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Economic Estimation of Health and Productivity Impacts of Traffic Congestion: A Case of Bengaluru City

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ECONOMIC ESTIMATION OF HEALTH AND PRODUCTIVITY IMPACTS OF TRAFFIC CONGESTION: A CASE OF BENGALURU CITY

Vijayalakshmi S[1] and Krishna Raj[2]

Abstract

Traffic congestion in urban areas is mainly due to the exponential growth of the vehicular population. It imposes a huge economic cost in the form of the opportunity cost of time and alsohealth cost. It is observed that urban residents, particularly commuters, are the main sufferers of traffic emissions. These costs are incurred in the form of morbidity and mortality. The epidemiological evidences show that there is a strong causal relationship between vehicular emissions and possible health impacts. The present study substantiates this interrelationship with empirical evidences. Using the ARDL approach, the study establishes empirically that an increase in vehicular mobility results in increased traffic-induced air pollution. Further, various research studies found that constant exposure to traffic pollution for more than an average of 38 minutes per day not only cause high incidence of respiratory-related illness among commuters, but also reduced their economic productivity. To quantify these impacts for Bengaluru city, India, the study has adopted the cost of illness approach by classifying the costs into direct and indirect costs. The results show that the direct and indirect cost of illness due to traffic congestion amounted to an average of 1.17 per cent and 11.2 per cent of theannual income of the respondents respectively.

Key words: Traffic Congestion; Health; Productivity; emissions; ARDL; RSPM; COI.

Travelling in personal vehicles has both benefits and costs. Travel that is free from traffic congestion has an economic gain in terms of the opportunity cost of saving time. On the other hand, traffic congestion imposes acost on health, affecting the economic productivity of commuters. Being a universal phenomenon, traffic congestion hasresulted in increased travel time and a constant exposure to air pollution. A World Health Organization (2016) report states that 80 per cent of urban residents of the world are exposed to air pollution above the WHO standard, half of which can be attributed to vehicular pollution. Research studies (HEI, 2010) proved this relationship with the aid of epidemiological and clinical evidences.

In a developing country like India, traffic congestion has become a serious problem as it imposes a high cost on health and productivity. HEI (2019) reports that among the top ten developing countries, India ranks second, next only to China, with the highest mortality attributable to air pollution. Studies on air pollution in India, especially by OECD (2014) cite air pollution as the major cause due to a lack of control over vehicular emissions, which resulted in a 12 per cent increase in the number of deaths and three per cent increase in years of life in 2012. The Central Pollution Control Board (CPCB, 2011) also observed that urban air pollution is escalating in recent years (1990 to 2010) mainly due to growing private vehicle ownership.

Though the issue of air pollution has been studied widely in the world, traffic congestion-led air pollution and pollutants' density at traffic junctions and its economic impacts like morbidity and mortality remain less studied. As motor vehicles emit a large quantity of carbon dioxide (CO_2), carbon

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monoxide (CO), nitrogen oxides (Nox), and particulate matter (PM) whose concentration and density increases at traffic junctions, causing adverse health effects on commuters who are exposed continuously for more than 38 minutes every day (See Table 9). In this background, the present study has selected Bengaluru to assess the economic impact of traffic congestion on commuters. The rationale behind the selection of the city is that being a dynamic city in the country, its vehicular population is growing at the rate of 10 per cent per annum which contributes around 40 per cent for Respirable Suspended Particulate Matter (RSPM) in the city (TERI, 2015[3]). Further, the city has been ranked among the cities with the worst traffic congestion (IBM, 2011).

This paper is organized into five sections: The *first section* identifies traffic-related air pollutants and their epidemiological evidences; the *second section* reviews literature on economic estimation of health costs; the *third section* deals with the methodology adopted for the study and the *fourth section* analyses the economic estimates of health impacts due to traffic-related air pollution; the *final section* concludes with policy suggestions.

Traffic-related Air Pollutants and Epidemiological[4] Evidence

Research studies have found scientific and statistical evidences for the causal relationship between vehicular emissions and health impact (HEI, 2010). But it is hypothesized in the present study that vehicular emissions, especially at traffic junctions, tend to have a high concentration of pollutants due to greater vehicular density, inflicting a negative health impact on commuters. To prove this hypothesis, the study relies on the epidemiological evidences from the literature as medical enquiry is not in the scope of the present research. In the following section, the study identifies the major pollutants from automobiles and their epidemiological evidences.

Traffic-related Air Pollutants

Vehicular emissions can be classified into primary pollutants and secondary pollutants. Primary pollutants are the ones which get generated at source and then dispersed. In the case of vehicular emissions, the primary pollutants are carbon dioxide, carbon monoxide, hydrocarbon, particulate matter (PM), nitrogen oxide and substances called mobile source air toxics like benzene, aldehyde, acetaldehyde and 1,3-butadiene. Secondary pollutants are formed due to chemical interactions with air. For example, oxidation of NO turns into NO_2 and ozone (O_3). Further, the nature of pollutants is linked to the type of vehicle (light or heavy-duty vehicles), age, operating and maintenance condition, type and quality of the fuel used.

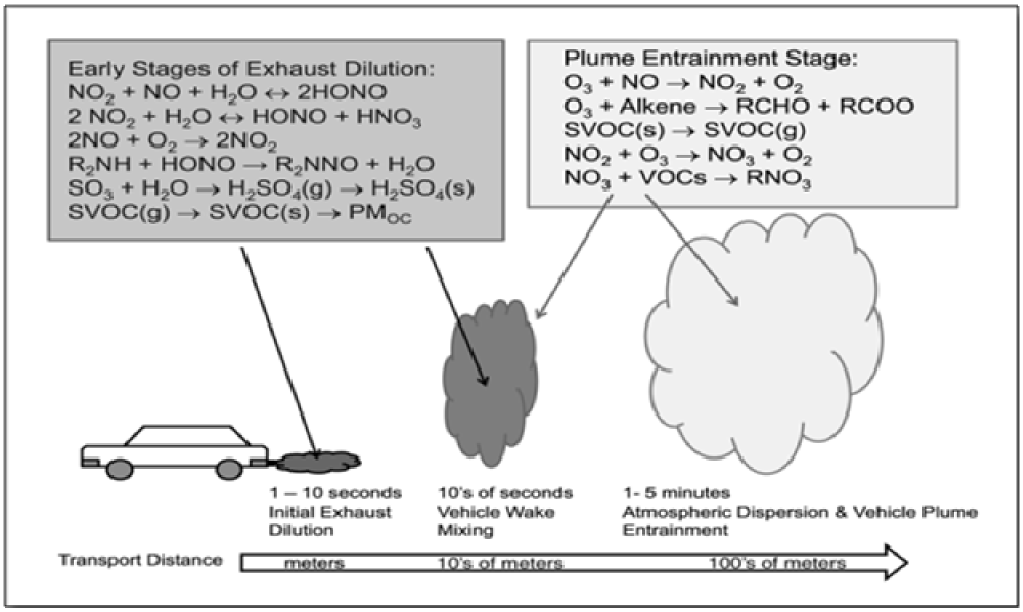
Queued up vehicles near traffic signals, with their engines on, tend to have high emissions and the commuters constantly get exposed to pollutants. For example, the average concentration of $PM_{2.5}$ due to vehicle exhaust is 2.5 times higher and CO is six times higher than in a normal environment (Chan CC *et al*, 1991; Adams *et al*, 2001; Kaur *et al*, 2005). Figure 1 provides a graphical representation of the emissions due to vehicles and how chemical transformation would take place. The early stage of

[3] As per the report, it is only in Bengaluru that automobiles are the major contributor of RSPM compared to other metropolitan cities of the country.

