. To study the impact of air pollution on individual mental health, this study uses data from the Iranian Student Mental Health Survey (IRSMHS) and a precise Poisson regression model based on the air quality index (API). According to the study, air pollution significantly impacts individual mental health. Depression and mental health are worse when air pollution levels are high. Furthermore, heterogeneity analysis determined that men and urban populations were more sensitive to air pollution, while this effect did not appear in women and rural groups. As part of the effort to improve people's mental health, this article stresses the importance of intensifying efforts to control air pollution and winning the battle to defend the blue sky as soon as possible.

1. Introduction

Pollutants with the strongest evidence for public health concerns include particulate matter (PM), carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO2), and sulfur dioxide (SO_2). Health problems can result from both short- and long-term exposure to these various pollutants. For some pollutants, there are no thresholds below which adverse effects do not occur[1].

Particulate Matter: Particulate matter (PM) refers to inhalable particles composed of sulfate, nitrates, ammonia, sodium chloride, black carbon, mineral dust, or water. The health risks associated with particulate matter of less than 10 and 2.5 microns in diameter (PM10 and PM2.5) are especially well documented. PM can penetrate deep into the lung and enter the bloodstream causing cardiovascular (ischaemic heart disease), cerebrovascular (stroke), and respiratory impacts. Both long-term and short-term exposure to particulate matter is associated with morbidity and mortality from cardiovascular and respiratory diseases. Long-term exposure has been further linked to adverse perinatal outcomes and lung cancer. In 2013, it was classified as a cause of lung cancer by WHO's International Agency for Research on Cancer (IARC). It is also the most widely used indicator for assessing the health effects of exposure to air pollution[2].

Black carbon is a major component of PM2.5 and a potent warming agent in the atmosphere; and contributes to regional environmental disruption and accelerates glacier melting[1].

Carbon Monoxide: Carbon monoxide is a colorless, odorless, and tasteless toxic gas produced by the incomplete combustion of carbonaceous fuels such as wood, petrol, charcoal, natural gas, and kerosene. Carbon monoxide diffuses across the lung tissues and into the bloodstream, making it difficult for the body's cells to bind oxygen. This lack of oxygen damages tissues and cells. Carbon monoxide exposure can cause difficulty breathing, exhaustion, dizziness, and other flu-like symptoms. Exposure to very high levels of CO can lead to death[2].

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Nitrogen Dioxide: Nitrogen dioxide is soluble in water, reddish-brown in color, and a strong oxidant. NO2 results from combustion processes such as those used for heating, transport, and power generation. Exposure to nitrogen dioxide can irritate airways and aggravate respiratory diseases. NO_2 is an important ozone precursor, a pollutant closely linked to asthma and other respiratory conditions[3].

Ozone: Ground-level ozone is a major component of smog. It is formed from photochemical reactions with pollutants such as nitrogen oxides (NOx) emitted from vehicles and industry. Due to the photochemical nature, the highest levels of ozone are seen during periods of sunny weather. Exposure to excessive ozone can cause problems breathing, trigger asthma, reduce lung function and lead to lung disease[4].

Methane is a potent greenhouse gas. It contributes to the formation of ozone. Methane is emitted by the incomplete combustion of biomass, biofuel, and fossil fuels in simple stoves, open fires, or wick lamps[1].

Household activities such as cooking and heating with dirty technologies, and lighting with kerosene, generate emissions of harmful health pollutants as described below. Activities such as boiling water for bathing or cooking animal fodder can also add to household air pollution exposures[4].

Particulate matter (PM) refers to inhalable particles composed of sulfate, nitrates, ammonia, sodium chloride, black carbon, mineral dust, or water. The health risks associated with particulate matter are especially well documented. Particulate matter is also the most widely used indicator to assess the health effects of exposure to ambient air pollution[2].

Particles with a diameter of 10 microns or less (PM10), including fine particles with a diameter of 2.5 microns (PM2.5), can penetrate deep into lung passageways and enter the bloodstream, causing serious cardiovascular, cerebrovascular, and respiratory impacts. Both long-term and short-term exposure to particulate matter is associated with morbidity and mortality from cardiovascular and respiratory diseases. Long-term exposure has been further linked to adverse perinatal outcomes and lung cancer. In 2013, particulate matter was classified as a cause of lung cancer by WHO's International Agency for Research on Cancer (IARC)[2].

The greatest source of particulate matter around the home is generally the combustion of polluting fuels in open hearths or poorly vented, inefficient stoves or space heaters. In addition to household activities like cooking, space heating, and lighting, other activities can be important sources of particulate matter pollution in the home environment, such as preparing animal fodder, heating water for bathing, and brewing beverages [1].

Black carbon is a major component of PM2.5 and a potent warming agent in the atmosphere. And contributes to regional environmental disruption, and accelerates glacier melting[5].

Polycyclic aromatic hydrocarbons (PAH) are a group of chemicals formed primarily from combustion in coke ovens, diesel engines, and wood-burning stoves. They are present in the atmosphere in particulate form. They are a broad class of compounds called polycyclic organic matter (POM). Long-term exposure to PAH has been linked to lung cancer[3].

Carbon monoxide is a colorless, odorless gas produced by the incomplete combustion of carbonaceous fuels such as wood, petrol, coal, natural gas, and kerosene in simple stoves, open fires, and wick lamps. Carbon monoxide diffuses across the alveolar membrane, dissolves in the blood, and binds to hemoglobin with a greater affinity than oxygen, thus decreasing the amount of oxyhemoglobin in blood and resulting in tissue hypoxia. Exposure to carbon monoxide has many health risks, including reduced exercise ability among healthy individuals, reduced time to angina, increased rates of asthma in children, increased rates of bronchiolitis, and increased rates of cardiovascular disease, cardiac disease, cardiac failure, and ischaemic heart disease among the elderly. Exposure to high levels of carbon monoxide can be deadly[6].

