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DEVELOPMENT ECONOMICS | RESEARCH ARTICLE

Association of air quality parameters and socio-demographic towards the human health in India using regression analysis

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Abstract: This paper investigates the socio-economic impact of air pollution on human health in India. The data on vehicle emissions and health effects are obtained from secondary sources, and data relating to the source of fuel, type of kitchen, household income, age, education, respondents' social class, and air-related diseases were collected through a primary source. Face-to-face interviews were conducted to collect primary data from selected 300 households using a structured questionnaire in rural and urban areas in India. The study results show that the higher-income households use alternative clean fuels like Liquefied Petroleum Gas (LPG) and electricity. The results indicate that the solid fuel users who used a kitchen without a partition wall were mostly affected by air-related diseases compared to other fuel users. The regression results indicate that the age of the household head has a positive 9.3%, gender of the household head has a negative 35.5%, the social class (caste) has a positive 20%, education of the household head has a negative 11.8%, household income has a negative 62.8%, kitchen type has a positive 23.7%, type of stove has a negative 30.7%, and type of fuel has a positive 33.1% effect on air related diseases. The study concluded that there is a need to prioritize promoting income and employment opportunities for the poor rural community. The infrastructure development activities could reduce the pollution from

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the vehicle. Implementing environmental education programs and campaigns could reduce the health problems in rural and urban areas in India.

Subjects: Development Studies; Health & Development; Population & Development; Urban Development; Environment & the Developing World

Keywords: Indoor air pollution; outdoor air pollution; human health; CO_2 emission

1. Introduction

The air we breathe, the water we drink, and the soil in which plants grow are all polluted by human activities. Solid fuels used in homes and gasoline for driving vehicles emit large quantities of pollutants into the atmosphere, endangering human health. Managing man-made air pollution is a major public health risk worldwide; roughly 9 million deaths are recorded yearly (Fuller et al., 2022).

Technological innovation and energy foster economic development at the cost of environmental degradation. Most of the air pollution in the cities is caused by point and non-point sources. For example, the release of fossil fuel smoke from factories and electric power plants can be easily traced back as a point source. On the other hand, even though the number of pollutants emitted by motor vehicles might be small, it becomes massive air pollution and a non-point source when added up. Even in industrialized countries, road traffic is the leading cause of air pollution in cities. Carbon fuels (coal, oil, wood, natural gas) cannot be completely burned, emitting CO and producing hydrocarbons. When nitrogen in the atmosphere is combined with oxygen during the combustion of fossil fuels, nitrogen oxide (NOx) is formed.

Human activities have increased the amount of volatile organic compounds (VOCs) and NOx due to petroleum, chemical industries, transportation, and NOx from power plants and automobiles. Particles are released into the air mostly due to combustion from mobile and stationary sources, contributing to poor air quality, particularly in urban areas. When coal and sulfur from fuel oils oxidise, sulfur dioxide is produced (SO2). These fuels are mainly used for processing in various industries and vehicles used for transportation, producing excessive amounts of pollutants in the atmosphere. However, the pollutants emitted by industrial plants or motor vehicles directly affect the environment and human health. The respective authority is monitoring these pollutants. Among the pollutants contributing to air pollution are carbon monoxide (CO), carbon dioxide (CO2), nitrate (NOx), sulfate (SO2), particulates smaller than 2.5 micrometers (PM2.5), particulates lesser than 10 micrometers (PM10), hydrocarbons (HC), and nitrogen dioxide (NO2; Magazzino et al., 2021c). The emission of carbon dioxide (CO_2) at the global level is expected to increase by 2.7% (37.1 billion tonnes) in 2018 due to significant growth in coal use and continuous growth in oil and gas usage (Dhital & Rupakheti, 2019).

Air pollution has various negative health effects. Air pollution has two types: indoor air pollution (air pollution from the household sector) and outdoor air pollution (air pollution from industries including power plants, automobiles, and other human activities that release gases), particulate matter, and smog. The ambient air can harm sensitive and vulnerable individuals even on a low-pollution duration. When air pollutants are inhaled even for a short period of time, they cause chronic obstructive pulmonary disease, coughing, wheezing, asthma, and hospitalizations (a measurement of morbidity; Pekince, Md & Baccioglu, Md, 2022). The Residents of large urban areas tend to be affected the most by air pollution, as road emissions are the greatest contributor to the degradation of air quality (Gu et al., 2019).

Developing countries are particularly affected by air pollution due to overpopulation, uncontrolled urbanization, and the country's industrialization (Manucci and Franchini, 2017). In India, environmental pollution, particularly air pollution, has become a major health concern. It has experienced extreme air pollution, with air quality becoming hazardous. India's capital city, New

Delhi, is one of the most polluted cities. Due to rapid industrialization, urbanization, and increased motorcycle travel, both rural and urban areas of India are affected by pollution.

Nonetheless, biomass burning associated with household heating and cooking is a major source of air pollution in India (Kankaria et al., 2014). India is the third contributor to CO_2 emissions after China, with a total of 2.6 billion tonnes and 7% of the global emission. In India, the use of coal, oil, and gas for energy extraction and the burning of solid fuels for household purposes are the main reasons for the rise in the quantum of pollutants in the air, increasing the health issue rapidly (International Energy Agency Report, 2018 in Down to Earth).

Many researchers focused on indoor and outdoor air pollution because a large population lives in big cities in industrialized countries such as India. However, people spend their time indoors according to age, gender, job, and health condition. Good air quality can protect residents' health and increase productivity. With the design of building infrastructure with the installation of better ventilation and air cleaning devices, the indoor air quality appears to be better than outdoor air quality. However, indoor and outdoor air quality studies found that indoor air pollutant concentrations were higher than outdoor pollutants (Chen and Zhao, 2011). These studies further emphasize the importance of conducting additional studies to understand better the causes of problems and the associated remedial measures for indoor and outdoor air pollution.

Meanwhile, the number of publications on air pollution has skyrocketed in recent decades. Many of these studies have confirmed that indoor air quality is heavily influenced by and dependent on outdoor air quality. Therefore, to solve our pollution problems, we must consider both the indoor and outdoor environments. Similarly, air pollution (AP), causes, types, and Occurrence of Air Related Diseases (OARD) have been studied extensively in the existing literature. However, most of the previous studies used secondary data and focused mainly on the impact of air pollution on human health i.e., hospitalization, disabilities, deaths, and economic loss. This study is the first comprehensive empirical research to understand the socio-economic aspects of air pollution and its health implications in India. Moreover, to address the environmental problem holistically, the researchers have formulated a unique conceptual framework by including socio-demographic factors such as the age of household head, gender of household head, caste, education, household income, kitchen type, and stove type. The study developed an innovative regression model to examine the relationship between household's socio-demographic factors, fuel use practice, and air pollution-related health impacts in India. This study expands the existing literature of environmental studies related to air pollution and OARD by incorporating diverse households' socioeconomic and demographic factors. Therefore, the study contributes a theoretical understanding of the interactions between the natural environment and human health that have not been explored in-depth in previous environmental literature. In this regard, the empirical findings of the present paper reinforce the necessity to develop and test the commonly accepted notion of the relationship between AP and OARD is complex. Undoubtedly, the current model, observations, and results of this study contribute significantly to the existing knowledge and can serve as a benchmark for similar studies in the future. In this connection, the current study focused on indoor and outdoor air pollution in two steps. In the first step, the study measured outdoor air pollution by a field study using different indicators, such as the number of vehicles on the road, emission norms, and kilometers run per day in the studied area. And in the second step, the study analyzed the effect of indoor sources of air pollution on human health along with some demographic factors in rural and urban areas in India.