[4] Study of distribution and determinants of health related events (diseases) (WHO).

the exhaust contains CO_2, H_2O, CO, NO, NO_2, HC, semi volatile organic compounds, inorganic materials and PM from the exhaust of tailpipes at relatively high temperature and concentration. This exhaust of foreign material mixes with (entrains) background air in the environment and there is a chance of chemical diffusion and a limited reaction takes place. This phenomenon is very localized and likely to occur within 100meters of the source. This shows that commuters are particularly susceptible to the vehicular pollutants in traffic junctions.

Figure 1: Schematic Representation of Possible Chemical Transformation of Motor-Vehicle Emissions



Source: HEI, 2010

Health Effects of Traffic-related Air Pollution: Epidemiological Evidences

Although there exists vast evidence on the impacts of air pollution on human health, isolating the impact of traffic-related air pollutants on health is quite challenging. WHO has given several criteria for assessing human exposure to transportation led air pollution which includes a concentration of pollutants in $\mu g/m^3$ or any other equally valid metric; duration of exposure; the setting like workplace and transport mode and exposed population (WHO, 2005). Based on this definition, this study concludes that commuters are exposed to a high concentration of pollutants in traffic junctions and are highly susceptible to negative health impacts.

1. Impact on Health by Type of Traffic-related Air Pollutants

Vehicular emissions have different types of effects on human health, which vary from itchy eyes to chronic lung disease or heart failure (McCubbin and Delucchi, 1999). Notable studies have proved that criteria pollutants[5] have adverse effects on human health (Pervin *et al*, 2008). In Table 1, major automobile-related pollutants and their impact on human health is described.

Table 1: Traffic-related Pollutants and Their Possible Health Impacts

Pollutant	Short term impact	Long term impact	Source
Fine Particulates: $PM_{2.5}$ and PM_{10}	Hospital admission for respiratory disease; Exacerbated lung and heart condition	Premature death; affects quality of life	McCubbin and Delucchi, 1999; COMEAP, 2009
Ozone (O_3)	Respiratory irritation, asthma	Cardiovascular disease through prolonged inflammatory effects on lungs; myocardial infarction and cardiac arrhythmias in older people	McCubbin and Delucchi, 1999; Portney and Mullahy, 1986; WHO, 2005
Nitrogen dioxide (NO_2)	Bronchocontriction, increased bronchial reactivity, airway inflammation	Decreased pulmonary function, inflammation of lung and immunological changes	HEI, 2010; COMEAP, 2011
Carbon Monoxide (CO)	Heart troubles Headaches	It binds with hemoglobin in the blood to form carboxyhemoglobin. This reduces the oxygen carrying capacity of the blood and limits the release of oxygen from circulating hemoglobin	McCubbin and Delucchi, 1999; Schwartz and Zeger, 1990

2. Morbidity Impacts and Their Causal Pollutant Relations

The above table establishes that diverse epidemiological evidences have strongly established the causal relationship between traffic emissions exposure and respiratory issues, cardio-health outcomes like heart related diseases and adverse cardiovascular events. Hoffmann *et al* (2006 as reported in HEI, 2010) conducted a cohort study on adults in various cities of Germany and found a causal relationship between coronary heart disease and long-term exposure to traffic-related air pollution. Similar studies are listed in Table 2.

[5] Criteria pollutants are non-toxic air pollutants (CO, NO_2, PM, SO_2, lead, ozone), excess concentration of these would be hazardous to health.

Table 2: Morbidity Impact Studies

Morbidity issue	Study/Author[6]	Pollutant/area	Impact/Finding
Cardiovascular morbidity	Peters *et al* (2004)	Traffic-related air pollution	Found association between traffic exposure and myocardial infarction
	Rosenlund *et al* (2006) Stockholm	NO_2	0.89% increase in cardiovascular morbidity per 30μg/m^3 increase in NO_2
Asthma & Breathing problems	Modig *et al* (2006)	Residents near main roads	1.1% of residents of Lulea, Sweden had incidence of asthma
	Burr *et al* (2004) North Wales, UK	5.7% improvement in respiratory symptoms among residents near major road due to traffic diversion	
	Livingstone *et al* (1996 HEI 2010) London	High incidence of asthma among residents of main road	
	Bayer & Oglesby (2006) Switzerland	0.9 to 1.3% of residents living in main road suffer from wheezing and breathing problem respectively	
	Oosterlee *et al* (1996) Netherlands	Incidence of asthma, wheezing, cough are common among residents near busy streets	
Issue of Asthma and respiratory issues among Children	Studies reviewed in HEI (2010)	Found high incidence of asthma among school children near busy roads	
Respiratory Allergy and Hospital Admission	WHO (2005)	NO_2 and PM_{10}	Each 50 μg/m^3 increase in NO_2 concentration would increase respiratory hospital admission by 2.5 per cent and 10 μg/m^3 increase in PM_{10} would lead to 0.8 per cent increase in respiratory hospital admission
	Cesaroni *et al* (2008)	$PM_{2.5}$ and NO_2	Allergy incidences, itchy rashes, eczema, otitis media, outdoor aeroallergens, hay fever, self reported rhinitis are most common issues
Lung issue and lung cancer	Brunekreef *et al* (1997)	Traffic emissions	The study found significant association between lung function and density of lorry traffic
	Hrisch *et al* (1999) Dreseden	NO_2, CO and Benzene	The study found association of lung function with high level of exposure to benzene
	Northridge *et al* (1999) New York	Diesel exhaust	Association to asthma
	Nyberg *et al* (2000) Stockholm	NO_2	Association of lung cancer and prolonged exposure to transport related air pollution
	Nafstad *et al* (2003) Norway	NO_2	There is risk ratio of 1.08 per 10 μg/m^3 increase in average concentration of nitrogen oxide with lung cancer among residents
	Beelen *et al* (2008)	NO_2	Cases of lung cancer associated with black smoke and NO_2 from traffic. It was found that an increase of 30 μg/m^3 of NO_2 would increase the risk of lung cancer by 0.86 per cent and 10 μg/m^3 increase in Black smoke would increase the case of lung cancer by 1.03 percent
Occupational exposure	Hansen *et al* (1998)	Increased risk of lung cancer among Danish drivers	
	Jakobsson *et al*, 1997	The risk of lung cancer was high among urban drivers than the rural areas in Sweden	
	De Paula Santos *et al* (2005)	Found incidences of BP and stress closely associated with CO, SO_2 and NO_2	
	Evans *et al* (1988)	Found respiratory symptoms and lung function as common incidences among male toll takers in tunnels of New York	

[6] This information is sourced from HEI (2010) and McCubbin and Delucchi (1999).

3. Epidemiological Evidences from Indian Studies

A few studies are available in India that analyzed the economic impact of urban air pollution, that too inthe case of traffic-related air pollution.

