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Spatio-temporal trends in deaths due to cardiovascular diseases attributable to air pollution in India and its states: evidence from the Global Burden of Disease study 2019

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Evidence in Context

• Analyzes trends in CVD deaths from air pollution in India (1990-2019). • Uses Global Burden of Disease data and advanced statistical methods. • Finds increasing deaths from ambient pollution, decreasing from household pollution. • Highlights significant regional disparities in CVD impact across Indian states. • Emphasizes region-specific air quality management for better public health.

To view Article

Abstract

Background: Cardiovascular disease (CVD) is the predominant cause of global mortality, has been growingly linked to air pollution, which paradoxically aligns with economic growth. This study aims to examine the trends and patterns in CVD mortality caused by air pollution.

Methods: This study uses data from the State-Level Disease Burden Initiative in India, from 1990 to 2019. Age-standardized death rates were examined through the application of joinpoint regression analysis, while the impact of air pollution on CVD mortality was assessed by estimating the combined effects of age, period, and cohort using age-period-cohort (APC) analysis.

Results: Relative risks are notably low across genders at younger ages, with males at 0.09 (95% CI: 0.08-0.10) and females at 0.11 (95% CI: 0.10-0.12) at 25-29 years, which increases with age, with individuals aged 85-95 years facing the highest risk. Period effect shows that the risk of deaths due to air pollution increased in 2015-19 compared to 2000-04. Deaths attributable to ambient particulate matter pollution exhibit a net increasing trend with an average annual percent change (AAPC) of 1.13 (95% CI 0.98-1.3). Deaths from household air pollution consistently show a significant downward trend, with an AAPC of -3.62 (95% CI -3.79 to -3.4).

Conclusion: Enhanced and region-specific air quality management strategies, including ambient and household air pollution controls, can provide substantial public health benefits and aid in the country's economic advancement.

Keywords: *global burden of disease study, GBD, air pollution, cardiovascular disease, age-period-cohort, joinpoint regression, India*

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Introduction

Cardiovascular diseases (CVDs) stand as the predominant cause of global deaths, with approximately 17.9 million deaths in 2019, which accounted for 32% of all worldwide deaths [1]. Of all cardiovascular diseases, 85% of the deaths were due to stroke and heart attack [1]. The burden of CVD worldwide is increasingly linked to environmental exposures [2]. The global health landscape has been increasingly marred by the nexus of air pollution and CVD, a duo responsible for a significant burden of morbidity and mortality across diverse regions. In the year 2020, it was observed that household air pollution (HAP) had associations with an estimated 3.2 million fatalities on an annual basis [3]. The combined impact of outdoor and HAP contributes to around 6.7 million premature deaths yearly [3]. According to a study, air pollution accounted for 8·0 percent of all Disability-Adjusted Life Years (DALYs) in 2021, making it the primary cause of disease worldwide [4]. Exposure to various diseases in individuals is commonly attributed to air pollution [5] which is considered a predominant environmental risk factor. Particulate matter (PM2.5) and HAP, primarily from the combustion of biomass fuels, have been identified as critical environmental determinants of elevated blood pressure and IHD, leading to a surge in global CVD deaths.

In the year 2019, air pollution accounted for 18% of the total number of fatalities within the geographical region of India [6]. Although India has experienced a decline in the death rate attributable to HAP, the death rate from outdoor air pollution has increased during 1990-2019 by 115%. Moreover, premature deaths and morbidity from air pollution resulted in an economic loss of about 14% of the GDP [6]. In India, open burning of dumped waste has been evidenced as a potential source of atmospheric pollution of gaseous and particle bound organic toxicants [7,8]. The primary contributors to outdoor particulate matter pollution in India include the burning of biomass in homes and businesses, dust carried by the wind, combustion of coal for power production, emissions from industries, burning of crop residues in agriculture, incineration of waste, construction work, operation of brick-making furnaces, emissions from transportation, and the use of diesel-powered generators [9,10]. Furthermore, the primary factor contributing to indoor air pollution is the use of solid fuels for cooking activities [11,12]. In India, the interconnection between air pollution and CVD emerges with stark clarity against the backdrop of its escalating cardiovascular disease epidemic. Studies have emphasized the association between personal exposure to pollutants like PM2.5 and CO with increased blood pressure among pregnant women and a broader CVD risk among the general population [10,13]. The situation is exacerbated by socio-economic development, where economic growth paradoxically aligns with increased CVD burden, possibly due to heightened exposure to air pollution from vehicular emissions and industrial activities [14]. This complex scenario presents a unique challenge for India, distinguishing its experience from global patterns and underscoring the need for targeted research and policy interventions.

Previous studies have underscored the pervasive impact of air pollution on cardiovascular health, highlighting an elevated risk across various cohorts from resource-poor settings in Guatemala, Peru, India, and Rwanda to the Eastern Mediterranean Region (EMR) [15,16]. Exposure to HAP and ambient particulate matter, particularly PM2.5 and black carbon, has been linked to increased blood pressure in pregnant women, a known risk factor for cardiovascular diseases [10]. Furthermore, long-term exposure to HAP has been associated with a rise in ischemic heart disease (IHD) mortality, emphasizing the adverse effects of air pollution on health [17]. A body of evidence underscores the critical impact of air pollution on cardiovascular health through mechanisms such as oxidative stress, inflammation, atherosclerosis, and vascular dysfunction, leading to an array of cardiovascular issues, including heart disease, stroke, and arrhythmias [18]. This global perspective is essential for understanding the profound implications of air pollution on CVD, necessitating a nuanced exploration of specific regional contexts to tailor public health interventions effectively.

India faces a unique challenge with a high ambient and HAP burden due to its reliance on solid fuels for cooking, industrial emissions, vehicular pollution, and agricultural burning. These factors contribute significantly to the national health burden, especially cardiovascular diseases. The rationale for focusing on the trends and patterns in deaths due to CVD attributable to air pollution, especially within the Indian context, stems from a critical gap in the existing literature and the urgent need to understand the evolving dynamics of this public health issue. Despite global awareness, the specific impact of air pollution on CVD in India requires further elucidation, Particularly considering the country's rapid urbanization, industrialization, and unique socio-economic landscape. Examining these trends can help us identify the age, period, and cohort effects of air pollution on health, assess the effectiveness of interventions over time, and understand the impact of economic development on air quality and public health.

Methods

Data Source

Data from India's State-Level Disease Burden Initiative was used in this analysis. which is a part of the Global Burden of Disease (GBD) Study. This gives information on the burden of 333 illnesses, injuries, and risk factors for each state in India from 1990 to 2019. In this investigation, we used information on air pollution-related mortality from cardiovascular disease, namely household and ambient air pollution, from a publicly accessible web link (https://vizhub.healthdata.org/gbd-compare/india#0). The current study used the 2019 database to methodically summarise and examine changes in CVD deaths attributable to air pollution in India between 1990 and 2019.

Statistical Analysis

Changes in Age Standardized Death Rates of cardiovascular disease attributable to ambient and household air pollution were calculated using joinpoint regression analysis [19]. The model provides the average percentage change (APC) and average annual percentage change (AAPC), where APC indicates the rate of change between two joinpoints and AAPC represents the overall rate of change. The estimated APC in each segment is averaged geometrically to get the AAPC, with the segment lengths acting as weights [20]. Intrinsic Estimator (IE) method was used to estimate the net age, period, and cohort effects on CVD deaths due to air pollution from observed age-specific death rates [21,22]. The degree of model fitting was evaluated using deviation, Akaike's information criterion (AIC), and the Bayesian information criterion (BIC). Standard error (SE) coefficients and risk ratios were calculated.