2. Literature Review and Hypotheses Development

A sufficient body of evidence suggests that people in lower socio-economic groups and deprived communities have experienced a higher risk of air pollution and health problems. Previous studies have highlighted that poor and vulnerable households are exposed to higher levels of environmental pollution. Although there is a clear scientific understanding of the causes and impacts of air pollution, the links between households' socio-demographic factors and air quality remain unclear. The theory of energy choice is developed based on the "energy stack" and the "energy ladder" models (Fuss et al., 2016). These models assume that households choose alternative energy sources to meet their needs (Magazzino et al., 2021a). The energy ladder model was designed as a hierarchical relationship between household income, socio-economic status, and the type of energy used for cooking and heating (Barnes & Floor, 1999; Ipek & Ipek, 2021).

2.1. Indoor and Outdoor Air Pollution

Inefficient burning of unclean fuels produces a huge volume of particulate matter and chlorinated organic, free radicals, oxygenated organics, nitrogen dioxide, hydrocarbons, and carbon monoxide (Shan et al., 2018). Combining solid fuels in traditional stoves emits 50 times more pollution than gas stoves (Naeher et al., 2007). A study finds that household income influences the amount of energy used. Higher-income households use cleaner and more efficient energy (Umut, 2020). However, the transition to clean fuel has remained almost constant at 25% since 1975 (Zhu et al., 2020). Around 2.7 billion populations still cook primarily with polluting stoves and unclean fuels (International Energy Agency IEA, 2006).

The poorest communities in developing nations depend heavily on solid fuels for cooking and household activities (Becerra et al., 2020). In India, 780 million people live in 160 million households; 66% of all households get their energy from wood, crop residues, or cow dung, and 86% are rural households (Census 2017; Venkataraman et al., 2010). India's average particulate matter (PM2.5) concentration in indoor air is 375 micrograms per cubic meter (Indian Council for Medical Research, 2001). However, the indoor peak concentration of PM10 can exceed 2000 μg/m3 in several developing countries (Regalado et al., 2006). The 24-hour mean (daily average) particulate matter level is set as per the guidelines of WHO as; 25 μg/m3 for PM2.5 and 50 μg/m3 for PM10 (World Health Organisation, 2016).

Man-made outdoor air pollution has become a serious health issue recently. Moreover, the industrial revolution has significantly increased the use of biomass and fossil fuels for energy extraction. Vehicles are the primary source of outdoor air pollution, contributing to 60% of overall air pollution worldwide (Dash et al., 2020; Wu et al., 2018). The pollutants from automobiles spread out to the near-ground level, which affects the breathing of living animals. In India, nearly 90% of CO_2 is emitted by automobiles (JPN/Bureau, 2010) because of the personalized mode of transport (cars and two-wheelers), increasing disposable income, and sustained economic growth (Toledo de Almeida Albuquerque et al., 2020; Mele et al., 2021a). Cars and motorbikes subscribe for 11% and 78% of the pollution load, respectively (Mahendra & Krishnamurthy, 2005; Parhizkar et al., 2020). Motor vehicles that run on internal combustion engines do not burn all the fuel into the combustion chamber as the car ages. More than 20% of vehicles in India are very old and poorly maintained (Nesamani, 2010), creating a much higher pollution level than new vehicles.

Many countries have implemented rigorous emission controls and steadily reduced motor vehicle emissions (Parhizkar et al., 2020). Therefore, newly manufactured light motor vehicles emit around 90% lower toxins than the old generation of motor vehicles. Meanwhile, a record increase (around 140%) in total vehicle miles driven annually. Therefore, the overall emission reduction has remained the same, as the new generation of vehicles produces lower emissions, and the number of miles driven has increased sharply. Gasoline is still the main source of energy to drive vehicles through new vehicles using cleaner energy have been developed (Idris, Hoque, Susanto et al., 2022). The increased demand for road transport is reflected in the increased number of vehicles produced globally. With more vehicles on the road, congestion rises, and vehicles are the most significant source of outdoor air pollution. Indian cities have the world's highest levels of urban air pollution (Bansal, 2016).

2.2. Air Pollution and Health Status

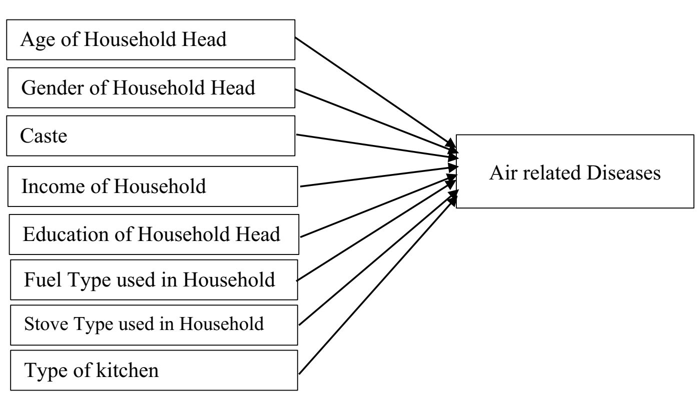
The pollutants in the air cause many diseases and deaths over the globe. Inhalation is the basic route for pollutants to enter the human body. A person inhales about 20,000 liters of air daily, consisting of dangerous chemicals (Zeng & He, 2019). Venkatesh (2016) found that fine particulate matter causes 7 to 8 million deaths annually and costs $5.11 trillion in welfare loss (SC, The Hindu, 06.12.2018).

Nearly 77% of Indians were exposed to air pollution and related illnesses and deaths in 2017; 6.7 lakh deaths were attributed to outdoor air pollution and 4.8 lakh to indoor air pollution, i.e., 26% of premature deaths and disease burden in India. (In the haze, State of Global Air Report, 2018; Balakrishnan, 2018; International Energy Agency IEA, 2006). In 2040, it is projected to reach 7.5 million, 4.5 million because of outdoor and indoor air pollution. After water-related diseases, air pollution is considered the second most important environmental cause of the disease (Aye & Edoja, 2017). The negative impact of air pollution has created a socio-economic impact on the socially vulnerable and poor people compared to other households due to their weak crisis coping options (Mattiuzzi & Lippi, 2020). The challenge for India is more formidable than that faced by many other emerging economies. Koshy (2016) found that air pollution leads to 12 times higher disease burden in India than in China due to the high pollution levels.

Developing countries have a substantial problem with indoor air pollution because it exposes people to various health problems such as respiratory diseases, lung cancer, chronic obstructive pulmonary disease, and cardiovascular diseases (Caravaggio et al., 2019). In 2016, the WHO reported that solid fuel combustion is responsible for 2.7% of the global disease burden and the 10th leading cause of avoidable deaths (World Health Organisation, 2016). Indoor air pollution alone contributes to 6% of the disease burden in India (Prasad, 2015). Around 40.24% of deaths were from residential biomass burning (In the haze, State of Global Air Report, 2018 in Data Point). The WHO estimates that 3 million people die annually from indoor air pollution, 60% of those being children and women (World Health Organisation, 2016). Indians also have the poorest lung function globally (Koshy, 2016). Nevertheless, socio-economic, gender, age, and experience levels are related to the health effects (Bruce et al., 2000).