Table 3: Epidemiological Evidences from Indian Studies

Study/Author	Study area	Findings
Parikh and Parikh (1997)	Mumbai	Significant association is found between urban air pollution and morbidity
Cropper *et al* (1997)	Delhi	Impact of PM is analyzed and found that mortality is high among age group of 14-15 years
Giri *et al* (1997)	Kathmandu	Impact of PM emissions and found 95 deaths out of 10000 attributable.
Dewaram *et al* (1997)	Kolkata, Chennai, Delhi and Mumbai	The study found increasing episodes of illness and premature death due tohigh level of SPM released from automobiles
Paramesh (2004)	Bengaluru	Increase in cases of asthma from 20 per cent to 36.6 per cent (from 1999 to 2004)
Ravi (2014)	Bengaluru	Every 10µg/m^3 decrease in PM_{10} and $PM_{2.5}$, the average mortality would reduce from acute respiratory infection by eight percent, cardiopulmonary illness by six per cent and lung cancer by five percent
TERI (2015)	Indian cities	10µg/m^3 increase in PM_{10} concentration would lead to increase in mortality by 0.22 per cent in Bengaluru and 0.20 per cent in Mumbai

The epidemiological studies discussed in this section establish the fact that traffic-induced pollutants, mainly in urban areas, cause severe health issues. In the next section, an elaborate review of the literature on the valuation of such health impacts due to traffic-related air pollution is provided.

Review of Literature on Economic Estimation of Health Cost due to Traffic-related Air Pollution

Some research studies have quantified the ill-effects of air pollution at large and traffic air pollution in specific. In this section, a brief literature is provided on the estimates of costs due to air pollution and more elaborated evidences for traffic-related air pollution costs on human health. Such economic estimation of urban air pollution enables policy makers to design measures to improve the air quality by increasing the remedial benefits which will reduce the cost of pollution.

The economic valuation of air pollution is largely based on the role of individual preference in valuing the environmental damage (Shin *et al*, 1992). There are two broad categories of valuation techniques to estimate the costs of air pollution viz., the physical linkage approach and the behavioural linkage approach. The physical linkage method, also called as the damage function approach, estimates the effects of pollution with the application of market prices (Ligus, 2018). The behavioural linkage approach, on the other hand, is based on the behavioural changes due to environmental damage[7]. A number of studies have used these methods to derive the air pollution cost estimates.

For instance, a WHO study (1997) on the economic cost of air pollution used Cost of Illness and Human Capital Approach (COI & HCA). El Fadel and Masood (2000) and Friedrick and Bickel (2001)

[7] An elaborate explanation of these methods is provided in Section III.

estimated the loss due to air pollution using the same methodology (COI & HCA). On other hand, studies by Farber and Rambaldi (1993) and Loehman *et al* (1979) derived Willingness To Pay (WTP) for improved air quality as a method to value the loss from air pollution. Berger *et al* (1987) used both the COI and WTP approaches to estimate the urban air pollution in the USA.

Economic Estimation of Health Cost due to Traffic Pollutants

Disentangling the impact of traffic pollutants is a complicated task, and the same is true with quantification of individual pollutants' impact on human health. There are a few studies which have attempted such estimation for traffic pollutant emissions. The following section will provide a brief review of them[8].

Particulate matter is a primary and dangerous pollutant from automobiles that affects human health. Research studies have considered the impact of this pollutant and tried to quantify it using different approaches. For instance, Zimrou *et al* (1999) used the Cost of Illness Approach to measure the direct cost of health due to exposure to PM_{10} in France and the Human Capital Approach to measure the productivity loss. The direct cost (medical expenses) ranged from US$ 6.60 to $ 1.25 million and productivity loss was around US$ 5.10 – $ 8.72 million (1994 US dollars) and the total societal cost was estimated to be US$ 13.43 to $ 22.95 million.

Alberni and Krupnick (2002) used the COI and WTP approach for Taiwan. They estimated that the direct loss through medical expense amounted to around US$ 510,491 for 100µg/m^3 reductions in PM_{10} and US$ 117,575 to $244,477 for productivity loss (using the HCA Approach). Kan and Chen (2003) estimated that US$ 67-82 million would be lost as the direct cost of health expenses due to exposure to PM_{10}emissions in Shanghai city of China. The study adopted the Contingent Valuation Method (CVM) to estimate the productivity loss due to premature mortality which accounted around US$ 557.58 million.

DSS Management Consulting Inc. (2000) estimated the pollution cost of ozone and PM_{10} exposure in Canada. They adopted the COI and HCA methods and estimated a loss of US$ 674 million on medical cost, US$ 2,696 million due to productivity loss and intangible cost of US$ 3,370 million. A World Bank study (2002) also examined the impact of the same pollutant as DSS Management Consulting Inc, and estimated the cost for metropolitan Mexico City (ZMV) which amounted to US$ 760 million (1999 US $) of societal cost.

Voorhees *et al* (2000) examined the impact of NO_2 on health in Tokyo, Japan. By using both COI and HCA approaches, the study estimated a direct cost of US$ 6,860 million and productivity loss cost of US$ 6,330 million and non-health cost of US$833 million, totalling up to a societal cost of US$ 14,023 million. Rozan (2005), on the other hand, estimated the cost of air pollution in total[9] for Strasbou city of France. The study used COI and HCA approaches to estimate the direct cost of pollution and used the CVM approach to estimate the intangible cost of pain and suffering. The direct cost included doctor visit of US$ 24.91 per patient and medical cost of US$ 74.75 per patient. The

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8 In these studies, motor vehicles are the major source identified but not the only source. Hence, pollutant-wise cost estimates are given more prominence.

9 The study did not separate the impact of pollutant

indirect cost included productivity loss of US$ 21,299 due to wage loss from air pollution. With the WTP approach, the intangible cost was estimated to be around US$ 46.83 per patient. Neidell (2004) estimated a cost of US$ 5.2 million spent for illness caused due to CO in California, USA using the COI approach.

Among a few Indian studies on estimation of pollution cost, anotable study was conducted by Srivastava and Kumar (2002) for Mumbai city using the COI and HCA methods for direct cost and WTP for premature mortality due to NO_2, CO, HC and PM. The study reported a direct cost of US$ 232.34 million and productivity loss of US$ 76.32 million which accounted for a societal cost of US$ 308.66 million (1997 US$). Another study by Saksena and Dayal (1997) applied the HCA and COI methods for direct cost and Value of a Statistical Life (VOSL) for mortality impact. The study aggregated the cost and reported the direct cost due to PM_{10} exposure as US$ 199.11 million and productivity loss of US$ 18,784 million (1995 US $). Ravi (2014) estimated the productivity loss due to urban air pollution in Bengaluru as around Rs. 4,253/year per person and out of pocket expenditure as around Rs. 990 per year using the COI and WTP approaches.

These evidences of estimates not only indicate the severity of the issue on the health of individuals but also point at the productivity loss caused to the economy. As the cities of developing countries are emerging as economic hubs of the world, the problem of traffic congestion has become severe and hence it is the need of the hour to quantify its impact so that better policy solutions could be obtained. In this effort, the present study stands as the first of its kind to examine the impact of traffic-related air pollution on the health of commuters in the city of Bengaluru, one of the most dynamic cities of the World. The study observed the impact in terms of mortality and morbidity which will help for prudent policy suggestions to tackle the city congestion issues.