Results

Table 1 illustrates India's state-wise CVD burden for 2019, capturing incidence, mortality, and DALYs alongside age-standardized rates for these indicators. The data reveal substantial variability across different states, underscoring the country's heterogeneous nature of CVD impact. Uttar Pradesh and Maharashtra bear the brunt of the CVD epidemic, with the highest recorded incidences (1,230,923.77 and 891,281.63, respectively) and mortalities (328,687.54 and 276,151.82, respectively). In contrast, smaller states like Sikkim report much lower figures (3,971.77 incidences and 781.14 deaths), highlighting regional disparities in health outcomes. States with high DALYs, such as Uttar Pradesh (8,853,294.35) and Maharashtra (6,567,292.73), reflect not only high mortality but also significant morbidity, suggesting widespread and severe impact of CVD. States like Punjab, Tamil Nadu, and Karnataka exhibit high age-standardized mortality rates. For instance, Punjab shows the highest age-standardized incidence rate (833.91 per 100,000) and mortality rate (306.85 per 100,000), suggesting a disproportionately higher CVD burden relative to its demographic profile. Northeastern States like Mizoram and Nagaland have some of the lowest absolute numbers. Still, when standardized for age, the metrics tell a different story, with relatively higher morbidity and mortality rates than expected. Despite having better overall health indicators nationally, Southern States like Kerala and Andhra Pradesh show considerable CVD burden in absolute and age-standardized terms.

Table 1: State-wise deaths due to cardiovascular disease attributable to air pollution in Indian states incidence, mortality, and DALYs in 2019

	Incidence (95% UI)	Mortality (95% UI)	DALYs (95% UI)	Age-standardized incidence rate (95% UI)	Age-standardized mortality rate (95% UI)	Age-standardized DALY rate (95% UI)
Jammu & Kashmir and Ladakh	78859.81(72520.37-85278.15)	24179.89(20663.9-28904.31)	593200.05(502580.5-701151.51)	757.61(694-824.74)	265.87(228.15-317.94)	5625.02(4779.46-6661)

Arunachal Pradesh	6674.02(6130.48-7221.95)	1281.36(1036.25-1618.59)	33780.48(27237.47-42941.84)	718.96(654.68-787.95)	180.57(147.26-222.85)	3703.89(3010.53-4638.16)
Uttarakhand	74394.44(67930.04-81018.09)	21504.53(17601.03-26662.26)	569060(462558.83-696216.74)	759.17(695.87-825.6)	252.99(213.09-317.02)	5683.66(4640.95-6968.91)
Himachal Pradesh	56727.82(51629.88-61820.06)	14985.44(12343.56-18699.21)	360212.44(296232.92-440072.81)	743.58(679.49-810.73)	213.87(176.83-265.56)	4637.88(3838.8-5665.24)
Other Union Territories	23176.12(21118.77-25305.11)	6715.52(5361.94-8197.34)	161820.39(128776.84-200607.26)	729.33(664.61-799.88)	257.3(208.44-309.98)	5119.58(4111.59-6248.05)
Andhra Pradesh	445964.66(411654.23-482745.48)	130491.12(103324.43-159663.6)	3069169.48(2423369.56-3776770.6)	817.03(755.32-882.93)	259.5(206.83-316.24)	5580.73(4420.43-6852.02)
Assam	192673.12(178076.64-207861.59)	55927.11(46914.89-65685.83)	1549069.03(1306081.14-1821689.62)	764.05(704.92-825.04)	263.05(221.64-306.89)	5959.98(5047.35-7006.16)
Delhi	108418.73(99234.84-118090.24)	28696.43(24408.28-33194.98)	717087.11(606822.32-834333.24)	712.57(652.98-774.53)	236.46(203.19-271.93)	4720.21(4041.94-5439.91)
Goa	12355.58(11248.98-13580.19)	3968.9(3123.81-4808.16)	85004.09(66376.68-104397.93)	707.47(647.6-774.14)	255.8(203.04-306.92)	4898.79(3860.77-5969.42)
Haryana	181854.82(167202.65-196605.68)	50620.93(42201.83-59994.11)	1336733.99(1121631-1569854.42)	752.76(689.47-816.84)	224.45(187.61-265.64)	5307.73(4452.16-6234.77)
Karnataka	494366.58(456109.64-534476.81)	170633.51(141699.83-202245.67)	4319326.85(3564430.41-5119153.88)	799.31(736.62-864.91)	294.17(245.88-349.03)	6760.31(5617.51-7999.59)
Kerala	353482.28(324051.15-383604.96)	102233.7(83794.61-120417.96)	2125351.87(1755809.25-2504541.34)	790.21(728.71-853.58)	239.41(197.25-281.43)	4759.24(3945.49-5586.01)
Maharashtra	891281.63(820375.03-962098.47)	276151.82(225085.73-327818.06)	6567292.73(5391583.36-7804760.18)	760.82(700.66-821.25)	255.34(210.17-301.85)	5528.57(4538.99-6549.85)
Manipur	19937.45(18300.27-21714.12)	5058.38(4028.17-6042.59)	127340.61(101021.86-155711.32)	757.48(693.97-824.42)	235.77(191.41-278.28)	4876.18(3927.16-5857.4)
Meghalaya	14546.61(13365.89-15818.6)	2841.74(2327.17-3547.17)	72096.87(58803.28-90763.48)	733.75(668.96-802.46)	186.66(152.48-226.58)	3774.42(3120.15-4700.66)
Mizoram	5596.53(5108.96-6125.47)	714.35(538.37-1256.1)	18170.58(13880.99-31620.52)	632.62(574.85-693.39)	103.16(79.45-173.37)	2082.36(1604.68-3529.37)
Nagaland	9464.72(8711.76-10262.26)	2451.72(1939.81-2989.17)	57094.71(44534.16-70829.49)	775.85(709.77-847.77)	238.42(192.36-289.24)	4736.97(3734.25-5820.31)
Odisha	306760.98(281553.11-333030.73)	76975.93(61827.12-95717.37)	1951266.9(1599619.16-2404123.97)	716.99(660.33-775.08)	206.31(164.82-254.43)	4522.91(3707.76-5570.27)
Punjab	255734.72(234716.5-277136.85)	88809.6(71639.14-103560.87)	2256710.58(1831948.52-2650765.88)	833.91(767.02-901.87)	306.85(250.05-355.25)	7162.17(5837.08-8386.74)
Rajasthan	430184.37(396767.35-465627.17)	100596.96(80815.6-136175.5)	2796977.51(2278654.04-3584901.84)	731.75(674.82-790.12)	195.14(156.71-267.97)	4624.12(3764.28-5984.94)
Sikkim	3971.77(3614.31-4352.63)	781.14(637.9-970.72)	19338.56(15491.5-24130.92)	768.46(698.22-841.81)	180.63(149.45-221.19)	3735.4(3026.97-4625.64)
Tamil Nadu	651933.7(597408.47-708017.22)	220384.38(177640.16-262074.53)	5388839.08(4321953.67-6416554.62)	814.71(747.5-883.74)	331.85(271.22-389.36)	6713.43(5464.1-7928.74)

