ORIGINAL RESEARCH ARTICLE

A Community-Based Cross-Sectional Study of Indoor Air Pollution and Its Mental Health Implications Among Rural Households

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ABSTRACT

Introduction: Emerging research indicates that air pollution can affect the central nervous system through various pathways, leading to inflammation and oxidative stress. This process leads to neurotoxicity and raises the risk of neurodevelopmental and neurodegenerative disorders, as well as anxiety and depression.

Materials and methods: The present study is a cross-sectional study conducted over two years, involving rural households that use solid fuels. Air quality was measured using high-quality instruments. Mental health statuses such as anxiety and depression among residents of these households were assessed using standardized tools. The chi-square test was applied to examine associations, with a p-value less than 0.05 considered statistically significant.

Results: Out of 812 residents, the majority belonged to the 31 to 40 years age group, male gender, a nuclear family, and the upper middle class of Modified BG Prasad Classification 2023. 25.6% had marked to severe anxiety, and 23.2% had mild depression. The AQI of rural households revealed that 192 (23.6%) were of poor standards as per the National guidelines. Anxiety and depression mental health status had a statistically significant association with AQI.

Conclusion: The present study adds to the small but growing evidence indicating that exposure to indoor air pollution can be associated with mental health issues like Anxiety and Depression.

Keywords: Mental health, Anxiety, depression, rural households, Indoor Air quality

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Introduction

For many developing countries, indoor air pollution remains one of the most significant environmental problems, as many lack access to clean fuels for cooking, which is the most common cause of indoor air pollution. According to World Health organization (WHO), Household air pollution or Indoor Air pollution is generated by the use of inefficient and polluting fuels and technologies like inefficient devices used to cook in and around the home that contains a range of health-damaging pollutants, including small particles that penetrate deep into the lungs and enter the bloodstream. In poorly ventilated dwellings, indoor smoke can have levels of fine particles 100 times higher than acceptable. This pollution can originate from the burning of solid fuels, such as crop waste, dung, charcoal, and coal, for cooking and heating in households. Burning these fuels produces particulate matter, a significant health risk, especially for respiratory diseases, which has been studied extensively.[1] Indoor air pollution also includes diverse biological contaminants, such as allergens (mainly house dust mites), as well as insects, pollen, animal sources, molds, and bacterial endotoxins. Other components include chemical pollutants such as gases, particulate matter, formaldehyde, and volatile organic compounds (VOCs).[2] AQI Recent literature also shows that indoor air pollution is a risk factor for several leading causes of death worldwide, including heart disease, pneumonia, stroke, intrauterine growth retardation, diabetes, and lung cancer. Burning such fuels in enclosed spaces, such as small households, significantly increases the risk of exacerbating these diseases.[3] Indoor air pollution results not only from physical substances like dust, ash, and suspended particulate matter (SPM), but also from chemicals such as pesticides, insect repellents, carbon monoxide (CO), and nitrogen oxides (NO2), as well as biological agents like bacteria, fungi, microbial spores, and animal dander.[4] Despite liquid petroleum gas becoming more widespread in many parts of the world and countries, other sources also play a significant role, such as cigarette and beedi smoking, and burning of agarbathi, etc.[5] Emerging research indicates that air pollution can affect the central nervous system through multiple pathways. Inflammation and oxidative stress are recognized as standard underlying mechanisms through which air pollution may induce neurotoxicity, thereby increasing the risk of neurodevelopmental and neurodegenerative disorders.[6]

Depression is characterized by a persistent depressed mood or a loss of interest or pleasure in activities for most of the day, nearly every day, for at least two weeks. Anxiety involves excessive fear, worry, and related behavioral disturbances. Several types of anxiety disorders include generalized anxiety disorder, panic disorder, social anxiety disorder, and separation anxiety disorder.[7] Meta-analyses and systematic reviews have shown evidence that air pollution can cause neuroinflammation, oxidative stress, and cerebrovascular damage, which are associated with the onset of depression due to neurotransmitter depletion and hormonal dysregulation affecting the balance of serotonin and noradrenaline in the central nervous system.[8] Understanding the link between air pollution and mental health requires further investigation. Studies are needed to establish a causal relationship between air pollution and mental illness. A longitudinal study conducted by Wang et al. in Taiwan demonstrated that exposure to air pollutants may increase depression risk among older adults.[9] With Sustainable Development Goal 7, particularly indicator SDG 7.1.2, which measures the proportion of the population relying primarily on clean fuels and technologies.[10] With this background, the study was started with the objectives to find out the Indoor air quality among rural households and also to find out the association of Indoor air quality with Depression and Anxiety among residents of rural households.

