Air pollution attributed disease burden and economic growth in India: Estimating trends and inequality between states

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Summary

Background Air pollution is one of the major contributors to the disease burden in India after malnutrition. We examined the relation, and state-wise disparities in air pollution attributed to disease burden (APADB) concerning gross state domestic product (GSDP) and growth in motor vehicles in India.

Methods We retrieved disability-adjusted life year (DALY) estimates for India due to air pollution from the Global Burden of Disease Studies, injuries, and Risk Factors Study (GBD). We examined the association between APADB with GSDP and the growth in the number of registered motor vehicles in India during the 2011 to 2019 period. Concentration indices and Lorenz curves were used to explore the variation in APADB across individual states.

Findings Except for a few states, APADB is inversely proportional to GSDP. Growth in motor vehicles was also negatively correlated with the APADB in n=19 states. The concentration index explained a 47% inequality in APADB between individual states and exhibited a decline (45%) during 2019 compared to 2011. The unevenness in APADB among Indian states is evident from the analysis as the states occupying the 6th or 7th decile and above in terms of GDP, urbanization and population contribute more than 60 per cent of the total APADB.

Interpretation The APADB is inversely correlated with GSDP for most of the states, and the negative correlations were conspicuous when APADB per 100,000 population was analysed. The concentration index and Lorenz revealed the presence of APADB inequality between states in terms of GSDP, population, urbanisation, and total factories.

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Introduction

As natural resources are scarce, rapid economic growth is associated with a deteriorating environment triggered by exploitation.[1] Imbalances in the environment due to air, water, sound, and soil pollution will increase morbidity and mortality.[2] Also, increase in population will make the situation even worse.[3] India accommodates nearly 18% of the world's population,[4] and urbanisation trends are at an accelerated pace.[5] The population density and resource dependence are very high in India, and so is the exposure to pollution and its related morbidity.[6]

The contribution of communicable diseases (CDs) to the total disease burden in India dropped from 61% to 36% during the 1990–2016 period.[7] This gain in health was overshadowed by a corresponding increase in non-communicable diseases (NCDs) from 30 to 55% for the same period.[7] The epidemiological transition is evident in states like Kerala, Tamil Nadu, and Goa and relatively lower in Bihar, Jharkhand, and Uttar Pradesh.[8] Healthcare becomes more vulnerable to the increasing air pollution and climate change burdens.[9] Air pollution is one of the major factors affecting respiratory ailments and associated infections, and it is the second major risk factor causing disease burden in India after malnutrition.[9] Landrigan and colleagues reported a risk of preterm birth and low birth weight

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Research in context

Evidence before this study

Air pollution-attributed disease burden estimates were already available in the public domain from the GBD study. However, the association of APADB with economic growth and its equality aspects among individual states were unavailable.

Added value of this study

APADB is inversely associated with GSDP for most states. To achieve economic growth in the country, APADB must be curtailed. The unevenness in APADB among Indian states is also evident as the industrialized and economically progressed states contribute to the inequality in APADB in Indian states.

Implications of all the available evidence

A reduction in APADB is essential to achieve a rise in productive capacity. The Lorenz curve and concentration index exhibited a remarkable variation in APADB among individual states in India in terms of GSDP, Population, urbanisation, and the number of working factories. However, the inequality among states in APADB with the number of new motor vehicles was low.

among women who were exposed to air pollution.[10] The impact of air pollution on premature mortality and disease burden is more evident in low-income and middle-income countries than in high-income countries.[11]

The Global Burden of Diseases (GBD), Injuries, and Risk Factors Study 2019 is an ongoing effort to prepare comprehensive database[12] for disease burden estimation across more than 200 countries in the world. The GBD initiative comprises disease burden in terms of all standard epidemiological measures and disability-adjusted life years (DALY) from 1990 to 2019 for all individual states in India.[13] It also serves as the major source of data for APADB in India. The India State-Level Disease Burden Initiative, 2017 reported a favourable outcome for household air pollution; still, outdoor air pollution is worsening every year.[8] As a result, the APADB in India remains high.[8] The updated GBD study (2019) also reported a decreasing trend in household air pollution but with a subsequent increase in ambient particulate matter pollution.[9]

Air quality is considered a prerequisite for good health.[13] APADB is one of the major contributors to the total disease burden in India.[3,14] An increase in population, high urbanisation, motor vehicle growth, and industrialisation trigger air pollution and have a long-term impact on human health.[6,15] Hence, population growth/urbanisation, vehicle growth and industrialisation can be regarded as the major determinants of air pollution.[16,17] Thus, it is thoughtful to analyse the relationship between APADB and its contributing factors in India, which could serve as a baseline for identifying the weakness and forewarning to control future adversities. In this regard, we explored the status and trends in APADB concerning economic growth and its direct and indirect measures (new vehicles registered and the number of functional industries) for each state in India adjusting for potential confounders. To better understand the result, we also analysed the trends in ambient particulate matter pollution disease burden (APMDB) and household air pollution disease burden (HAPDB) as a subgroup of APADB. Supportive evidence was also generated on the unevenness in the distribution of APADB between individual states in line with other determinants of air pollution, such as growth in factories and population/urbanisation in India.