Tripura	26860.31(24665.58-29104.52)	8345.57(6925.95-9978.79)	204195.64(166309.06-248524.16)	795.56(730.33-863.77)	283.46(237.21-335.79)	5976.69(4930.61-7203.19)
West Bengal	703807.68(651945.32-755953.71)	220217.77(179568.91-257862.23)	5373199.05(4395205.51-6305999.58)	782.38(724.65-840.68)	286.06(233.76-334.72)	5951.18(4873.82-6942.87)
Bihar	606758.97(560231.83-658639.68)	165213.26(137013.37-195297.55)	4277407.8(3570358.62-5040433.62)	726.27(670.72-785.86)	233.68(195.25-275.82)	5152.85(4307.4-6076.44)
Chhattisgarh	189447.55(175274.8-205185.77)	65044.07(54439.75-75849.16)	1721358.08(1441947.45-2018356.41)	780.41(721.25-843.28)	304.53(256.28-352.84)	6921.41(5825.95-8063.62)
Jharkhand	204002.5(187489.56-222536.26)	43685.78(37010.23-51043.02)	1068954.81(913819.61-1247721.83)	698.56(641.52-759.51)	176.81(149.02-205.77)	3728.24(3199.42-4309.64)
Madhya Pradesh	477932.43(440806.13-515050.07)	144634.96(120912.23-169870.97)	3771790.1(3161055.71-4430075.03)	721.42(665.6-776.84)	252.59(212.45-293.4)	5596.3(4703.95-6539.47)
Uttar Pradesh	1230923.77(1133763.91-1330644.35)	328687.54(274455.78-409006.32)	8853294.35(7448469.09-10806920.14)	729.13(672.25-785.64)	237.41(198.68-297.96)	5294.6(4444.03-6491.56)
Gujarat	442275.61(407130.13-480125.71)	138462.3(114188.95-164175.08)	3668583.18(3040361.63-4360658.33)	779.45(716.64-845.22)	281.85(233.56-333.39)	6250.66(5207.14-7395.46)
Telangana	246583.49(226625.73-267381.67)	74114.05(57083.57-95178.67)	1832743.54(1429142.85-2363869.3)	738.76(680.58-799.46)	274.59(215.04-347.38)	5522.11(4347.65-7026.1)

Table 2 delineates the changes in the proportion of CVD deaths attributable to different types of air pollution from 1990 to 2019 across Indian states, segmented into HAP and ambient particulate matter (PM) pollution. The data indicate a significant transition in the burden of CVD deaths from household air pollution to ambient PM pollution over three decades. States with traditionally lower access to clean fuels and technology, like Bihar (23.28%), Chhattisgarh (28.08%), and Odisha (26.76%), reported high percentages, reflecting the prevalent reliance on solid fuels which emit particulate matter. The influence of ambient air pollution was considerably lower in rural and less industrialized states such as Arunachal Pradesh (2.93%) and Mizoram (4.84%), while Delhi displayed markedly higher levels at 8.07%. Delhi, being more urbanized even in 1990, had a significantly lower contribution from household air pollution at 2.14%, indicative of earlier adoption of cleaner fuels in urban centers. By 2019, a noticeable decline in the percentage of CVD deaths attributable to household air pollution from solid fuels is observed across most states, with significant reductions in states like Delhi, where it plummeted to 0.13% from 2.14% in 1990. However, the mortality contribution from ambient particulate matter surged from 8.07% in 1990 to 27.74% in 2019, suggesting a drastic deterioration in air quality.

Table 2. The proportion of CVD deaths attributable to air pollution among Indian states in 1990 and 2019

	1990		2019	
	Household Air Pollution	Ambient air pollution	Household air pollution from solid fuels	Ambient particulate matter pollution
Jammu & Kashmir and Ladakh	21.13 (15.19-27.29)	8.07 (3.79-13.5)	7.03 (4.13-10.6)	19.49 (15.48-23.18)
Arunachal Pradesh	25.56 (20.42-31.3)	2.93 (0.96-6.17)	13.87 (10.14-17.58)	8.51 (5.44-11.57)
Uttarakhand	21.04 (14.4-27.63)	8.36 (3.75-14.47)	6.19 (3.42-9.73)	20.91 (17.01-24.62)
Himachal Pradesh	22.69 (16.74-28.63)	6.28 (2.77-11.28)	8.13 (4.57-12.76)	17.17 (12.89-21.29)
Andhra Pradesh	27.73 (22.02-34.62)	3.48 (1.2-7.31)	11.04 (7.71-14.97)	13.7 (10.23-17.29)
Assam	26.01 (20.47-31.83)	5.18 (2.08-9.57)	15.76 (11.67-20.19)	12.36 (8.58-15.88)
Delhi	2.14 (0.91-4.1)	25.85 (22.15-29.15)	0.13 (0.05-0.28)	27.74 (25.77-29.7)

Goa	15.63 (11.41-19.76)	9.34 (4.5-15.69)	1.81 (0.77-3.45)	19.12 (15.69-22.72)
Haryana	17.72 (11.17-24.75)	12.59 (6.94-18.92)	5.3 (3-8.35)	24.68 (21.43-27.71)
Karnataka	25.96 (20.98-31.37)	3.99 (1.49-8.03)	11.7 (8.02-15.83)	14.76 (11.14-18.34)
Kerala	22.72 (18.25-27.08)	5.27 (2.3-9.61)	6.57 (3.49-10.76)	15.41 (12.07-18.46)
Maharashtra	20.13 (15.24-25.68)	8.13 (3.75-13.39)	6.76 (4.14-9.88)	20.17 (16.9-23.09)
Manipur	22.09 (16.65-27.27)	6.63 (2.79-12.24)	10.11 (6.4-14.5)	15.57 (10.76-20.3)
Meghalaya	23.01 (18.14-28.37)	4.08 (1.67-7.89)	13.03 (9.47-17.16)	10.59 (7.24-13.74)
Mizoram	16.31 (12.25-20.59)	4.84 (2.03-8.82)	5.38 (3.26-7.9)	12.04 (9.45-15.07)
Nagaland	23.3 (17.66-28.61)	6.23 (2.63-11.18)	11.98 (7.82-16.75)	13.93 (9.74-17.78)
Odisha	26.76 (20.92-33.05)	4.04 (1.46-8.32)	14.39 (10.44-18.84)	12.97 (9.25-16.76)
Punjab	17.48 (11.53-23.62)	11.75 (6.23-17.61)	5.28 (2.93-8.49)	24.61 (21-27.7)
Rajasthan	23.54 (16.06-31.63)	6.96 (2.89-12.47)	11.23 (7.62-15.29)	17.42 (13.57-21.06)
Sikkim	20.87 (15.58-26.01)	5.65 (2.33-10.53)	6.69 (3.94-10.27)	16.79 (12.13-21.18)
Tamil Nadu	24.12 (19.43-29.34)	4.6 (1.87-8.71)	6.42 (3.77-9.7)	15.4 (12.3-18.48)
Tripura	26.52 (20.2-32.52)	5.76 (2.27-11.03)	12.59 (8.65-17.12)	15.88 (11.53-20.36)
West Bengal	23.75 (17.08-30.49)	8.63 (4.1-14.21)	11.66 (7.98-16.15)	18.9 (14.86-22.67)
Bihar	23.28 (15.79-31.32)	7.75 (3.09-14.09)	13.13 (8.85-18.43)	15.68(11.27-19.9)
Chhattisgarh	28.08 (21.87-34.72)	4.68 (1.8-9.34)	16.1 (11.71-21.1)	13.96 (9.99-18.41)
Jharkhand	25.54 (17.85-33.48)	5.97 (2.21-11.96)	12.99 (9.04-17.55)	14.44 (10.56-18.29)
Madhya Pradesh	24.81 (17.78-32.09)	6.84 (2.98-12.44)	12.96 (9.19-17.21)	16.19 (12.52-19.83)
Uttar Pradesh	20.3 (12.67-28.32)	9.51 (4.29-16.04)	8.82 (5.59-12.87)	19.44 (15.65-22.83)
Gujarat	17.4 (11.01-23.91)	12.11 (6.47-18.45)	6.05 (3.79-9.14)	22.51 (19.06-25.63)
Telangana	24.83 (19.38-31.1)	4.43 (1.65-8.76)	8.23 (5.65-11.48)	15.51 (12.46-18.55)