Methodology

This was a community-based cross-sectional study conducted over two years, from January 2023 to December 2024. Study participants were residents of rural households who had lived in the village. Kolar Taluk has 15 primary health centers (PHCs), and five of them were randomly selected. All villages within these PHCs were included in the study. A study in Kolkata showed that 49% of the rural population still used firewood for indoor fuel, indicating a high prevalence of indoor air pollution (p). With a margin of error (d) of 5% and a 95% confidence interval, the sample size was calculated to be 400, using the formula: Sample size = 4 pq/d^2.[11] With a cluster effect of 2, the final sample size was 800. From each selected PHC, all villages were included. Details of all households were line-listed by the Medical Officer in charge of each PHC, with assistance from Accredited Social Health Activists (ASHAs). Households were chosen using simple random sampling with probability proportionate to size. Participants aged between 18 and 60 years from these households were included. Residents who had lived in the village for over 10 years, used solid fuels such as dung or wood, and kept livestock were included in the study. Residents over 18 years living in brick-and-cement or kaccha houses built with wood, mud, straw, or dry leaves, and with no history of mental health illness, were also included. Houses that were locked were excluded. A pretested semi-structured questionnaire was used to collect socio-demographic data and housing standards. Indoor air quality was assessed using the Prana Air Laser Air Quality Monitor, which measures PM2.5, PM10, CO_2, HCHO, temperature, and humidity. Nitric oxide (NO) and sulfur dioxide (SO_2) were measured with the Honeywell BW Solo single gas detector. Both instruments are validated and highly sensitive and specific. To evaluate mental health, levels of anxiety and depression were assessed through interviews lasting no more than 15 minutes. The interview was done by an Associate professor who had prior experience in using these mental health tools. Socio-demographic information was collected via the semi-structured questionnaire. Depression was measured using the Zung Self-Rating Depression Scale, a 20-item survey that quantifies depression severity across various aspects such as pervasive effects, physiological symptoms, mood disturbances, and psychomotor activity. Each item is scored from 1 (none or some of the time) to 4 (most or all of the time), with total scores ranging from 20 to 80; higher scores indicate more severe depression. Scores are categorized as 20–44 (Normal), 45–59 (Mildly Depressed), 60–69 (Moderately Depressed), and 70 and above (Severely Depressed).[12] To assess anxiety, the Zung Self-Rating Anxiety Scale (SAS) was used. It consists of 20 items scored on a four-point scale, which evaluate symptoms related to the cognitive, autonomic, motor, and central nervous system. Raw scores range from 20 to 80 and are converted into an index score, obtained by multiplying the raw score by 1.25. The final index scores are interpreted as follows: below 45 as within the normal range, 45-59 as minimal to moderate anxiety, 60-74 as marked to severe anxiety, and 75 and over as the most extreme anxiety.[13] To assess socio-economic status of the study participants, Modified BG Prasad classification 2024 was used.[14]

Air Quality indices and various parameters of AQI were based on the National Air quality index (AQI) as launched by Ministry of Environment, Forest and Climate change. Air Quality Index is a tool for effective communication of air quality status to people in terms, which are easy to understand. It transforms complex air quality data of various pollutants into a single number (index value), nomenclature and colour. There are six AQI categories, namely Good, Satisfactory, Moderately polluted, Poor, Very Poor, and Severe. Each of these categories is decided based on ambient concentration values of air pollutants and their likely health impacts (known as health breakpoints). Air Quality sub-index and health breakpoints are evolved for eight pollutants which are Particulate matter (PM10), Particulate matter (PM 2.5), Nitrous oxide (NO_2), Sulphur dioxide (SO_2), Carbon monoxide (CO), Ozone (O_3), Ammonia (NH_3) and Lead (Pb) for which short-term (up to 24-hours) National Ambient Air Quality Standards are prescribed. Based on the measured ambient concentrations of a pollutant, sub-index is calculated, which is a linear function of concentration. According to the National standards of air quality standards, 0-50 is considered good, 51- 100 as satisfactory, 101-200 is considered moderate, 201-300 as poor, 301 to 400 as very poor and more than 401 as severe.[15]

