RESEARCH ARTICLE

The impact of air quality index (AQI) and particulate matter 2.5 (PM) concentration on the incidence of stroke in Karachi, Pakistan: A bidirectional cohort study

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Abstract

Objective: To investigate the association between air pollution and the incidence of ischaemic and haemorrhagic strokes.

Method: The bidirectional cohort study was conducted at the Neurology Department of Liaquat National Hospital, Karachi, from August 10, 2022, to February 5, 2024, and comprised newly hospitalised patients who experienced an acute onset of stroke, including both ischaemic and haemorrhagic types. Precise documentation of stroke onset dates and times was done. Air pollutant data, specifically the Air Quality Index and particulate matter 2.5 concentrations, was sourced from the relevant Swiss website, which provides extensive real-time and historical air quality measurements. For each patient, air quality data was collected for the three days preceding the stroke onset. The association between stroke type and exposure variables was explored, and the odds of stroke occurrence in relation to particulate matter 2.5 exposure were worked out. Data was analysed using SPSS version 27.

Results: Of the 228 patients,149(65.4%) were males and 79(34.6%) were females. The overall mean age was 62.15±14.20 years. Stroke subtype and onset time had no significant association with air quality index readings or or with particulate matter 2.5 at days 1, 2 and 3 (p>0.05). Males exhibited a heightened propensity for experiencing ischaemic strokes compared to females (odds ratio: 1.179, p=0.606). Moreover, individuals afflicted with ischaemic heart disease demonstrated an elevated risk of suffering ischaemic strokes compared to those without the comorbidity (odds ratio: 2.986, p=0.051).

Conclusion: Short-term rise in air quality index readings and particulate matter 2.5 concentrations were found to have no association with the incidence of ischaemic and haemorrhagic strokes.

Keywords: Ischemic stroke, Haemorrhagic stroke, Air Quality Index, Particulate matter, Air pollution, Environmental exposure. (JPMA 76: 226; 2026) **DOI: https://doi.org/10.47391/JPMA.21691**

Introduction

Stroke is one of the leading causes of disability and the second leading cause of mortality worldwide.[1] According to the Global Burden of Disease Study 2019, there were approximately 12.2 million incident cases of stroke in 2019. The number of prevalent cases ranged from 93.2 million to 111 million, indicating a significant ongoing burden. The number of deaths due to stroke was around 6.55 million, and the disability-adjusted life years (DALYs) attributed to stroke were between 133 million and 153 million.[2,3]

Besides the traditional risk factors such as age, gender and family history, and modifiable risk factors, such as hypertension, hypercholesterolaemia and diabetes,[4] new modifiable elements, such as air pollution and specifically fine particulate matter (PM), are becoming a high-risk factor for stroke, further increasing the burden of disease.[5]

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Air pollution, on the other hand, is described as a combination of PM and several toxic gases in the atmosphere which differs from region to region. In an urban city, like Karachi, the main cause of air pollution stems from traffic and industry, and the most common particulates include carbon monoxide, black carbon, nitrogen oxides and sulfates.[6]

Atherosclerosis is not the only way air pollution affects blood vessels, there are many other underlying factors, like the particles in air pollution that disrupt the cardiovascular system and its homeostasis, resulting in altered blood supply to the heart and decreasing the heart rate. Both of these factors increase the risk of atrial fibrillation which is a major risk factor of ischaemic stroke. Similarly, this variation in blood pressure can contribute to the development of haemorrhagic strokes.[7]

The literature regarding air pollution and stroke incidence presents conflicting findings, suggesting a controversial aspect surrounding the association between these factors. A 2017 study in China stated that an increase in ambient air pollution, specifically the concentration of carbon monoxide (CO), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2), resulted in increased hospitalisation due to stroke,

and there were more cases of ischaemic stroke than haemorrhagic. There was no association found between haemorrhagic stroke and air pollutants.[8]

The underlying mechanism by which air pollution causes stroke stems from inflammation, endothelial dysfunction and artery calcification. The air pollutants activate platelets that cause blood coagulation, resulting in the formation of thrombus, while recent study shows that exposure to small PM has been linked to an increase in blood pressure and heart rate, resulting in altered haemodynamics and vascular dysfunction.[9] All these factors together increase the risk of atherosclerosis in large vessels, and can lead to the dislodging of the thrombus from its parent artery and the occluding of one of the main arteries that supply blood to the brain, resulting in ischaemic stroke.