Outdoor air pollution, especially from motor vehicles, increases morbidity and mortality, revealed through vision impairment, bronchial problems, eye irritation, nausea, headache, and cough (Ain et al., 2021). Respiratory disease development is the most common effect of outdoor air pollution. It also rapidly harms the central nervous and cardiovascular systems (Dong et al. (2019). About 1.4% of total mortality is attributed to outdoor air pollution. Most deaths attributable to disability-adjusted life years (DALY) occur in people aged 60 or older, representing 81% of all deaths. Under five-year-olds account for 3% of total attributable deaths and 12% of disability-adjusted life years (World Health Organisation, 2016). Respiratory illnesses related to particulate matter remain the top health concern, especially among children (Song et al., 2020). In this connection, Bangalore has been titled the asthma capital of India due to the high prevalence of this disease; approximately 50% of the children and 10% of its population suffer from outdoor air

Figure 1. Conceptual Framework.



ailments (Bansal & Rukmini, 2016). Following are some conceptual frameworks (Figure 1) and hypotheses derived from the discussion above.

H_{01}: The age of the household head significantly affects household air-related diseases.

H_{02}: The gender of the household head significantly affects household air-related diseases.

H_{03}: The caste significantly affects air-related diseases in the households.

H_{04}: The household's income significantly affects air-related diseases in the households.

H_{05}: The education of the household head significantly affects household air-related diseases.

H_{06}: Fuel type used in the household significantly affects household air-related diseases.

H_{07}: Stove type has a significant effect on households' air-related diseases.

H_{08}: The kitchen type significantly affects households' air-related diseases.

3. Methodology

3.1. Study Area

The study was conducted in Kanniyakumari in the Tamil Nadu district, located in the southern part of India. It is the smallest and the most urbanized district in Tamil Nadu. The total geographical area of this district is 1672 square kilometers. The district is purely agriculture-oriented, and its economy depends on agricultural production and allied activities. Indeed, Tamil Nadu State is one of the most industrially backward districts. As per the 2011 Census, the total population of this district was 1,870,374, out of which 926,345 were males and 944,029 were females. It is ranked first in literacy rate (91.75%) and second in population density (1119 per sq. km) and urbanization (60.64%) at the top of the state's Human Development Index with 0.944 (Ramakrishnan, 2017). As of 31 March 2021, the district's total number of motor vehicles on the road was 654,012 (Statistical Handbook of Kanyakumari District, 2017,08,09,10,11,12,16 & 21). The vehicle penetration in the district was 350 per 1000 in 2021, which is higher than the nationally registered motor vehicle of 225 in 2019 (Road Transport Yearbook, 2017-18 & 2018-2019). In Tamil Nadu, the State Road Transport Corporation (TNSRTC) runs vehicles registered in the 1950s. Consequently, pollutants, particularly carbon monoxide in the air, have increased significantly. For example, in the Periyar bus stand in Madurai, Tamil Nadu, the presence of carbon monoxide amounts to 400 μg/m3 (Ganesh, 2017). Thus, people are highly threatened by energy-related air pollution in almost all parts of India, including the Kanniyakumari District.

3.2. Data and Model

This study used both primary and secondary data. Data regarding vehicular emission coefficients and health effects of air pollution were collected from secondary sources, and data related to the source of fuel, type of kitchen, household income, age, gender, education, the caste of informants, and the number of persons affected by air-related diseases are collected through a primary survey. The study used a multi-stage random sampling technique for selecting the respondents. In the first stage, two areas (rural & urban) were selected randomly; in the second stage, three regions (hilly, coastal & midland) from each area were selected; thus, six regions were selected randomly. In the last stage, 50 households from each region were selected randomly. Thus, 300 households were selected for the study as the unit of analysis is household, and data has been collected from the head of household. Moreover, the vehicular traffic data on the district's main roads were collected using the Tally method. Based on the vehicle category, each vehicle on the street is counted manually and recorded carefully on three average working days for one hour at four-hourly intervals, i.e., at 05:00 hours, 09:00 hours, 13:00 hours, 17:00 hours, and 21:00 hours. Based on these data, the average daily flow was estimated for the entire day.

To estimate the quantum of vehicular pollution in the Kanniyakumari district, the researcher counted the number of vehicles and estimated the average kilometers they run according to their category. The primary data collected through a field study are supplemented by secondary data on emission coefficient factors such as CO, NO_x, HC, and PM for different categories of vehicles. The emission norms per vehicle were obtained from Central Pollution Control Board (CPCB, 2010). However, since the emission factors are available for a few broadheads, namely, two-wheelers, cars and jeeps, buses, goods vehicles, and others, the present study has assumed the emission factors of all other categories and certain non-transport vehicles such as rigs, cranes, road-rollers, fire engines and so on to be the same as that of others. It is then calculated by multiplying the average kilometer traveled by each category of vehicles and the emission factors corresponding to various emission stages, such as pre-euro and euro norms. Thus, the total emissions of various pollutants are calculated. The on-road motor vehicle emission inventory can be summarised as the product of an emission rate (e.g., gram/km) and an associated vehicle activity (e.g., km/day).

$$P_{it} = \Sigma\ V_{it} * U_{it} * E_{it}$$

Where,

- P—Pollutants emitted by vehicles per day.
- V—Number of Vehicles on the road per day.
- U—Vehicle utilization (Trip length per vehicle per day in KM)
- E—Emission norms g/KM (CO, HC, NO_X, PM)
- i—Vehicle mode (Heavy vehicle, Light vehicle, Three-wheeler, Two-wheeler)
- t—Calendar per day

The study applied descriptive analysis to assess outdoor air pollution and its relationship with human health in Tamil Nadu. Moreover, multiple linear regression is carried out to determine the significant impact of indoor air pollution on air-related diseases in rural and urban parts of Tamil Nadu, India. Ordinary Least Squares estimates the equation separately for rural and urban areas. In this model, the dependent variable is the incidence of air-related diseases, while the explanatory variables are the household's demographic and socio-economic variables

$$\begin{aligned}\text{OARD} = \alpha + \beta_1\text{Fuel Type} + \beta_2\text{Type of Stove} + \beta_3\text{Type of Kitchen} + \beta_4\text{AGE} + \beta_5\text{GENDER} + \beta_6 \\ \text{CASTE} + \beta_7\text{INCOME} + \beta_8\text{EDU} + U_i\end{aligned} \tag{1}$$

OARD = air-related disease measured by counting the number of household members affected by asthma, eye irritation, lung cancer, acute respiratory disease (ARI), and chronic obstructive pulmonary disease (COPD). Eight explanatory variables are included in the model (1), consisting of various socio-economic indicators to determine the amount of air pollution generated by human activity, such as Fuel Type used in the household, Type of Kitchen, Type of Stove in the household, age of the household head (AGE), gender of household head (male/female); Caste of households belong to the social class, level of education attained by the household head; monthly income of the household in Indian Rupees; in this current model parameters from β_1 to β_7 have to be estimated, and U_i (which represent the unexplored factors) serves as an error term. We select the variables to include in each model based on a general to the specific model selection process.