Statistical analysis: All data were entered into a Microsoft Office Excel sheet and analyzed using SPSS v22 (IBM Corp, USA). Descriptive statistics were applied as needed. To explore the association between Housing standards, Indoor air quality, and anxiety and depression, the Chi-Square Test was used, with a significance level set at a p-value less than 0.05. Multinomial logistic Regression analysis was performed to estimate the odds ratio.

Ethical clearance was obtained from the Institutional Ethics Committee (SDUMC/KLR/IEC/348/2023-24) prior to commencing the study. Informed written consent/assent was obtained from participants by explaining the benefits and risks involved in the local language. Autonomy of the study participants were maintained for all the study participants making Participation in the study voluntary. Confidentiality was also maintained as the participants' names and personal details were not recorded. The present study was an ICMR STS project. (STS 2023-04750).

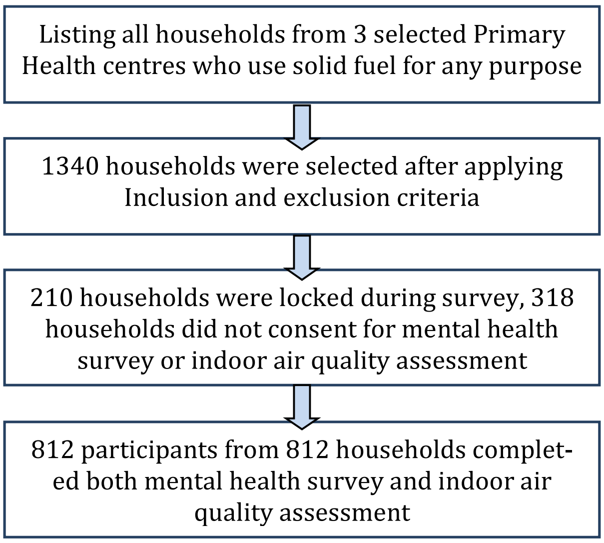

Figure 1: Flowchart of selection of study participants

RESULTS

Out of 812 study participants who took part in the study, 208(25.6%) belonged to 31 to 40 years and 188(23.2%) belonged to 41 to 50 years, 384(47.3%) were male gender, 700(86.2%) belonged to nuclear family and 488(60.1%) belonged to upper middle class of Modified BG Prasad Classification 2023. Out of 812 study participants who took part in the study, 356(43.8%) had mild to moderate anxiety levels, followed by 208(25.6%) who had marked to severe anxiety levels as assessed by the Zung anxiety scale. Out of 812 study participants who took part in the study, 180 (22.2%) had Moderate Depression and 96 (11.8%) were severely depressed according to the Zung Depression scale. (Table 1)

Out of 812 households, 580 (71.4%) had Moderate AQI standards, 772 (95.1%) had PM10 levels at Moderate levels, 568 (70%) had satisfactory PM 2.5 levels, 792 (97.5%) had satisfactory O3 levels,780 (96.1%) had satisfactory Carbon monoxide levels, 428 (52.7%) had good TVOC levels, 748 (92.1%) had satisfactory Carbon dioxide levels. All houses had zero Sulfur dioxide (SO2) and Nitric oxide (NO2) emissions. (Table 2)

256 (71.9%) of participants' households that had Moderate AQI levels had Mild to Moderate anxiety levels, and this association between anxiety levels and AQI was statistically significant, with a p-value less than 0.05. 76(79.2%) participants who had Moderate AQI levels were severely depressed, and this association between depression levels and AQI was statistically significant, with a p-value less than 0.05. (Table 3)

Table 1: Distribution of study participants according to clinico-socio-demographic profile