Methane is a potent greenhouse gas. It contributes to the formation of ozone. Methane is emitted by the incomplete combustion of biomass, biofuel, and fossil fuels in simple stoves, open fires, or wick lamps[7].

Other pollutants emitted as indoor air pollution from non-combustion sources with negative health impacts are listed below. Further information on each can be found by clicking the pollutant name[4].

Radon is a radioactive gas that emanates from certain rock and soil formations, concentrating in the basement or ground levels of homes without inadequate ventilation or evacuation systems. Recent studies on indoor radon in Europe, North America, and Asia indicate that lung cancers may range from 3% to 14%, making radon the leading cause of lung cancer among non-smokers[5].

Lead and lead compounds pose health risks of particular concern for children and pregnant women. The health impacts for children exposed to lead include behavior and learning problems, lower IQ and hyperactivity, slowed growth, hearing problems, and anemia. In rare cases, ingestion of lead can cause seizures, coma, and even death. For pregnant women, health risks include reduced fetus growth and premature birth. Adults exposed to lead also have a higher risk of cardiovascular effects increased blood pressure, hypertension, decreased kidney function, and risk of reproductive problems in both men and women. Lead can be found in the home in contaminated dust from products such as paints, ceramics, pipes and plumbing materials, solders, gasoline, batteries, ammunition, and cosmetics [8].

Volatile organic compounds (VOCs) are found in combustion emissions and emitted by building construction materials. VOCs, including formaldehyde, can be emitted from household products such as paints, paint strippers, wood preservatives, wax, pesticides, aerosol sprays, carpets, and many cleaning, disinfecting, cosmetic, and degreasing products. The health effects of VOCs include increased rates of asthma, eye, nose, and throat irritation, headaches, loss of coordination, nausea, damage to the liver, kidney, and central nervous system, and some are suspected or known to cause cancer [5].

Moisture build-up, mould, and bacterial growth can result from structural building faults, inadequate heating and insulation, or inadequate ventilation. These produce allergens and irritants that can cause asthma attacks among those allergic to mould. They also irritate the eyes, skin, nose, throat, and lungs of mould-allergic and non-allergic people [8, 9].

Whether air pollution impacts personal health, domestic and foreign scholars have systematically researched two aspects of physical health and mental health. Among them, the impact on physical health mainly includes various diseases and mortality. For example, according to Ref. [12], in our era, air pollution is one of the greatest problems due to its impact on climate change and public and individual health due to the increase in morbidity and mortality. A variety of pollutants cause human disease. Particulate Matter (PM), particles with varying sizes and very small diameters, penetrate the respiratory system through inhalation and cause respiratory and cardiovascular disease, reproductive and central nervous system dysfunction, and cancer. Ozone in the stratosphere plays a protective role against ultraviolet irradiation, but at ground level, it has harmful effects on the respiratory and cardiovascular systems. In addition, nitrogen oxide, sulfur dioxide, volatile organic compounds (VOCs), dioxins, and polycyclic aromatic hydrocarbons (PAHs) are all considered air pollutants harmful to humans. When inhaled at high levels, carbon monoxide can even cause direct poisoning. Depending on exposure, lead can cause direct poisoning or chronic intoxication when absorbed into the body.

Among the diseases caused by the above substances are respiratory problems such as Chronic Obstructive Pulmonary Disease (COPD), asthma, bronchiolitis, cardiovascular events, nervous system dysfunctions, and cutaneous diseases. As a result of pollution, climate change affects the geographical distribution of many infectious diseases, as do natural disasters. Until public awareness is combined with a multidisciplinary approach from scientific experts, we will not be able to tackle this problem; national and international organizations must address the threat and propose sustainable solutions. A study by Ref. [13] examines the effects of short-term and long-term exposure to AAP on respiratory morbidity, mortality, and premature mortality in the exposed population. 59 studies have been reviewed to examine the effects of short-term exposure (n = 23); long-term exposure (n = 18); and premature mortality (n = 18). COPD, respiratory illnesses, and hospital admissions or visits strongly correlate with short-term exposure to ambient pollutants. Many studies have looked at the long-term effects of AAP, including lung function deficits, asthma, heart attacks, cardiovascular mortality, and premature mortality. Particulate matter (PM2.5 and PM10) is primarily responsible for respiratory health problems. Out of 18 literature reviews on premature mortality, most (12 of 18) studies have statistically significant associations between AAP exposure and increased premature mortality risk. Another European study by Ref. [14] states that air pollution is responsible for more than 40000 deaths, or 6% of total mortality. More than half of all mortality cases caused by air pollution are related to motorized traffic, which accounts for more than 25 000 new chronic bronchitis (adults); more than 290 000 episodes of bronchitis (children); and more than 16 million person-days of restricted activities. The public health impacts of current air pollution patterns are estimated in this assessment. The health risks of air pollution for individuals are relatively small, but their public health effects are substantial. European public health continues to focus on air pollution caused by traffic. Environmental health policy decisions should be guided by our results, which have also been used for economic valuation.

Even in recent Covid-19, many researchers have suggested a positive relationship between the spread of Covid-19 and climate parameters since the pandemic's beginning. To study the association between chronic exposure to air pollutants and the death rate in Iran due to Covid-19, an ecological study was conducted in 12 Iranian cities using the report of daily deaths from Covid-19 (March to August 2020). It validated data on air pollution, taking into account the average concentration in each city during the last year by Ref. [15]. With generalized additive models and adjustment variables, Poisson regression models were used. A significant increase of 2.7% (IC(95%) 2.6–4.4) was found in the mortality rate due to Covid-19 due to an increase of 1 μg/m3 of NO2. It appears that NO2 exposure is related to Covid-19 mortality. A more precise analysis is conducted to approximate the risk associated with air pollution. This paper's results are also consistent with studies from other regions; the findings can be useful to public health policymakers in making decisions to contain the spread of Covid-19.