Methodology of the Study

Valuation of health damage has been a critical aspect of the study and requires an inter-disciplinary approach. One important element of the valuation lies in establishing the dose-response function of the pollutant under study. With the epidemiological evidence established in Section I, it is established that primary pollutants (PM) from automobile emissions would have a serious impact on the health conditions of commuters. Particulate matter has been studied by various researchers who have proved epidemiologically that commuters in especially high emissions-concentrated areas (traffic junctions) are highly prone to serious health issues. An attempt is made in the study to estimate the impact of traffic congestion on the health of commuters.

Economic Estimation of Traffic Pollution and Morbidity

The morbidity effects of air pollution are commonly valued using the Cost Of Illness (COI) approach. There are basically three different costs involved in COI. Direct costs involve medical treatment; indirect costs include loss of productive days and intangible costs are the cost of suffering and pain. Since the third cost is highly subjective in nature, which is often difficult to capture, the current study considers the first two costs of illness: direct and indirect costs. Under direct cost, the medication expenses for traffic-related health issues are estimated. In the case of the indirect cost of illness, productivity loss due to illness is estimated using the number of workdays lost and wage lost per day. The indirect cost also includes preventive expenditure such as expenses made by commuters to avoid the congested route. In our study, the toll paid by commuters and metro train users are taken as a proxy for preventive costs. Hence the estimation of morbidity cost includes:

Cost of illness = direct cost (cost of medicines) + indirect cost (productivity loss & preventive expenses)

Pollutants Considered for the Study

The primary element of vehicular emissions is RSPM which is found above set standard (60µg/m^3). Further the study does not consider sulphur dioxide (SO_2) as the pollutant is within the standard limits and also there is lack of strong evidence that SO_2 has an impact on health by being an independent pollutant. Though in the literature we may find some arguments that SO_2 might be linked with incidences of cough, wheezing, eye irritation, runny nose and discomfort in chest, epidemiological evidence shows that there is no strong causation proved (Studies reported in HEI, 2010).

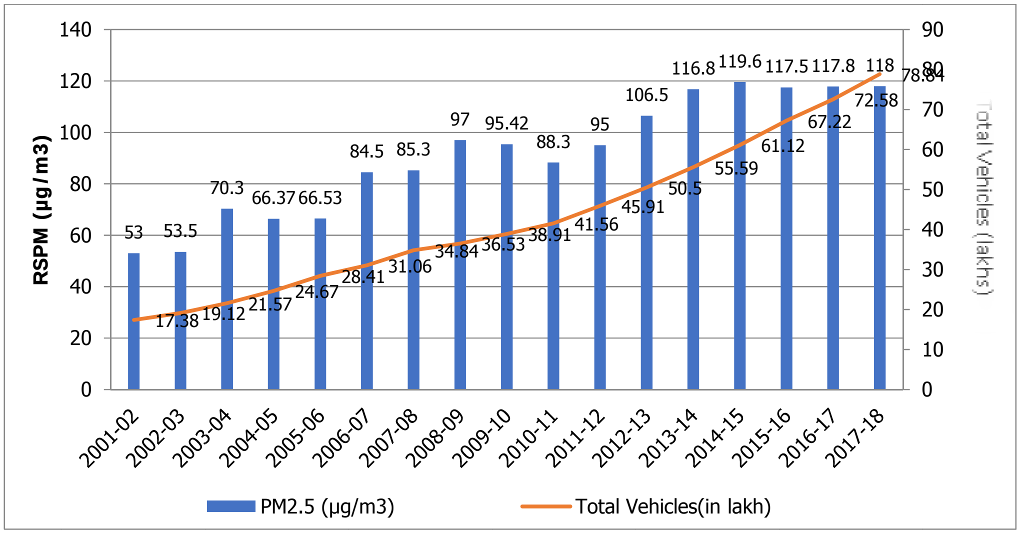
Major limitations of the study are: The study assumes that commuters are exposed to these pollutants regularly. Further, the study has not classified the pollutants based on vehicle type, age, operating and maintenance condition and quality of fuel used, though these are some relevant factors affecting the emissions level. Since consideration of these parameters requires micro-level data and more engineering specifications, the study is limited on these aspects. Though the study acknowledges that existence of different types of pollutants from vehicles (combustion and non-combustion), since emissions monitoring data do not have such classification, the present analysis refrains from such classification and considers primary pollutants for estimation (RSPM).

Health Profile of Study Area and Estimation of Traffic-related Health Cost

Traffic-induced Pollution in the City: Econometric Analysis

Based on the literature review, it was identified that primary pollutants from vehicular emissions are respiratory suspended particulate matter (RSPM). This pollutant has awide range of health impacts, irrespective of the socio-economic conditions of the study area (Dockery *et al*, 1993; Pope *et al*, 1995; Ostro, 1994). Even in the study area, the levels of RSPM concentration is showing a trend of increasing in parallel with the vehicular population.

Figure 2: RSPM Level and Number of Registered Vehicles in Bengaluru



Source: KSPCB and Transport Department of Karnataka Annual reports from 2001-2018

With an annual growth of vehicular population by 9.9 per cent from 2001-2018, the RSPM level is increasing at 3.8 per cent annually and from Figure 2, it is evident that both variables have an association. To know this causal relationship, the study adopted the time-series econometric approach in the next section.

Econometric Model

The study specifies the following equation to know the relationship between the RSPM and vehicular population and private vehicle kilometer travelled as[10]. The data on RSPMand vehicles has been taken from a monthly series of studies from January 2015 to December 2018. In the same manner, the vkt is calculated based on the IRC guidelines.

$$\ln(rspm_t) = \beta_0 + \beta_1 \ln(vhcl) + \beta_2 \ln(vkt) + u_t \qquad \text{.................. (1)}$$

where rspm, vhcl and vkt represent respiratory suspended particulate matter, vehicular population and private vehicle kilometer travelled[11], while ln is the natural logarithmic form of the series. β_0, β_1, β_2 and β_3 are the long-run elasticities of rspm with respect of vhcl and vkt respectively. A summary descriptive statistics of the variables used in the model is provided in Table 4.

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[10] Though there are other factors like road dust etc which affect the RSPM level, the study assumed that they are the result of vehicular population (TERI, 2015).

[11] Private vehicle kilometer travelled (VKT) is derived from IRC (1990) guidelines for Bengaluru city using average trip length and total vehicles called theload factor. Load factor is the average distance travelled by a category of vehicle in a day. Load factor for private transport=15kms/day.

Table 4: Descriptive Statistics

	Vehicle	VKT	RSPM
Mean	42.69471	19496.76	91.26000
Median	38.91000	18773.00	95.00000
Maximum	78.84000	35475.00	119.6000
Minimum	17.38000	8421.000	53.00000
Std. Dev.	19.04045	8111.269	23.06230
Skewness	0.445202	0.459575	-0.267799
Kurtosis	2.072887	2.228247	1.816360

Data source: KSPCB, RTO, author's analysis

To test the long run relationship, the most popular methods followed are Engle and Granger (1987) test and Johansen-Juselius (1990) test. These methods impose the conditions that the variables in the model should be stationary at first difference i.e I (1). Hence, the said model needs to be tested for stationarity to continue for further analysis. For this purpose, the unit root test is conducted using Augmented Dickey Fuller (ADF) and Philip Perron (PP) tests whose results are given in Table 5.