Variables	Participants (%)
Age in years	
21 to 30 years	104 (12.8)
31 to 40 years	208 (25.6)
41 to 50 years	188 (23.2)
51 to 60 years	196 (24.1)
61 years and above	116 (14.3)
Gender	
Male	384 (47.3)
Female	428 (52.7)
Family structure	
Nuclear	700 (86.2)
Joint	112 (13.8)
Modified BG Prasad Classification 2024	
Upper Class	100 (12.3)
Upper Middle Class	488 (60.1)
Middle Class	152 (18.7)
Lower Middle Class	60 (7.4)
Lower Class	12 (1.5)
Anxiety levels	
Normal Range	232 (28.6)
Mild to moderate Anxiety levels	356 (43.8)
Marked to Severe Anxiety levels	208 (25.6)
Extreme Anxiety Levels	16 (2)
Depression levels	
Severely Depressed	96 (11.8)
Moderate Depressed	180 (22.2)
Mildly Depressed	188 (23.2)
Normal range	348 (42.9)

Table 2: Distribution of rural households according to Air Quality Indices (AQI) and various other AQI parameters

Variables	Participants (%)
Air Quality Index (AQI)	
Satisfactory	40 (4.9)
Moderate	580 (71.4)
Poor	192 (23.6)
Particulate Matter 10 (PM10)	
Moderate	772 (95.1)
Poor	36 (4.4)
Very Poor	4 (0.5)
Particulate Matter 2.5 (PM2.5)	
Good	80 (9.9)
Satisfactory	568 (70)
Moderate	144 (17.7)
Poor	16 (2)
Severe	4 (0.5)
Ozone (O3)	
Satisfactory	792 (97.5)
Moderate	16 (2)
Poor	4 (0.5)
Carbon monoxide (CO)	
Satisfactory	780 (96.1)
Moderate	32 (3.9)
Total Volatile Organic Compounds (TVOC)	
Good	428 (52.7)
Unhealthy	384 (47.3)
Carbon Di-oxide (CO2)	
Satisfactory	748 (92.1)
Moderate	52 (6.4)
Poor	8 (1)
Very poor	4 (0.5)

After multinomial logistic regression analysis, TVOC (Total Volatile Organic Compound) had higher odds 1.78(1.2-2.6) for having Mild to moderate anxiety with a statistically significant p value. (Table 4)

In regression analysis, Particulate matter 10 (PM10) had higher odds, i.e., 3.1 (1.3-7.5), of having severe depression, and this was statistically significant with a p-value less than 0.05. Carbon monoxide (CO) had higher odds, i.e., 14.5(4.3-50.0), for having severe depression, and this was statistically significant with a p-value less than 0.05. Carbon dioxide (CO2) had higher odds, i.e., 4.8 (2.3-9.9), for having severe depression, and this was statistically significant with a p-value less than 0.05. Carbon Dioxide (CO2) had higher odds, 2.6 (1.3-5.2), of experiencing moderate depression, and this was statistically significant with a p-value less than 0.05. Carbon monoxide (CO) had higher odds, i.e., 4.2 (1.2-14.8), of experiencing mild depression, and this was statistically significant with a p-value less than 0.05. Carbon dioxide (CO2) had higher odds of 2.9 (1.4-5.9) for having mild depression, which was statistically significant with a p-value less than 0.05. (Table 5)

The table 6 presents the Pearson correlation coefficients between anxiety and depression scores with different air quality parameters. Significant correlations are indicated with asterisks (*p <0.05, **p <0.01). Correlating anxiety scores with Air quality index parameters, PM10 showed a weak positive correlation (r = 0.122, p = 0.001), suggesting that higher PM10 levels are modestly associated with higher anxiety scores. PM 2.5 had no significant correlation with anxiety scores (r = -0.002, p = 0.959). O3 had a weak negative correlation with anxiety scores (r = -0.076, p = 0.030). CO had a significant positive correlation (r = 0.152, p = 0.0001), indicating that higher CO levels are associated with higher anxiety levels. TVOC had a weak positive correlation with anxiety scores. (r = 0.126, p = 0.000). CO2 had a weak positive correlation with anxiety scores (r = 0.121, p = 0.001). Correlating depression scores with Air quality index parameters, **PM10** had a weak positive correlation with depression scores (r =0.078, p = 0.027). **PM2.5** had no statistically significant correlation with depression scores (r = 0.058, p = 0.097). **O_3** had no significant correlation with depression scores (r = 0.010, p = 0.778). **CO** had a weak positive correlation with depression scores (r = -0.160, p = 0.000). **TVOC** had a weak positive correlation with depression scores (r = 0.120, p = 0.001) and **CO_2** had a stronger positive correlation compared to others with depression scores (r = 0.223, p = 0.0001), suggesting a more consistent association between higher CO_2 levels and increased depression scores.