In addition, some scholars have studied the impact of air pollution on personal mental health from the perspective of personal subjective well-being. For example, Ref. [16] took ten European countries as the research object, explored the relationship between air pollution and subjective well-being through panel data, and found that air pollution significantly differs subjective well-being between countries and time. Prediction effect. Ref. [17]

used an ordered response model to estimate and found that residents' well-being decreased significantly with the increase in urban air pollution, and the impact of air pollution on well-being was significantly heterogeneous. Men and rural residents are more affected. Ref. [18] used the method of Poisson regression to study the relationship between subjective air pollution and residents' well-being based on introducing the concept of a national environmental protection model city. It is believed that improving air pollution improves happiness; conversely, for residents living in non-model cities, subjective air pollution deterioration reduces their happiness; objective air quality does not adversely affect their happiness. Ref. [19] took Taiwan as a sample, based on a multi-level model and a potential growth curve model, to explore the impact of regional ambient air pollution (including $PM_{2.5}$, PM_{10}, and NO_2) on adolescent well-being and its effect over time. It was found that increasing concentrations of all three air pollutants resulted in lower well-being among adolescents but did not find that air pollution levels were associated with changes in well-being during the study period (3 years later).

At the same time, some scholars have studied the relationship between air pollution and mental health from the perspective of self-assessment of mental health. These scholars chose to use the Depression Scale (CES-D) developed by Ref. [20] to calculate the self-rated mental health score index. Compared to subjective measures of well-being, the CES-D scale highlights the multidimensional emotions that affect people in a shorter period. This paper also chooses to use this indicator to measure personal mental health. Among them, Ref. [21] used the 2014-2015 China Household Tracking Survey data to regress the temperature inversion as an instrumental variable of $PM_{2.5}$. They found that the average $PM_{2.5}$ concentration increased by one standard deviation (18.04) in the past month was associated with severe mental illness. The probability of scoring increases by 6.67 percentage points, or 0.33 standard deviations. According to another study by Ref. [22], out of 1,806 participants at baseline, 191 were diagnosed with Alzheimer's during follow-up, and 111 were diagnosed with vascular dementia. Participants in the highest exposure group were more likely to develop dementia (Alzheimer's disease or vascular dementia) than those in the lowest exposure group, with a hazard ratio (HR) of 1.43 (95% CI: 0.990, 2.05). Alzheimer's disease (HR 1.38) and vascular dementia (HR 1.47). An HR of 1.48 (95% CI: 1.03, 2.11) was associated with dementia in the third quartile compared to the lowest quartile. A subanalysis excluding the youngest sample retested after only five years of follow-up indicated stronger associations with exposure than the full cohort (HR = 1.71; 95% CI: 1.08, 2.73 for the highest vs. the lowest quartile). According to the results of Ref. [23] and based on 2,457 repeated attention test performances, an increase of 30 $\mu g/m^3$ exposure to NO_2 12 h was associated with lower cognitive throughput (beta = −0.08, 95% CI: −0.15, −0.01) and higher response time (beta = 0.07, 95% CI: 0.01, 0.14) (increase inattentiveness). Moreover, an increase of 30 $\mu g/m^3$ exposure to NO_2 12 h was associated with higher self-perceived stress (beta = 0.44, 95% CI: 0.13, 0.77). We did not find statistically significant associations between inhibitory control and subjective well-being.

Ref. [24] conducted a study on an elderly population in China and found a significant positive correlation between air pollution and depression, people are more sensitive to pollution caused by $PM_{2.5}$, PM_{10}, and SO_2, and their body health, gender, relative income, marital status, and social status were also associated with older adults' mental health and depression. Reviewing relevant literature shows that the empirical evidence of the causal relationship between air pollution and mental health is less than that of air pollution affecting physical health. Most literature chooses single or multiple indicators for separate analysis when selecting pollutant indicators. However, Ref. [25] chose the air pollution index (API) as a comprehensive indicator; this indicator does not include PM 2.5, an important pollutant. In selecting measurement methods, most pieces of literature use the instrumental variable method [11], logistic model, logit model [15], etc. Poisson Regression analysis methods are rarely used. Because of this, this paper uses the air quality index as a distribution variable and establishes a Poisson regression model to study the causal relationship between air pollution and personal mental health in the form of a quasi-natural experiment to provide new research on this issue. Using the Air Quality Index to measure air pollution has two advantages. First, the air quality index uses a conceptual value to represent the air quality status and air pollution degree in stages to reflect air quality more simply and intuitively; second, the air quality index combines various routine testing methods. Air pollutant concentrations (including fine particulate matter $PM_{2.5}$, inhalable particulate matter PM_{10}, sulfur dioxide SO_2, nitrogen dioxide NO_2, ozone O_3 and carbon monoxide CO, etc.) can be air pollution assessed from a more comprehensive perspective Effects on mental health.

In recent years, the issue of air pollution has attracted much attention. Although the governments have taken some positive measures in environmental protection, the air pollution problem still exists. According to the "Iranian student healthcare policy" issued by the Iranian ministry of science and technology, in 2016, among the 12 Iranian metropolises, nine cities had air quality exceeding the standard, accounting for 59.8%. The air pollution situation across the country is evident, which seriously affects the civilian's sense of gain, happiness, and security, especially the impact on personal health, which needs special attention. Air pollution harms people's physical health in many ways. Many studies