Table 5: Unit Root Test Result

Variable	ADF (t-stat)	Result	PP (t-stat)	Result
lnrspm	-3.02*	I (0)	-3.06*	I (0)
lnvhcl	-19.74*	I (1)	-18.25*	I (1)
lnvkt	-6.18*	I (0)	-12.42*	I (0)

*Significant at 1% level; ** Significant at 5% level; *** Significant at 10%level

Clearly the variables are of mixed order (I(0) & I(1)) and hence our study is restricted to the use the popular methods of cointegration like Engle and Granger or Johansen-Juselius tests. To overcome the limitations of these tests, Pesaran, Shin and Smith (1996) have developed an alternative approach called Autoregressive Distributed Lag (ARDL) which was further developed by Pesaran *et al* (2001). This approach gained popularity over other approaches by providing the inclusion of variables at different order (Pesaran and Pesaran, 1997). The main advantage of ARDL is that it corrects both the residual correlation and endogenity problems among the variables, and hence provides robust and consistent results of long run coefficients (Pesaran and Shin, 1991).
On this basis, the present study has adopted the ARDL model and the long run equation is as follows:

$$\Delta \ln(rspm_t) = \beta_0 \sum_{i=1}^{q} \beta_{1i} \Delta \ln(rspm_{t-i}) + \sum_{i=1}^{q} \beta_{2i} \Delta \ln(vhcl_{t-i}) \sum_{i=1}^{q} \beta_{3i} \Delta \ln(vkt_{t-i}) + \beta_4 \ln(rspm_{t-1}) + \beta_5 \ln(vhcl_{t-1}) + \beta_6 \ln(vkt_{t-1}) + u_{ti} \quad ..(2)$$

Where Δ is the first difference operator, q is optimal lag length, β_1, β_2, β_3 represent the short-run dynamics of the model and β_4, β_5, β_6 are long run elasticities. ARDL model of co-integrating vector is reparametrized into Error Correction Mechanism (ECM). The error correction model for equation (2) will be:

$\Delta lnrspm_t = a_{10} + a_{11}[lnrspm_{t-1} - b_{11}lnvhcl_{t-1} - b_{12}lnvkt_{t-1}] + \gamma_{11}\Delta lnrspm_{t-i} + \gamma_{12}\Delta lnvhcl_{t-i} + \gamma_{13}\Delta lnvkt_{t-i} + \varepsilon_{ti}$ ..(3)

The coefficient a_{11} indicates the speed of adjustment to equilibrium and its corresponding value in the bracket is the error correction term. The γ coefficients indicate the short-term relation. For the cointegration, these coefficients must be significantly different from zero and estimates of them must not be too large (it must lie between 0, -2). The reparametrized result gives the short run dynamics and long run relationship of the variables (Nkoro & Uko, 2016). In order to find out the long run relationship, a Bounds test on equation (3) is conducted using Bound F statistics with two bounds, i.e., lower and upper bound.

H_0 (null Hypothesis) – there is no cointegration among variables.

The rule of thumb is if the calculated F-statistic is greater than the upper bound, then the null hypothesis is rejected and if it is less than the lower bound, the null hypothesis is accepted and if it falls between the lower and upper bounds, the test is inconclusive (then we check for the error correction term for finding the relationship). With respect to lag length, the Schwarz Bayesian Criterion is used to select the optimal lag length of variables, which gives the optimal lag length 1. Since the data is in anannual series, we expect the impact will be captured with a lag of one year.

1. Empirical Findings

The long run result of the model is given in Table 6. From the model, it can be seen that the variables under consideration have a positive impact on RSPM. A one per cent increase in total vehicular population will increase theRSPM level in the city by 2.22 per cent,whereas vehicle kilometre travel will increase the RSPM level by 3.62 percent.

Table 6: Short and Long-term Estimates of the Models

Long term estimates*

Regressor	Coefficient	t-stat
Constant	26.4	2.41*
$Ln(vhcl_t)$	2.22	1.89**
$Ln(vkt_t)$	3.62	2.43*

*Significant at 1% level; ** Significant at 5% level; *** Significant at 10% level

Short term estimates[1]

$\Delta ln(rspm_t)$ = - 0.61EC* + 0.56 Δln(rspm(-1))* + 0.39 Δln(rspm (-2))* + 142.14 Δln(vhcl)*
(-6.03) (3.29) (2.31) (2.14)
+ 395.3 Δln(vhcl (-1))* + 46.97 Δln(vhcl(-2))* + 0.88 Δln(vkt)*
(4.71) (2.57) (2.23)
+ 0.79 Δln(vkt (-1))* + 0.26 Δln(vkt(-2))* + 0.08 d2017* - 0.03d2009*
(3.47) (3.79) (1.38) (-3.8)

$R^2 = 0.98$; Adj. $R^2 = 0.96$; DW = 2;

* denotes significance of the coefficient at 1 per cent level.

[1] t-values are in parenthesis.

The short- run error correction (EC) term is negative and significant, which indicates that there is co-integration among the variables. The speed of adjustment i.e., 0.61 suggests that nearly 61 per cent of disequilibrium occurred in the short run is corrected in the longrun. ARDL model co-integration is verified with the F-statistics. The computed F-statistics of themodel is above upper critical bound I (1) value according to Pesaran and Pesaran (1996) & Pesaran *et al* (2001) which confirms that the variables have long run relationships.

Table 7: Bound F-statistics

F Statistics	Lower bound I (0)	Upper bound I (1)[12]
7.21 (2)	2.63	3.33

Further to test for the stability of the selected ARDL, the cumulative sum of recursive residuals (CUSUM) test has been conducted. Appendix 1 will provide the plots of CUSUM which shows that the plots remain within critical bounds at 5 per cent level of significance which indicates that the model is structurally stable. The results on Multicollinearity, Heteroskedasticity and normality tests are provided in Appendix 2.

Sample Details of the Study Area and Health Profile

The first step involved in themeasurement of the health impact due to traffic-related air pollution is to establish the dose-response function. This involves a detailed epidemiological analysis, which is out of the scope of the present study. Hence, the study relied on the evidences provided by other studies. One caution taken is that the results of these studies should be supported by clinical and toxicological evidences to have strong evidence for the relationship (Lvovsky, 1998) and the epidemiological study conducted should be either in the study area or inanother location similar to the study area (geographical and socio-economical). Based on these conditions, the present study borrows the epidemiological evidence for Bengaluru city from major studies like TERI (2015), Cropper *et al* (1997), Srivastava and Kumar (2002).

Since the study was concerned with urban commuters, the secondary data on their health status is not available. Hence the study relies on primary survey using structured questionnaire, by conducting both direct and indirect[13] interviews. The survey is conducted in the Central Business District (CBD) of Bengaluru which is mainly under the BBMP jurisdiction (Bruhat Bengaluru Mahanagara Palike). This area is classified into four zones based on the report of Bangalore Metropolitan Region (BMR) – 2031 published in 2018 namely CBD (Central Business District), adjacent CBD, inner periphery and periphery[14]. 12 major junctions with volume to capacity ratio (V/c) greater than 2 (V/C<0.5 is ideal as per IRC, 1990) are identified[15]. In these junctions, the traffic stream stays for more than three minutes

[12] The lower and upper bounds are taken from Table CI(iii) Case III: Unrestricted intercept and no trend given in Pesaran et al. (2001).