Discussion

The present study was a cross-sectional study carried out for a period of two years, where rural households using solid forms of fuel for any reason were included. The air quality indicator of such rural households was estimated using high-quality and validated instruments. Mental health status, such as anxiety and depression, among residents of these households was assessed using standardized tools. Eight hundred twelve residents of such households participated in the study, out of which 208 (25.6%) belonged to the 31- to 40-year age group, 384 (47.3%) were male, the majority belonged to a nuclear family, and the majority were from the upper middle class according to the Modified BG Prasad Classification 2023. Mental health assessment of rural household study participants revealed 25.6% had marked to severe anxiety and 23.2% had mild depression. The AQI of rural households revealed that 192 (23.6%) were of poor standards.

Table 3: Association between mental health statuses and AQI

Mental health status	Air Quality Index (AQI)			P value#
	Satisfactory (n=40) (%)	Moderate (n=580) (%)	Poor (n=192) (%)	
Zung Anxiety Status				
Normal Range	12 (5.2)	168 (72.4)	52 (22.4)	**0.001**
Mild to moderate Anxiety levels	12 (3.4)	256 (71.9)	88 (24.7)	
Marked to Severe Anxiety levels	12 (5.8)	148 (71.2)	48 (23.1)	
Extreme Anxiety Levels	4 (25.0)	8 (50.0)	4 (25.0)	
Zung Depression Status				
Severely Depressed	8 (8.3)	76 (79.2)	12 (12.5)	**0.001**
Moderate Depressed	20 (11.1)	96 (53.3)	64 (35.6)	
Mildly Depressed	0 (0.0)	144 (76.6)	44 (23.4)	
Normal range	12 (3.4)	264 (75.9)	72 (20.7)	

#Chi-square test

Table 4: Multinomial Logistic regression analysis of various AQI factors with Anxiety levels

Anxiety Status	Beta coefficient	Std. Error	P Value	Odds ratio	95% Confidence Interval	
					Lower Bound	Upper Bound
Mild to moderate Anxiety levels						
Intercept	.869	.788	.270			
PM10	.278	.333	.404	1.321	.688	2.536
PM2.5	-.076	.180	.672	.926	.650	1.319
CO	-.935	.396	.018	.393	.181	.854
O3	-.510	.334	.127	.600	.312	1.156
AQI	.091	.220	.679	1.095	.712	1.685
TVOC	.587	.189	**.002**	**1.798**	1.243	2.603
CO2	-.086	.212	.686	.918	.606	1.391
Marked to Severe Anxiety levels						
Intercept	32.31	993.4	.974			
PM10	-.950	.572	.097	.387	.126	1.186
PM2.5	.062	.211	.769	1.064	.704	1.608
CO	-16.01	746.7	.983	1.108	.181	0.74
O3	-14.40	655.2	.982	5.535	.140	0.6
AQI	-.008	.248	.975	.992	.610	1.612
TVOC	.284	.210	.177	1.328	.880	2.006
CO2	-1.32	.504	.009	.266	.099	.714
Extreme Anxiety Levels						
Intercept	41.91	2555.	.987			
PM10	-14.21	1885.	.994	6.702	.000	.854
PM2.5	.112	.574	.846	1.118	.363	3.443
CO	-15.69	.000	0.45	1.52	1.5	2.8
O3	-14.66	1724.	.993	4.26	.004	1.20
AQI	-.627	.682	.357	.534	.140	2.032
TVOC	.575	.553	.299	1.777	.601	5.253
CO2	.363	.433	.402	1.438	.615	3.360

Table 5: Multinomial Logistic regression analysis of various AQI factors with Depression levels