have shown that air pollution is significantly associated with respiratory diseases, pneumonia, stroke, cardiovascular and cerebrovascular morbidity, and mortality [10]. As more and more people begin to pay attention to mental health, researching whether there is a causal relationship between air pollution and mental health has certain significance for the government to formulate better air pollution control policies in the future and how people can improve their mental health [11, 12]. This paper matches personal data from the 2022 Iranian Student Mental Health Survey (IRSMHS) with the average air quality index of the province where the universities are located in the year students attend. It selects a simplified version of the CES-D scale in the IRSMHS survey. As an indicator to measure the degree of mental health, according to the air quality index rating standard and the air quality index value range of the samples used in this paper, AQI=50 and AQI=100 are used as critical points. A Poisson regression model (PR) is established, To study the short-term causal effects of air quality and individual mental health. The study found that air pollution does have a significant adverse effect on personal mental health. The more serious the air pollution, the worse the personal mental health becomes. Next, this paper tests the validity and robustness of the regression results, conducts heterogeneity analysis from the perspective of gender differences and urban-rural background differences and finds that air pollution significantly impacts. Still, this effect does not Emerge among women and rural populations.
The possible contributions of this paper are as follows: First, the air quality index is selected as an indicator to measure air pollution. It integrates many air pollutants such as PM 2.5 and PM 10 and can study the effect of air pollution on individual mental health from a more comprehensive perspective. Overall impact. Second, an Poisson regression model is used, and the air quality index is directly used as a distribution variable. The latitude difference as a distribution variable, this paper provides a new perspective on the selection of distribution variables for this kind of research. Third, although this article uses cross-sectional data, the short-term effects of air pollution on individual mental health care are provided by matching individual data in the IRSMHS with the average air quality index of the province where the university was located one year before the study time.

2. Materials and methods

Before studying the causal relationship between air pollution and mental health, we must first clarify the possible endogeneity between the two. First, there may be omitted variable bias. This paper adds age, gender, marital status, social class, education level, rural or urban background, and self-assessed health status as covariates in the model to solve this problem. Second, there may be bidirectional causality. While air pollution affects people's mental health, mental health may affect anthropogenic emissions and air pollution by affecting worker productivity [17]. Third, there may be a measurement error problem. So the flow of the research will be according to figure 1.

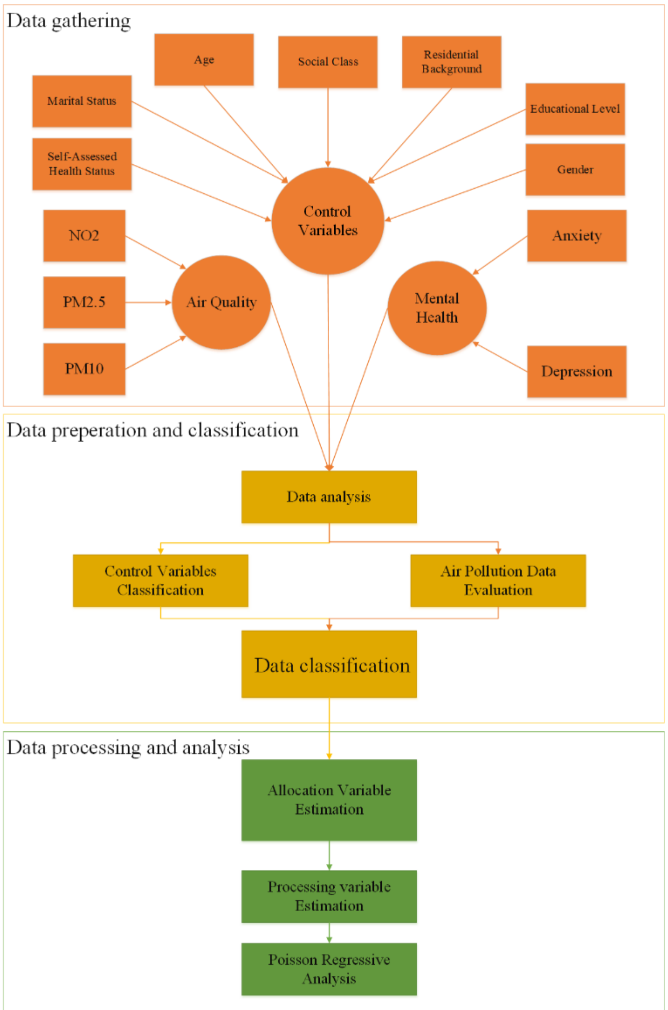

Figure 1. flowchart of the research

Some governments may falsify data on air quality indicators to pursue political achievements, such as selecting national environmental protection model cities so that the estimation model is endogenous. We build an exact Poisson regression model (sharp RD) to overcome the above endogeneity problem. The model uses the continuous air quality index AQI variable as the initial assignment variable, also known as the forcing variable. In the sample selected in this paper, the value of AQI ranges from (22-130). According to the air quality index standard, when the AQI is between 0 and 50, the air quality is excellent; when the AQI is between 51 and 100, the air quality is good; when the AQI is between 101 and 150, the air quality is lightly polluted. Therefore we choose AQI=50 and AQI=100 as critical values. Referring to the treatment of multiple critical values in Ref. [13], the AQI is decentralized, and the following functions are defined as the final model (see figure 2).

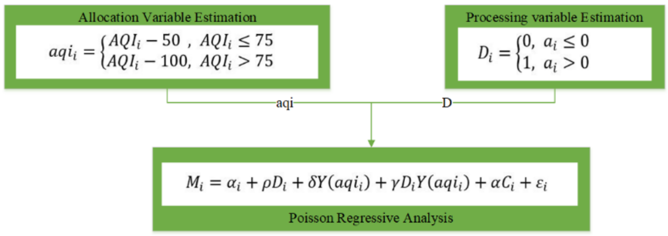

Figure 2. Research model design

Among them, *M* represents the mental health status, which is measured by the mental health score of the CES-D 6-item scale; $Y(aqi_i)$ is a polynomial function of distribution variables; C_i is all control variables, including age, gender, marriage, social class, years of education, household registration location, and self-assessed health status; α_i is a constant term; ε_i is the error term. Including self-rated health in the model is that people's subjective feelings about their health may affect their mental state. When individuals think their health is not good, their anxiety and depression will also increase, and their psychological pressure will increase, increasing the risk and probability of mental illness [19]. In addition, this paper will test the validity of the Poisson regression method and the robustness of the estimated results. In terms of validity, we will test the continuity of the distribution variables and the continuity of the control variables; in terms of robustness, we choose to change the bandwidth and the functional form of the distribution variables. If the estimation results are not affected, the results are robust. Since the classification standard of the air quality index is objective, different air quality levels will impact people's lives, so this paper will not conduct a placebo test to change the critical point.