Table 1. Households' fuel use in rural and urban areas

Fuel Type	Area		Total (%)
	Rural	Urban	
Solid Fuels (Unclean Fuel)	38	21	59 (19.67)
Non-Solid Fuels (Clean Fuel)	112	129	241(80.33)
Total	150	150	300 (100)

Table 2. Household fuel use by income category

Income per month (Rs)	Agriculture waste	Kerosene	LPG	LPG & Electricity	LPG & Kerosene	Total
0–1000	32	25	0	0	0	57
1001–2000	17	10	0	0	0	27
2001–5000	7	40	27	2	8	84
5001–10,000	2	20	50	4	11	87
10,001–25,000	1	4	14	7	9	35
25,001+	0	0	1	9	0	10
Total	59	99	92	22	28	300

Table 3. Distribution of households for kitchen types

Kitchen Type	No of Households (%)
Indoor kitchen without partition	65 (21.7)
Indoor kitchen with partition	154 (51.3)
Separate kitchen outside the house	54 (18.0)
Open-air kitchen	27 (9.0)
Total	300 (100)

4. Results and Discussions

4.1. Descriptive Statistics

The use of solid fuels for cooking and emissions from vehicles (energy-related air pollution) are the two major causes of ill-health and premature deaths in India. Commonly, young children and women spend a major proportion of time in poorly ventilated kitchens, and hence they are vulnerable to indoor air pollution. This study examined how solid fuels and the types of kitchens affect people's health. The types of fuel used for domestic needs can be categorized into solid and non-solid fuels. Solid fuels are the most unclean fuel among the fuels, including dung, wood, agriculture waste, charcoal, and crop residues. Non-solid fuels, such as kerosene, LPG, bio-gas, and electricity, are clean fuels. Most of the respondents from rural and urban areas have used non-solid fuels. Only 20% of respondents have used solid fuels in the study area (Table 1).

Using clean fuel for cooking is a prerequisite for better indoor air quality and human health. However, clean fuel is typically more expensive than solid fuel, and economically backward households mainly use solid fuels. Table 2 shows that households with a low income (2000 rupees and below monthly income) used agricultural wastes and kerosene. The high-income households with incomes range 2000 rupees and above used LPG and electricity.

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Table 4. Vehicular flow per day by locations

Vehicle	Kottar	Marthandam	Ozhinasery	Parvathipuram	Total
Heavy vehicle	1634 (5.3)	14,475 (47.2)	9469 (30.9)	5105 (16.6)	30,683 (11.3)
Light vehicle	5865(9.2)	29,915(46.7)	15,363(24.0)	12,920(20.2)	64,063(23.6)
Three-wheeler	4873(20.9)	11,096(43.8)	6755(26.7)	2612(10.3)	25,336(9.4)
Two-wheeler	22,474(14.9)	66,483(44.1)	40,224(26.7)	21,679(14.4)	150,860(55.7)
Total	34,846 (12.9)	121,969 (45.0)	71,811(26.5)	42,316 (15.6)	270,942(100)

Table 5. Average distance traveled by the surveyed vehicles

Vehicle	Total Kilometres Run (in' 000)					Average km/vehicle
	Kottar	Marthandam	Ozhinasery	Parvathipuram	Total	
Heavy	65	758	724	306	1853	60.39
Light	147	538	1047	517	2248	35.09
Three-wheeler	29	34	89	21	173	6.83
Two-wheeler	337	804	1994	542	3678	24.38
Total	578	2133	3854	1386	7952	29.35

Table 6. Carbon monoxide released by vehicles in the survey locations (in gm/day)

Locations	Heavy Vehicle	Light Vehicle	Three-Wheeler	Two-Wheeler	Total
Kottar	215	303	190	1188	1896
Parvathipuram	153	1068	888	1910	4019
Ozhinasery	248	1112	2197	2836	6393
Marthandam	651	2165	2099	7031	11,946
Total	1267	4648	5374	12,965	24,254

Table 7. Hydrocarbon Released by Vehicles in the Surveyed Locations (in gm/day)

Locations	Heavy Vehicle	Light Vehicle	Three-Wheeler	Two-Wheeler	Total
Kottar	53	49	132	898	1132
Parvathipuram	248	171	95	1443	1957
Ozhinasery	614	178	153	2142	3087
Marthandam	586	347	402	5311	6646
Total	1501	745	782	9794	12,822

Table 8. Nitrogen Oxide Released by Vehicles (in gm/day)

Locations	Heavy Vehicle	Light Vehicle	Three-Wheeler	Two-Wheeler	Total
Kottar	698	57	3	43	800
Parvathipuram	3270	200	2	69	3541
Ozhinasery	8087	208	3	103	8400
Marthandam	7726	405	8	254	8394
All places	19,780	870	16	469	21,135

The results indicate that increasing household income influences people to use clean fuels like LPG and electricity. The results support the energy ladder model of Gerald Leach (Holdren et al., 2000). The type of kitchen used by the households is the most influencing factor for indoor pollution. The data shows that 51% of the respondents used the kitchen with a partition followed by the household's indoor kitchen without participation (22%), resulting in the spread of smoke all over the house, affecting the people's health inside the home. Separate kitchen outside the house and kitchen in the open-air account for 27% of respondents (Table 3). The study's result indicates

Table 9. Particulate Matter Released by Vehicles (in gm/day)

Locations	Heavy Vehicle	Light Vehicle	Three-Wheeler	Two-Wheeler	Total
Kottar	287	4	5	38	333
Parvathipuram	461	15	3	176	655
Ozhinasery	684	16	6	436	1141
Marthandam	1695	30	15	416	2156
All places	3126	65	29	1065	4285

Table 10. Location-wise Total Emission Load of Counted Vehicles (in gm/day)

Place	CO	HC	NO_x	PM	Total
Kottar	1896	1132	800	333	4161
Parvathipuram	4019	1957	3541	655	10,172
Ozhinasery	6393	3087	8400	1141	19,021
Marthandam	11,946	6646	8394	2156	29,142
All places	24,254	12,822	21,135	4285	62,496

Source: Calculated from Primary Data

Table 11. Category-wise total emission load of surveyed vehicles (in gm/day)

Vehicle Category	CO	HC	NO_X	PM	Total
Heavy Vehicle	5374	1501	19,780	3126	29,781
Light Vehicle	4648	745	870	65	6328
Three-Wheeler	1267	782	16	29	2094
Two-Wheeler	12,965	9794	469	1065	24,293
Total	24,254	12,822	21,135	4285	62,496

that most households do not have a separate kitchen with proper ventilation, which may produce less exposure to indoor air pollution.

4.2. Measurement of Outdoor Air Pollution

The data relating to the average number of vehicles running in the study areas in the Kanniyakumari district and the estimated air pollution emitted by the vehicles are presented. The vehicular traffic data show that 56% of the vehicles are two-wheelers, 44% of the total vehicles surveyed were plying in Marthandam, and 26% were plying in Ozhinasery. Out of the total vehicle surveyed, 24% were light vehicles, and around 47% of light vehicles were playing in the Marthandam location (Table 4).