Depression status	Beta coefficient	Std. Error	P value	Odds ratio	95% Confidence Interval	
					Lower Bound	Upper Bound
Severely Depressed						
Intercept	-4.760	1.200	0.001			
PM10	1.162	.438	**0.008**	**3.197**	1.35	7.54
PM2.5	-1.024	.271	0.001	.359	.211	.61
CO	2.678	.630	**0.001**	**14.562**	4.23	25.03
O3	.208	.571	0.716	1.231	.402	3.77
AQI	.082	.320	0.797	1.086	.580	2.03
TVOC	-.445	.274	0.105	.641	.374	1.09
CO2	1.585	.364	**0.001**	**4.881**	2.39	9.95
Moderate Depressed						
Intercept	-3.132	1.019	0.002			
PM10	.441	.417	0.290	1.554	.687	3.51
PM2.5	-.174	.198	0.378	.840	.570	1.23
CO	1.087	.641	0.090	2.966	.845	10.41
O3	-.267	.407	0.511	.766	.345	1.69
AQI	.350	.236	0.138	1.419	.89	2.25
TVOC	-.172	.199	0.386	.842	.57	1.24
CO2	.971	.356	**0.006**	**2.641**	1.31	5.31
Mildly Depressed						
Intercept	-4.225	1.015	0.000			
PM10	.364	.459	0.428	1.439	.58	3.54
PM2.5	-.650	.195	0.001	.522	.35	.765
CO	1.454	.634	**0.022**	**4.281**	1.23	14.81
O3	.371	.295	0.210	1.449	.812	2.58
AQI	.509	.227	**0.025**	**1.664**	1.06	2.59
TVOC	.302	.198	0.127	1.352	.918	1.99
CO2	1.086	.353	**0.002**	**2.964**	1.48	5.92

Table 6: Correlation between AQI with Anxiety and depression scores

	AQI PM10	AQI PM 2.5	AQI O3	AQI CO	AQI	AQI TVOC	AQI CO2
Anxiety scores							
Pearson Correlation	.122**	.002	-.076*	.152**	.022	.126**	.121**
Sig. (2-tailed)	**0.001**	0.959	**0.030**	**0.0001**	0.523	**0.0001**	**0.001**
Depression scores							
Pearson Correlation	.078*	.058	.010	.160**	.044	.120**	.223**
Sig. (2-tailed)	0.027	0.097	0.778	**0.0001**	.210	**0.001**	**0.0001**

	ZDS	ZAS	AQI
ZDS	1	0.63	0.029
ZAS	0.63	1	0.017
AQI	0.029	0.017	1

Figure 2: Here's the heat map showing the correlation between the variables Zung Depression Scale, Zung Anxiety Scale, and Air Quality Index. The values indicate how strongly each pair of variables is linearly related. A value close to **1** or **-1** means a strong relationship. A value close to **0** suggests a weak or no linear relationship.

External environmental factors, such as independent access to the street, being away from smoke nuisance, smell, traffic, and the breeding of flies, had a statistically significant association with AQI. Internal environment factors, such as the type of house, number of living rooms, ratio of window space to floor area, ratio of combined door-window space area, cross ventilation, and overcrowding, had a statistically significant association with AQI. Anxiety and depression mental health status had a statistically significant association with AQI. After multinomial logistic regression analysis, air quality factor TVOC (Total Volatile Organic compounds) had higher odds for having Mild to moderate anxiety, and PM10, CO, and CO2 air quality factors had higher odds for severe depression, air quality factor CO2 for Moderate depression, and air quality factors CO and CO2 for Mild depression.