A study in Taiwan, focussing on short-term pollutant exposure in Asia, revealed a significant association between air pollution and both ischaemic and haemorrhagic stroke types.[10] However, two other studies conducted in the same region did not find any such association.[11,12] Some investigations conducted on the mortality and hospital admission rates of acute stroke cases also produced inconsistent findings. For instance, a study in Shanghai demonstrated significant association of PM with diameter <10mm (PM10) and NO2 exposure with acute stroke mortality.[13] Conversely, a study in Hong Kong found no association between air pollution and cerebrovascular mortality.[14]

Similarly, two studies conducted in South Korea found that short-term exposure to air pollutants, such as PM10, NO_2, SO_2, CO and ozone (O_3), had significant association with both haemorrhagic and ischaemic stroke deaths, as well as stroke mortality.[15] Additionally, three studies conducted in Europe indicated that cerebrovascular admissions were significantly linked to short-term exposure to NO_2 and PM10.[16-18]

A 2021 study in Karachi showed that during the coronavirus disease-2019 (COVID-19) pandemic when there was a lockdown across the world, there was a significant improvement in the air quality and a major drop in hospitalisation of stroke patients in one of the largest tertiary hospitals in Pakistan.[19] However, that stusy had the limitation of relying on a single-centre dataset.

The current study was planned to investigate the association between air pollution and the incidence of ischaemic and haemorrhagic strokes. It was hypothesised that air pollutants may significantly impact acute stroke events.

Patients and Methods

The bidirectional cohort study was conducted at the Neurology Department of Liaquat National Hospital (LNH), Karachi, from August 10, 2022, to February 5, 2024. After approval from the institutional ethics review committee, the sample size was calculated using the Wan Nor Arifin calculator[20] with a prevalence of ischaemic stroke of 81.9%[21] and a margin of error 5%. The sample was collected through non-probability consecutive sampling. Those included in the sample were individuals of either gender having at least one year of residence in Karachi, and who had been diagnosed with stroke, both ischaemic and haemorrhagic, with a documented time of stroke onset. Those with pre-existing neurological disorders, such as arteriovenous (AV) malformations, aneurysms, chronic migraines, and brain tumours were excluded. Written informed consent was taken from all the participants.

Data was collected using a standardised questionnaire comprising three sections. The first section encompassed demographic details, including age, residence, smoking profile and medical history, including comorbidities. The second section featured questions concerning stroke, such as the type of stroke, time of onset, findings of magnetic resonance imaging (MRI) brain scan, and National Institute of Health Stroke Scale (NIHSS) score.[22] The final section of the questionnaire contained tables for recording the air quality index (AQI) of the preceding three days from stroke onset, a table recording PM 2.5 concentration from the onset of stroke up to three days thereafter. Meteorological data was gathered from the website of Swiss company IQAir, which features a locator tool that enables users to access air quality information for specific areas within a city,[23] including Karachi, utilising satellite-linked monitoring systems. The three days preceding the stroke onset were labelled as lag 1, lag 2 and lag 3.

Data was analysed using SPSS version 27. Results were expressed as frequencies and percentages, or as mean ± standard deviation, as appropriate. Mean values were compared using an independent t-test. Chi-square/Fisher exact test was applied to check associations between variables, whereas odds ratios (ORs) and 95% confidence interval (CI) were calculated using binary logistic regression. $P<0.05$ was considered significant.