Data on the trip length refers to the number of kilometers traveled by an observed vehicle. In contrast, the total distance traveled indicates the total kilometers run by a category of vehicles. Table 5 shows that heavy vehicles' trip lengths are 60 km and 35 km for light vehicles. Two-wheeler vehicles traveled longer than three, 24% and 7%, respectively.

4.3. Vehicular Emission Loads

The internal combustion engine requires a mixture of air and fuel to propel the vehicle, i.e., to burn and produce energy. The entire fuel that enters the engine is not burnt out, but a portion is unburnt and exhausted. The exhaust contains several pollutants. Carbon monoxide, hydrocarbons, nitrogen, and particulate matter are major pollutants.

4.3.1. Carbon Monoxide (CO)

Carbon monoxide is an incomplete combustion product that occurs when the carbon within the fuel is partially oxidized. Gasoline engines emit more CO than diesel engines because they have lower combustion temperatures. Table 6 shows the CO emissions by different vehicle categories in different locations. The results show that the highest CO emissions occur in Marthandam and the lowest emissions in Kottar (Table 6).

4.3.2. Hydrocarbon (HC)

Hydrocarbon emission is the consequence of fuel evaporation and incomplete combustion. It reacts with nitrogen oxides and sunlight and forms ground-level ozone. Table 7 shows the HC emissions by different categories of vehicles at different surveyed locations. According to the results, HC emissions were the highest in Marthandam and lowest in Kottar (Table 7).

4.3.3. Nitrogen Oxide (NO_x)
Motor vehicles burn a small proportion of the nitrogen found in air and fuels. As diesel engines require higher combustion temperatures, they produce more volumes of NO_x than petrol engines. The NO_x emissions of different categories of vehicles at different surveyed locations are illustrated in Table 8. Results show that the largest NOx emissions were recorded in Marthandam and the smallest in Kottar (Table 8).

4.3.4. Particulate Matters (PM)
Tiny particles contain many substances, including polycyclic aromatic hydrocarbons, carbon, and metals. Furthermore, diesel engines emit more Particulate Matter (PM) than petrol engines. Particulate matter emission levels are higher in heavy diesel-engine vehicles than in light vehicles. The PM emitted by different categories of vehicles shows that the PM emission was the highest in Marthandam, and the lowest emissions were found in Kottar (Table 9). Heavy vehicles released relatively higher PM emissions compared to other types of vehicles.

4.3.5. Total Vehicular Emissions
The surveyed vehicles' total daily pollutants in the selected four locations are 62,496 grams. Out of total emissions, CO produces 24,254 gm/day, HC produces 12,822 gm/day, NO_x produces 21,135 gm/day and PM produces 4,285 gm/day (Table 10). The results show that the emission loads were highest in Marthandam, followed by Ozhinasery in the study area. Heavy and two-wheeler vehicles produced the highest emissions from various pollutants among the vehicle types.

4.4. Air Pollution and Health Status
Air pollution affects people's health in different ways, such as smaller particles affecting the smaller respiratory tract called alveoli, which are positioned deep into the lungs, and large particles of atmospheric pollutants affect the upper respiratory tract of the lungs. The respondents reported five main air-related diseases: asthma, eye irritation, lung cancer, acute respiratory disease (ARI), and chronic obstructive pulmonary disease (COPD). The area-wise family members affected by air-related diseases are presented in Table 11 and Table 12. The results show that 58% of urban respondents were affected by air-related diseases, while 42% were affected in rural areas. Among the different geographical locations, midland dwellers were more affected in urban and rural areas (Table 12). The lowest number of people were affected in the hilly areas with relatively low air pollution.

Table 13 shows that air-related diseases mainly affected children below ten and elderly people between 50 and 60 years old.

Men usually spend more time outside their homes (outdoor) for occupational purposes; they are more likely to be affected by outdoor air pollution than women. On the other hand, indoor pollution affects more women and children compared to men. The present study also reveals that men are more affected by air-related diseases than women, while more women are affected by eye irritation and acute respiratory diseases than men (Table 14).

Results presented in Table 15 show a negative relationship between caste and the incidence of air-related diseases in the study area. The ST and SC groups among the castes were more affected by air-related disease, 26%, and 20%, respectively. An average of 15% of respondents who belong to the other castes in the survey area were affected.

Table 16 shows that the air-related disease affected family members without formal education. The attainment of primary and secondary education was more affected by air-related diseases

Table 12. Persons affected by air-related diseases in the study location

Area		COPD	ARI	Lung cancer	Eye irritation	Asthma	Affected	Total
Rural	Hilly	6	7	2	1	4	20	**81(42%)**
	Coastal	12	6	4	1	5	28	
	Midland	10	3	8	5	7	33	
Urban	Hilly	5	5	3	4	9	26	**112(58%)**
	Coastal	18	3	0	5	8	34	
	Midland	16	11	10	6	9	52	
Total		67	35	27	22	42	193	**193(100)**

Table 13. Age of Persons Affected by Air-related Diseases

Age	COPD	ARI	Lung cancer	Eye irritation	Asthma	Affected (%)	Not Affected (%)
0–10	0	19	0	1	0	20 (20)	78 (80)
11–20	1	3	0	2	4	10 (5)	211 (95)
21–30	3	0	1	2	5	11 (4)	260 (96)
31–40	12	0	2	3	4	21 (12)	154 (88)
41–50	21	11	9	4	7	52 (24)	167 (76)
51–60	24	2	9	4	15	54 (38)	90 (62)
61–70	4	0	2	5	7	18 (35)	33 (65)
≥71	2	0	4	1	0	7 (50)	7 (50)
Total	67	35	27	22	42	193 (16.18)	1000 (83.82)

Table 14. Air-related diseases affected by gender

Gender	COPD	ARI	Lung cancer	Eye irritation	Asthma	Affected (%)	Not Affected (%)
Male	41	9	16	10	31	107 (16.95)	524 (83.1)
Female	26	26	11	12	11	86 (15.30)	476 (84.7)
Total	67	35	27	22	42	193	1000

Table 15. Distribution of air-related disease affected persons by caste

Caste	COPD	ARI	Lung cancer	Eye irritation	Asthma	Affected (%)	Not affected (%)
FC	5	2	0	1	4	12 (14)	72 (86)
BC	38	24	17	19	26	124 (16)	662 (84)
MBC	8	3	5	0	7	23 (14)	139 (86)
SC	14	3	5	2	4	28 (20)	110 (80)
ST	2	3	0	0	1	6 (26)	17 (74)
Total	67	35	27	22	42	193	1000

than the members who attained higher education. The result clearly shows a negative relationship between education and the incidence of air-related diseases.

Household income is positively associated with better health. Table 17 shows that a greater number of people who belong to the lower-income group are relatively more affected by air-related disease than high-income households.

Table 18 shows that agricultural waste users were the most affected (27%) by air-related diseases among the respondents who used various fuel types. The LPG users were the least affected (11%) by the study area's air-related disease. Similar results were presented in Table 1, in which 59 households use solid fuels for cooking and other domestic uses.