Methods

Data sources

The "India State-Level Disease Burden Initiative", as part of the Global Burden of Diseases, Injuries, and Risk Factors Study 2019, report the trends of disease burden (in DALYs) attributable to air pollution (i.e. long-term exposure to combined ambient particulate matter, household air pollution and ozone levels) for individual Indian states.[12,18]

Relevant data of all the 28 states and two union territories for the present study were pooled from various repositories; details of the sources are listed in Table 1.[4,12,18–22] Geographical locations of these states and union territories are available in figure 1 and supplement figures 1, 3, 5 & 6. The state-wise gross APADB and APADB per hundred thousand population were the indicators of the disease burden attributable to the air pollution in their respective states. Gross state domestic product (GSDP) data and annual new vehicles registered, and the number of functional industries reported in each state was respectively regarded as the direct and indirect measures of state's productivity. Data on age standardised APADB[12,18] from the Global Burden of Diseases, Injuries, and Risk Factors Study 2019, and geoclimatic varaibles[23,24] (change in rainfall and temperature) for individual states from India meteorological department and published literature were used for adjusting the influence of potential confounders.

Estimation of unevenness and inequality in the distribution of APADB

The unevenness and inequality in APADB among the states were estimated by Lorenz curves and concentration index. Lorenz curve and concentration index are conventionally helpful in estimating the socio-economic-related inequality in various health

S. N.	Data	Sources	Explanation
1	Air pollution attributed disease burden	GBD web repository [1,2]	Disease burden data for the individual Indian states from "India State-Level Disease Burden Initiative", as part of the Global Burden of Diseases, Injuries, and Risk Factors Study 2019.
2	Gross state domestic product	Handbook of statistics on Indian states, 2021.[3]	Annual gross domestic production of each Indian states
3	Data on motor vehicles registered	Ministry of Road Transport & Highway yearbooks[4]	Number of new motor vehicles registered annually in each state
4	Population	Census reports[5,6]	Total population and total urban population in each state in India
5	Data on number of functional factories	Handbook of statistics on Indian states, 2021.[3,7]	Total number of functional factories in each state
6	Age standardized Air pollution attributed disease burden	GBD web repository [1,2]	Age adjusted disease burden data for the individual Indian states from "India State-Level Disease Burden Initiative", as part of the Global Burden of Diseases, Injuries, and Risk Factors Study 2019.
7	Geoclimatic variables	Meteorological Department, GoI,[8] Published Literature[9]	High and low temperature changes and changes rain fall for individual states in India for the year 2020.

***Table 1*: Details on data sources used in the current study.**

indicators.[25–27] Briefly, the concentration index identifies the unevenness and extent of difference in the health parameters under the spectrum of socio-economic indicators being considered. The concentration index spans from 0 to 1, where zero implies no inequality while one indicates severe (100%) inequality. Hence, the indicators close to zero are inferred to have no/less inequality, while values close to 0.5 and above are regarded to have high inequality. Concentration index values with $P > 0.05$ is considered not significant. The Lorenz curve is the graphical (visual) representation of the concentration index. The Lorenz curve is a two-dimension (X and Y axis) scatter plot with a diagonal straight reference line. The curve (plotted on this graph) close to the reference line indicates low inequality, while the curve deviating from the reference line represents inequality. The extent of inequality is represented by the extent of deviation from the reference line.

Analysis

We have analysed the state-wise APADB and its association with direct and indirect markers of gross domestic product. Pearson's product-moment correlations and partial correlations were independently estimated to determine the associations between the APADB - GSDP (at a constant price for the base year 2011–12) and those between APADB - annual state-wise motor vehicles registered during 2011–2019. Further, the partial correlations were estimated by using the geoclimatic variables to derive the adjusted associations. Lastly, Pearson's product-moment correlations and partial correlations were independently estimated using the age standardized APADB for obtaining the age adjusted associations.

The state-wise relation between APADB and GSDP and that of annual new vehicles were explored using four-quadrant scatter-plot graphs. The four quadrants are read clockwise, with the first quadrant right upper, the second right lower, the third left lower, and the fourth left upper quadrant. Briefly, the stat-wise correlation coefficients associating APADB and GSDP for the period 2011–2019 were plotted across X-axis, while the state-wise correlation coefficient associating APADB and annual new vehicles registered were plotted across Y-axis. States represented in the first (X, Y) and third (-X, -Y) quadrants exhibit concordant relation between the two correlations, while those appearing in the second (X, -Y) and fourth (-X, Y) quadrant exhibit discordant relation between these two correlations. States represented in the first quadrant suggest increasing state productivity (i.e., GSDP and new vehicles consistently) with raising APADB. Contrastingly, those in the third quadrant are suggestive of improved state productivity with declining APADB. The states exhibiting discordant relation indicate a raising APADB with raising motor vehicles but inversely associated with GSDP (fourth quadrant), while vice versa in states plotted in the second quadrant. Similar four-quadrant scatter plots were constructed to explore the state-wise relation between APADB and GSDP and that of total annual functional factories registered.

