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ORIGINAL ARTICLE

Air Pollution and Cardiovascular Disease Burden: Changing Patterns and Implications for Public Health in India

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Introduction The link between air pollution-attributed cardiovascular disease (APACVD) burden and its contributing factors can aid in detecting vulnerabilities and providing forewarnings for India.

Methods We examined the association between the status and trends of the APACVD burden obtained from the Global Burden of Diseases and Injuries study with the two development metrics in India; the human development index (HDI) and indirect indices of economic development, namely annual new motor vehicle registration and the number of functional factories for 10 years from 2009 to 2019. Lorenz curves and concentration index were used to estimate the inequalities in the state-APACVD burden and the burden per 100,000 population.

Results At the state level, APACVD burden was inversely related to the HDI value in India for the years 2009 (r=-0.48), 2014 (r=-0.47), and 2019 (r=-0.37), and the association was statistically significant ($p<0.05$). The correlation between state-level APACVD burden with the annual new motor vehicle registration and the number of functional factories in India for these years was also positive and significant ($p<0.05$). The APACVD was 53% unequally distributed across the states, with a concentration index of 0.53 in 2009.

Discussion We observed that at the state level, the APACVD burden was inversely related to HDI. But the APACVD burden increased with the country's economic development. Also, the excess APACVD burden appears to be attributable to the economically developed states.

Conclusion At the state level, APACVD burden decreased as HDI rose over time, indicating that the burden increased with the country's economic development. It is noticeable that the economically developed states may be contributing a higher share of the APACVD burden in India.

Keywords DALY • CVD • Air pollution • Equality

Introduction

Air pollution could pose an existential challenge to human health, caused by a shift in the atmospheric conditions owing to anthropogenic activity [1,2]. The interactions between air pollution and health outcomes are diverse and complex and include multiple exposure pathways that may lead to the development of cardiovascular disease (CVD) [2]. Air pollution is a well-known risk factor for CVD morbidity and mortality, ranking fourth, following high blood pressure, dietary risks, and smoking [3,4]. Many epidemiological studies have shown a positive association between air pollution levels and total and cause-specific mortality [5]. Air pollution is associated with three of the leading causes of death in the world with significant shares of air pollution-related mortality: stroke (26%), ischaemic heart disease

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(20.2%), and primary cancer of the trachea, bronchus, and lung (19%) [6]. Overall, air pollution has been linked to eight million deaths worldwide and more than 100 million disability-adjusted life years (DALYs) annually [7], with a USD$5trillion global economic impact annually [8].

Air pollution is one of the primary causes of respiratory illnesses and associated infections, and it is the second major risk factor causing disease burden in India after malnutrition [9]. Pandey et al. [2021) recently reported the economic loss due to morbidity and mortality associated with air pollution using the Global Burden of Diseases (GBD) data [10]. The number of DALYs in India owing to air pollution has declined from 68 million in 1990 to 53.5 million in 2019 [4], despite reducing household air pollution, ambient air pollution has worsened over the years. India in the past decades has seen rapid economic growth accompanied by changes in people's quality of life brought on by urbanisation and globalisation [11]. These changes, along with an increased penetration by various health agencies raising awareness of indoor pollution, have led to the reduction of wood-burning stoves and indoor smoking [12,13]. Nevertheless, evidence of systemic inequalities in indoor air pollution exposure is increasing globally [14–16].

India's air pollution-attributed burden of cardiovascular disease (APACVD) remains high [9,17]. As a result, examining the link between the APACVD burden and its contributing elements in India is prudent, and can aid in detecting vulnerabilities and providing forewarnings. This evidence can assist in raising awareness and decision-making on the need to reduce the APACVD burden. Also, the present study forms the initial basis for providing status, trends and inequality in APACVD burden with respect to the human development index (HDI) and economic development in India, so that future studies may test and integrate other pertinent indicators to explore the specific reasons for the trends observed. In this regard, we explored the current status and trends of the APACVD burden concerning two development metrics in India: the HDI and indirect indices of economic development, namely annual new motor vehicle registration and the number of functional factories during a 10-year period from 2009 to 2019. This evidence can assist in raising awareness and decision-making on the need to reduce the APACVD burden.