Similarly, HAP from solid fuels decreased in Delhi from 21.13% to 0.13%, reflecting changes in domestic energy use patterns. Delhi shows the most dramatic increase in CVD deaths attributable to Ambient Particulate Matter Pollution, soaring to 27.74% in 2019 from 8.07% in 1990, highlighting the severe impact of increased vehicular emissions, industrial activities, and urban congestion. States like Gujarat and Haryana also show a significant increased by 22.51% and 24.68%, respectively, correlating with their industrial growth and urban sprawl over the decades.

Table 3 offers an in-depth look at the sex-specific relative risks (RR) of CVD deaths attributable to air pollution, analyzed by age, period, and cohort effects. Relative risks are notably low across genders at younger ages, with males at 0.09 (95% CI: 0.08-0.10) and females at 0.11 (95% CI: 0.10-0.12) which increases with age, with individuals aged 85-95 years facing the highest risk (RR = 3.69; 95% CI 3.34-4.08 for total population), suggesting that older adults are particularly vulnerable to air pollution-related CVD outcomes. The analysis also highlights that females generally experience higher relative risks compared to males in older age groups. For instance, RR for females aged 85-89 is 4.03 (95% CI 3.71-4.37) versus males at 3.22 (95% CI 3.02-3.45).

In the early 90s (1990-94), there is relatively low risks at 0.85 (95% CI: 0.83-0.88) for the total population, however from 2005-09, the risk slightly increases to 1.01 (95% CI: 0.99-1.04) and more substantially by the latest period (2015-19) to 1.15 (95% CI: 1.12-1.17). Cohort effects reveal that earlier cohorts (1900-1924) experienced higher risks compared to later cohorts. Individuals born in 1900-04 had higher relative risk, i.e., RR: 3.06 (95% CI: 2.12-4.42), which dropped subsequently for individuals, and the 1985-89 cohort had the lowest risk of deaths from CVD attributable to air pollution 0.42 (95% CI: 0.37-0.47).

Table 3: Sex-specific relative risks of CVD death attributable to air pollutions in India due to age, period, and cohort effects

	Male	Female	Total
Age	RR (95% CI)	RR (95% CI)	RR (95% CI)
25-29	0.09*** [0.08-0.1]	0.11*** [0.1-0.12]	0.1*** [0.09-0.11]
30-34	0.17*** [0.16-0.18]	0.14*** [0.13-0.16]	0.16*** [0.15-0.17]
35-39	0.26*** [0.24-0.27]	0.19*** [0.17-0.21]	0.23*** [0.22-0.25]
40-44	0.39*** [0.37-0.41]	0.31*** [0.28-0.33]	0.36*** [0.34-0.38]

45-49	0.62*** [0.6-0.65]	0.49*** [0.46-0.53]	0.58*** [0.55-0.6]
50-54	0.94*** [0.91-0.98]	0.77*** [0.73-0.82]	0.88*** [0.85-0.91]
55-59	1.32*** [1.28-1.37]	1.19*** [1.13-1.26]	1.27*** [1.23-1.31]
60-64	1.69*** [1.64-1.75]	1.73*** [1.65-1.81]	1.69*** [1.64-1.75]
65-69	2.12*** [2.05-2.19]	2.32*** [2.21-2.42]	2.17*** [2.11-2.24]
70-74	2.44*** [2.36-2.53]	2.82*** [2.69-2.96]	2.56*** [2.48-2.65]
75-79	2.83*** [2.71-2.95]	3.49*** [3.31-3.68]	3.05*** [2.94-3.17]
80-84	2.97*** [2.83-3.13]	3.72*** [3.5-3.97]	3.23*** [3.08-3.38]
85-89	3.22*** [3.02-3.45]	4.03*** [3.71-4.37]	3.5*** [3.29-3.71]
90-95	3.43*** [3.07-3.83]	4.2*** [3.68-4.8]	3.69*** [3.34-4.08]
Period			
1990-94	0.84*** [0.81-0.86]	0.86*** [0.83-0.9]	0.85*** [0.83-0.88]
1995-99	0.92*** [0.89-0.94]	0.94*** [0.91-0.97]	0.93*** [0.91-0.95]
2000-04	1 [0.97-1.02]	0.97** [0.93-1]	0.99 [0.96-1.01]
2005-09	1.03*** [1.01-1.05]	0.99 [0.96-1.03]	1.01 [0.99-1.04]
2010-14	1.12*** [1.1-1.15]	1.08*** [1.04-1.11]	1.1*** [1.08-1.12]
2015-19	1.13*** [1.1-1.16]	1.19*** [1.15-1.23]	1.15*** [1.12-1.17]
Cohort			
1900-04	2.88*** [1.93-4.31]	3.32*** [2.01-5.49]	3.06*** [2.12-4.42]
1905-09	2.6*** [2.19-3.1]	2.92*** [2.36-3.61]	2.73*** [2.33-3.19]
1910-14	2.26*** [2.02-2.54]	2.45*** [2.12-2.81]	2.33*** [2.1-2.58]
1915-19	2.03*** [1.86-2.22]	2.19*** [1.96-2.45]	2.09*** [1.92-2.26]
1920-24	1.77*** [1.64-1.91]	1.89*** [1.72-2.07]	1.81*** [1.69-1.94]
1925-29	1.54*** [1.44-1.64]	1.61*** [1.48-1.74]	1.56*** [1.47-1.66]
1930-34	1.35*** [1.27-1.43]	1.37*** [1.27-1.48]	1.35*** [1.28-1.43]
1935-39	1.19*** [1.13-1.25]	1.21*** [1.13-1.3]	1.19*** [1.13-1.25]
1940-44	1.01 [0.97-1.07]	1.03 [0.96-1.1]	1.01 [0.97-1.06]
1945-49	0.91*** [0.87-0.96]	0.93** [0.87-1]	0.92*** [0.88-0.96]
1950-54	0.79*** [0.75-0.82]	0.8*** [0.75-0.86]	0.79*** [0.76-0.83]
1955-59	0.74*** [0.71-0.78]	0.73*** [0.68-0.78]	0.74*** [0.71-0.77]
1960-64	0.71*** [0.68-0.75]	0.69*** [0.65-0.75]	0.71*** [0.67-0.74]
1965-69	0.66*** [0.63-0.69]	0.7*** [0.65-0.76]	0.67*** [0.64-0.7]
1970-74	0.61*** [0.58-0.65]	0.58*** [0.53-0.63]	0.6*** [0.57-0.63]
1975-79	0.57*** [0.53-0.61]	0.55*** [0.49-0.61]	0.56*** [0.52-0.6]
1980-84	0.5*** [0.47-0.55]	0.44*** [0.38-0.5]	0.48*** [0.44-0.53]
1985-89	0.45*** [0.4-0.5]	0.36*** [0.3-0.43]	0.42*** [0.37-0.47]
1990-94	0.33*** [0.27-0.42]	0.28*** [0.2-0.38]	0.31*** [0.25-0.39]
Deviance	11463.05	15003.16	17632.44
AIC	150.49	192.17	224.43
BIC	11250.37	14790.48	17419.76