In view of the evident COVID-19 pandemic repercussion on the gross production[28–30] and APADB[31–34]; the present analysis was not extended beyond 2019 (i.e. the more recent pre-pandemic period). Pearson's product-moment correlation coefficient statistic and graphical representation were used to observe and analyse the state-wise trends. All tests were deemed statistically significant at a p-value <0.05. The non-significant results in excel maps presented in white, followed by red and blue, denote positive and negative correlations, respectively. We used Microsoft Excel[35] version 2019 for data visualisation and STATA[36] software version 16 for statistical analysis.

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The authors have received no funding for this paper.

Results

Gross state domestic production and APADB correlations
Annual change in the estimated APADB was inversely related to the gross state domestic product (GSDP) for most states, with Punjab, Maharashtra, Karnataka, Gujarat, Goa, Himachal Pradesh, and Manipur being the exception. Few states exhibited a strong negative association (Uttarakhand, Madhya Pradesh, Nagaland, and Haryana) while few, viz. Tripura, Jammu & Kashmir, Kerala, Meghalaya, Mizoram, Goa, and Himachal Pradesh exhibited a statistically non-significant association ($p > 0.05$) (Figure 1, Supp Table 1,2,6).

Annual new motor vehicles and APADB correlations
Consistent with the earlier observation, the annual new vehicle registered (an indirect measure of productivity) exhibited inverse association in most states (i.e., n=19). Among these, few states (n=6), i.e., Kerala, Madhya Pradesh, Jammu & Kashmir, Meghalaya, Mizoram, and Uttar Pradesh, exhibited a trend of negative association without statistical significance (i.e., $p > 0.05$). The remaining 11 states exhibited positive association; though, the results were not significant for states such as Andhra Pradesh, Himachal Pradesh, Jharkhand, Rajasthan, and Tripura ($p > 0.05$) (Suppl Figure 1, Supp Table 3).

Combined cross-evaluation of GSDP – APADB and annual new vehicle registered-APADB correlations
The majority (19) of the states appeared in the 3rd quadrant of the four quadrant scatter plot representations of GSDP-APADB (along the horizontal axis) and annual new motor vehicles registered – APADB (along the vertical axis) correlations (Figure 2). While 18 exhibiting significant correlations (both variables) were represented in the first and third quadrants (Five in the first quadrant and 13 in the third quadrant) (Figure 2), suggesting the concordant relation between the two correlates. However, few states, viz. Andhra Pradesh, Rajasthan, Jharkhand, and Tripura exhibited discordant relations, wherein the APADB was positively associated with annual new motor vehicle registration but inversely associated with GSDP (Figure 2).

Combined cross-evaluation of GSDP-APADB and annual functional factories registered-APADB correlations
The majority (n=20) of the states appeared in the third quadrant of the four quadrants scatter plot representations of GSDP-APADB (along the horizontal axis), and the number of working factories – APADB (along the vertical axis) correlations (Suppl Figure 2). While 17 exhibiting significant correlations ($p < 0.05$) (both variables) in the first and third quadrants (three in the first and 14 in the 3rd) were represented in the 3rd quadrants (Suppl Figure 2), suggesting the concordant relation between the two correlates. However, states viz. Andhra Pradesh, Arunachal Pradesh, Delhi (in the fourth quadrant) and Maharashtra (in the second quadrant) exhibited discordant relations, wherein the APADB was positively associated with the number of working factories, however inversely associated with GSDP (Suppl Figure 2, Suppl Table 4).

Gross state domestic production and APADB per 100,000 population correlations
The GSDP was negatively associated with APADB per 100,000 population for the majority (n=29) of the states, few with statistical non-significance (Karnataka, Maharashtra, and Punjab) while the rest with statistical significance ($p < 0.05$) (Suppl Figure 3). However, Goa exhibited a trend of positive association without significance ($p > 0.05$).

Combined cross-evaluation of GSDP-APADB per 100,000 population and annual new vehicle registered-APADB correlations
The majority (27) of the states appeared in the third quadrant of scatter plot representations of APADB per 100,000 populations - GSDP (along the horizontal axis) and annual new motor vehicles registered – APADB per 100,000 populations (along the vertical axis) correlations (Figure 2). Explorative four quadrants scatter plot analysis with APADB for 100,000 population revealed a consistent negative relationship between the two correlates. Twenty-seven (90%) states were represented in the 3rd quadrant, suggesting the APADB for