There is good evidence from human and animal studies that exposure to air quality impurities induces oxidative stress, which is neurotoxic and associated with structural brain changes. This also influences stress hormone production, altering mental health equilibrium. Neuroinflammation induced by air impurities appears to play an essential role in both depression and psychosis in mental health. However, once neurotoxicity is established and permanent changes in brain structure happen, there would likely be chronic effects, mainly when exposures occur in early life and adolescence.[16] Inflammation of neurons because of oxidative and nitrosative stress has been hypothesized as a potential mediating pathway for depression, including psychosocial stressors, physical inactivity, obesity, and lack of sleep.[17] It has been observed that exposure to these harmful chemicals can also disrupt the HPA axis which regulates the body's stress responses through the production of hormones such as cortisol has emerged as a potentially crucial etiological factor in anxiety and depression.[18] Studies have found that PM 2.5-exposed mice displayed more depressive-like responses and higher pro-inflammatory cytokines than mice exposed to filtered air. On histological examination, it was found to have ultrafine PM deposition, gliosis, and vascular pathology associated with neuro-inflammation, accelerating the evidence that it impacts mental health. A study has revealed that indoor air pollutants can decrease gray matter volume in the cortico-striato-thalamo-cortical neurocircuitry. Additionally, it found white matter hyper-intensities in the prefrontal lobe, which is also attributed to neuroinflammation and oxidative stress in the central nervous system, affecting the mental health of individuals and increasing the risk of depression and suicidality.[19] Supporting the possibility that PM exposure may act through this pathway, a robust association was reported between indoor air pollution exposure and participants' serum cortisol levels in Li H et al.'s randomized double-blind crossover trial using indoor air purifiers.[20]

Air pollution, a mixture of solid particles and gases in the air, is a well-known environmental hazard. There is also growing evidence showing adverse effects on cognitive function. Several studies support the findings of the present study. The present study showed PM10 had higher odds (3.19) among severely depressed. A cross sectional study done by Vert et al in Barcelona where estimation of PM2.5, PM2.5 absorbance (PM2.5 abs), PM10, PM coarse, NO_2 and NO_x showed that there is increased odds of self-reported history of depression disorders about long-term exposure to air pollution however associations regarding anxiety disorders did not reach statistical significance.[21] Review study done by Riva, Rebecchi, Capolongo, and Gola shows that housing conditions and indoor air quality can influence mental health issues like depression and anxiety. Overall mental health was worse when several parameters, including carbon dioxide, indoor air chemicals, outdoor ambient air, and organic solvent pollutants, exceeded specific concentrations. It was found that there were negative correlations with long-term exposure to air pollutants, such as nitrogen dioxide, mercury, manganese, organic solvents, and fine particulate matter (PM2.5), which may contain endotoxins, possibly leading to neurodegeneration and depression.[22] A systematic review and meta-analysis done by Braithwaite et al showed that there is a statistically significant association between long-term exposure to PM2.5, PM10 and anxiety and depression.[23] A study conducted by Xie, Yuan, and Zhang in China has revealed that information about worsening air quality has a direct impact on mental health, serving as a source of stressors and an indirect behavioral effect. Air quality also affects indoor physical activity and contributes to an increased mental health burden.[24] Systematic review done by Fan et al showed that short-term exposure to NO_2 was associated with an increased odds of depression; however, Long-term PM2.5, PM10, SO_2, and O_3 and NO_2 exposure was not associated with depression.[25] Systematic review done by Buoli M et al showed that PM levels were associated with worsening of mental health and also increased hospitalization rates among those who already have a mental illness, suggesting air pollutants had definitive roles in mental health.[26] Study done in China by Ao, Dong, and Kuo showed that both indoor and ambient air pollution have adverse effects on elderly mental health and depressive symptoms.[27] Study done by Khan et al in the United States of America, where sensitivity analysis for the association between air quality and bipolar disorder showed that regions with the highest air pollution and worst air quality had a strong association with depression, especially Bipolar disease, notably suggesting that air quality is the strongest environmental predictor of bipolar disorder. A multi-country longitudinal study conducted by Laurent et al. in the United States among office workers showed a significant association between PM $_{2.5}$ and the cognitive functions of individuals.[29] The present study showed that CO2 had higher odds for severely depressed (OR:4.8), moderately depressed (OR: 2.6) and Mild depression (OR:2.9). Meta-analysis done by Radua et al on impact of air pollution and climate change on mental health outcomes showed that associations concerning air pollution focused, in decreasing order of frequency, on PM2.5, airborne particular matter ≤10 μm in diameter (PM10), nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), carbon monoxide (CO), PM coarse, nitrogen oxides (NOx), solvents, pesticides, metals, solid fuels, diesel PM, polycyclic aromatic hydrocar bons, or multiple pollutants together. It also mentions that indoor air pollutants can be directly related to the exacerbation of postpartum depression, suicidality, and bipolar disorders.[30] One more meta-analysis done by Lin LZ et al suggested that there is acceptable and adequate evidence of linking particulate matter exposure with neurodevelopment disorders, suggesting indoor air pollutants exhibit neurotoxicity and cause mental health issues like postpartum depression, autism, and other neurodevelopment disorders.[31]