RR denotes the relative risk of CVD death attributable to a particular age, period, or birth cohort relative to the average level of all ages, periods, or birth cohorts combined. CI, confidence interval; AIC, Akaike Information Criterion; BIC, Bayesian Information Criterion. Age-standardised Death rates (Per 100,000 population)

Table 4 displays the trends in age-standardized CVD mortality rates and DALYs attributable to various sources of air pollution from 1990 to 2019, as determined by Joinpoint Regression Analysis. The AAPC of 1.13 indicates a net increasing trend in deaths linked to ambient PM pollution (95 percent CI 0.98-1.3). By comparison, deaths attributable to solid fuel-related home air pollution have been steadily declining, with an AAPC of -3.62. (95 percent CI -3.79 to -3.4). Most recently, there has been a decrease in the APC of air pollution-related deaths across all categories. DALYs linked to ambient particulate matter pollution have AAPC of 2.27 and show a net increasing trend (95 percent CI 2.15-2.38). On the other hand, with an AAPC of -3.71, the number of deaths associated with indoor air pollution from solid fuels continuously exhibits a notable decrease

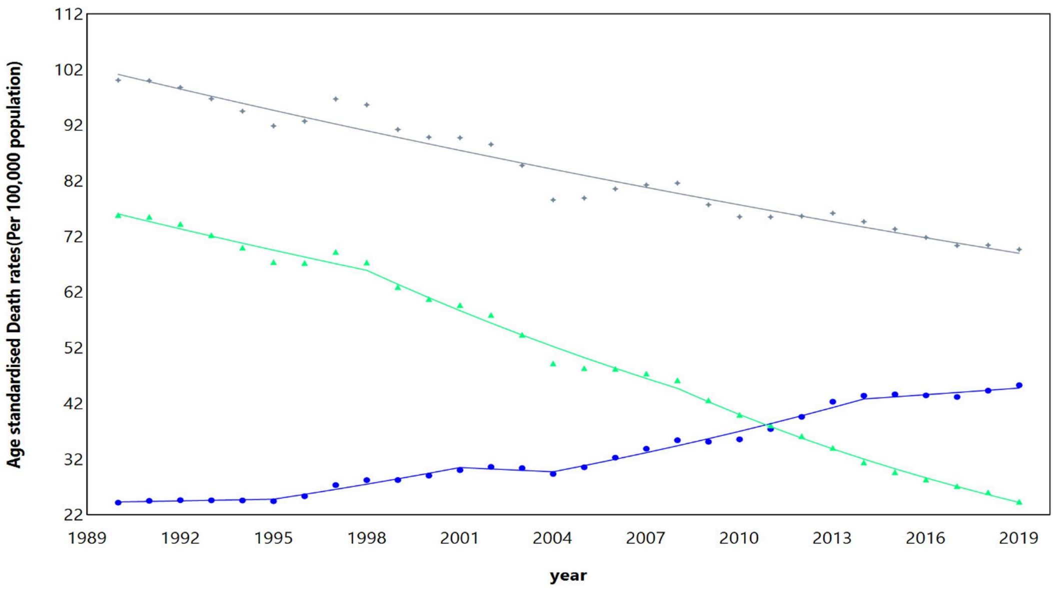
Trend (95 percent CI -3.83 to -3.59). The graph obtained from joinpont regression analysis has been shown in **Figure 1**.

Table 4: Trends in Age-Standardized death rates due to Cardiovascular disease attributable to air pollution in India from 1990 to 2019 using Joinpoint Regression Analysis

Death rates	Segment	Lower Endpoint	Upper Endpoint	APC	Lower CI	Upper CI
Ambient particulate matter pollution - 3 Joinpoints	1	1990	1995	-0.77	-3.77	0.68
	2	1995	2001	2.24*	0.92	4.97
	3	2001	2004	-1.9	-3.15	2.05
	4	2004	2019	1.95*	1.59	2.47
Household air pollution from solid fuels - 2 Joinpoints	1	1990	1998	-1.92*	-2.76	-0.34
	2	1998	2008	-3.71*	-4.26	-2.04
	3	2008	2019	-4.75*	-6.52	-4.34
Particulate matter pollution - 2 Joinpoints	1	1990	2001	-1.21	-1.76	0.28
	2	2001	2004	-3.80*	-4.87	-0.08
	3	2004	2019	-0.94	-2.01	0.14
				AAPC		
Ambient particulate matter pollution	Full	1990	2019	1.13*	0.98	1.3
Household air pollution from solid fuels	Full	1990	2019	-3.62*	-3.79	-3.44
Particulate matter pollution	Full	1990	2019	-1.34*	-1.51	-1.14
Disability Adjusted Life Years (DALYs)				APC		
Ambient particulate matter pollution - 4 Joinpoints	1	1990	1995	0.27	-1.49	1.01
	2	1995	1998	5.04*	3.23	6.08
	3	1998	2005	1.06	-0.11	1.5
	4	2005	2013	4.47*	4	5.32
	5	2013	2019	1.12*	0.32	1.73
Household air pollution from solid fuels - 3 Joinpoints	1	1990	1998	-1.57*	-2.14	-0.85
	2	1998	2005	-4.45*	-6.33	-3.69
	3	2005	2008	-1.26*	-3.6	-0.16
	4	2008	2019	-5.42*	-5.84	-5.09
Particulate matter pollution - 4 Joinpoints	1	1990	1995	-1.68*	-3.33	-0.97
	2	1995	1998	1.1	-0.53	2

	3	1998	2005	-2.78*	-3.64	-2.34
	4	2005	2008	1.5	-0.29	2.25
	5	2008	2019	-1.13*	-1.46	-0.91
				AAPC		
Ambient particulate matter pollution	Full	1990	2019	2.27*	2.15	2.38
Household air pollution from solid fuels	Full	1990	2019	-3.71*	-3.83	-3.59
Particulate matter pollution	Full	1990	2019	-1.13*	-1.23	-1.04

(A)



(B)

