PERIODICO di MINERALOGIA Volume 91, No. 5, 2022
ISSN: 0369-8963

# Vehicle Emissions in Madurai, India: A Quantitative Study and Analysis

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## Abstract

*Rapid urbanization paved way for social, economic and technological development that has improved the country in so many ways. This being the global truth also has undisputed drawbacks of population explosion, traffic congestion, air and thermal pollution, urban heat islands and so on. This study acknowledges the prevalence of air pollution due to vehicle exhaust and ponders on the causes and effects of fast-growing vehicle population. The study is focused on Madurai city which has been facing exponential population growth, vehicle growth and urban sprawl. The major routes were identified for estimation and field observations and their results discussed. The study has revealed that, although vehicular emissions contribute higher than any other source within the urban borders, the activities relating to transportation play an important role as well. The disparity between the vehicular count and the availability of space paired with the non-existence of non-motorised transportation systems have been identified to be at the core of the issue.*

Keywords: *Vehicular emission, Air quality, Madurai city, fine particle matter, particulate matter, suspended particulate matter*

## Introduction

### Madurai city – An introduction

Madurai city is one of the oldest cities of South India with an inhabitation of 14,70,755 people as per the 2011 census [1]. The city is the functional headquarters of the district and is historically significant owing to its longstanding heritage. Madurai city is a pilgrim center with several world-famous temples such as Meenakshi Amman temple, Skanda temple at Tirupparankundram[2], churches, mosques and palaces[3]. The city was home to several kings and has been the epicenter of the Tamil Sangam, Literature, Art and Culture[4].

The city was initially developed around the world-famous Meenakshi Amman Temple. The temple is still serving as one of the hearts of the business districts for Madurai city housing various businesses catering to home needs, tourism and even production. The city has been known for its small-scale and medium-scale industries right from its inception[5]. Since its roots are religious, the city hosts a couple of major Hindu festivals like Chitherai festival[6] which brings tourists and pilgrims from all over the state. Much of the original city architecture revolved around the movement of people in and out of the temple and the palaces. With urbanization, the surrounding villages have now merged with the city that now spreads around 150 sq.km which is divided into 100 wards and five administrative zones[7]. This historic city has faced has an exponential growth in population[8]. Though this has been facilitated with technological and employment opportunities, the rural population has rapidly moved to the urban areas of Madurai since 1990[9]. This has led to a rapid urban sprawl thus leading to longer travel distances, higher fuel consumption, higher levels of vehicle ownership and usage[3]. A change in the urban sprawl pattern has also been observed as it has become more linear as opposed to a mono-centric design in its initial stage as shown in Fig.2. The development of the city as an inhabitation from one side of the river Vaigai

 https://doi.org/10.37896/pd91.5/91548

ISSN: 0369-8963

to a staggering 346% of urban migration. Detection of urban sprawl changes have resulted in this tremendous increase in urban land cover as the reduction in forest cover has been identified to be 58.64% [10].