Methods

Data Sources

The "India State-Level Disease Burden Initiative", as part of the GBD, Injuries, and Risk Factors Study 2019, reports the trends of disease burden (in DALYs) attributable to air pollution in India [4,18]. The GBD initiative comprises disease burden in terms of all standard epidemiological measures and DALYs from 1990 to 2019 for all individual states in India.[19] It also serves as the key source of data for India's APACVD burden. Relevant data from 28 states and two union territories for the present study was pooled from various repositories and is presented in Table 1 [4,18,20–23]. The gross state-level APACVD burden and state-level APACVD burden per 100,000 population (a marker of population density-adjusted influence) were the indicators of the cardiovascular disease burden attributable to the air pollution. Annual new motor vehicles registered [20] and the number of functional factories [21,23] reported per annum were regarded as indirect indices of the country's economic development. HDI data is available at three time points for India: 2009, 2014, and 2019 [22]; hence, we considered the same three time points.

Table 1 Details on data sources used in the study.

S. N.	Data	Sources	Explanation
1	Air pollution-attributed cardiovascular disease burden	GBD web repository [4,18]	"India State-Level Disease Burden Initiative", as part of the Global Burden of Diseases, Injuries, and Risk Factors Study 2019.
2	Air pollution-attributed cardiovascular disease burden per 100,000 population	GBD web repository [4,18]	"India State-Level Disease Burden Initiative", as part of the Global Burden of Diseases, Injuries, and Risk Factors Study 2019.
3	Data on motor vehicles registered	Ministry of Road Transport & Highway yearbooks [21]	Number of new motor vehicles registered annually in each state
4	Data on number of functional factories	Handbook of statistics on Indian states, 2021 [20,21]	Total number of functional factories in each state
5	Human Development Report	United Nations Development Programme [22]	State wise (i.e., By State) Human development index score for 2009, 2014 and 2019 periods

Inequality Assessment With the Distribution of APACVD Burden

The unevenness and inequality in the APACVD burden were estimated by Lorenz curves and concentration index, which were conventionally helpful in assessing the socio-economic-related inequality in the indicators of interest [24–26]. The concentration index detects the unevenness and magnitude of variance in health parameters across a range of socio-economic characteristics. The concentration index ranges from 0 to 1, with 0 indicating no inequality and 1 indicating significant (100%) inequality. The concentration index is represented graphically via the Lorenz curve. The Lorenz curve is a two-dimensional scatter plot (X and Y axes) with a diagonal straight reference line. The curve closest to the reference line reflects minimal inequality, whereas the curve that deviates from the reference line represents inequality. The divergence from the reference line represents the degree of inequality.

Statistical Analysis

We have analysed the state-specific APACVD and its association with HDI values. Further, the APACVD is correlated with the indirect indices of development i.e., number of motor vehicle and annual number of factories in India. The inequality across states in terms of air pollution disease burden with HDI and the other two indirect measures of development were estimated and reported using concentration index and Lorenz curve. We used Pearson's product-moment correlation coefficient statistic and graphical representation to analyse the trends and associations between the state-level APACVD burden and HDI and economic development for ten years from 2009 to 2019. All tests were deemed statistically significant at a p-value <0.05. We used Microsoft Excel [27] version 2019 for data visualisation and STATA (Stata Corp LLC, College Station, TX, USA) [28] software version 16 for statistical analysis.