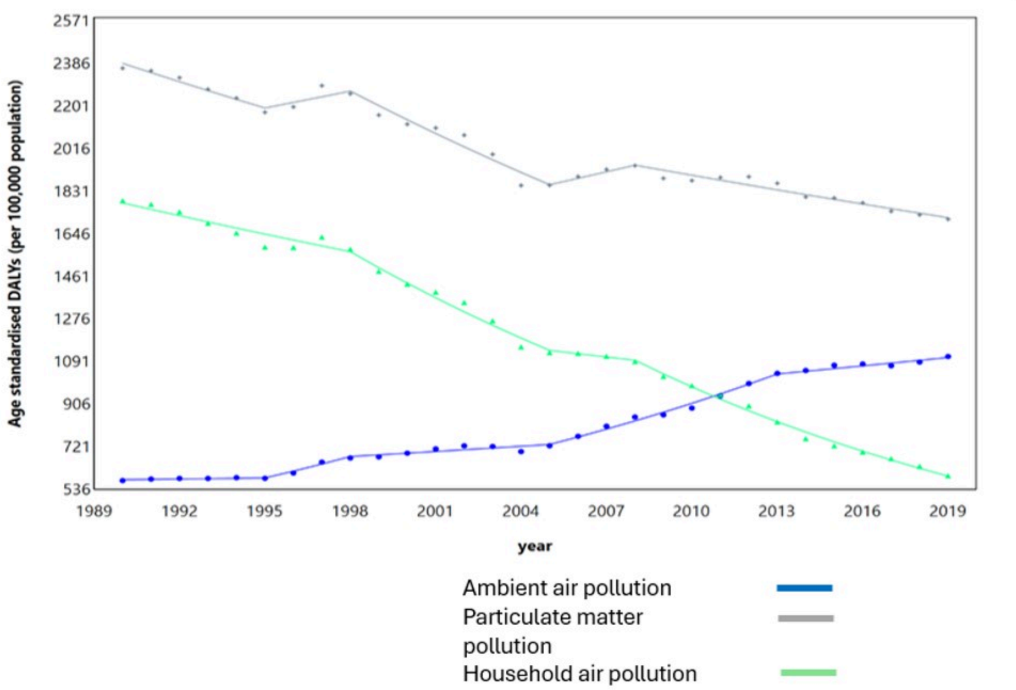


Figure 1: Trends in Age-Standardized rates due to Cardiovascular disease attributable to air pollution (a) Death rates (b) and DALYs in India from 1990 to 2019 using Joinpoint Regression Analysis

Figure 2 displays the ranks of age-standardized CVD death rates attributable to air pollution per 100,000 population for all ages across various states in India, comparing the years 1990 and 2019. States such as Delhi, Telangana, Andhra Pradesh, and Kerala have moved from lower levels of ASDRs to higher levels of ASDRs due to CVD attributable to air pollution. On the other hand, Mizoram, which had the lowest death rate in 1990 (ranked 1st), still maintains the lowest death rate in 2019. However, Uttar Pradesh, Haryana, Bihar, Jammu Kashmir, and Uttarakhand have recorded a steep decline in ASDRs due to CVD deaths attributable to air pollution from 1990-2019.

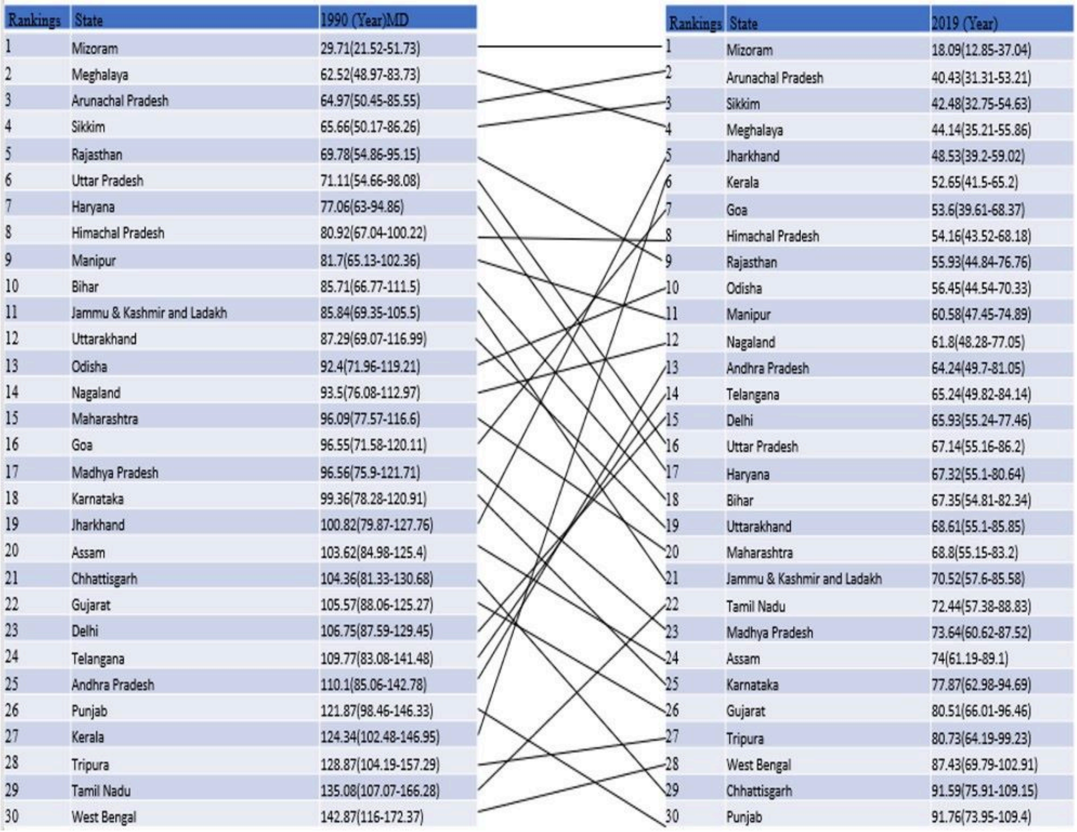


Figure 2: Ranks of Age-Standardized CVD attributa to air pollution death rate per 100,000 population for all ages in 1990 and 2019 in India

Discussion

The current study explores the burden of CVD attributable to air pollution across various states in India, analyzing data from 1990 to 2019. Our results showing an increase in CVD mortality related to ambient PM and a decrease in CVD deaths linked to reductions in HAP align well with broader research trends [23,24]. Additionally, a study by Cohen et al [25] emphasized that ambient PM2.5 was a significant mortality risk factor globally, highlighting a rising burden due to inadequate air quality management in low and middle-income countries. Similarly, a study highlighted a global decrease in CVD risks associated with improved household energy utilization [26], which reflects our findings of declining HAP impacts due to advancements in cleaner cooking technologies. Consistent with previous findings [18,27], our study underscores the significant role of ambient particulate matter (PM2.5) in increasing the risk of CVDs. This is aligned with the evidence that ambient air pollution, particularly PM2.5, contributes to oxidative stress, inflammation, and atherosclerosis, leading to cardiovascular morbidity and mortality. Our study also highlights a significant reduction in CVD deaths attributable to household air pollution, a trend supported by Adekoya and colleagues [26], who found a consistent decline in health risks associated with improved household energy use in low- and middle-income countries (LMICs). This reflects successful public health initiatives aimed at reducing exposure to HAP through adopting cleaner cooking technologies, which has effectively mitigated CVD outcomes.