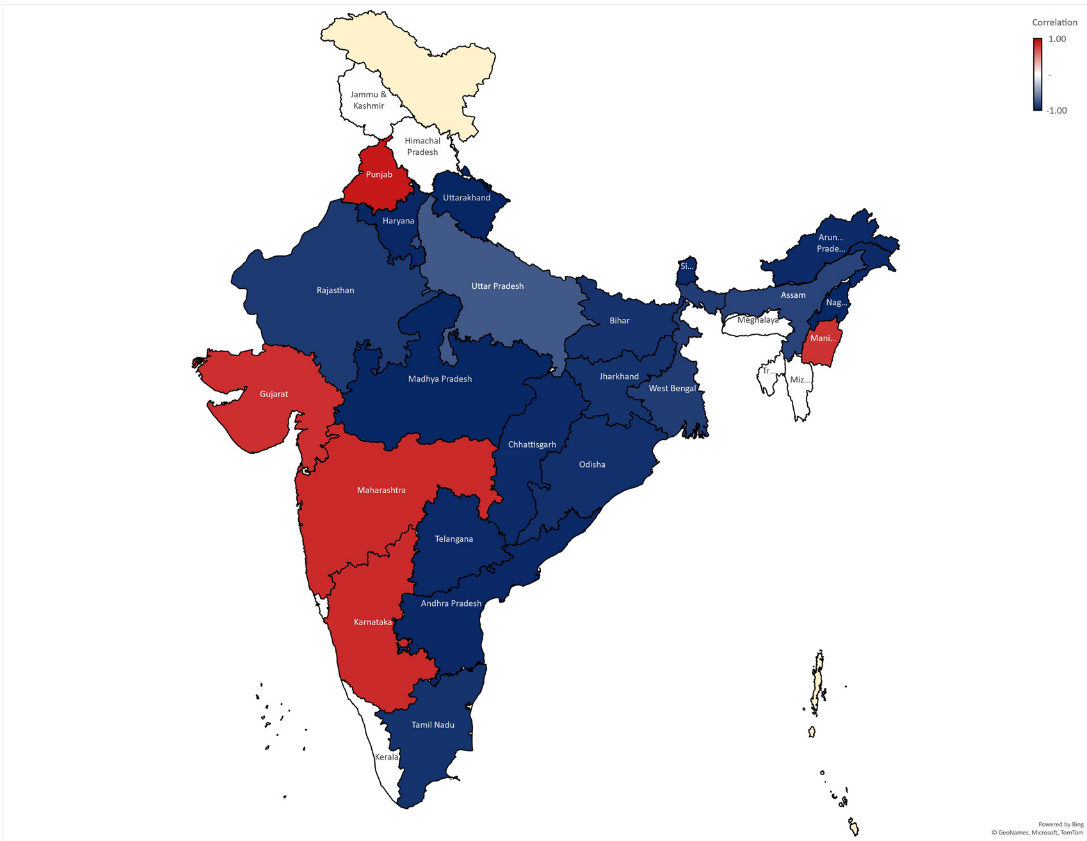


Figure 1. Correlation between the annual change in Air pollution attributed to disease burden and Gross state domestic product in India.

[Colour red represents a strong positive correlation and colour blue for the strong negative correlation. The light blue colour indicates a weak negative correlation. Correlation with non-significant results (p>0.05) are represented in white].

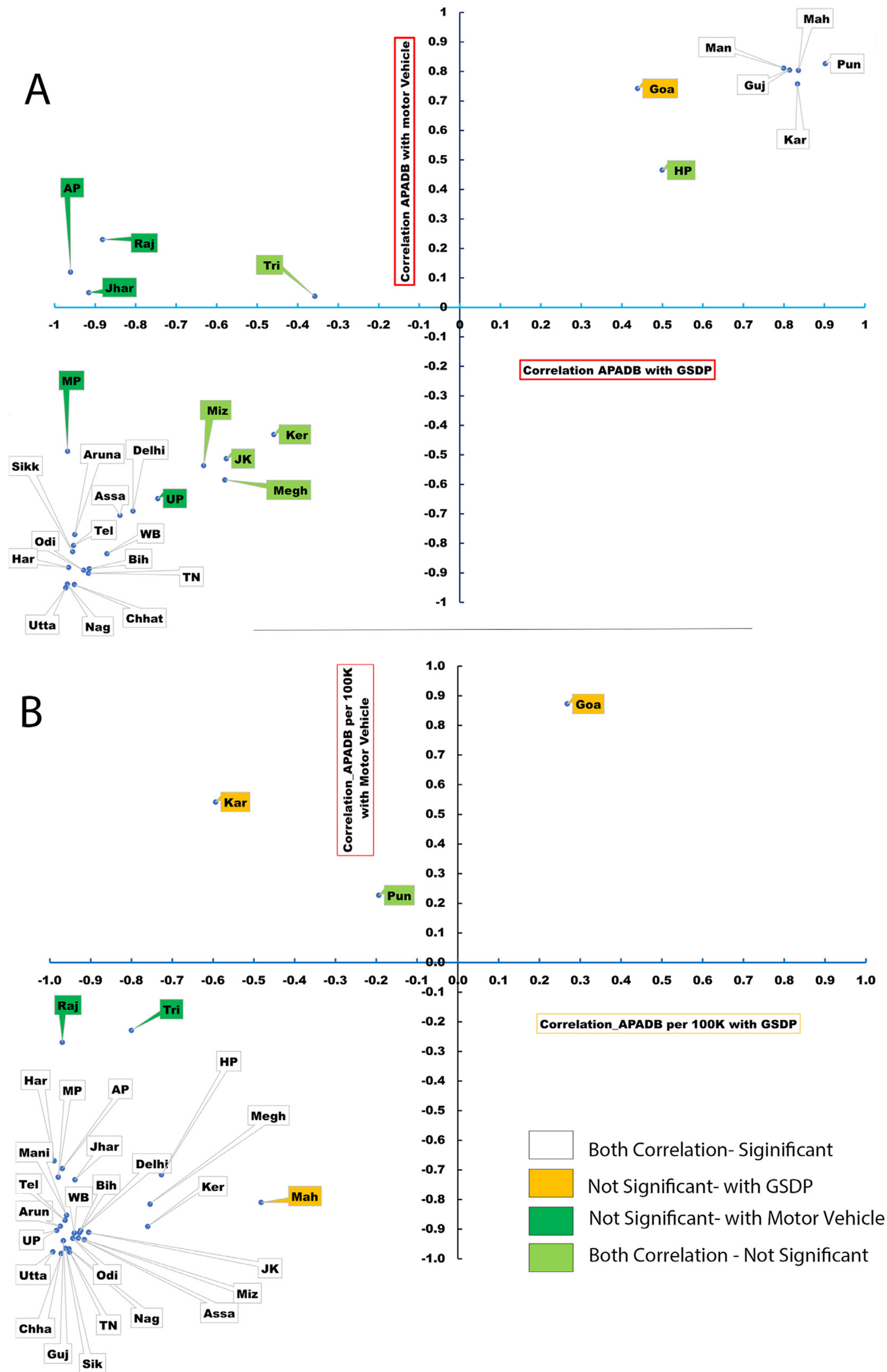
all these states were negatively associated with annual new motor vehicles registered as well as the GSDP (Figure 2). However, two states, Karnataka and Punjab, exhibit discordant relations, wherein the APADB was positively associated with the number of motor vehicles and inversely associated with GSDP (Figure 2).