Results

Of the 228 patients, 149 (65.4%) were males and 79 (34.6%) were females. The overall mean age was 62.15±14.20 years. Most of the subjects, 162 (62.7%), were aged >60 years, 211 (92.5%) had lived in Karachi for their entire lives, and 71(31.1%) reported smoking cigarettes or using other tobacco products. Of the total, 27(11.8%) subjects reported

living or working near major sources of air pollution, 45(19.7%) experienced respiratory symptoms, 57(25%) had been hospitalised for medical conditions in the preceding year, 5.3% were familiar with the term 'Air Quality Index', or AQI, and 0.9% reported checking AQI levels before going outdoors. Mean time spent outdoors was 4.39±3.99 hours per day. Overall, 154(68.4%) subjects said they had observed changes in air quality in Karachi over the preceding year, noting increased pollution 85(54.5%), dust 54(34.6%) and smoke 16(10.3%).

Regarding stroke types, 172(75.4%) patients had ischaemic and 56(24.6%) had haemorrhagic strokes. The majority of strokes 136(75.4%) occurred during the daytime. Over three days, AQI data indicated predominantly unhealthy air quality. On day 1, 115(50.4%) of AQI readings were classified as Unhealthy, followed by 95(41.7%) as Moderate, 17(7.5%) as Very Unhealthy, and 0.4% as Good. The day 2, there was an increase in Unhealthy readings to 116(50.9%) and Moderate readings to 96(42.1%), with Very Unhealthy readings decreasing to 15(6.6%) and Good air quality remaining at 1(0.4%). On day 3, Unhealthy readings rose to 123(53.9%), Moderate decreased to 88(38.6%), Very Unhealthy slightly increased to 16(7.0%), and Good remained at 1(0.4%).

Among the participants, 188(82.5%) reported having pre-existing medical conditions, while 40(17.5%) reported none. Of those with medical conditions, the most prevalent was hypertension, 154(81.9%), followed by diabetes, 90(47.9%). Other conditions included ischaemic heart disease 38(20.2%), chronic kidney disease 3(1.6%), valvular heart disease 3(1.6%), prior stroke 2(1.1%), heart bypass surgery 2(1.1%), atrial fibrillation 2(1.1%), osteoarthritis 1(0.5%) and asthma 1(0.5%).

A significant association was found between stroke type and ischaemic heart disease (p<0.05). However, no significant associations were found with gender (95% CI: 0.630-2.207, *p*=0.606), age group (95% CI: 0.327-1.111, *p*=0.103), stroke occurrence time (95% CI: 0.687-2.325, *p*=0.451), tobacco use (95% CI: 0.940-3.901, *p*=0.071), living/working near major air pollution sources (95% CI: 0.216-1.178, *p*=0.109), prior respiratory symptoms (95% CI: 0.540-2.559, *p*=0.684), past hospitalisations (95% CI: 0.920-4.441, p=0.076), any pre-existing medical condition (95% CI: 0.772-3.417, p=0.199), diabetes (95% CI: 0.776-3.100, *p*=0.213), hypertension (95% CI: 0.260-1.763, p=0.423), chronic kidney disease (95% CI: 0.052-6.639, *p*=0.543), or AQI on day 1 (*p*=0.409), day 2 (*p*=0.934) and day 3 (*p*=0.837). Males were more likely than females to experience an ischemic stroke (OR: 1.179, *p*=0.606). Individuals aged <60 had a lower risk of ischaemic stroke compared to those aged >60 (OR: 0.602, *p*=0.105). Patients with ischaemic heart disease had a higher risk of ischaemic stroke compared to those without this comorbidity (95% CI: 0.996-8.957, OR: 2.986, *p*=0.051). Associations and ORs with stroke type were noted in detail (Tables 1-2).

No significant association was found between stroke occurrence time and gender (95% CI: 0.628-1.906, *p*=0.750), age group (95% CI: 0.403-1.198, *p*=0.189), stroke type (95% CI: 0.687-2.325, *p*=0.451), tobacco use (95% CI: 0.464-1.447, *p*=0.493), living/working near major air pollution sources (95% CI: 0.221-1.117, *p*=0.086), respiratory symptoms (95% CI: 0.523-1.981, *p*=0.957), past hospitalisations (95% CI:

Table-1: Association of risk factors and odds ratio (OR) for stroke type.