Reflecting on the economic analysis from the India State-Level Disease Burden Initiative [6], our findings about the substantial health burdens of air pollution in India are confirmed. Our study

Also highlights regional disparities in CVD burden, with higher burdens observed in industrially advanced states. This is consistent with a finding which suggested an inverse relationship between state-level human development indices and APACVD burden, indicating that economically thriving states might also be those most affected by air pollution due to higher industrial and vehicular activities [14]. The increasing impact of ambient particulate matter, particularly noted in states with growing industrialization and urban sprawl like Maharashtra and Tamil Nadu, underscores the urgent need for implementing robust air quality management policies to curb pollution sources and mitigate their health impacts. A study has reported the highest mortality share for ‘X’ class cities and north India [28], in line with our higher mortality concentration in Delhi.

In line with our findings, a study reported a considerably high mortality burden in cities such as Chandigarh, Ludhiana, Dehradun, Patna, Kolkata and Delhi, etc [28]. Indigenous emission sources account for 76% of all premature deaths in the Indo-Gangetic Plain region, which includes cities like Delhi, Dehradun, Ghaziabad, Kanpur, Lucknow, and Patna [29]. Cross-border transportation and natural resources account for the remaining 15% of premature deaths [29]. These variations in the prevalence of CVD among areas with varying levels of socio-economic development primarily pointed to an imbalance in air quality management and the provision of CVD healthcare [24]. The economic impact, particularly in states with lower per-capita GDP, emphasizes the dual challenge of health and economic growth hindered by air pollution. These economic insights are critical for policy-makers, underlining the need for targeted air quality improvements to bolster public health and economic productivity.

Results from age, period, and cohort analysis indicated that the risk of CVD increases with age, with older cohorts experiencing higher risks and more pronounced health impacts. This age effect likely reflects cumulative exposure to air pollution and the physiological vulnerabilities that escalate with aging. It was observed that at an older age, the relative risk of death attributable to air pollution is higher, especially among women. In contrast, at younger ages, the death rates are higher for males than females. Another factor contributing to the higher prevalence of CVD in the elderly population is their susceptibility to PM2.5 exposure [30]. This was due to the fact that older individuals had longer exposure times and cumulatively more harmful effects of ambient PM2.5 on their cardiovascular systems [31]. The elderly's physiologic reserve and toxicodynamic restoration were hampered by their frailty and weakened immune systems [32].

Furthermore, older people are more likely to have preexisting chronic lung and cardiovascular diseases, making them more susceptible to PM2.5 exposure [33]. The period effects observed suggest that there have been fluctuations in CVD incidence related to environmental and policy changes over the study periods. Notably, recent periods have shown worsening trends, potentially linked to increased industrialization and urbanization, leading to heightened air pollution levels. Cohort effects reveal a more complex picture, with earlier cohorts (born in the 20th century) experiencing higher CVD risks, which gradually decrease in later cohorts for both sexes. This trend aligns with improving healthcare, lifestyle changes, and perhaps shifts in exposure patterns due to evolving pollution control policies. In major cities with a population of one million or more, Nair and colleagues estimated an improvement of 1.01 percent in premature death in major cities due to air pollution by 2024. This improvement can be attributed to policy intervention through the National Clean Air Action Programme [28].

Our analysis aligns with findings that identify vulnerable subpopulations that suffer disproportionately from air pollution-related CVDs, particularly in Asian countries [34,35]. Elderly populations and those with morbidities are at higher risk, necessitating targeted interventions to protect these high-risk groups. There is consistent evidence linking short-term exposure to particulate matter and nitrogen oxides to elevated risks of hypertension, myocardial infarction (MI), and stroke (both fatal and nonfatal). On the other hand, prolonged exposure to PM2.5 was principally associated with a higher risk of incident MI, atherosclerosis, hypertension, stroke, and stroke death [27]. Despite global efforts to improve air quality, the upward trend in CVD burden from ambient air pollution calls for reinforced policy actions. Previous research suggests that stringent air pollution control measures can derive significant health benefits, particularly in rapidly urbanizing and industrializing regions like India [5,25].

Conclusions

The thorough analysis offered in this paper emphasises the need to address air pollution as a significant public health issue in India, together with supporting data from regional and international studies. Enhanced and region-specific air quality management strategies that include ambient and household air pollution controls can lead to substantial public health benefits and aid in the country's economic advancement. The findings advocate for an integrated approach that considers socio-economic dynamics, regional vulnerabilities, and the broader environmental context to effectively mitigate the CVD burden associated with air pollution in India. This study highlights significant regional variations and the detrimental effects of particulate matter. Our research corroborates the pressing need for aggressive air quality management and targeted health interventions, particularly in urbanizing regions facing dual environmental and public health degradation challenges. To address this, we recommend a series of policy measures to tighten air quality standards, enhance public awareness and health infrastructure, promote cleaner technologies, and foster inter-sectoral collaboration. By adopting these integrated strategies, policy-makers can significantly mitigate the cardiovascular health risks associated with air pollution, thereby improving public health and enhancing the quality of life for all citizens.

Supporting information

None

Ethical Considerations

None

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Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

1. World Health Organization. Cardiovascular diseases (CVDs). Available from: https://www.*who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds); 2021. Accessed July 2, 2024. [Crossref][PubMed][Google Scholar]*

2. Rajagopalan S, Landrigan PJ. Pollution and the Heart. N Engl J Med. *2021;385(20):1881-92. [Crossref][PubMed][Google Scholar]*

3. World Health Organization. Household air pollution. ed 15 December 2023. *Available from: 2023. Accessed July 2, 2024. [Article][Crossref][PubMed][Google Scholar]*

4. Collaborators GBDRF. Global burden and strength of evidence for 88 risk factors in 204 countries and 811 subnational locations, 1990-2021: a systematic analysis for the Global Burden of Disease Study 2021. Lancet. *2024;403(10440):2162-203. [Crossref][PubMed][Google Scholar]*

5. Collaborators GBDRF. Global burden of 87 risk factors in 204 countries and territories, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet. *2020;396(10258):1223-49. [Crossref][PubMed][Google Scholar]*

6. India State-Level Disease Burden Initiative Air Pollution C. Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019. Lancet Planet Health. *2021;5(1):e25-e38. [Crossref][PubMed][Google Scholar]*

7. Chakraborty P, Gadhavi H, Prithiviraj B, Mukhopadhyay M, Khuman SN, Nakamura M, et al. Passive Air Sampling of PCDD/Fs, PCBs, PAEs, DEHA, and PAHs from Informal Electronic Waste Recycling and Allied Sectors in Indian Megacities. Environ Sci Technol. *2021;55(14):9469-78. [Crossref][PubMed][Google Scholar]*

8. Chandra S, Chakraborty P. Air-water exchange and risk assessment of phthalic acid esters during the early phase of COVID-19 pandemic in tropical riverine catchments of India. Chemosphere. *2023;341:140013. [Crossref][PubMed][Google Scholar]*

9. GBD MAPS Working Group. Burden of Disease Attributable to Major Air pollution Sources in India. Boston, Massachusetts: Health Effects Institute; 2018. *[Crossref][PubMed][Google Scholar]*

10. Ye W, Thangavel G, Pillarisetti A, Steenland K, Peel JL, Balakrishnan K, et al. Association between personal exposure to household air pollution and gestational blood pressure among women using solid cooking fuels in rural Tamil Nadu, India. Environ Res. *2022;208:112756. [Crossref][PubMed][Google Scholar]*