In terms of mental health indicators, the data is gathered from the Iranian ministry of science and technology healthcare department. The six questions in the IRSMHS survey asked respondents how often different psychological symptoms occurred during the past week. This 6-item scale is a simplified version of the CES-D that is highly correlated with the standard 20-item CES-D scale and has sufficient psychometric properties to reflect a person's level of depression [13]. Specific symptoms include: "I feel down," "I find it hard to do anything," "I don't sleep well," "I feel lonely," "I feel sad," and "I feel like life can't go on." The survey sets four options to reflect the frequency of the above questions, then assigns values to the four options, and finally obtains a personal mental health score, with a value range of (0, 24). The higher the score, the higher the degree of depression and the worse the mental health. The specific assignments are shown in the following table 1. In addition, the control variables in the model, including age, gender, marriage, social class, years of education, location of household registration, and self-assessed health status, are also obtained from IRSMHS 2018 data. The specific meanings of some variables are shown in table 1.

Table 1. Variable definition

Variable name	**Numeric Scale**				
Gender	0 for women		1 for men		
Marital status	0 for unmarried		1 for married		
Social class	Based on the logarithmic scale of family total income				
Residential bacground	0 for rural		1 for urban		
Self-assessed health status	1 for great	2 for very good	3 for relatively good	4 for so so	5 for not good
Mental Health Score	1 for Rarely (<1 day)	2 for Seldom (1-2 days)	3 for Often (3-4 days)	4 for Usually (5-7 days)	
Educational level	1 for BSc	2 for MSc	3 for PhD	4 for Post. PhD	

Table 2. Descriptive Statistics of Variables

variable	**name**	**sample size**	**mean**	**standard deviation**	**minimum**	**maximum**
AQI	Air quality index	5760	57.583	16.284	23.668	143.413
aqi	Adjusted air quality index	5760	-3.705	12.989	-31.332	33.413
mental	Mental health score	5760	15.082	4.984	9.6	24
age	Age	2193	24.019	10.072	16	39
gender	Gender	2193	0.658	0.539	0	1
marriage	Marital status	2193	0.928	0.399	0	1
educ	Education level	2193	3.071	1.196	1	4
lincome	Social class	2193	11.233	1.076	5.34	15.005
rb	Residential background	2193	0.808	0.295	0	1
unhealth	Self-assessed health	2193	3.071	1.196	1	5

The air quality index is compiled from data published on the website of the Iranian meteorological organization (IMO). Since each respondent's province and interview time in the IRSMHS survey are different, this paper matches the respondent's relevant data with the provincial average AQI of the year before the interview time according to the respondent's university location. This paper uses respondents' data from Jan to April 2022, and the corresponding AQI is the data of each province from Jan 2021 to April 2022. The reason for choosing the mean AQI of the year before the interview was to explore the short-term effects of air pollution on individual mental health. Table 2 shows the descriptive statistics of each variable in the model.

3. Analysis results

Table 3 shows the results, respectively, of the effects of air pollution on mental health. Since the value range of aqi is [-31.332, 33.413], this paper chooses to control the bandwidth at [-35, 35]. From the figure, we can find that whether it is linear fitting or nonlinear, the mental health score jumps up significantly at the critical point, and the confidence intervals on the left and right sides of the critical point do not overlap, indicating that air pollution has a significant effect on mental health. When air pollution is more serious, the mental health status of individuals is worse; that is, the degree of depression is higher. Columns (1) and (2) in Table 3 list the basic regression results before and after adding control variables. The coefficient for the treatment variable D represents the average treatment effect at the critical point. When the control variable was not included, the treatment variable D was significant at the 1% level; after adding the control variable, the treatment variable D was also significant at the 5% level. When the air quality index increased by ten units, An individual's mental health score would increase by about 2.35 points or 2.35 units of depression.

Table 3. Basic regression results for exact critical point estimation

Variable	Mental health	
	Without control variables	With control variables
D	0.311***	0.235**
P(D)	(0.069)	(0.109)
aqi	-0.003	-0.002
P(aqi)	(0.005)	(0.005)
D*aqi	-0.022***	-0.013
P(D*aqi)	(0.005)	(0.008)
sample size	5760	2193
R.sq	0.002	0.095

Note: Robust standard errors are in parentheses; ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively. The control variables included in the estimation in column (2) include age, gender, marriage, social class, years of education, location of household registration, and self-assessed health status, as are the control variables for the following regressions.

In this part of the paper, we will explore the effectiveness of the PR method by carrying out the continuity test of the distribution variables and the local smoothness test. Due to the possibility of tampering with the air quality index by relevant departments, we test the continuity of the distribution variables. Density functions that assign variables near critical points will not happen if there is no human manipulation. Since this paper selects two points, namely AQI=50 and AQI=100, Figures 3 and 4 are the density function distribution diagrams of the air quality index at these two points; it is not difficult to find from the figure that the density function curve of AQI is smooth at both points, and there is no delta peak. Therefore, the assumption of the randomness of the assigned variables in the PR design is met.