	Stroke Type			Un-Adjusted
	Ischaemic	Hemorrhagic	*p*-value	Odds Ratio (95% CI)
Stroke occurrence time				
Day	105(61)	31(55.4)	0.451	1.264(0.687-2.325)
Night	67(39)	25(44.6)		Ref
Use of cigarette/tobacco products				
Yes	59(34.3)	12(21.4)	0.071	1.914(0.940-3.901)
No	113(65.7)	44(78.6)		Ref
Live/work near major air pollution sources				
Yes	17(9.9)	10(17.9)	0.109	0.505(0.216-1.178)
No	155(90.1)	46(82.1)		Ref
Experienced any respiratory symptoms				
Yes	35(20.3)	10(17.9)	0.684	1.175(0.540-2.559)
No	137(79.7)	46(82.1)		Ref
Hospitalized for medical conditions in past				
Yes	48(27.9)	9(16.1)	0.076	2.022(0.920-4.441)
No	124(72.1)	47(83.9)		Ref
Have any pre-existing medical conditions				
Yes	145(84.3)	43(76.8)	0.199	1.624(0.772-3.417)
No	27(15.7)	13(23.2)		Ref

Chi-square/fisher exact test was applied; Binary logistic regression was applied; *p*-value<0.05, considered as significant; CI: Confidence interval.

Table-2: Association of air quality index (AQI) and odds ratio (OR) for stroke type.

Air Quality Index	Stroke Type			Un-Adjusted
	Ischaemic	Hemorrhagic	p-value	Odds Ratio (95% CI)
Day 1				
Good (0 to 50)	1(0.6)	0(0)	0.409	NA
Moderate (51 to 100)	73(42.4)	22(39.3)		2.323(0.791-6.820)
Unhealthy (101 to 200)	88(51.2)	27(48.2)		2.281(0.792-6.570)
Very unhealthy (201-300)	10(5.8)	7(12.5)		Ref
Day 2				
Good (0 to 50)	1(0.6)	0(0)	0.934	NA
Moderate (51 to 100)	73(42.4)	23(41.1)		0.793(0.206-3.058)
Unhealthy (101 to 200)	86(50)	30(53.6)		0.717(0.189-2.714)
Very unhealthy (201-300)	12(7)	3(5.4)		Ref
Day 3				
Good (0 to 50)	1(0.6)	0(0)	0.837	NA
Moderate (51 to 100)	66(38.4)	22(39.3)		1.364(0.427-4.359)
Unhealthy (101 to 200)	94(54.7)	29(51.8)		1.473(0.473-4.589)
Very unhealthy (201-300)	11(6.4)	5(8.9)		Ref

Chi-square/fisher exact test was applied; Binary logistic regression was applied; p-value<0.05, considered as significant; CI: Confidence interval.

0.450-1.513, *p*=0.533), pre-existing medical conditions (95% CI: 0.558-2.224, *p*=0.760), diabetes (95% CI: 0.721-2.329, *p*=0.387), hypertension (95% CI: 0.306-1.477, *p*=0.321), chronic kidney disease (95% CI: 0.119-14.971, *p*=1.000), and ischemic heart disease (95% CI: 0.643-2.854, *p*=0.423)

Table-3: Association of risk factors and odds ratio for stroke occurrence time.