## Research Significance

For a city based on historic architecture, Madurai town continues to face an urban sprawl that disrupts the very fabric of the historic city plan. The planned city center that predominantly focused on the temple and its activities have been expanded to an extent where the city no longer has one city center but rather a few centers all bustling with activity. This can be attributed to the fast paced urban sprawl happening in Madurai since the turn of 1990[3]. The increased industrial, educational and social growth has led to accelerated rural-urban migration which has drained the nearby villages despite the population growth[3], [8]. The urban sprawl and population boom brings into effect increased vehicle usage and traffic congestion[11]. The practical difficulty in modifying streets and roads as per the growing needs and the loss of green cover has negatively impacted the living conditions. The narrow roads to today's traffic requirements have brought upon a challenging situation to preserve the historical streets while accommodating wider roads with safety protocols[12]. Although this still remains an unattainable milestone, constant changes are being made to accommodate the constraints along with the needs[13]. The growth of urban population has led to a tremendous increase in housing shortage and urban population density. This phenomenon has ultimately driven people out of the city and thus the urban sprawl. The sprawl has reached the borders of the administrative district and directly influences the need for longer travel[14]. The usage of motorized vehicles for daily commute to work, education and other essential activities has driven out the favoritism towards walking and cycling if people can help it. Thus, the number of vehicles on road throughout the city has grown to an all -time high as with the busiest cities in India. The ever-growing vehicle count on the urban roads has impacted the livability of the urban population. The increased air pollution contributed by the vehicle growth has also directly influenced the safety of the people using non-motorized modes. It has been determined that this is brought on by an insufficient allotment of space for both motorised and non-motorized traffic movement[15]. The preference for catering for motorised transportation has almost eliminated the pedestrian routes. Since the average speed of the vehicles is substantially higher than the average cyclist, the slower cyclists have been forced into the main stream, endangering the riders. Due to the lack of faster speeds and shorter journey times, this phenomenon has gradually reduced the demand for non-motorized transportation. The rise in vehicular population has paved way to more than one stream of livability issues for the urban sector and an uni-directional approach as in the past is least likely to solve the multitude of issues faced. The urban air is affected by the presence of emission sources of gaseous pollutants and weather conditions such as Atmospheric Boundary Layer (ABL) [16]. The predominant gaseous pollutants are carbon oxides, nitrogen oxides, sulfur oxides, hydrocarbons and particulate matter. The emissions due to transportation can be directly related to the quantities of gasoline and diesel consumption. The increase in emissions has been influenced by the increase in the number of motor vehicles and increase in the distances these vehicles travel[17]. Increase in motor vehicle ownership has been observed at an average of 5% per year in India since 1950 while the compounded growth rate of road length was 4.2% [18]. The growth of vehicles has outpaced the growth of available road length which evidently explains the overflowing roads that a city dweller experiences on a daily basis. In response to this congestion, vehicles move more slowly, which in turn causes a concentration of pollutants in congested areas [17], [19]. These pollutants have


https://doi.org/10.37896/pd91.5/91548

ISSN: 0369-8963

damaging health risks which may even be fatal or disabling for lifetime when exposed to for a longer period. Prolonged consistent exposure to fine particulate matter causes irreversible damage to the respiratory and cardiovascular system [20].The probability of dying from non-communicable diseases(NCD) between the ages of 30 and 70, also known as premature mortality, was 23.3 in 2015 and has almost remained the same since then. Four main NCDs are cardiovascular diseases, cancer, chronic respiratory diseases and diabetes[21]. Fine particulate matter and physical inactivity are attributed as causes for cardiovascular diseases and chronic respiratory diseases[22][23]. Air pollution also happens due to various reasons like industrial use, construction, burning etc. [17] For the scope of this paper, the authors have restricted the study to vehicular emissions that are affecting the health of the urban public [24].

## Research flow

The authors have identified the constituents of air pollution, the vehicle types, their emission factors and coefficients of fuel types used through intent literature study. The traffic flow data of the major roads identified in Madurai city were assimilated and analyzed according to vehicle type. The emissions for each vehicle type were estimated [19]. The estimates along the major roads are analyzed and discussed for commonalities and anomalies. The presence of particulate matter was investigated against the vehicle volume count during the observation period of 30 days using a portable electro-chemical sensor as an experimental study. Observations during the day while in movement atop a vehicle and an average of three stationary points were made. The observations were collated and presented in a table. The research flow is presented in Fig.1.