Combined cross-evaluation of GSDP-APADB per 100,000 population and annual functional factories registered-APADB correlations

Nearly 83 % (n=25) of the states appeared in the third quadrant of the four quadrants scatter plot representations of GSDP-APADB per 100,000 population (along the horizontal axis) and the number of working factories – APADB per 100,000 population (along the vertical axis) correlations (Suppl Figure 4). Amid 25 states exhibiting significant correlations ($p < 0.05$) in both variables, n=22 were represented in the third quadrants (Suppl Figure 4), suggesting the concordant relation between the two correlates. A few states viz. Goa, Himachal Pradesh, Karnataka, and Punjab exhibit concordant yet non-significant associations ($p > 0.05$). However, Andhra Pradesh, Arunachal Pradesh, Maharashtra, and Delhi exhibited discordant relations, wherein the APADB was positively associated with the number of working factories, though inversely associated with GSDP (Suppl Figure 4).

GSDP – APMDB, annual new vehicle registered - APMDB and annual functional factories registered - APMDB correlations

Annual change in the estimated ambient particulate matter pollution disease burden (APMDB) was positively correlated to the GSDP for most of the states, with Delhi and Jharkhand being the exception. While few states viz. Bihar, Goa, Haryana, Jharkhand, Nagaland, Rajasthan, and Sikkim exhibited a statistically non-significant association ($p > 0.05$) (Suppl Figure 5). The


A
Correlation APADB with motor Vehicle
Correlation APADB with GSDP
Mah
Man
Pun
Goa
Guj
Kar
HP
AP
Raj
Tri
Jhar
MP
Miz
Ker
JK
Megh
UP
Aruna
Delhi
Sikk
Assa
Tel
WB
Odi
Har
Bih
TN
Utta
Nag
Chhat
B
Correlation_APADB per 100K with Motor Vehicle
Correlation_APADB per 100K with GSDP
Goa
Kar
Pun
Raj
Tri
HP
Har
MP
AP
Megh
Mani
Jhar
Delhi
Tel
WB
Bih
Ker
Mah
Arun
UP
JK
Utta
Odi
Miz
Assa
Nag
TN
Chha
Guj
Sik
Both Correlation- Siginificant
Not Significant- with GSDP
Not Significant- with Motor Vehicle
Both Correlation - Not Significant

association between APMDB and the number of new vehicles was also positive for all the states except Delhi and Jharkhand. However, states such as Andhra Pradesh, Bihar, Haryana, Jharkhand, Madhya Pradesh, Nagaland, Rajasthan, Sikkim, and Tripura revealed a trend without statistical significance (Suppl Figure 5, Supp Table 7). Consistent with the earlier observation, the association between APMDB and annual functional factories for most states also exhibited a positive correlation, as Maharashtra and Jharkhand are the exceptions. The result was significant for all states except Bihar, Delhi, Haryana, Jharkhand, Madhya Pradesh, Nagaland, Punjab, and Sikkim (Suppl Figure 5).