	Time of stroke			Un-Adjusted
	Day	Night	*p*-value	Odds Ratio (95% CI)
Stroke Type				
Ischemic	105(77.2)	67(72.8)	0.451	1.264(0.687-2.325)
Hemorrhagic	31(22.8)	25(27.2)		Ref
Smoke cigarette				
Yes	40(29.4)	31(33.7)	0.493	0.820(0.464-1.447)
No	96(70.6)	61(66.3)		Ref
Live/work near major air pollution source				
Yes	12(8.8)	15(16.3)	0.086	0.497(0.221-1.117)
No	124(91.2)	77(83.7)		Ref
Experienced any respiratory symptoms				
Yes	27(19.9)	18(19.6)	0.957	1.018(0.523-1.981)
No	109(80.1)	74(80.4)		Ref
Hospitalized for medical conditions in past				
Yes	32(23.5)	25(27.2)	0.533	0.825(0.450-1.513)
No	104(76.5)	67(72.8)		Ref
Have any pre-existing medical condition				
Yes	113(83.1)	75(81.5)	0.760	1.114(0.558-2.224)
No	23(16.9)	17(18.5)		Ref

Chi-square/fisher exact test was applied; Binary logistic regression was applied; *p*-value<0.05, considered as significant; CI: Confidence interval.

Table-4: Association of air quality index (AQI) and odds ratio (OR) for stroke occurrence time.

Air Quality Index	Time of Stroke			Un-Adjusted
	Day	Night	*p*-value	Odds Ratio (95% CI)
Day 1				
Good (0 to 50)	1(0.7)	0(0)	0.722	NA
Moderate (51 to 100)	53(39)	42(45.7)		0.883(0.310-2.517)
Unhealthy (101 to 200)	72(52.9)	43(46.7)		1.172(0.415-3.307)
Very unhealthy (201-300)	10(7.4)	7(7.6)		Ref
Day 2				
Good (0 to 50)	1(0.7)	0(0)	1.000	NA
Moderate (51 to 100)	57(41.9)	39(42.4)		0.974(0.321-2.958)
Unhealthy (101 to 200)	69(50.7)	47(51.1)		0.979(0.327-2.933)
Very unhealthy (201-300)	9(6.6)	6(6.5)		Ref
Day 3				
Good (0 to 50)	1(0.7)	0(0)	0.921	NA
Moderate (51 to 100)	51(37.5)	37(40.2)		1.072(0.366-3.140)
Unhealthy (101 to 200)	75(55.1)	48(52.2)		1.215(0.424-3.480)
Very unhealthy (201-300)	9(6.6)	7(7.6)		Ref

Chi-square/fisher exact test was applied; Binary logistic regression was applied; *p*-value<0.05, considered as significant; CI: Confidence interval.

The AQI values on days 1, 2 and 3 were categorised in four ordinal levels. ORs for AQI categories were computed using Very Unhealthy as the reference. AQI on day 1 (*p*=0.772), day 2 (*p*=1.000) and day 3 (*p*=0.921) did not show significant association.

ORs across AQI levels ranged from ~0.88 to 1.21, all having wide CIs, suggesting insufficient evidence of a clear effect.

Males were more likely than females to experience a stroke during the daytime (OR: 1.094, p=0.750). Individuals aged <60 had a lower risk of daytime stroke compared to those aged >60 (OR: 0.695, *p*=0.190). Patients with ischemic heart disease had a higher risk of daytime stroke compared to those without (OR: 1.355, *p*=0.424). Associations and ORs with respect to stroke occurrence time were noted in detail (Tables 3-4).