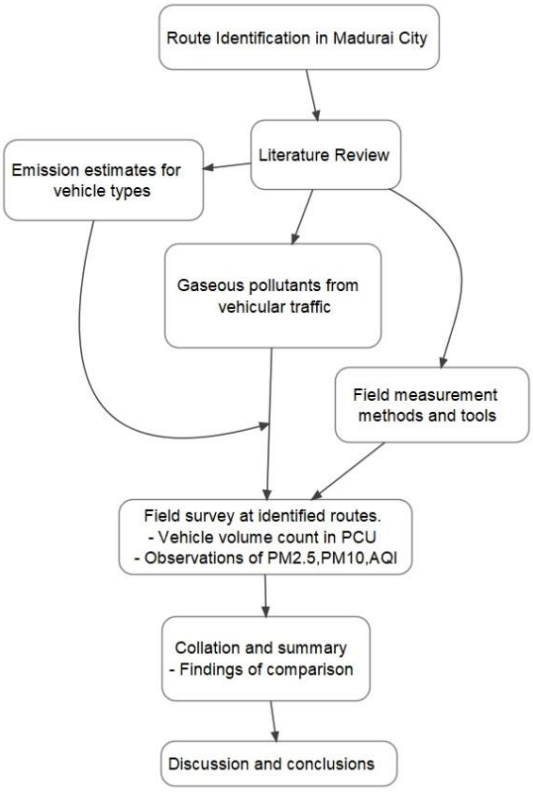


Fig. 1 Research Flowchart


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ISSN: 0369-8963

## Vehicular emissions as estimates

The emission of vehicle type were estimated by multiplying the number of vehicles of that vehicle type, V with D, their distance travelled in a year in kilometers and e, the emission factor for the pollutant under consideration , E = (V * D) * e . The emission estimated is derived in g/km [19]. For the scope of this study, the estimation of emission for two wheelers, Cars, Buses and HCV are calculated. The emission factor is calculated for every vehicle type based on factors such as fuel consumption, average fuel efficiency, upload factor, driving power etc. [17] For two wheelers, the emission factor is derived by the average fuel efficiency over fuel emission factor. Although the Indian scenario has different varieties of two wheelers based on engine capacity, the reported fuel efficiency value is taken as 44.5 KMPL [25]. Similarly, emission factors for buses and HCV are calculated. Vehicular pollution also takes into account the presence of particulate matter. Table 1 presents the emission factors taken into consideration for calculation of emissions. When charted, the carbon dioxide emissions due to the movement of buses is found higher than the two-wheeler emissions, especially along R18 which is the central business district of Madurai around the world famous Meenakshi Amman temple. This area is one of the most crowded places in the city as it doubles as a pilgrim center, a heritage site, business hub and a marketplace to the locals. There are schools, churches, entertainment theatres, government offices and a bus stand. The presence of the Bus stand might single handedly explain the high emission levels but with the recent Smart city mission, the Periyar Bus stand has received a complete makeover. This Smart City project has in its making an unified Periyar Bus stand with a roundabout-like structure that allows seamless transport.

Table 1
Emission factors of vehicle types for gaseous pollutants

| Pollutants | Two-wheeler | Cars, Jeeps | Bus | Trucks, lorries | Reference |
|---|---|---|---|---|---|
| $CO_2$ | 26.6 | 223.6 | 515.2 | 515.2 | [26][27] |
| CO | 2.2 | 1.98 | 3.6 | 3.6 | [26] |
| $CH_4$ | 0.18 | 0.17 | 0.09 | 0.09 | [28][29] |
| $SO_2$ | 0.013 | 0.053 | 1.42 | 0.28 | [17], [19] |
| $NO_x$ | 0.19 | 0.2 | 12 | 6.3 | [25] |
| PM | 0.05 | 0.03 | 0.56 | 0.28 | [19] |
| HC | 1.42 | 0.25 | 0.87 | 0.87 | [19] |

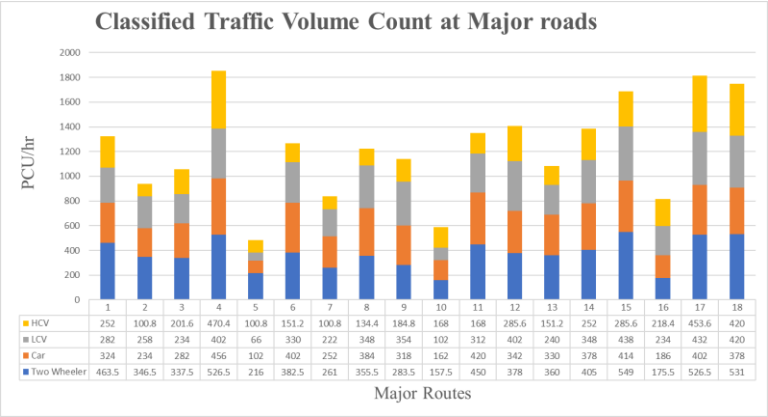
The Smart city project that is currently being implemented has a multi-level parking system [30] that aims to reduce the congestion and movement of vehicles that would need to enter into the Central Business District. This will ensure free flow of public transport which is otherwise majorly blocked by the extensive parking on the narrow roads surrounding the Temple. A city of 14.5 lakh population services a floating population of 202 lakhs during peak tourist seasons[30]. The multi-level parking system as part of the combined Bus stand project is aimed to remove the on-street parking throughout the four iconic roads surrounding the Temple and to enable walkability around the temple which houses various kinds of businesses from textiles to jewelry and electronics. The reduction in slow moving vehicles due to congested roads is expected to directly bring a reduction of the fine particle pollution in that area. However these plans seem to have little effect in improving the air quality around the area.