[13] Involved both over the telephone and emailing the questionnaire.

[14] The study has limited its scope to the BBMP jurisdiction of 198 wards.

[15] As per the report of DULT 2011

and they face heavy traffic congestion. Since the objective of the study is to estimate the traffic specific pollution impact on health, it was justified to select the daily commuters in these junctions. A stratified random sampling technique is adopted to cover different sections[16] of the commuter population in the city and the number of sample selected is provided in Appendix 3.

The study mainly considered the working section of the population as they are the regular commuters with fixed origin and destination. The health history of the respondents was obtained through specific questions on the travel-related health issues they were suffering from for at least the previous three or more months. Table 8 provides prevailing traffic-related health issues as reported by respondents.

Table 8: Health Issues Reported by the Respondents

Health Issues	Percentage of respondents reported[17]
Stress and Blood Pressure	39.8
Headache	38.4
Back pain[18]	31.6
Cough	28
Respiratory infection	26.9
Skin allergy	24.4
Irritation in throat	24.4
Asthma	16.9

Source: Primary Data

From 427 interviews with the respondents, it was found that 73.5 per cent of the commuters suffer from certain health issues due to long travels for work[19]. Among them, cases of stress, BP, headache and back pain are very high (30%). Acute diseases like respiratory infections and cough are also common among the commuters.

One major factor influencing the health status of respondents is age. Among various health issues suffered by individuals during their life spans, travel-related health issues are some of the prominent issues which will have confounding impacts. From the field observation, it is evident that traffic-related health issues are more common in the age group of 26-45 years than in the younger

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[16] The sample is classified into three levels of employment.

First level of employees includes professionals like doctors, chief engineers, professors, general managers, purchase managers, team mangers, sales managers, project managers and chief executives;

Second (middle) level of employees includes assistant managers, assistant engineers, assistant administrative officers, second division clerks, supervisors, HR assistants, Business associates, floor managers, executive engineers, traffic police constables, operational assistants, senior process managers;

Third (entry) level ofemployees includes positions like salespersons, construction workers, carpenters, security guards, street vendors, cleaners, mechanics, petty shop owners, trainees, drivers and service boys. This level also includes informal sector employees.

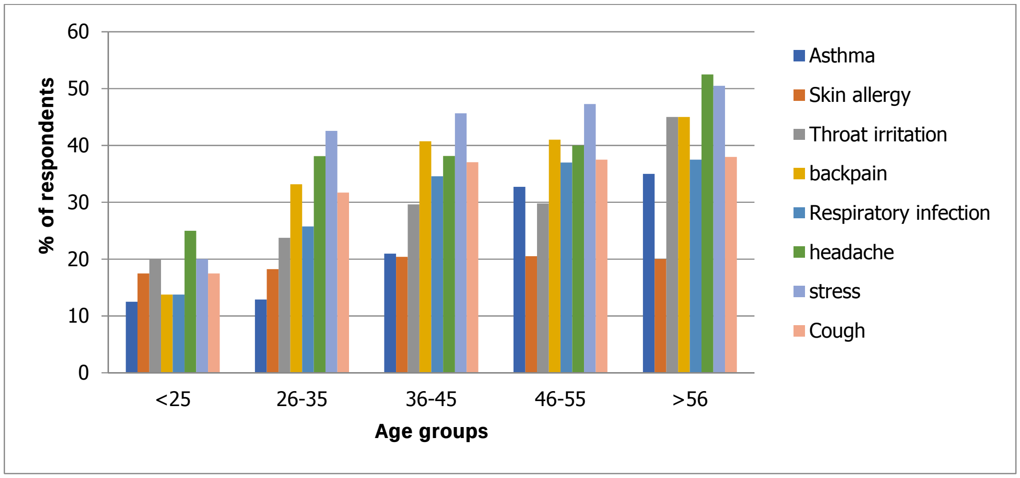
[17] Since these are multiple answers, the percentagewill not add up.

[18] Though it is not a health issues due to traffic-related air pollution, due to long travel time, often commuters reported the issue of back pain.

[19] The data is controlled for smoking habits among respondents.

agegroup (less than 25 years). The traffic-related health issues get aggravated with age. Figure 3 provides details about the age-wise health issues reported by the respondents in the study area.

Figure 3: Age-wise Travel-related Health Issues Reported (%)



Source: Primary Data

Figure 3 clearly indicates the severity of the travel-related health issues growing with age. Among the age group of less than 25 years, the prominent health issues suffered was headache (25%), throat irritation and stress (20%), skin allergy and cough (both 17.5%). Among the age group of 26-35 years, most of the respondents reported that stress (42.6%) is a major health issues due to traffic followed by headache (38.1%), back pain (33.2%) and cough (31.7%). Stress (45.7%), back pain (40.7%) and headache (38.1%) are the traffic-related health issues most commonly reported by the age group of 36-45 years. Among the age group of 46-55 years, more than 35 per cent of the respondents were suffering from most of the traffic-induced illnesses. Among them, headache (52.5%), stress (50.5%), back pain and throat irritation (45%) cough (38%) and asthma (35%) were very common.

Another factor related to traffic-related health issues is the duration of exposure and travel distance. It has been established already that traffic junctions have a high concentration of pollutants and long exposure could lead to high incidence of diseases. Owing to this hypothesis, Table 9 provides details about the exposure duration and distance travelled by respondents with disease type.

Table 9: Average Traffic Exposure and Distance Travelled with Disease Type Classification

Details	**Asthma**	**Stress**	**Cough**	**Headache**	**Respiratory infection**	**Back pain**
Average distance travelled (kms/day)	34.5	30.5	33	14	35	32.25
Average traffic exposure (min/day)	43.5	38.5	40.6	22.4	42.7	32.7

Source: Primary Data

The primary survey reveals that if a commuter travels more than 34kms a day and is exposed to 43.5 minutes/day of traffic emissions, he/she would be likely to suffer from the issue of asthma and 35kms of travel and 42.7 minutes of exposure would lead to respiratory infections. Even the epidemiological literature also supports this argument that cases of asthma and respiratory issues would be high if individuals are exposed to high levels of RSPM. Having established the epidemiological evidence for the study area, the next section will provide the economic valuation of health due to traffic air pollution.

Economic Valuation of Morbidity

Under the direct cost of illness, the present study estimated the cost of medication (as it is an important element of the COI) and under indirect cost, productivity loss and preventive expenditure are accounted for. Studies have provided evidence that exposure to increased level of RSPM (which is a primary pollutant of vehicular emissions) would lead to certain morbidity issues like respiratory infection, asthma and other ailments. Similar results are also found in the present study where the working commuters in the city have a high incidence of respiratory infection, cough and stress related issues.

From the primary survey, it is observed that respondents do not resort to immediate medical attention for all the health issues; rather they prefer certain non-medical solutions (taking rest or home remedies). But it is also observed that such cases are reported mainly among the younger age group, below 35 years. Hence, it can be argued that as emissions exposure increases with age, certain issues get compounded and aggravated, resulting in the sufferers seeking medical attention. For estimation purpose, the study has not considered those respondents who reported that they do not seek medical attention.