GSDP — HAPDB, annual new-vehicle registered - HAPDB and annual functional factories registered - HAPDB correlations

Unlike the earlier observation, the association between Household Air Pollution Disease Burden (HAPDB) and GSDP exhibited a statistically significant negative correlation for all individual states under consideration (Suppl Figure 6). Consistent with this, the annual new vehicle registered also showed inverse association in most states (i.e., n=28) except Andhra Pradesh and Jharkhand. However, a few states, viz. Andhra Pradesh, Jharkhand, Madhya Pradesh, Meghalaya, Rajasthan, and Tripura exhibited trends without statistical significance (Suppl Figure 6, Supp Table 7). All the states except Andhra Pradesh, Arunachal Pradesh, Delhi, and Maharashtra exhibited a negative association between APMDB and annual functional factories correlation. Among these, few states (n=2), i.e., Maharashtra and Punjab, exhibited a trend without statistical significance (i.e., $p > 0.05$) (Suppl Figure 6).

GSDP - Age standardised APADB, annual new vehicle registered - Age standardised APADB and annual functional factories registered- Age standardised APADB correlations

Consistent with earlier observations, APADB despite adjusting for age was negatively associated with individual state's productivity. The age standardised APADB was significantly and inversely associated with GSDP for all states (Suppl fig 7). The age standardised APADB was inversely associated with annual new vehicle registrations for most states, however Andhra Pradesh, Jharkhand and Rajasthan exhibited a trend of positive association ($p > 0.05$) (Suppl Figure 8). Similarly, the age standardised APADB was inversely associated with functional factories registered for most states, while the states Andhra Pradesh, Delhi, Arunachal Pradesh, and Maharashtra were exceptions exhibiting a trend of positive associations (Suppl Figure 9).

GSDP — Geoclimatic confounder's adjusted APADB, annual new vehicle registered - Geoclimatic confounder's adjusted APADB and annual functional factories registered- Geoclimatic confounder's adjusted APADB correlations

Data on the geoclimatic variables were available for the year 2020. The APADB — geoclimatic variables (maximum temperature, minimum temperature and change in rainfall) correlations exhibited trend of independent positive correlation with the change in maximum and minimum temperatures and inverse correlations with the change in annual rainfall, however, these results are statistically not significant ($p > 0.05$).

The associations between APADB and the markers of productivity were similar, despite adjusting for the geoclimatic confounding variables. Unlike the earlier observations, the APADB was positively associated with GSDP while keeping the potential geoclimatic confounders constant ($p < 0.05$). A similar trend without statistical significance ($p > 0.05$) was pronounced for APADB with annual new vehicles and the number of factories.

Unevenness and inequality in the distribution of APADB

Concentration index and Lorenz curve of APADB, revealing the unevenness and inequality with respect to the state's development and population indicators for 2011 and 2019 (Figure 3, Suppl Figure 10 to 13).

1. **APADB compared with GSDP:** The APADB was 47% unequally distributed across the GSDP, with the concentration index for 2011 of 0.47 (Table 2). The Lorenz curve explains a high unevenness across the spectrum of GSDP distribution in terms

Figure 2. Cross comparison of correlation between GSDP and growth in the motor vehicle with air pollution attributed disease burden in India & Cross comparison of correlation between GSDP and growth in the motor vehicle with air pollution attributed disease burden for 100,000 population in India.

[Scatter plot with the x-axis representing the correlation coefficient of air pollution attributed to disease burden and State-specific gross domestic product; and the y-axis representing the correlation coefficient of air pollution attributed to disease burden (per 100,000) and annual new vehicles registered in the state. White boxes represent statistically significant results (p<0.05) for both correlations. (AP- Andhra Pradesh, Arun- Arunachal Pradesh, Assa- Assam, Bih- Bihar, Chhat- Chhattisgarh, Guj- Gujarat, Har- Haryana, HP- Himachal Pradesh, Jhar- Jharkhand, Kar- Karnataka, Ker- Kerala, MP- Madhya Pradesh, Mah- Maharashtra, Man- Manipur, Megh- Meghalaya, Miz- Mizoram, nag- Nagaland, Odi- Odisha, Pun- Punjab, Raj- Rajasthan, Sikk- Sikkim, TN- Tamil Nadu, Tel- Telangana, Tri- Tripura, Utta- Uttarakhand, UP- Uttar Pradesh, WB- West Bengal)].

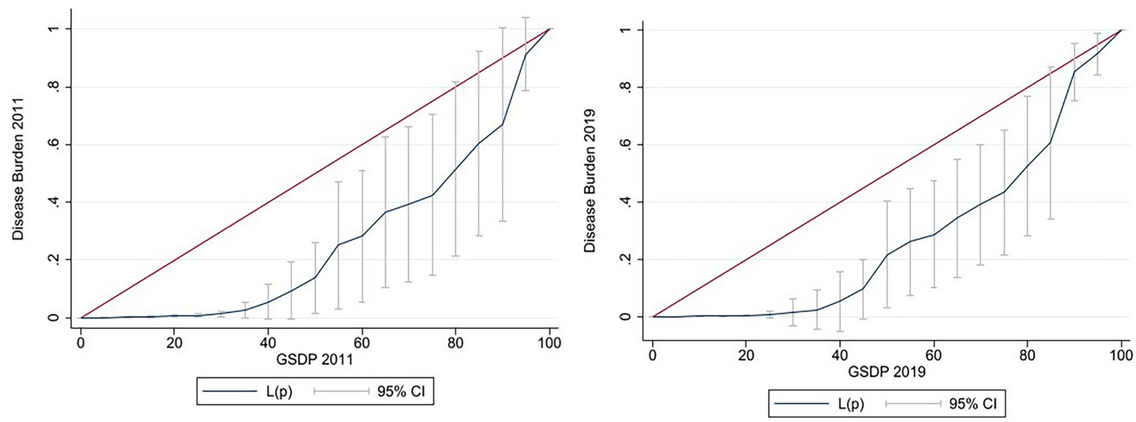


Figure 3. Lorenz curve for Air pollution attributed Disease burden compared with GSDP in India for 2011 and 2019.