https://doi.org/10.37896/pd91.5/91548

ISSN: 0369-8963

## Selection of routes and study points

Madurai city is divided into five zones and 100 wards as administrative borders[7][31]. The major roads selected and classified traffic volume count collected are shown in Fig. 2. These routes have been visited and confirmed for their length and the land use category they fall into. The majority of Madurai is of mixed land use that has been both a blessing and a curse in different ways to the public. The housing scenario is highly flexible thus reducing the need for longer travel times but has resulted in increasing the population density. This has proved to have a negative effect on the air quality owing to the increase in particulate matter due to the industrial emissions. Although this study is focused on the vehicular emissions, industrial and household emissions are intertwined with the city's fabric that higher particulate matter levels have been recorded even amidst little to no vehicular movement.




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HCV | 252 | 100.8 | 201.6 | 470.4 | 100.8 | 151.2 | 100.8 | 134.4 | 184.8 | 168 | 168 | 285.6 | 151.2 | 252 | 285.6 | 218.4 | 453.6 | 420 |
| LCV | 282 | 258 | 234 | 402 | 66 | 330 | 222 | 348 | 354 | 102 | 312 | 402 | 240 | 348 | 438 | 234 | 432 | 420 |
| Car | 324 | 234 | 282 | 456 | 102 | 402 | 252 | 384 | 318 | 162 | 420 | 342 | 330 | 378 | 414 | 186 | 402 | 378 |
| Two Wheeler | 463.5 | 346.5 | 337.5 | 526.5 | 216 | 382.5 | 261 | 355.5 | 283.5 | 157.5 | 450 | 378 | 360 | 405 | 549 | 175.5 | 526.5 | 531 |

Fig.2 Classified Traffic Volume Count at Major roads of Madurai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ISSN: 0369-8963

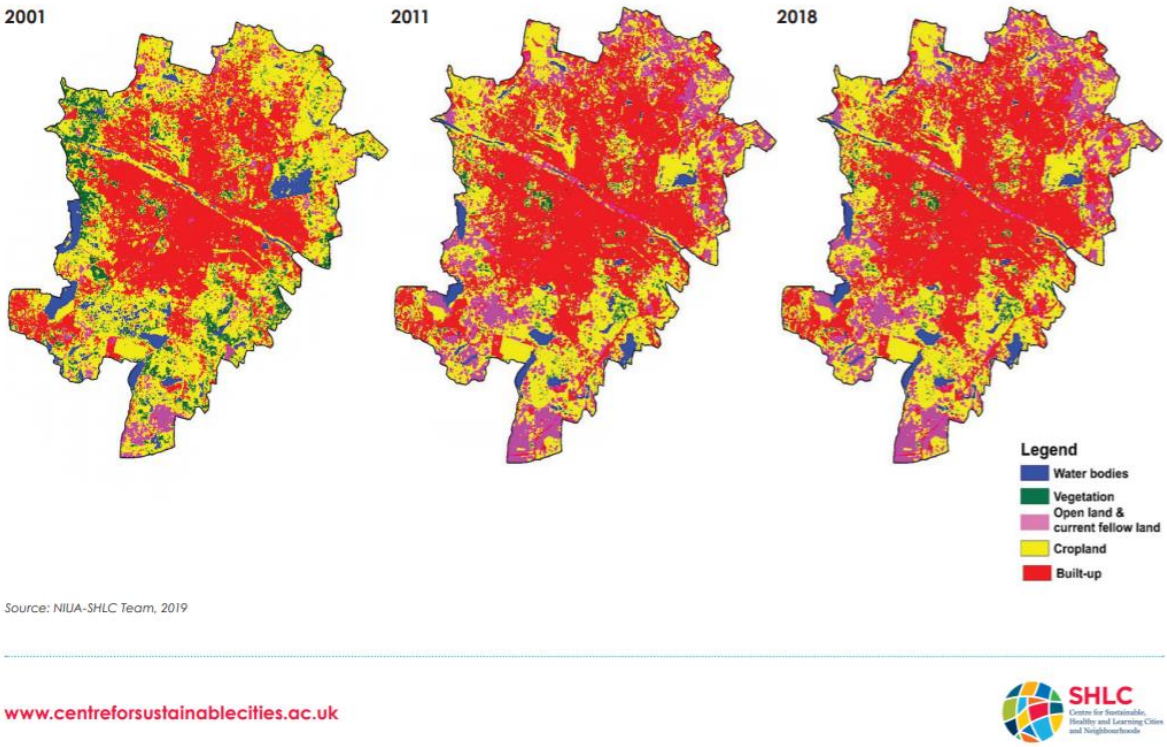
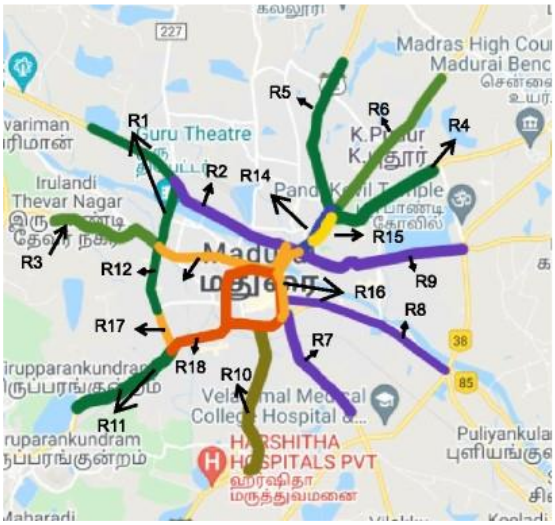