1. Direct Cost of Illness: Cost of Medicines

Among the total number of respondents who suffer from traffic-related health issues (73.5%), almost 67.19 per cent reported that they seek some medical aid. The rest (32.8%) although reporting that they suffer from incidences of headache, cough and back pain, said they avoid medical help as the issue subsides in a day or two. An important observation made from the data is that among 32.8 per cent of respondents who did not seek the medical aid, a majority (78%) belong to the age group below 30 years which indicates that with increased travel and by age, the issue may get aggravated over time. Table 10 provides details about the traffic-related health issues for which medical attention was sought.

Table 10: Medical Treatment Sought for Health Issues

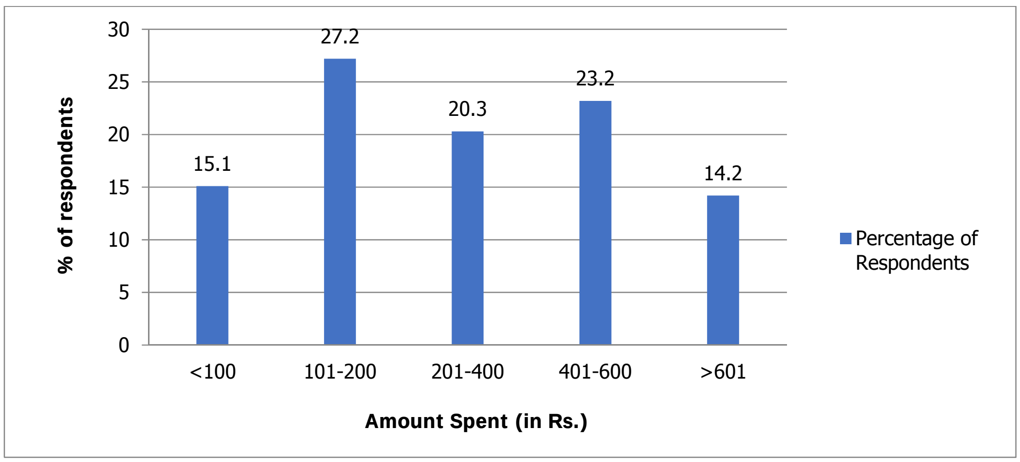
Health issues	Percentage of respondents seeking medical help
Respiratory infection	30.5
Asthma	27.4
Headache	20.7
Back pain	10.2
Skin allergy	5.4

Source: Primary Data

Among the various health issues, stress and blood pressure are the commonly reported and treated health issues (30.3%). Though these health issues can be linked with the age factor and tend to aggravate with the type of occupation and micro environment, long delays due to traffic congestion might compound these issues. Further, asthma and cough are the next major issues which often require medical attention (27.4 and 18% respectively).

With the details of the health status of respondents from the study area, the next section will estimate the direct cost of illness, that is cost of medication. For the estimation, the study considered only those respondents who have bought medicines in a month exclusively for travel-related health issues from out of pocket expenditure (without any health insurance claims). Among the total 67.19 per cent of medical assistance seekers, nearly 27 per cent of the respondents incurred cost ranging from Rs. 101-200, and around 23.2 per cent of them incurred cost ranging from Rs. 401-600.

Figure 4: Percentage of Respondents Incurring Cost towards Medicines



Source: Primary Data

Further, in Table 10, details of the cost of medicines for the type of disease were given. It is evident from the survey that respiratory related issues like asthma and respiratory infection incur a high cost of Rs. 690 and Rs. 354 per month respectively[20].

Table 11: Cost Incurred towards Medicines

Disease	Average cost of medicines (Rs. P.M)
Asthma	690
Respiratory infection	354
Back pain	325
Cough	286
Stress and BP	222
Headache	116

Source: Primary Data

[20] These costs do not include any major medical investigation costs.

On an average, a commuter in the city would spend around Rs. 412 per month as cost of medicine due to travel-related health issues. This would sum up to Rs. 4,944 per year spent as cost of illness, which is the direct or out of pocket expenditure.

2. Indirect Cost of Illness: Productivity Impacts

In the previous section, there was an estimation of out-of-pocket expenditure (cost of medicines), but there are certain implicit costs borne by the commuters if they suffer from the traffic-related health issues for a long time which makes them to take the workday off (sick leave). This measures the cost of foregone earnings due to traffic-related illness which inflicts productivity loss to the workplace (though certain workplaces provide sick leave provisions) and hence has economic cost implications.

In this background, the study estimated the productivity impacts by collecting the data of sick leave days[21] from the work due to traffic-related health issues. The utmost care was taken while gathering the information on sick leave days from the respondents, as there might be other reasons for the sick leave and they might be paid leave[22]. To avoid overestimation, the study collected the data on sick leave due to traffic-induced health problems only. Further, to avoid recall bias, data was collected for the previous three months and cross verified with the employers wherever possible. The details of the percentage of respondents taking sick leave are reported in Table 12.

Table 12: Percentage of Respondents on Sick Leave due to Traffic-related Health Issues

No of days of sick leave in last three months	Percentage of respondents
Below 2 days	83.0
3 days	10.8
4 days	3.0
5 days	1.9
More than 6 days	1.0

Source: Primary Data

From Table 12, it is evident that majority of the respondents reported that they have taken sick leave of less than 2 days in last three months due to traffic-related health issues (apart from casual leave). Since the sick leave will have productivity loss to the workplace (even though there is provision of medical leave) the study has estimated these days loss by attaching theper day income of the respondents in Table 13.

[21] It is apart from casual leave (CL)

[22] Though they are paid leave, there is economic loss to the employer due to worker being absent due to traffic induced health issues.

Table 13: Details on Productivity Loss due to Traffic-related Health Issues

Health issues suffered	Percentage respondents	Average days of sick leave in a year
Asthma	39.6	12
Respiratory infection	19.8	12
Cough	19.8	08
Headache	2.9	04
Stress and BP	10.8	08
Skin allergy	4.9	08
Total	100	08 days on average

Source: Primary Data

Commuters reported that major issues for which they have taken sick leave are respiratory infection and asthma. The average days of sick leave taken by the respondents for traffic-related health issues are 12 days in a year which could lead to productivity loss of Rs. 15, 520/person per year. The number of days of sick leave taken also depends on the type of issues suffered due to traffic congestion. Evidently, cardiovascular issues would lead to more sick leave than other issues.

2.1. Preventive Measures

Preventive measures are measures to avoid traffic-related air pollution or travel on a congested route. It may be in the form of diversion of route or shifting to less congested mode. In this section, both measures are considered as preventive measures and an effort is made to estimate their cost. The rationale behind this estimate is: Commuters in Bengaluru reported that they prefer travelling in less congested roads even if they have to pay a toll amount for it and some commuters would prefer shifting their transport mode to metro trains from bus or private vehicles. In the first case, toll amount paid by commuters is taken as an additional cost due to traffic congestion and in the second case, difference in the ticket fare amount compared to bus fare[23] is taken as an additional cost of traffic congestion.

Table 14: Preventive Measure: Tolled Road Users

Disease Type	% of commuters using tolled road	Average toll amount per day[24] (in Rs.)
Asthma	31.57	175
Cough	57.8	135
Headache	55.8	130
Back pain	55.8	130
Respiratory issues	47.36	91.25
Stress	47.36	91.25

Source: Primary Data

[23] Assuming the bus fare is comparatively cheaper than other modes of transport in the city.