The type of kitchen is an important factor that influences air-related diseases. Table 19 presents the number of people affected by the kitchen category. The results show that people who used

Table 16. Distribution of air-related disease-affected persons by education

Education Level	COPD	ARI	LC	EI	Asthma	Affected (%)	Not affected (%)
Illiterate	13	10	0	1	6	30 (28)	78 (72)
Primary	9	12	1	3	0	25 (21)	94 (79)
High School	13	6	6	9	9	43 (20)	177 (80)
H.S.S.	10	2	11	2	6	31 (11)	245 (89)
Degree	15	5	8	4	16	48 (15)	265 (85)
Professional	6	0	1	1	5	13 (10)	113 (90)
Technical	1	0	0	2	0	3 (10)	28 (90)
Total	67	35	27	22	42	193	1000

EI = Eye irritation, LC = Lung cancer,

Income (Rs.)	COPD	ARI	LC	EI	Asthma	Affected (%)	Not affected (%)
0–1000	15	16	7	14	13	65 (22)	228 (78)
1001–2000	7	5	6	1	10	29 (20)	113 (80)
2001–5000	16	8	7	4	16	51 (14)	310 (86)
5001–10,000	22	4	5	1	1	33 (13)	218 (87)
10,001–25,000	5	2	1	2	2	12 (11)	99 (89)
25,001+	2	0	1	0	0	3 (9)	32 (81)
Total	67	35	27	22	42	193	1000

Table 17. Distribution of air-related disease-affected persons by household income

Table 18. Prevalence of air-related diseases by fuel category (%)

Fuel types	Number of Family Members		
	Affected	Not affected	Total
Agriculture waste	65(27)	177 (73)	242 (100)
Kerosene	57(14)	347 (86)	404 (100)
LPG	40(11)	324 (89)	364 (100)
LPG & Electricity	16(20)	65 (80)	81(100)
LPG &Kerosene	15(15)	87(85)	102 (100)
Total	193	1000	1193

indoor kitchens without partitions were more affected by air-related diseases than other kitchens with partitions.

The results support the results presented in Table 3, where 65 households have an indoor kitchen without a partition wall, where 267 people live, and out of them, 68 (25%) persons are affected by air-related diseases.

4.5. Regression Findings

Multiple linear regression analyses were performed to analyze various socio-economic factors' effects on air-related disease. In the first stage, multicollinearity and auto-correlation were analyzed to confirm the basic assumption of linear regression. VIF and tolerance were computed for collinearity statistics. Tolerance, which ranges from 0 to 1, is associated with each independent

Table 19. Prevalence of air-related diseases by kitchen types (%)

Kitchen type	Number of Family Members		Total
	Affected	Not affected	
Indoor kitchen without partition	68 (25)	199 (75)	267 (100)
Indoor kitchen with partition	57 (9)	540 (81)	597 (100)
Separate kitchen outside the house	42 (19)	42 (19)	225 (100)
Open air kitchen	6 (6)	98 (94)	104 (100)
Total	193 (16.2)	1000 (83.8)	1193 (100)

Table 20. Correlation

Air related Diseases		Age	Gender	Caste	Education	Total Income	Kitchen Type	Type of Stove	Type of Fuel
Air related Diseases	1.000								
Age	0.088	1.000							
Gender	0.032	−0.085	1.000						
Caste	0.019	0.031	0.153	1.000					
Education	0.033	−0.349	0.073	0.051	1.000				
Total Income	0.443	0.056	−0.010	−0.043	0.155	1.000			
Kitchen Type	0.046	0.091	−0.102	−0.138	−0.169	−0.117	1.000		
Type of Stove	−0.060	0.063	0.081	−0.004	−0.294	−0.191	0.303	1.000	
Type of Fuel	0.088	−0.061	−0.039	0.069	0.090	0.083	−0.055	−0.290	1.000

Table 21. Regression Coefficients

	Rural Model	Urban Model	Overall Model	Collinearity Statistics	
	β	β	β	Tolerance	VIF
(Constant)	0.685	2.982	1.514	–	–
Age	0.013**	0.034**	0.093**	0.853	1.172
Gender	−0.272*	−0.667*	−0.355*	0.960	1.042
Caste	0.386*	0.150*	0.208**	0.965	1.036
Education	−0.066*	−0.105**	−0.118*	0.787	1.271
Total Income	−0.542**	−0.727**	−0.628**	0.976	1.025
Kitchen Type	0.283*	0.194**	0.237*	0.914	1.094
Type of Stove	0.201*	0.261*	−0.307*	0.734	1.363
Type of Fuel	0.229*	0.249*	0.331*	0.846	1.181
R Square	0.389	0.271	0.449		
F-statistic	5.186	9.876	13.545		
Model Sig.	0.000	0.001	0.000		
Durbin-Watson	2.009	2.114	2.064		
N	160	140	300		

Dependent Variable: Air-related Diseases
Note: * indicates a 1% level of significance; ** indicates a 5% level of significance

variable and is used in applied regression analysis to assess levels of multicollinearity. Tolerance quantifies how much the presence of other predictor variables in a model affects beta coefficients, and smaller tolerance values indicate higher levels of multicollinearity. Allison (1999) observes that there is no hard and fast tolerance cut-off, but tolerances less than 0.40 cause concern.

Furthermore, a VIF above 4 or a tolerance below 0.25 indicates the potential for multicollinearity and requires further study. A significant multicollinearity correction is required if the VIF is greater than 10 or the tolerance is less than 0.1. However, the value of VIF and tolerance are less than the threshold value for all variables used in the current model, indicating no multicollinearity problem in the model, as shown in Table 21.

Similarly, The Durbin Watson (DW) statistic is a test for autocorrelation in statistical model or regression analysis residuals. The Durbin-Watson statistic has a constant value between 0 and 4. A value of 2.0 indicates that no autocorrelation was discovered in the sample. Values ranging from 0 to less than 2 indicate positive autocorrelation, while values from 2 to 4 indicate negative autocorrelation. Meanwhile, the calculated values of Durbin Watson for the current model indicate no auto-correlation issue in current models, as shown in Table 21.

Furthermore, the correlation coefficients were used to examine the relationship among all the variables used in the current model, such as air-related diseases, age of the household head, gender of the household head, caste, education of the household head, total income of the household, kitchen type, type of stove and type of fuel used in the household. The calculated correlation coefficient values in Table 20 show that type of stove negatively correlates with air-related disease, and the rest of the variables positively correlated with air-related diseases.

After confirming the diagnostic test results, multiple linear regression analyses were performed to analyze various socio-economic factors' effects on air-related disease in the second stage. Three regression models were analyzed; the first model was regressed based on rural household data, the second was regressed based on urban household data, and the third was regressed based on overall data (rural & urban).

The R square value of the rural model is 0.389, which indicates that 38.9 per cent of the variation in air-related diseases is due to present predictors. For the urban model, R square's value is 0.271, indicating that 27.1 per cent variation in air-related diseases is due to present predictors. Similarly, the value of the R square of the overall model is 0.449, indicating that 44.9 per cent of the variation in air-related diseases is due to present predictors, as shown in Table 21. The F-statistic value of all three models is higher than the threshold value, indicating that the models are statistically significant.