Fig. 3 Madurai city growth of built-up urban sprawl area[32]




| Code | Road name |
|---|---|
| R1 | Dindigul highway |
| R2 | Kudal nagar |
| R3 | Theni route |
| R4 | Mattuthavani road |
| R5 | Natham Road |
| R6 | Alagar kovil road |
| R7 | Chintamani road |
| R8 | Ramanathpuram Road |
| R9 | Sivagangai road |
| R10 | Avaniyapuram road |
| R11 | Thirumangalam Road |
| R12 | CR(Elice Nagar to Kalavasal ) |
| R13 | CR(Kalavasal Junction to Madurai) |
| R14 | CR (Natham Road) |
| R15 | CR(Alagar Kovil Road) |
| R16 | CR(Sivagangai Road to CBD) |
| R17 | CR (Byepass Road) |
| R18 | CR(Madurai CBD Road) |

Fig 4 The selected routes and their codes

Table 2
Field observation data


https://doi.org/10.37896/pd91.5/91548

ISSN: 0369-8963

| Code name | Road name | PCU Count at the time of observation | | | | PM 2.5 | PM 10 | AQI |
|---|---|---|---|---|---|---|---|---|
| | | Two-Wheeler | Car | LCV | HCV | | | |
| R1 | Dindigul highway | 463.5 | 324 | 282 | 252 | 53.10 | 66.27 | 103 |
| R2 | Kudal nagar | 346.5 | 234 | 258 | 100.8 | 32.37 | 68.67 | 93 |
| R3 | Theni route | 337.5 | 282 | 234 | 201.6 | 36.53 | 46.27 | 87 |
| R4 | Mattuthavani road | 526.5 | 456 | 402 | 470.4 | 32.70 | 76.43 | 85 |
| R5 | Natham Road | 216 | 102 | 66 | 100.8 | 32.13 | 38.20 | 80 |
| R6 | Alagar kovil road | 382.5 | 402 | 330 | 151.2 | 25.67 | 39.20 | 72 |
| R7 | Chintamani road | 261 | 252 | 222 | 100.8 | 42.60 | 86.70 | 89 |
| R8 | Ramanathpuram Road | 355.5 | 384 | 348 | 134.4 | 35.73 | 82.60 | 115 |
| R9 | Sivagangai road | 283.5 | 318 | 354 | 184.8 | 34.30 | 59.30 | 73 |
| R10 | Avaniyapuram road | 157.5 | 162 | 102 | 168 | 43.57 | 39.90 | 62 |
| R11 | Thirumangalam Road | 450 | 420 | 312 | 168 | 17.27 | 29.67 | 66 |
| R12 | CR(Ellis Nagar to Kalavasal) | 378 | 342 | 402 | 285.6 | 31.77 | 80.60 | 97 |
| R13 | CR(Kalavasal Junction to Madurai) | 360 | 330 | 240 | 151.2 | 43.80 | 84.87 | 85 |
| R14 | CR (Natham Road) | 405 | 378 | 348 | 252 | 17.00 | 28.07 | 61 |
| R15 | CR(Alagar Kovil Road) | 549 | 414 | 438 | 285.6 | 33.00 | 84.03 | 145 |
| R16 | CR(Sivagangai Road to CBD) | 175.5 | 186 | 234 | 218.4 | 28.50 | 31.07 | 138 |
| R17 | CR (Byepass Road) | 526.5 | 402 | 432 | 453.6 | 32.97 | 67.13 | 83 |
| R18 | CR (Madurai CBD Road) | 531 | 378 | 420 | 420 | 31.63 | 37.43 | 76 |