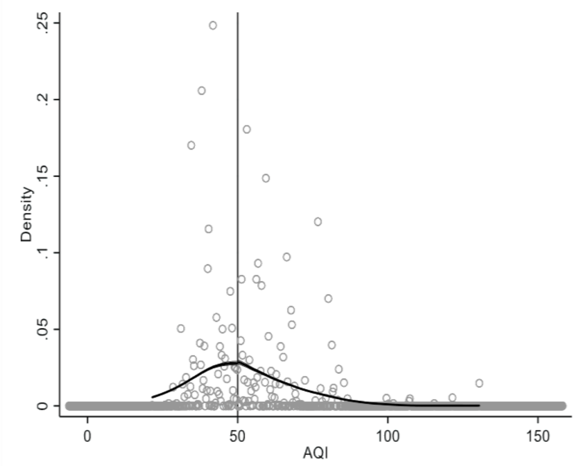

Figure 3. density function distribution at AQI=50

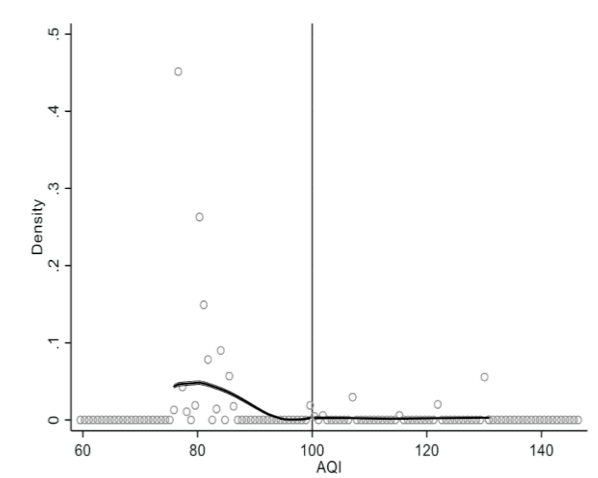

Figure 4. density function distribution at AQI=100

The local smoothness test means that, except for the outcome variable (mental), all other variables have no treatment effect at the critical point; there is no obvious delta peak. So we set all the control variables as dependent variables, set the bandwidth to (-35, 35), and observe whether they have obvious delta peaks at the critical points.

As can be seen from the results, except for social class, the rest of the control variables have no significant delta peaks at the critical points. At the same time, this finding also shows that air pollution may affect social class, and income has a significant downward delta peak at the critical point. One of the possible reasons is that air pollution reduces labor productivity [19, 20]. Thus, the specific impact mechanism remains to be further explored to reduce the income of the labor force. In the design of Poisson regression, bandwidth is one of the key factors affecting the robustness of the estimation result. When the estimation result has a weak dependence on the bandwidth, changing the bandwidth will not affect the result, so the result is considered robust. But when the bandwidth is too small, it contains too few samples and may invalidate the estimate. This article changes the bandwidth to (-30,30), (-25,25), (-20,20), (-15,15) and (-10,10), observe whether the peaking situation at the critical point changes. According to the results, it is found that when the bandwidth is (-30,30), (-25,25), (-20,20), (-15,15) in all critical points, an obvious peak happens, but when the bandwidth is (-10, 10), there is no obvious peak, which may be due to the invalid estimation caused by too small bandwidth an insufficient sample size.

Further, it is obtained in Table 4 by performing regression estimation under different bandwidths. The coefficients of the processing variable D under different bandwidths are all around 0.3, and there is no significant change. Although we do not see obvious jumps under the bandwidth limit of (-10,10), it is found from the table below that the processing variable D corresponding to the bandwidth (-10,10) is still at the level of 5% significantly.

Table 4. Estimated Results of Bandwidth Dependency Test

Variable	Mental health				
	[-30,30]	[-25,25]	[-20,20]	[-15,15]	[-10,10]
D	Yes	Yes	Yes	Yes	Yes
P(D)	0.301***	0.305***	0.311***	0.377***	0.336**
aqi	(-0.109)	(-0.108)	(-0.111)	(-0.138)	(-0.158)
P(aqi)	-0.001	-0.001	-0.001	-0.003	0.023
D*aqi	(-0.006)	(-0.006)	(-0.007)	(-0.011)	(-0.016)
P(D*aqi)	-0.02**	-0.02**	-0.022**	-0.031*	-0.076***
sample size	(-0.009)	(-0.009)	(-0.01)	(-0.017)	(-0.024)
R.sq	2193	2193	2075	1602	1209
D	0.094	0.096	0.096	0.093	0.096

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 5 shows the regression results of the distribution variables from the 2nd to the 5th order function form. We will find that although the coefficient of the processing variable D changes under different function forms, the change is not large, and the sign is the same. In terms of statistical significance, it was consistently significant at the 1% or 10% level, suggesting that the effects of air pollution on mental health were not affected by the functional form of the distribution variable. Therefore, the estimation results are robust in changing the functional form of the distribution variable.

Table 5. Estimation results of different functional forms of allocation variables

Variable	Model polynomial order							
	2nd order polynomial		3rd order polynomial		4th order polynomial		5th-degree polynomial	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
control variable	no	yes	no	yes	no	yes	no	yes
D	0.188*	0.187*	0.465***	0.398***	0.459***	0.387***	0.256*	0.248*
P(D)	(0.103)	(0.103)	(0.124)	(0.133)	(0.127)	(0.135)	(0.152)	(0.156)
sample size	2193	2053	2193	2053	2193	2053	2193	2053
R.sq	0.002	0.099	0.006	0.098	0.005	0.097	0.002	0.097

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

After demonstrating the validity of the Poisson regression and the robustness of the estimated results, we will further conduct a heterogeneity analysis of the causal relationship between air pollution and mental health. This paper chooses to explore whether air pollution affects the mental health of different individuals from the aspects of gender and household registration. Since the number of samples for each regression is small after limiting the samples, we found that the effect of using linear fitting is better than quadratic fitting, so the following critical point graphs use linear fitting.

When the samples are regressed according to gender, the obtained graphical results and specific estimated results are shown in Table 6. From the results, it can be found that air pollution has a significant adverse effect on men's mental health; that is, the more severe the air pollution, the worse the mental health of men. After adding control variables, each 10-unit increase in the air quality index was associated with an increase of about 2.94 points in the mental health score, that is, an increase in the degree of depression by about 2.94 units. However, we did not find a significant effect of air pollution on women. As shown in Table 6, the confidence intervals on both sides of the critical point overlap greatly, so the treatment effect is insignificant. The reason may be that men spend more time outdoors than women and are more sensitive to air pollution. This finding is similar to Ref. [14] 's conclusion that there is gender heterogeneity in the effects of air pollution on individual mental health.