A cohort study by Wang R et al. showed that severe indoor pollution was associated with a 40% increased risk of depression (HR: 1.40, 95% CI: 1.07, 1.82) compared to living without indoor pollution.[32] A systematic review conducted by Lian et al. showed that Ozone exerts a short-term impact on depression in young populations. In contrast, delicate particulate matter (PM2.5) and NO_2 have a long-term effect.[33] Study done by Manczak EM et al among adolescents showed that exposure to ozone is a risk factor for negative mental health showing that adolescents who live in census tracts with relatively higher average ozone are at greater risk for experiencing trajectories of increasing depressive symptoms over time relative to teens who live in areas with lower levels of ozone.[34] These studies collectively establish a causal relationship between ambient air pollution and mental health issues, particularly with particulate matter.

The strengths of the present study are numerous. First, indoor air quality has been linked to mental health status. Although many research studies connect ambient air quality to mental health, very few focus on indoor air pollution and its impact on mental health. The second strength of the study is the use of validated instruments with high sensitivity and specificity to assess household indoor air quality standards. The study has some limitations. First, it only evaluated the recent air quality of households, without measuring previous or cumulative exposure, which could significantly influence causation. Second, the study cannot establish a temporal relationship, that is, cause (AQI) to effect (mental health status). More rigorous study designs, including multicenter trials, cohort studies, and longitudinal research, are needed to establish causation. The third limitation is that body sample analysis, such as urine, blood, or tissue samples, was not performed. Analyzing body accumulation of indoor air pollutants and their association with mental health issues would have strengthened causal inferences but was not done here. The fourth limitation is that inflammatory markers, such as serum cortisol levels, were not measured in this study. The final limitation is that the study does not account for many confounders, such as socioeconomic stress, lifestyle factors, smoking, occupational exposure, or psychological stressors, which can influence mental health issues like anxiety and depression. The present study recommends to avoid various factors related with Indoor air pollution like burning solid fuels at households, usage of improper devices for cooking. The rural households should also improve their housing conditions at these rural households. Regular cleaning and dust removal at houses and usage of indoor plants which can take carbon dioxide and release oxygen are advisable. Usage of exhaust fans and other ventilation devices can be instrumental at rural households as they are affordable and efficient. Health education to all households in the form of leaflets or pamphlets regarding various adverse health effects of Indoor air pollution can bring a healthy transformation.

CONCLUSION

The present study adds to the small but growing evidence indicating that exposure to indoor air pollution might be linked with an increased risk of developing mental health problems. The present study also integrates Housing standards and Indoor air quality. Exposure to air pollution is widespread among the rural population, who often use solid fuels as a primary source of energy at the household level. Reducing ambient air pollution may prevent a substantial number of mental health illnesses, especially in more polluted and densely populated rural areas. Trapped within the walls are the powerful neurotoxic substances like particulate PM $_{2.5}$, particles with an aerodynamic diameter ≤2.5 μm, PM $_{10}$ particles with an aerodynamic diameter ≤10 μm, and gaseous pollutants like nitrogen dioxide (NO_2), sulphur dioxide (SO_2), Ozone (O_3), and carbon monoxide (CO). The present study synthesizes evidence about indoor air pollution being a possible risk factor for mental health illness, which has been rarely studied. Modest research has shown that Outdoor air pollution has been related to various mental health illnesses; however, Indoor air pollution studies are very scant, and their relation to mental health is very meagre. The present study generates evidence on Indoor air pollution and its plausible mental health implications.

In conclusion, the present study suggests an association between AQI and mental health status; the exact relation between AQI and mental disorders still needs to be elucidated through better study designs. The present study adds to the growing evidence that air quality may have broader implications beyond physical health and could also impact mental well-being. More studies are needed, as the precise mechanisms regarding the relationship between exposure to air pollution and mental health illnesses remain unclear, with exact causation still uncertain. More efforts must be made to establish the pathophysiological and socio-psychological causation, suggesting that it is biologically plausible, especially in vulnerable populations.

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