Particulate matter of the size 2.5$\mu m$ causes long term respiratory issues when found in higher concentrations[20]. The PM2.5 is the fifth largest mortality factor listed for the year 2015 and is responsible for the negative environmental, atmospheric and climatic impacts such as fog, degradation of visibility etc.[33]. The PM2.5 concentration is considered hazardous than Suspended Particle Matter (SPM) or Particulate Matter 10(PM10) due to its smaller size.

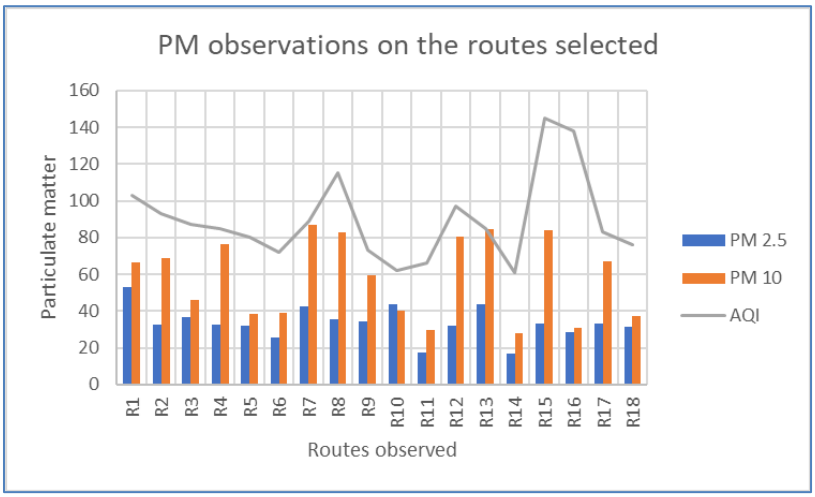



Fig. 5 Particulate matter observations on the routes selected


https://doi.org/10.37896/pd91.5/91548

ISSN: 0369-8963

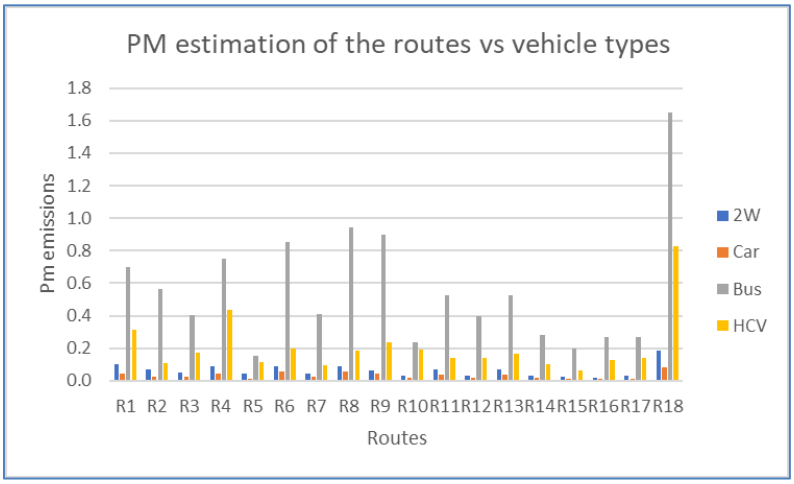



Fig. 6 Particulate matter estimation on the routes Vs. Vehicle types.