Furthermore, current results suggest that the age coefficient is positive and statistically significant in rural and urban areas of Tamil Nadu, India. Age significantly affects air-related diseases in all three models, with β-value 0.013, 0.034, and 0.093, respectively, for rural, urban, and overall models. This result shows that a 1-year increase in age will bring a 1.3 per cent increase in air-related diseases in rural areas, 3.4 per cent in urban areas, and 9.3 per cent with the overall model. This result is significant at a 5 per cent level of significance. Thus, the first hypothesis is rejected. The result indicates that people are affected by air-related diseases as they get older, and these results are in line with existing literature and the realities across the country (Balakrishnan, 2018).

The coefficient of gender is negative and statistically significant in urban areas. Gender was measured through binary variables with only two values, 0 or 1, and 0 was the base category representing males. The gender of the head of household indicates a negative and significant effect on air-related diseases in all three models, with β-value −0.272, −0.667, and −0.355, respectively, for the rural, urban, and overall models. This result shows that moving from 0 to 1 will bring a − 27.2 per cent increase in air-related diseases in rural areas, −66.7 per cent in urban areas, and −0.355 per cent in the overall model. This result is significant at a 1 per cent level of significance. Thus, the second hypothesis is rejected. The results indicate that male and female members work outside their homes in urban areas. They use a relatively better house and kitchen space in the indoor and common vehicles in the outdoor environment. Urbanization could reduce the air-related disease for the men in rural areas who usually work outside the home. On the other hand, the women in the rural areas affected by indoor pollution could hardly resist the air-related disease. Because women are responsible for cooking and spend long periods at home due to their gender role in India, these findings are consistent with existing literature and the realities of the country (Bansal & Rukmini, 2016).

Similarly, the current results show that the coefficient of the caste is positive and statistically significant in both rural and urban areas. Caste measured through five categories, namely, 1) forward caste (FC), 2) backward caste (BC), 3) most backward caste (MBC), 4) schedule caste (SC), and 5) schedule tribe (ST). For rural, urban, and overall models, caste significantly affects air-related diseases in all three models, with β-value 0.386, 0.150, and 0.208, respectively. This result shows that moving from base category 1 to every next category will bring a 38.6 per cent increase air related diseases in rural areas, 15 per cent in urban areas, and 20.8 per cent with overall all models, and the result for rural model and urban model is significant at 1 per cent level of significance; however, the overall model is significant statistically at 5 per cent level of significance. Based on the results, the third hypothesis is rejected. Previous research found that scheduled caste and tribe households had less access to LPG and consumed less electricity than upper-caste households. This is due, in part, to the fact that these marginalized groups tend to live within their cluster. Scheduled caste households are frequently segregated in hamlets outside the main village perimeter in rural India, making it easier for electrical or gas suppliers to discriminate against them. Members of scheduled tribes frequently live in outlying areas. However, inequality in energy access appears to be caused by scheduled caste and scheduled tribe households, which have lower returns on socio-economic capital, such as education or documentation (Becerra et al., 2020).

Moreover, the indoor and outdoor environment could be improved significantly through environmental awareness among the local communities. The coefficient of education is negative and statistically significant in rural and urban areas. The education of the household head has a negative and significant effect on air-related diseases in all three models, with β-value −0.066, −0.105, and −0.118, respectively, for the rural, urban, and overall models. This result shows that moving from base category 1 (Profession education) to the next category (Lower education) will bring a 6.6 per cent decrease air related diseases in rural areas, 10.5 per cent in urban areas, and 11.8 per cent in the overall model and result for rural model and overall model are significant at 1 per cent level of significance; however, the urban model is significant statistically at 5 per cent level of significance. Based on the results, the fourth hypothesis is also rejected. The results indicate that higher educational attainment will reduce air-related disease. The air-related disease could be reduced through mass education programs, especially environmental education programs in rural and urban areas. There is an urgent need to raise public awareness of indoor air pollution and the serious threat to people's health and well-being. Education should assist women in reducing exposure through better kitchen management and child protection at home for cleaner indoor air. Cleaner, higher-quality air will boost energy levels at work and home because polluted air depletes the overall energy level by making our lungs and the rest of our bodies work harder, reducing efficiency. Breathing cleaner air allows our organs (especially our lungs) to function better, resulting in better oxygen absorption by our brain, making us more mentally alert and energetic (Dong et al., 2019).

Moreover, the household's income coefficient has a negative and significant effect on air-related diseases in rural and urban areas, with β-value −0.542, −0.727, and −0.628, respectively, for the rural model, urban and overall model. This result shows that a 1 per cent increase in household income will bring a 54.2 per cent decrease in air-related diseases in rural areas, 72.7 per cent in urban areas, and 62.8 per cent with the overall model. This result is significant at a 5 per cent level of significance. Thus, the fifth hypothesis is rejected. The results indicate that a higher income level will reduce air-related disease. Household income rise could shift the living standard upward using more advanced household items. These could reduce air-related diseases significantly in the region. For their energy needs, approximately half of the world's population prefers coal or biomass fuels such as wood, animal manure, or crop residues (Magazzino et al., 2021b; World Health Organisation, 2016). Evidence shows that the shift from biomass to cleaner fuels in heating and cooking has been extremely slow, especially among low-income groups (Bruce et al., 2000). As a result, indoor air pollution and health issues have increased.

Additionally, the current results show that the coefficient of kitchen type is positive and statistically significant in rural and urban areas. The kitchen type is measured through four categories, namely, 1) indoor kitchen without partition, 2) indoor kitchen with partition, 3) separate kitchen outside the house, and 4) open-air kitchen. Kitchen type has a significant positive effect on air-related diseases in all three models, with β-value 0.283, 0.194, and 0.237, respectively, for the rural, urban, and overall models. This result shows that moving from base category 1 (indoor kitchen without partition) to every next category will bring a 28.3 per cent increase air related diseases in rural areas, 19.4 per cent in urban areas, and 23.7 per cent overall in all models. The result for all three models is significant at a 1 per cent significance level. Based on the above results, the sixth hypothesis is rejected. Devakumar et al. (2014) and Albalak etal. (2001) found higher concentrations in indoor kitchens compared to outdoor kitchens, with comparable results. The study also found higher concentrations in the household. The researchers also discovered that women aged 25 to 59 years had spent the most time in the kitchen near the domestic hearth preparing food using inefficient cookstoves and fuel (Koshy, 2016). Women spend approximately 4.2 hours per day in the kitchen; similarly, infants and children under five also spend most of their time with their mothers.

Additionally, the current results show that the coefficient of stove type used in households is positive and statistically significant in rural and urban areas. Kitchen type is measured through four categories, namely, 1) electric stove, 2) gas stove, 3) kerosene stove and 4) mud chulha stove. Stove type has a significant positive effect on air-related diseases in all three models, with β-value 0.201, 0.261, and 0.307, respectively, for the rural, urban, and overall model. This result shows that moving from base category 1 (electric stove) to every next category will bring a 20.1 per cent increase air related diseases in rural areas, 26.1 per cent in urban areas, and 30.7 per cent with the overall model. The result for all three models is significant at a 1 per cent significance level. Based on the above results, the seventh hypothesis is also rejected. Lastly, the empirical results also show that the coefficient of the fuel type used in households is positive and statistically significant in rural and urban areas.