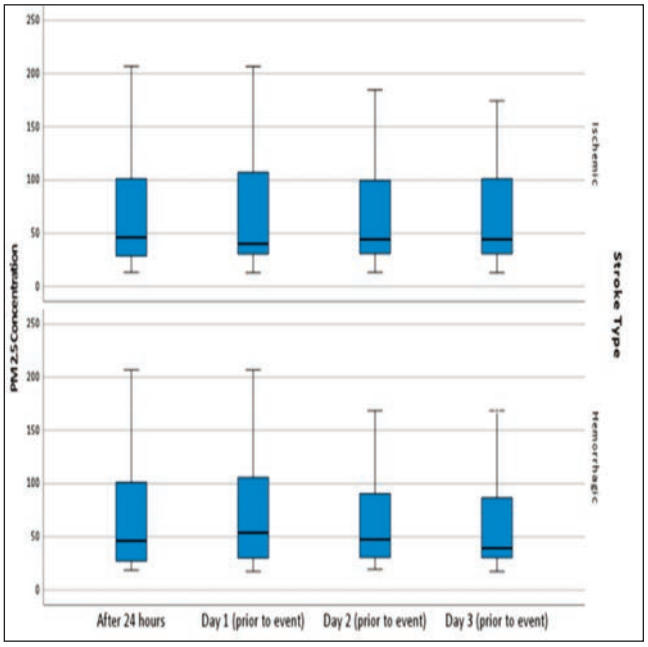

Figure-1: Particulate matter (PM) 2.5 concentration (microgram/cubic meter) at points of time frames according to stroke type in a box and whisker plot. *Right vertical axis: PM 2.5 concentration, Left vertical axis: Stroke type, Horizontal Axis: Time frames.*

Table-5: Comparison of particulate matter (PM) 2.5 concertation woth respect to stroke type and stroke occurrence time.

	PM 2.5 Concentration (mug/m³)			PM 2.5 Concentration (mug/m³)		
	Ischaemic	Hemorrhagic	*p*-value	Day	Night	*p*-value
At **24 Hours**	66.1±45.47	69.9±51.98	0.601	67.46±46.1	66.39±48.71	0.867
Day 1 (prior to event)	67.67±47.76	68.61±47.64	0.899	67.85±47.63	67.98±47.88	0.983
Day 2 (prior to event)	66.04±44.45	66.43±47.72	0.955	67.05±46.85	64.78±42.76	0.711
Day 3 (prior to event)	66.02±45.26	61.4±41.39	0.499	65.87±45.43	63.43±42.77	0.683

Independent t-test was applied. *p*-value<0.05, considered as significant

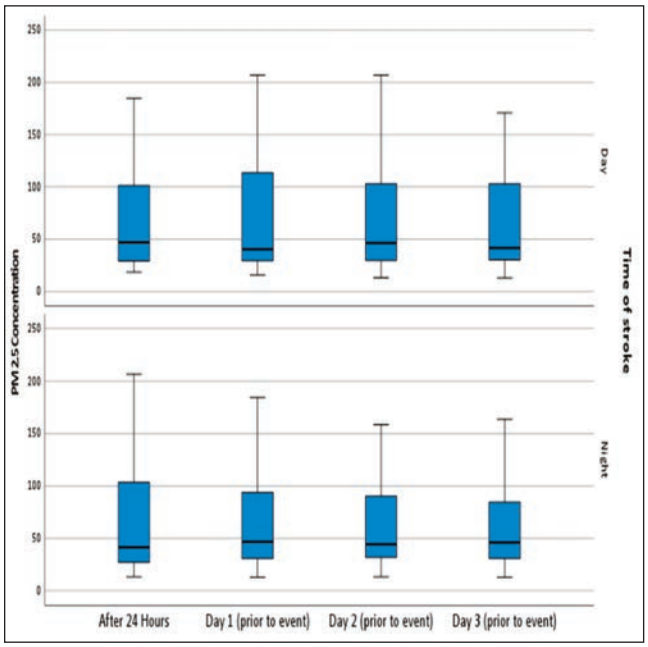

Figure-2: Particulate matter (PM) 2.5 concentration (microgram/cubic meter) at points of time frames according to stroke time (Day v/s Night) in a box and whisker plot. *Right vertical axis: PM 2.5 concentration, Left vertical axis: Stroke occurrence time, Horizontal axis: Time frames.*

No significant association was found between stroke type and time of onset with PM2.5 concentration days 1, 2 and 3 (p>0.05). Comparisons of PM 2.5 concentrations according to stroke type and stroke occurrence time were noted in detail (Table 5, Figures 1-2).