Table 6. Heterogeneity analysis results of gender differences

Variables	Female		Male	
	(1)	(2)	(3)	(4)
Control variable	no	yes	no	yes
D	0.127	0.113	0.323**	0.294**
P(D)	(0.178)	(0.184)	(0.138)	(0.142)
aqi	0.004	0.004	-0.008	-0.005
P(aqi)	(0.009)	(0.009)	(0.008)	(0.008)
D*aqi	-0.017	-0.006	-0.016	-0.013
P(D*aqi)	(0.015)	(0.015)	(0.012)	(0.012)
sample size	956	819	1237	1235
R.sq	0.000	0.086	0.002	0.084

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Next, we divided the sample into urban and rural hukou groups according to the type of hukou to find the heterogeneity of urban-rural differences. From the estimated results in Table 7, it can be found that the impact of air pollution on mental health is also heterogeneous in urban and rural areas. Air pollution significantly affects the mental health of the urban population, not the rural population. The reason may be that the air pollution in cities is more serious, and the urban population is more concerned about air quality, so they are more sensitive to air pollution.

Table 7. Heterogeneity analysis results of urban-rural differences

Variables	Rural		Urban	
	(1)	(2)	(3)	(4)
Control variable	no	yes	no	yes
D	0.139	0.126	0.444**	0.496**
P(D)	(0.128)	(0.125)	(0.191)	(0.193)
aqi	-0.004	-0.001	-0.001	0
P(aqi)	(0.007)	(0.007)	(0.011)	(0.011)
D*aqi	-0.008	-0.002	-0.034**	-0.036**
P(D*aqi)	(0.011)	(0.011)	(0.015)	(0.017)
sample size	956	819	1237	1235
R.sq	0	0.092	0.001	0.085

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

4. Discussion

Air pollution, as much as it affects the incidence and increase of physical illness and mortality, leads to numerous psychological injuries and increases the complaints of feelings of sadness, stress, and restlessness in people, and observing these symptoms is a quality of life and satisfaction[26]. In today's world, air pollution has become one of the most complex and ever-present problems of human life around the world[27]. Various studies show that particulate matter, greenhouse gases, and toxins harm human existence[28]. Various studies have shown the relationship between air pollution and skin, gastrointestinal, heart, and lung diseases. Still, more shockingly, according to various studies, air pollution also affects brain cells, causes depression in the body, and has become one of the most important concerns in society[29]. Recent evidence has shown that air pollution affects the physical health of people, and even on polluted days when air pollution is dangerous, an increase in mortality can be observed in high-risk groups such as the elderly and children[30]. As we observe changes in the physical health of people due to air pollution, air pollution also has devastating effects on mental health[31]. Recent evidence has shown that air pollution can affect mental health in three ways: how we adapt to environmental changes and our behaviors and mental functions. Finally, air pollution can have long-term effects[21]. It is toxic to brain growth and function to the point that it kills three million people worldwide each year and manifests its effects on mental health as a stressor with anxiety, stress, worry, and depression[18].

This study showed that long-term air pollution exposure was related to different mental and self-rated health dimensions in Iranian students[12]. Findings indicated that social and educational class affected part of the association between air pollution and mental or self-rated health [14]. The association between mental health outcomes and air pollution was stronger among the elderly and men. According to the paper results, the following discussion on the air pollution association with mental health among Iranian students[32].

Air pollution affects some people's personalities, so people who are interested in some activities and extroverted become introverted. It can also increase the suicide rate in people, especially those with mental disorders; air pollution negatively affects mental health. In general, it increases anxiety, increases brain inflammation, anemia, decreased vision, decreased mental capacity, depression and stress, muscle and mental tension, mental and emotional disorders, violence and aggression, reduces learning and concentration [17]. It also increases prematurity, in which a person develops self-illness and a feeling of fear is formed in him, and obsession increases significantly[33].

Anxiety, irritability, violence, and aggression, as well as depression, are among the psychological damage caused by air pollution and even reinforce the physical damage caused by psychosomatic; "Psychological disorders" refers to some of the mental illnesses that are directly related to brain damage and abnormalities in the chemical environment of the brain, as well as reinforcing violence and aggression and reducing adaptation to social environments, although individuals' reactions based on genetics family are different from environmental stimuli. Still, this infection generally reduces social resilience to social pressures by increasing anxiety[15]. Air pollution promotes violence and aggression. This is one of the most important challenges of industrial societies today, as it leads to numerous physical, psychological, and sometimes even irreparable and profound injuries[9].

In general, in addition to the above, air pollution causes mental and emotional disorders and concentration disorders and increases prematurity, in which case the person will suffer from self-illness. A feeling of fear will be formed in the person's obsession will increase significantly[34-37]. Of course, self-morbidity is one of the most important mental and psychological injuries of air pollution because this injury causes anxiety about the disease. In other words, the "self-sick" is concerned about the disease despite his physical health and constantly sees a doctor and asks for evaluation. And this worry will cause many problems in a person's life[19].

Lead has destructive effects on the psyche. According to research, in addition to the disorders caused by air pollution on the human psyche, if lead increases in the air, reduces efficiency, decreases performance, increases stress, decreases sensory and motor hearing, and Leads to auditory nerve disorders and learning disabilities. Suppose the lead is produced due to poor fuel. In that case, it can increase the symptoms of autism and hyperactivity in children, significantly reduce self-esteem and forgetfulness, and the occurrence of maladaptive behaviors in adults[17].

Air pollution can lead to Alzheimer's, dementia, and Parkinson's, as the central nervous system generally appears vulnerable to air pollution and can even lead to mental disorders such as depression, anxiety, and depression [18]. Evidence suggests that air pollution increases the likelihood of depressive and anxiety symptoms[22]. Communities, feelings of stress, and feelings of restlessness are seen more in people. These symptoms reduce people's quality of life and satisfaction and can reduce mental health and feeling good [23].