Results

Association Between State-Level Disease Burden with HDI

The state-level APACVD burden was inversely related to the respective HDI values for the years 2009 (r=-0.48), 2014 (r=-0.47), and 2019 (r=-0.37) and the association was statistically significant ($p<0.05$) (Supplementary Figure 1, Supplementary Table 1, 2 and 3). Consistent with the earlier observation, the state-level APACVD burden for the 100,000 population also exhibited a negative correlation with HDI value for the years 2009 and 2014 (r=-0.02 and -0.04, respectively); however, a trend of positive association (r=0.13) without statistical significance (i.e., $p>0.05$) was observed in 2019 (Supplementary Table 1, 2 and 3).

Association Between State-Level Disease Burden With Economic Development

a. Annual New Motor Vehicle Registration

The correlation between the annual new motor vehicle registration and state-level APACVD burden in India for the years 2009, 2014, and 2019 was positive (r=0.51, 0.50 and 0.47, respectively) and statistically significant ($p<0.05$). A similar positive association (r=0.52, 0.53 and 0.50) was observed between the state-level APACVD burden for the 100,000 population and the annual number of new motor vehicles for the same period ($p<0.05$) (Supplementary Table 1, 2 and 4).

b. Annual Functional Factories Registration

The correlation analysis between state-level APACVD burden (r=0.71, 0.68, 0.66 for 2009, 2014 and 2019, respectively) and burden for 100,000 population (r=0.51, 0 51, 0.52 for 2009, 2014 and 2019, respectively) with annual functional factories registered in Indian states also exhibited positive association with statistical significance ($p<0.05$) (Supplementary Table 1, 2 and 4).

Inequality Assessment

a. State-Level Disease Burden With the HDI

The APACVD was 53% unequally distributed across the states, with a concentration index of 0.53 in 2009 (Table 2). The Lorenz curve explains a high unevenness across the spectrum of HDI distribution in terms of APACVD, wherein the states occupying the sixth decile and above in terms of HDI contribute to 80% of total APACVD (Supplementary Figure 1). However, the inequality marginally increased to 54% in 2014 and 55% in 2019, despite the Lorenz curve

Table 2 Concentration index values.

Factor	2009		2014		2019	
	CI	P-value	CI	P-value	CI	P-value
APACVD burden with HDI	0.53	<0.01	0.54	<0.01	0.55	<0.01
APACVD burden per 100,000 with HDI	0.19	<0.01	0.18	<0.01	0.19	<0.01
APACVD burden with number of motor vehicles	0.54	<0.01	0.55	<0.01	0.57	<0.01
APACVD burden with number of factories	0.55	<0.01	0.56	<0.01	0.57	<0.01

Abbreviations: APCVD, air pollution attributed to cardiovascular disease; HDI, human development index; CI, concentration index.

demonstrating similar unevenness (Supplementary Figure 2), requiring further investigation to identify the cause. The concentration index for all three years was significant at 95% confidence intervals ($p<0.05$).

b. Population-Density-Adjusted State-Level Disease Burden with HDI

The 2009 assessment of unevenness and inequality in APACVD per 100,000 population compared to HDI in India using concentration index and Lorenz curve revealed an 18.7% inequality (Table 2). The results were almost similar for the rest of the study period as the rate of inequality minimally decreased to 18.3% in 2014 and further increased to 18.9% in 2019. The concentration index for all three years was significant at 95% confidence intervals ($p<0.05$). Due to this low inequality, the level of unevenness measured using the Lorenz curve is consistent with concentration index values, suggesting consistency in the distribution of APACVD among states (Supplementary Figure 3).

c. State-Level Disease Burden With Annual New Motor Vehicle Registration and Functioning Factories

The concentration index revealed a 54% inequality in APACVD burden based on the annual new motor vehicles in Indian states during 2009, and the inequality has increased to 57% by 2019 (Supplementary Figure 4, Table 2). About 80% of the APACVD burden is observed among states occupying the sixth decile and above in terms of the number of motor vehicles. Similarly, the 2009 concentration index value for APACVD burden with reference to the number of functional factories in Indian states was 0.549 and increased to 0.571 in 2019 (Supplementary Figure 5, Table 2). Indian states occupying the higher end of the development spectrum contribute nearly 80% of APACVD.