Discussion

The currentr study explored the relationship of AQI and PM 2.5 concentration with the incidence of stroke. Contrary to the null hypothesis, the study did not find a significant association between higher levels of AQI and PM 2.5 concentration with increased stroke incidence, suggesting that there might be other factors that played a more substantial role in stroke risk in the study population.

One study in the United States demonstrated a slight but significant 1.03% increase in ischaemic stroke admissions per interquartile range (IQR) increase in PM 10 concentration 1-2 days before stroke onset. Similarly, elevated stroke risks were observed for other pollutants, like NO_2, SO_2 and CO concentrations.[21]

However, studies in Europe and North America[22-24] did not validate such an association, akin to the present cohort. The variability in findings could stem from multiple factors, including differences in geographical locations, leading to varying median air pollution levels across studies. Additionally, the significance of short-term exposure effects may be influenced by variations in hourly or daily pollutant levels. However, the current study did not reveal significant fluctuations in pollutant levels throughout the three days.

In the current study, 75.4% of the cases presented with ischemic stroke, and 24.6% were diagnosed with haemorrhagic stroke. This predominance could be attributed to the higher incidence of risk factors, such as hypertension, diabetes and ischemic heart disease, which are well-established contributors to ischemic stroke. The association of stroke type with AQI showed that on day 1, ischemic stroke were predominantly observed in the Unhealthy air quality category (51.2%), while haemorrhagic strokes were also most common in this category (48.2%). Similar trends were observed on days 2 and 3. There was no significant differences in stroke type distribution across AQI categories for each day. This aligned with recent findings.[25]

The current study considered the impact of various effect modifiers on the incidence of stroke, such as gender, age and comorbidities. Specifically, males had higher odds of ischemic stroke than females though this was not significant. Age >60 years was also examined as a potential factor, along with the presence of ischemic heart disease. The presence of ischemic heart disease showed a higher OR, suggesting a higher risk of stroke in the studied population.

Across the three days, the current study observed no significant association between stroke timing and AQI categories. Furthermore, ORs for stroke timing between daytime and nighttime were consistently close to 1, indicating no significant differences in risk. These findings suggested that while air pollution may have varied through the day, it did not appear to exert a significant influence on the timing of stroke occurrences within the timeframe of the study.

Regarding the understanding and awareness of air quality, the majority of individuals 216(94.7%) had never heard of the term "Air Quality Index", but even then 156(68.4%) had noticed some fluctuations in the air quality. Generally, the prevailing belief is that the perception of air quality hinges on smell and visibility. However, while visibility can serve as a rough indicator of air quality, neither smell nor visibility consistently aligns with measured air quality.[26,27]

The current study has limitations related to exposure misclassification. The data was acquired from a webpage linked with satellite observations, presenting two primary challenges. Firstly, it amalgamates air pollutant concentrations for individuals regardless of whether they are at home or work, thus offering an overall estimate. Secondly, individual exposure is gauged using mean

concentrations. Consequently, a mean derived for a specific geographical area is utilised for individual exposure assessment, potentially leading to either an underestimation or overestimation of exposure levels. Another limitation is that the study only investigated the concentration of a single pollutant, which may have overlooked the combined effects of multiple pollutants commonly present in the environment. Another limitation involves the consideration of potential confounding factors and the necessity for appropriate adjustments through either multivariate regression analysis or propensity score matching.

For future studies, addressing exposure misclassification could involve the implementation of individual sensors for recording AQI level and PM concentration as well as self-reported questionnaires. Additionally, data collection from dedicated meteorological stations could enhance accuracy and reliability.

Conclusion

There was no significant association of short-term exposure to elevated AQI levels and PM 2.5 concentration with the incidence of both ischaemic and haemorrhagic strokes, or with the timing of stroke occurrences, whether during the day or night. There might have been other factors that played a more substantial role in stroke risk, highlighting the complexity of stroke aetiology across different environmental and temporal contexts.

Disclaimer: Preliminary data was presented at the Annual Stroke Conference held in Islamabad, Pakistan, in August 2023.

Conflict of Interest: None.

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