When we are exposed to polluted air, it is observed that in such situations, we are less likely to become mentally tired and have the ability to adapt normally to problems. People with fewer stimuli become anxious and have more anxiety-based reactions[38]. They show that reducing the body and brain's access to healthy air and adequate oxygen can also lead to increased reactions based on anxiety, immediate decisions, and impulsive behaviors, in which case the likelihood of fatigue and decreased mental function increases; in other words, air pollution[25]. It can make it harder for people to adjust to normal situations.

Studies and researches show the effects of air pollution on the growth and function of the brain and the incidence of psychological damage. Currently, animal studies have shown exposure for ten months and 6 hours a day in contact with polluted air with particles larger than 25 micrograms affects the growth of the brain, increases the likelihood of symptoms such as impaired concentration, and therefore when we are exposed to polluted air, not only are we at risk, but also for our brain function to cause psychological damage[13].

Previous studies' perception and knowledge of air pollution and its associated health risks varied significantly across genders and health statuses [9]. Male and female responses to smoke prevention in public areas and compromising on air pollution caused by Iran's industrialization showed significant differences ($p<0.05$). In contrast, there was no statistically significant difference between the genders' awareness of air pollutants and their associated diseases/disorders. There was a significant difference in awareness between the subjects, excluding awareness of major pollutants. Significant differences were observed for all sections of the questionnaire ($p<0.05$), resulting from different air pollution levels, media access, and government outreach programs regarding air pollution and its health risks. Air pollution levels may differ from city to city depending on whether they are production or consumption zones. Production sites (exports/imports, local/international) are directly related to trading. The size of the county may affect pollution levels in Iran's provinces. The provinces differ greatly in energy endowments and resources, lifestyles, population densities, and oil production. For example, pollution in southern Iran has increased rapidly, while they have stabilized or even declined in central Iran[39].

Educational level and knowledge of air pollution's adverse health impacts are linearly related [40]. There was also some evidence that social classes differed markedly in their knowledge and perception of air pollution [41]. Ref. [42] report that women are more concerned about air pollution than men. A significant difference ($p<0.05$) was observed between the preventative measures taken by males and females in this study; the female subjects were more cautious towards air pollution as they used more preventative measures, such as respiratory masks, goggles/glasses, drinking more water, and eating nutrient-rich meals to boost their immunity, than the males. Ref. [43] reported opposite findings, while Ref. [17] stated that younger people were more satisfied with air quality. The contradiction could be explained by the respondents' health conditions since healthier subjects were less worried, and the tendency of subjects to travel since subjects with travel experience were more worried or anxious about air pollution and its health risks [18]. There were no significant differences in awareness of air pollution and associated health risks between age groups, except for major air pollutants. Still, there were significant differences ($p<0.05$) between different age groups in awareness of toxic air pollutants.

The most important complication of air pollution is stress. Stress is an accelerating factor in physical and mental illnesses that cause feelings of helplessness, failure, and reduced life satisfaction. At the same time, air pollution significantly increases stress and carbon dioxide produced from fossil fuel consumption, aggravates anxiety, and greatly increases mental illness. Air pollutants also cause the most psychological damage to the psyche[9].

Children are also exposed to the negative effects of air pollution and are more likely to have impaired brain development. Evidence suggests that children may lose IQ in the long-term exposure to air pollution. Destructive air pollution should pay serious attention to brain development and mental health of children and as a serious problem in physical and mental health to take effective measures to address it because having children with low IQ and mental health problems will not benefit communities. And the child himself will suffer from these complications in the future, which may cause other mental disorders, leading to nervous weakness, hyperactivity, aggressive behaviors, and poor communication skills in children[8].

Apart from directly affecting mental health, air pollution can aggravate psychiatric symptoms such as anxiety and insomnia by exacerbating physical illnesses such as asthma and respiratory attacks. When shortness of breath increases, the patient causes stress and anxiety, and on the other hand, anxiety can delay the improvement of asthma symptoms. Air pollution can seriously impact our lives by affecting our physical and mental health, and we all need to pay attention to the problem of air pollution. Ability to play an effective role in our and our children's current and future health by controlling the underlying factors and reducing air pollution.

As with other surveys (funding, time, and survey duration), we tried to reach as many subjects as possible. Few rapidly growing cities in Iran should also be surveyed despite the study covering 12 major cities. Future studies should include other people besides Iranian students, as the current study involved only metropolis-located university students. Additionally, because of Iranian students' tight schedules and limited time frames, their baseline physiological conditions were not adjusted for mental and behavioral health. Additionally, the administered questionnaire contained closed-ended questions. Therefore, the responses were given "as asked" by the questions. To determine how self-assessed mental healthcare can be enhanced, a survey with an open-ended questionnaire is necessary so that we can better understand the population's perceptions, attitudes, knowledge, and awareness of the problems they face. Before conducting this study in another area, these key points should be considered, and the results should be cautiously applied to another population and location[25].

5. Conclusion

This paper establishes a precise Poisson regression model to study the short-term causal effects of air pollution on personal mental health and provides new evidence for the impact on personal mental health. The study found that air pollution significantly negatively impacts mental health. Then, we performed four tests to prove the effectiveness of the Poisson regression method, and the estimation results are still relatively robust after changing the functional form of the bandwidth and distribution variables. Finally, we performed a heterogeneity analysis of this causal relationship. We found that the impact of air pollution on individual mental health was heterogeneous in both gender and urban and rural background of each student, with air pollution significantly affecting the mental health of men and urban populations. Therefore, from improving people's mental health, it is of great significance to intensify efforts to control air pollution and win the battle to defend the blue sky as soon as possible. With the continuous advancement of the urbanization process and the continuous growth of urban population groups, it is more urgent to improve the city's air quality. Due to the internal and weak external validity of the Poisson regression analysis, it remains to be explored whether the conclusions obtained in this paper based on relevant data from Iran can be extended to other countries. In addition, this paper finds that air pollution has a causal relationship with the social class during the local smoothness test. Therefore, the impact of air pollution on social class has also become a problem that needs further research.

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