Discussion

We evaluated the association between APACVD burden with the measures of human and economic development and assessed the inequality in the state-level of disease burden due to APACVD. We observed that, as HDI rose over time, the total state-wise overall and population-density-adjusted APACVD burden reduced. In contrast, we also observed that the overall and population-density-adjusted APACVD burden increased with economic development. Both indirect indices of economic development: new motor vehicles registered, and functional factories registered per annum, showed that the burden of air pollution attributable to DALYs in CVD increased with the economic growth in the country.

The state-wise APACVD burden reduced over the years with an increase in HDI measured at three time points for the years 2009, 2014 and 2019. However, the state-wise population-density-adjusted APACVD burden had shown a trend reversal and increased even when the HDI rose from 2014 to 2019; however, the results were not statistically significant. The GBD studies report that the share of CVDs burden among total DALYs rose from 10% in 2009 to 14% in 2019 [4]. However, the share of air pollution contributing to total DALYs and CVD burden due to air pollution has remained more or less the same from 2009 to 2019 [4,18].

While considering state-wise inequality, the states with higher HDI contributed to most of the APACVD burden. However, considering the population-density-adjusted APACVD burden, there is relatively low inequality between states. The excess APACVD burden appears to be attributable to the economically developed states, as shown by the concentration index. Therefore, the economically developed states may be contributing a higher share to the APACVD burden in India. The inverse relationship between a country's level of development and exposure to air pollution; the positive relationship between ambient $PM_{2.5}$ concentration and mortality rate; and the positive relationship between the population's poverty level and exposure to polluted air have been tested and proven in other parts of the world [29]. Exposure to ambient air pollution was earlier considered a bigger issue in developing countries than in developed ones [30]. However, in India, economic development due to rapid industrialisation and urbanisation processes has increased the APACVD burden, and the results are consistent with the literature [31–33]. Counterintuitively, an increase in APACVD impacts the development paradigm since it limits the number of productive days of labour [10,34]. Some of the limitations of the study include, as previously reported, that study observations derived from the GBD and injuries study have inherent limitations [10,18]. The GBD data involves non-uniform reporting of exposure assessments related to time and location, taking into account only the long-term exposures to ambient particulate matter, household air pollution, and ozone levels [10]. From a methodological point of view, this paper does not isolate nor discuss the HDI deficiencies in detail. Further, the high spatial and temporal variability of air pollution may affect the generalisability of the result. The current analysis was restricted to only two indicators for economic development; however, both were also related to causation/contributor to air pollution.

Conclusion

Our study reports the status, trends and inequality in APACVD burden with respect to HDI and economic development in India. The state-level APACVD burden decreased as HDI rose over time, indicating that the burden increased with the country's economic development. Furthermore, the excess APACVD burden appears to be attributable to the more economically developed states. Present observation may guide towards potential directions for reducing the APACVD burden. The high APACVD burden and its associated substantial adverse economic impact from a loss of output could impede India's aspiration to be among the world's largest economies. It is critical to elucidate the impact of APACVD in Indian states. State-specific measures for the successful reduction of air pollution in India will lead to substantial benefits for both the population's health and the economy. In the future, there is a need to extend the analyses by testing and integrating other pertinent indicators to explore the specific reasons for the trends observed and to further estimate the economic burden of APACVD in monetary terms while striking a balance between comprehensiveness and accuracy.

Author's Contribution

Sajith Kumar: Data curation, formal analysis, original draft.
Akhil S: Original draft, review and editing.
Bagepally BS: Conceptualisation, formal analysis, investigation, methodology, results interpretation, inputs to original draft, review & editing.

Declaration of Conflict of Interest

None.

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Appendices

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.hlc.2022.10.012

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