[24] Though toll amount differs depending on the types of vehicles, the major objective of the estimation is to know the use of toll road by the type of disease.

A very low number of respondents (6%) use the toll road for their daily commute and a majority of the toll road users are four-wheelers (60%) as driving in the toll road is more convenient and faster. Among the road users, those with issues like cough (57.8), headache and back pain (55.8%) and respiratory infection (47.36%) would prefer the toll road. On an average, the toll paid by a commuter is Rs. 125 per day which can be anaverage of Rs. 30, 000 per year/person.

Table 15: Preventive Measure: Metro Train Users

Disease Type	% of metro users[25]	Distance commuted	Amount paid for metro ticket (Rs./month)	Additional cost of traffic congestion (Rs/month)
Asthma	22	8.8	1110	110
Cough	22	8	1107	107
Headache	33	9	1110	110
Back pain	29	12	1125	125
Respiratory infection	40	12	1120	120
Stress/BP	55	132	1130	130

Source: Primary Data

Among the total public transport users in the sample, 18 per cent of commuters are the metro users. These commuters have shifted to metro trains due to inconveniences faced due to traffic congestion while travelling in bus or in their own vehicle. Among the total metro users in the sample, 58 per cent of the respondents have shifted from bus to metro and reported that travelling in the metro is more convenient and faster than bus travel. The rest (42%) of the respondents who shifted to metro are owners of private vehicles who reported that travelling in their own vehicle is stressful due to traffic congestion.

In Table 15, metro train users have been examined in terms of disease. To calculate the preventive cost, the difference between the bus travel cost (average of Rs. 1000/month) and metro travel cost is calculated (as a majority of commuters have shifted from bus to metro). On an average, metro train users will bear an additional cost of Rs. 150/month as a preventive expenditure. Hence, annually, it would cost around Rs. 1800 per person. Further on average, the commuters would have to bear an annual additional cost of Rs. 31,800 which can be considered as preventive expenditure of traffic congestion.

2.2. Mitigative Measures

Under mitigative measures, common measures adopted by the commuters are wearing masks, closed helmets, closing car windows, using ACs in car or opting for work from home. From the primary data, we have collected the possible mitigative measures adopted by the commuters in the city. It is observed that 63 per cent of the respondents[26] who suffer from health issues wear face masks and closed helmets to avoid pollution due to traffic congestion. Among the car users, 80 per cent of respondents

[25] % to total metro users

[26] Two-wheeler users.

close their car window and use AC to avoid the pollution while travelling. Just eight per cent of the respondents prefer work from home to avoid traffic congestion in the city. A major issue faced in measuring the mitigation cost is the monetary valuation of these measures. Hence, the study has not accounted for mitigative measures in the cost estimation.

Total Cost of Illness

The total cost of illness would sum up the direct and indirect cost of illness.

Cost of illness = Direct cost + Indirect cost

The study has estimated the cost of illness by adding up the average cost of medication (Rs. 4,944 per year) and average loss of productivity (Rs. 15,520 per year) and average preventive measure cost of Rs. 31, 800 per year. This can be summed up as Rs. 4,944 of direct cost and Rs. 47,320 of indirect cost and a total of Rs. 52,264 per person/year is lost due to traffic congestion. This is accounted as an average of 1.17 per cent and 11.2 per cent of the annual income of the respondents respectively.

Conclusions

Being one of the dynamic cities of the world, Bengaluru city is inevitably caught in a gridlock of traffic congestion. Usually, commuters in any city complain about the long waiting times in traffic junctions or slow movement of vehicles, but they often ignore the health impacts of long exposure to traffic emissions. This study is novel in its approach to estimate these costs and calls for urgent attention from the policy makers to address the issue of traffic-related air pollution in the city.

Respirable Suspended Particulate Matter (RSPM), being the primary pollutant from vehicular emissions, tends to have various health impacts ranging from irritation in the eyes and throat to major issues like respiratory infections and cardiovascular problems. Having established the concentration response function between the traffic pollutants and health impact, the study estimated the economic cost of morbidity using the Cost of Illness approach, which accounted for approximately 13 per cent of the personal income of commuters being lost due to traffic congestion.

These estimates call for immediate policy measures to improve the city's air quality level. The increased affordability of automobiles (backed by easy finance facility) has imposed a huge health cost. To curb this, there is a need to make public transport affordable and efficient and in the meantime impose certain restrictions on the automobile finance facility.

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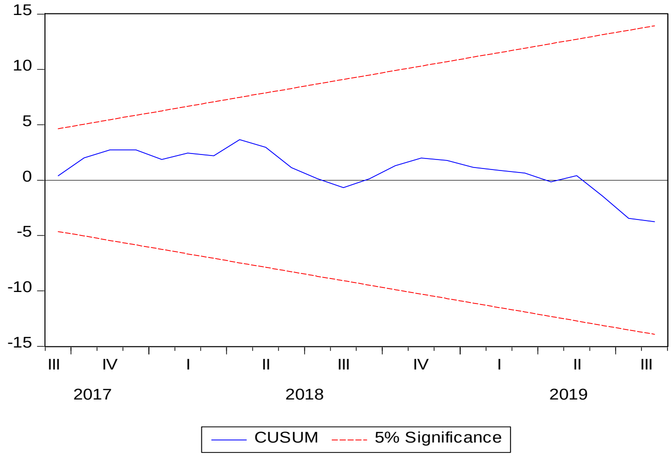
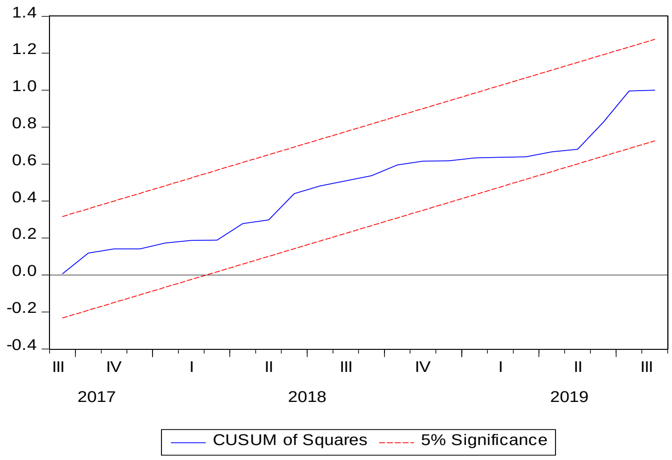
Appendix 1: CUSUM Test and CUSUM of Squares Test of ARDL Model

The straight line represents critical bounds at 5 per cent significance level





Appendix 2: Diagnostic Test Result of ARDL Model

LM test	BP test	Jarque-bera
0.65 (0.26)	0.66 (0.4)	0.62 (0.23)

Parenthesis is the probability values

Appendix 3: Zones and Junctions in Bengaluru City

Zone No.	***Zone Name***	***Junctions identified***	***Sample collected***
1	CBD	Corporation Circle, Hudson Circle, KR circle	107
2	Adjacent CBD	Trinity Circle, Richmond Circle, Navarang Junction, Oklipuram Signal	106
3	Inner Periphery	Magadi Road, Mehkri Circle, Sony World Junction, Silk Board	108
4	Periphery	BEL Circle, Hebbal Flyover, KR Puram Junction (Tin Factory), Marathhalli Bridge Signal	106
Total			***427***

Source: Author

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