11. Arku RE, Birch A, Shupler M, Yusuf S, Hystad P, Brauer M. Characterizing exposure to household air pollution within the Prospective Urban Rural Epidemiology (PURE) study. Environ Int. *2018;114:307-17. [Crossref][PubMed][Google Scholar]*

12. Balakrishnan K, Sankar S, Parikh J, Padmavathi R, Srividya K, Venugopal V, et al. Daily average exposures to respirable particulate matter from combustion of biomass fuels in rural households of southern India. Environ Health Perspect. *2002;110(11):1069-75. [Crossref][PubMed][Google Scholar]*

13. Kalra A, Jose AP, Prabhakaran P, Kumar A, Agrawal A, Roy A, et al. The burgeoning cardiovascular disease epidemic in Indians - perspectives on contextual factors and potential solutions. Lancet Reg Health Southeast Asia. *2023;12:100156. [Crossref][PubMed][Google Scholar]*

14. Sajith Kumar S, Sasidharan A, Bagepally BS. Air Pollution and Cardiovascular Disease Burden: Changing Patterns and Implications for Public Health in India. Heart Lung Circ. *2023;32(1):90-4. [Crossref][PubMed][Google Scholar]*

15. Nicolaou L, Underhill L, Hossen S, Simkovich S, Thangavel G, Rosa G, et al. Cross-sectional analysis of the association between personal exposure to household air pollution and blood pressure in adult women: Evidence from the multi-country Household Air Pollution Intervention Network (HAPIN) trial. Environ Res. *2022;214(Pt 4):114121. [Crossref][PubMed][Google Scholar]*

16. Motairek I, Ajluni S, Khraishah H, AlAhmad B, Al-Dulaimi S, Abi Khalil C, et al. Burden of cardiovascular disease attributable to particulate matter pollution in the eastern Mediterranean region: analysis of the 1990-2019 global burden of disease. Eur J Prev Cardiol. *2023;30(3):256-63. [Crossref][PubMed][Google Scholar]*

17. Wang T, Ma Y, Li R, Sun J, Huang L, Wang S, et al. Trends of ischemic heart disease mortality attributable to household air pollution during 1990-2019 in China and India: an age-period-cohort analysis. Environ Sci Pollut Res Int. *2022;29(58):87478-89. [Crossref][PubMed][Google Scholar]*

18. Abdul-Rahman T, Roy P, Bliss ZSB, Mohammad A, Corriero AC, Patel NT, et al. The impact of air quality on cardiovascular health: A state of the art review. Curr Probl Cardiol. *2024;49(2):102174. [Crossref][PubMed][Google Scholar]*

19. Kim HJ, Fay MP, Feuer EJ, Midthune DN. Permutation tests for joinpoint regression with applications to cancer rates. Stat Med. *2000;19(3):335-51. [Crossref][PubMed][Google Scholar]*

20. Clegg LX, Hankey BF, Tiwari R, Feuer EJ, Edwards BK. Estimating average annual per cent change in trend analysis. Stat Med. *2009;28(29):3670-82. [Crossref][PubMed][Google Scholar]*

21. Yang Y, Schulhofer-Wohl S, Fu WJ, Land KC. The intrinsic estimator for age-period-cohort analysis: what it is and how to use it. Am J Sociol. *2008;113(6):1697-736. [Crossref][PubMed][Google Scholar]*

22. Li C, Yu C, Wang P. An age-period-cohort analysis of female breast cancer mortality from 1990-2009 in China. Int J Equity Health. *2015;14:76. [Crossref][PubMed][Google Scholar]*

23. Taghian G, Fisher S, Chiles TC, Binagwaho A, Landrigan PJ. The Burden of Cardiovascular Disease from Air Pollution in Rwanda. Ann Glob Health. *2024;90(1):2. [Crossref][PubMed][Google Scholar]*

24. Liu YH, Bo YC, You J, Liu SF, Liu MJ, Zhu YJ. Spatiotemporal trends of cardiovascular disease burden attributable to ambient PM(2. 5) from 1990 to 2019: A global burden of disease study. *Sci Total Environ. 2023;885:163869. [Crossref][PubMed][Google Scholar]*

25. Cohen AJ, Brauer M, Burnett R, Anderson HR, Frostad J, Estep K, et al. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. Lancet. *2017;389(10082):1907-18. [Crossref][PubMed][Google Scholar]*

26. Adekoya A, Tyagi SK, Duru CN, Satia I, Paudyal V, Kurmi OP. Effects of Household Air Pollution (HAP) on Cardiovascular Diseases in Low- and Middle-Income Countries (LMICs): A Systematic Review and Meta-Analysis. Int J Environ Res Public Health. *2022;19(15):9298. [Crossref][PubMed][Google Scholar]*

27. de Bont J, Jaganathan S, Dahlquist M, Persson A, Stafoggia M, Ljungman P. Ambient air pollution and cardiovascular diseases: An umbrella review of systematic reviews and meta-analyses. J Intern Med. *2022;291(6):779-800. [Crossref][PubMed][Google Scholar]*

28. Nair M, Bherwani H, Mirza S, Anjum S, Kumar R. Valuing burden of premature mortality attributable to air pollution in major million-plus non-attainment cities of India. Sci Rep. *2021;11(1):22771. [Crossref][PubMed][Google Scholar]*

29. David LM, Ravishankara AR, Kodros JK, Pierce JR, Venkataraman C, Sadavarte P. Premature Mortality Due to PM(2. 5) Over India: Effect of Atmospheric Transport and Anthropogenic Emissions. *Geohealth. 2019;3(1):2-10. [Crossref][PubMed][Google Scholar]*

30. Chen R, Yin P, Meng X, Liu C, Wang L, Xu X, et al. Fine Particulate Air Pollution and Daily Mortality. A Nationwide Analysis in 272 Chinese Cities. *Am J Respir Crit Care Med. 2017;196(1):73-81. [Crossref][PubMed][Google Scholar]*

31. Yang BY, Qian Z, Howard SW, Vaughn MG, Fan SJ, Liu KK, et al. Global association between ambient air pollution and blood pressure: A systematic review and meta-analysis. Environ Pollut. *2018;235:576-88. [Crossref][PubMed][Google Scholar]*

32. Fougere B, Vellas B, Billet S, Martin PJ, Gallucci M, Cesari M. Air Pollution modifies the association between successful and pathological aging throughout the frailty condition. Ageing Res Rev. *2015;24(Pt B):299-303. [Crossref][PubMed][Google Scholar]*

33. Yang BY, Guo Y, Morawska L, Bloom MS, Markevych I, Heinrich J, et al. Ambient PM(1) air pollution and cardiovascular disease prevalence: Insights from the 33 Communities Chinese Health Study. Environ Int. *2019;123:310-7. [Crossref][PubMed][Google Scholar]*

34. Downward GS, Vermeulen R, Asia Cohort Consortium Executive B. Ambient Air Pollution and All-Cause and Cause-Specific Mortality in an Analysis of Asian Cohorts. Res Rep Health Eff Inst. *2023;2016(213):1-53. [Crossref][PubMed][Google Scholar]*

35. Mumtaz A, Rehman N, Haider A, Rehman S. Long-Term Air Pollution Exposure and Ischemic Heart Disease Mortality Among Elderly in High Aging Asian Economies. Front Public Health. *2021;9:819123. [Crossref][PubMed][Google Scholar]*

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