of APADB, wherein the states occupying the 7th decile and above in terms of GSDP contribute to 60 per cent of total APADB (Figure 3). However, the inequality marginally reduced to 45% during 2019, despite the Lorenz curve demonstrating similar unevenness (Figure 3), requiring further investigation to identify the cause. The concentration index for both years was significant at 95 per cent confidence intervals ($p<0.05$).

2. **APADB compared with the number of motor vehicles:** The 2011 assessment of unevenness and inequality in APADB compared to the total number of new motor vehicles registered state-wise in India using the concentration index revealed a 20.5 per cent inequality (Table 2). The results were almost similar for 2019, as the rate of inequality minimally increased (20.8%) (Table 2, Suppl Figure 10).
3. **APADB compared with total population:** States occupying the eighth decile and above in terms of the population contribute 60 per cent of the total APADB in India, which implies 58% inequality prevailed during 2011 (Suppl Figure 11). The unevenness and inequality rates among the states marginally increased to 59 % in 2019 (Table 2).
4. **APADB compared with the total urban population:** The Concentration index revealed 50.6% inequality in APADB based on the total urban population in Indian states (Table 2). About 60 per cent of the APADB is observed among states occupying the 85th decile and above in terms of their total urban population, and as a result, the disparity between states in terms of APADB is remarkably high (Suppl Figure 12). However, a faint fall (concentration index value of 0.49) is noticeable in the inequality during 2019 (Table 2).
5. **APADB compared with the number of factories:** The 2011 concentration index value for APADB with reference to the number of functional factories in Indian states was 0.42, and the concentration index for 2019 was 0.40 (Table 2). The Lorenz curve is consistent with concentration index values, suggesting inconsistency in the distribution of APADB. Interestingly one-third of the Indian states (occupying the higher end of the spectrum) contribute to 60% of APADB (Suppl Figure 13). In essence, the states with the most functional factories (registered) contribute to the major share of APADB in India.

Factor	2011		2019	
	CI	*P*-value	CI	*P*-value
APADB with GSDP	0.47	<0.01	0.45	<0.01
APADB with number of Motor Vehicle	0.21	<0.02	0.21	<0.03
APADB with Population	0.58	<0.01	0.59	<0.01
APADB with Urban Population	0.51	<0.01	0.49	<0.01
APADB with Number of Factories	0.42	<0.01	0.40	<0.01

***Table 2*: Concentration index values comparing 2011 and 2019.**
APADB- Air pollution attributed disease burden, GSDP- Gross State Domestic Product, CI-Concentration index.

Discussion

The study evaluated the association between state-wise APADB and their respective direct (GSDP) and indirect measures (new motor vehicles registered) of development. Data on APADB for individual states in comparison with GSDP and motor vehicle growth were extracted from various digital repositories and analysed.[4,8,12,18–22] Inequality in the distribution of APADB across individual states were analysed using the concentration index and Lorenz curve.

Briefly, the observations include a negative association between APADB and GSDP for most of the states (Figure 1), the negative association pronounced when APADB per 100,000 was included in the analysis (Suppl fig 3). Current observations suggest that economic growth increases with the reduction in APADB and therefore, rise in productive capacity could be possible with the control of the disease burden.

The present study recorded a negative association between APADB and the indirect measure of state productivity, i.e., annual new vehicles registered, consistent with our observations (Suppl fig 1). Though an increase in the number of new vehicles registered suggests a likely increase in the elevation in vehicular emission-related air pollution, however, given the strict enforcement of motor engines with the least CO_2 emission during the last decade, the vehicular emission-related air pollution increase is minimal.[37] Further, the combined estimation of GSDP and annual new motor vehicles registered revealed a consistent inverse association with APADB for most Indian states (Figures 2).

A similar negative association was observed for the number of functioning factories with APADB and GSDP across the states, as economic progress leads to a reduction in disease burden due to air pollution (Suppl Figure 2). The total APADB exhibited decreasing trend across the study period with a corresponding increase in the number of working factories (supp table 2, 4). This possibly indicates that the air pollution disease burden is decreasing with economic growth. Though the number of factories is increasing, the corresponding disease burden due to air pollution is decreasing. This trend might be a result of recent factories adhering strictly to the national & international regulations in reducing the emission of air pollutants making them relatively environmentally friendly; however, it needs a further appraisal to explore the specific reasons.