Fuel type is measured through four categories, namely, 1) Electricity, 2) LPG, 3) Kerosene and 4) Agriculture waste. Fuel type has a significant positive effect on air-related diseases in all three models, with β-value 0.229, 0.249, and 0.331, respectively, for the rural, urban, and overall model. This result shows that moving from base category 1 (electricity) to every next category will bring a 22.9 per cent increase air related diseases in rural areas, 24.9 per cent in urban areas, and 33.1 per cent with the overall model and the result for all three models are significant at 1 per cent level of significance. Based on the above results, the last and eighth hypothesis is rejected. These findings are consistent with previous research because people cook with various heat sources, including gas, wood, and electricity (Magazzino et al., 2021d). During cooking, each of these heat sources can cause indoor air pollution. Carbon monoxide, formaldehyde, and other harmful pollutants emitted by natural gas and propane stoves can be toxic to humans and pets. Cooking with a wood stove or fireplace can result in high levels of indoor air pollution due to wood smoke (Ganesh, 2017).

5. Conclusion and Policy Implications

In the present study, we examined the association of air quality parameters and socio-economic factors on air-related diseases in rural and urban areas in the Kanniyakumari district of the Tamil Nadu state in south India. The study used the primary survey to understand how air pollution occurs in rural and urban areas indoor and outdoor environments that create disease in the households. This review can assist environmental management practitioners, users, and policy-makers in facilitating environmental education to reduce health problems by identifying specific challenges and learning and applying strategies.

The descriptive analysis results show that socio-economic and demographic characteristics variables significantly contribute to the occurrence of air-related disease in the study areas. Among the variables, age, gender, caste, education, and income influenced the use pattern of fuel for various indoor and outdoor activities. The regression results indicate that the Age of the household head, Gender of the household head, caste, Education of the household head, Total Income of the household, Kitchen Type, Type of Stove, and Type of Fuel used in the household were statistically significant variables that influence the air-related disease occurrence. The significant contribution of education to public health suggests this variable is vital in reducing India's air-related diseases. More attention should be given to providing environmental education to rural households, particularly in environmentally vulnerable areas (Shan et al., 2018).

The results of the study have important implications. There is limited literature to understand household heterogeneity regarding socio-economic and demographic factors associated with exposure to air pollution and its implications on human health in India. The study's findings help cover the existing gap in the literature. The study provides a better understanding of household socio-economic factors associated with air pollution and health. The results suggest that households' social and economic status significantly improves environmental quality and public health. The study's findings are important to policymakers, environmental agencies, and non-government organizations to enhance environmental awareness programs in vast rural communities. The study is the first comprehensive empirical research to understand the socio-economic aspects of air pollution and its health implications in India. In light of the results, the following measures may be taken to reduce air pollution and the spread of air-related diseases at the household level.

- The indoor air pollution problem due to the burning of solid fuels affects mostly the poor people living in the rural areas of the study area (Mele et al., 2021b). In India, existing programs promote improved biomass cookstoves with chimneys attached to rural households. However, it is insufficient as many poor people living in rural areas use traditional stoves in the poorly ventilated kitchen. Therefore, economically empowering the poorest groups should be the priority of policymakers in the federal and state governments.
- The governments should make subsidized clean fuels such as kerosene, LPG, and electricity available central government schemes like the "Ujjwala Gas Stove" have helped millions of rural women switch from polluting traditional stoves to clean LPG ones. However, the scheme's success heavily depends on the stability of cylinder price; frequent changes in the cylinder price would discourage poor people from refilling gas cylinders.
- In the study area, the Government of Tamil Nadu has provided energy security to poor households, providing LPG connections and double burner gas stoves with LPG connections free of cost since 2007 (Statistical Handbook of Tamil Nadu, 2020). This scheme has largely helped the womenfolk who can save time and energy compared to those who used to collect firewood and cow dung. However, implementing the scheme is very slow due to a lack of coordination from the oil companies supplying the LPG cylinders. Therefore, the government should reinvigorate the scheme and ensure all deserving households get free LPG connections.
- The key elements of an effective control mechanism to reduce vehicle-related air pollution in urban areas are well-designed and appropriate vehicle emission standards for both old and new vehicle inspection and maintenance (I/M) programs (Parhizkar et al., 2020). In many developed countries, tough emission standards and strict implementation of those regulations have produced good results. Hence, there is an urgent need to revamp the vehicle emission standards of India to address the menace of outdoor air pollution.
- The government should improve the public transport system, similar to Ahmedabad Bus Rapid Transit System (BRTS), to reduce the kilometers traveled by private vehicles. Although there is a perfect road network connection with all rural villages in the study area, the need of the hour is good quality CNG buses at higher operating speeds. In urban areas of the study area, this will certainly reduce the number of two and three-wheelers on the streets, the main cause of outdoor air pollution (Wu et al., 2018).
- The government should develop a sound Transport policy to encourage green modes such as bicycles and walking. The result of the study indicates that a large chunk of journeys made by the two-wheelers, three-wheelers, and cars are for the short distance—less than six km. Meanwhile, there is no significant time advantage for traveling motor vehicles. In addition, vehicles also emit high levels of pollutants in short-distance travel because the engine consumes more fuel and cannot burn efficiently (Sharafian et al., 2019). However, there is a significant advantage in using green mode for a shorter distance, like reducing air pollution, and more importantly, cycling and walking give a huge health benefit.
- There is an urgent need to tackle traffic congestion problems from the supply side management in the study area. Improving signals, one-way traffic, prioritizing public transport, and traffic engineering measures for the road network could help ease traffic congestion (Sutandi, 2020). It is also important to highlight the need for improvement of road infrastructure, with a new road alignment for various road users, such as sub-ways, by-passes, bus bays, footpaths, and removal of encroachments positive impacts.
- Most Indian cities still lack demand-side management progress, such as road tax, fuel tax, parking fee, congestion tax, etc. It is a known fact that people do not appreciate any measure taken to restrict the

use of private vehicles. However, a gradual progressive approach of restricting the use of private vehicles and at the same time providing better facilities for public transport would eventually lead to a better situation. The people's choice of choosing two/three-wheelers and cars for public transport can be achieved through efficient delivery of demand management and improving public transport.

- Public advocacy needs to be strengthened in the study area to tackle the adverse health effects of indoor and outdoor air pollution. Public awareness about the harmful effects of air pollution can be made by networking with the government and non-government organizations to take the message to the grass-root level. Media and research institutions can be encouraged to study independently to help policymakers frame suitable policies.
- It is the most suitable time to have a new comprehensive national environmental policy to keep at bay the problems of environmental pollution, particularly energy-related air pollution and the consequent evils.

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Imitation of the study
The study investigated how air pollution affects human health in rural and urban populations. Diseases associated with air pollution are not only a problem, but it affects the negative impacts on the social and productivity of the human capital. There is a need to conduct an in-depth exploratory study to find the socio-cultural habits and anthropogenic activities in rural and urban areas. There is a need to develop a valid analytical technique to investigate the change in household energy use patterns in rural and urban areas.

Authors' contributions
All the authors are contributed significantly to current research and report writing.

Consent to Participate
The current search does not require formal participation consent.

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