However, considering the APADB separately into indoor (HAPDB) and outdoor (APMDB) air pollution exposed a negative association with economic growth for the former and a positive association for the latter. The correlation analysis between GSDP, annual new vehicles registered, and the number of working factories with APMDB exhibited a positive correlation tells that an increase in economic growth may lead to more ambient particulate matter pollution. Economic growth implies more vehicles, industrial production, and resource exploitation attributes to more pollution. On the contrary, the household air pollution revealed an inverse association with direct and indirect measures of growth implies that with economic growth, the HAPDB reduces. With a rise in GSDP, the economic status of families/people in the state goes up, and more families could afford to switch from conventional cooking methods to environment friendly measures.

Consistent with our earlier observations the association between age standardised APADB with GSDP, the number of factories and vehicles was negative. Thus, the state level association for APADB data and age standardised APADB data delivered identical results infers an impassive role for confounders like age structure. APADB is positively correlated to high and low temperatures and inversely with the change in rainfall, all without statistical significance. Therefore, the APADB is unaffected by geoclimatic confounders. Thus, even after adjusting for some of the state-level potential key confounders results were unaltered.

The concentration index revealed the presence of inequality among the states (Table 2), while the Lorenz curve exhibited higher inequality in APADB in terms of GSDP and other direct and indirect (population, urbanisation, and total factories) measures (Figure 3, Suppl Figure 11,12,13). While the Lorenz curve revealed lower inequality in the distribution of APADB in terms of motor vehicles registered (Suppl Figure 10), infers a consistency in APADB between individual states. However, the inequality in APADB, in terms of GSDP, urbanisation and number of functional factories registered, exhibited a faint decline during 2019 as compared to 2011 (Table 2). This necessitates further deliberations in understanding the reasons for these observed trends. Inequality in the disease burden (such as the APADB) may affect the linear productivity level.[38] The unevenness in APADB among Indian states is evident from the analysis as the states occupying the 6^{th} or 7^{th} decile, and above in terms of GDP, urbanisation and population contribute to over 60 % of the total APADB (Figure 3, Suppl Figure 8,9). Therefore, the industrialised and economically progressed states contribute to the inequality in APADB in Indian states. The vulnerability of air pollution and income levels were previously reported in other studies.[14,39,40]

The inverse association between APADB and gross production observed in the present study (Figure 1) is consistent with the literature.[14,41,42] Pandey et al. (2021) reported $36.8 billion losses in India due to morbidity and mortality attributable to air pollution (1.3 per cent of India's GDP).[14] Thus, though a reduction in APADB is perceptible (Suppl Figure 10), nevertheless, the current situation is strong enough to create a huge economic loss.[14] Thus, the problem of air pollution has a strong implication on the economic strength of individual states in India.

We analysed the relationship of APADB concerning economic growth in Indian states. Panda et al (2021) recently reported the economic loss due to morbidity and mortality associated with air pollution using the GBD data.[14] The cited study reported about 1.36 % of India's GDP (i.e., 36.8 billion USD) is attributed to air pollution-related morbidity and mortality using the cost of illness method. The present study analyses the potential impacts of APADB on state-level GSDP data. Further, the present study is perhaps the earliest to report the inequality and unevenness in APADB with respect to the direct (GSDP) and indirect (annual new motor vehicles registered, population, urbanisation and functional factories registered) measures of state development in the Indian subcontinent. Present observations guide towards potential directions for controlling the APADB, for the progress of individual states and the country.

However, current study observations are derived from secondary data available in the Global burden of disease study and therefore is associated with inherent assumptions. The GBD data involves non-uniform reporting of exposure assessment related to time and location further, APADB in GBD is restricted to DALY due to long-term exposure to ambient particulate matter, household air pollution and ozone levels. At the same time, the short impact was not included in the analysis.[14] Details on major limitations of GBD data are reported earlier and publicly available.[14,18] Certain trends like the state-specific high inequality in APADB, low inequality in terms of motor vehicles etc., need further investigation to explore the reasons. Due to the high spatial and temporal variability of air pollution, some of the indicators used for analysis may not be applicable to the entire population, and due to lack of sufficient data, the current analysis was restricted to the three direct and indirect measures of economic growth with potential bias. The adjustment for potential confounders were restricted to age and geo-climatic variables, while the other regional confounders and sociodemographics could not be adjusted given limited data availability.

Conclusion

The inverse associations observed between the APADB and markers of economic productivity for majority of the Indian states, may imply a drop in APADB would lead to the progress of the individual states as well as the nation. Further, the severity of air pollution influences the inequality in APADB and thereby the productivity of the Indian states. The observations from the current study mandate immediate action by the respective stakeholders to curtail/reduce air pollution Indoor air pollution requires attention from an individual, while particulate matter pollution requires government-level interventions. Hence, all these problems must be addressed and framing policies to cater for the impact of APADB is the need of the hour.

Contributors

BSB - conceptualisation of the study, investigation and methodology and provided the software. SK - data curation and drafted the manuscript. BSB and SK - formal analysis. BSB and BR - interpreted the results, provided inputs on the original draft, critical review and editing. All authors approved the final version of the manuscript. All authors had access to all the data in the study and had final responsibility for the decision to submit for publication.

Data sharing statement

All data used for the study are publicly available.

Editor note

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Declaration of interests

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.lansea.2022.100069.

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