https://doi.org/10.37896/pd91.5/91548

ISSN: 0369-8963

## Discussion on observations

The selected routes throughout the Madurai city focused around the central business district and its connecting roads. Madurai city was built in the 3rd century around the Meenakshi Amman Temple and the city survived the surrounding villages until the turn of 1900. Since then, Madurai city has faced an unprecedented sprawl that with further planning and development such as shifting corporation offices, parks and complexes, the urban sprawl has turned linear. The linear sprawl, though planned to an extent, has its demerits in view of environmental and mobility patterns. The linear urban sprawl has increased the travel distances and hence the vehicular emissions. The emissions from the vehicular movement were estimated and particulate matter pollution was observed to be compared against the vehicular population during the observation period. The results were tabulated and charted to enable better understanding of the levels. The levels prescribed by the Central Pollution Control Board are higher than the WHO threshold [34] [23]. The comparison of the estimate and the field observations reveal that the actual air pollution is predominantly due to large number of motorized vehicles. The presence of free-flowing vehicular movement avoids the suspension of particulate matters thus allowing the air to be cleaner thus reducing the level of particulate matter of 2.5 μm and PM10. Highly congested areas have shown a much lower PM2.5 level as well owing to the fact the lack of traffic movement thus allowing the heavy particles to be suspended. The observation from Fig 5 & 6 reveals that the AQI is highest where the PM levels are the lowest and route R16 has a much lower vehicle volume count compared to the other routes under observation. This route is characteristic of commercial vehicle flow more than the private and public vehicles explaining the low particulate matter levels. Routes R5 and R6 have recorded low traffic volume count but an equally lower Air Quality Index as well. However, the field visit revealed that the on-going construction work for the flyover constitutes to a higher percent of particulate matter pollution through that route.

## Conclusion

In transportation sector, pollution is the major problem which affects both human and environment. This study concludes that the pollution from vehicles can be minimized by using new as well as innovative technology, and government policies. For our future, we must work together in reducing global warming and reducing vehicle use across all transport sectors, hence the level of pollution can be reduced.

Madurai city does not generally face any visibility challenge due to vehicular emissions. As with other developing urban centres, the city faces an increase of urban temperature due to urbanisation contributing to thermal pollution. The PM2.5 levels, although not as high as PM10 levels observed in the experimental study, it has much drastic effects than its counterpart even in lower concentrations. Madurai city faces summer during March-May but even the lowest average temperature recorded is in December at 25oC . Particulate matter of the size 2.5 micro-meters are by nature swept away in rain or by wind but the city's temperature average does not aid to that situation. In addition, the windflow caused by the movement of vehicles does help in shifting the concentration of pollutant particles thus proving that solving the congestion issue on roads could inadvertently aid in reduction of pollution. The most sustainable solution is to minimise the number of vehicles on road. Minimisation of the vehicle count on urban roads needs to be approached holitstically to involve sustainable solutions such as improving non-motorised transportation, improving the quality of public transportation, accessibility and safety of the transportation network. However further study is required on this area to understand the relation between speed of vehicles and concentration of particulate matter. Further studies when focused on this relationship will bring solutions to the issue of growing vehicle ownership that is inevitable in the coming years. The city has seen an increase of 9.6% since 2001 as per the


https://doi.org/10.37896/pd91.5/91548

ISSN: 0369-8963

census handbook,2011 [9]. Learning from the example of the state capital, the district of Chennai which is growing at an average of 21% per decade since 2001[35], Madurai city needs to focus on the non-motorized transport facilities and walkability as it works toward growing into a smart city.

## Acknowledgment

The authors express their gratitude to the Thiagarajar College of Engineering (TCE) for supporting us to carry out this research work. Also, the financial support from TCE under Thiagarajar Research Fellowship scheme (File.no: TRF/Jan-2021/03) is gratefully acknowledged.

## References

[1] Ministry of Urban Development Government of India, "Class I cities census data," vol. 43, no. 11. pp. 931–937, 2004.
[2] C. Branfoot, "The Madurai Nayakas and the Skanda temple at Tirupparankundram," *Ars Orientalis*, vol. 33. pp. 147–180, 2003, doi: 10.2307/4434276.
[3] P. Saravanan and P. Ilangovan, "Identification of Urban Sprawl Pattern for Madurai Region Using GIS," *Int. J. Geomatics Geosci.*, vol. 1, no. 2, 2010.
[4] S. Sm, K. Chandrabose, U. Umamaheshwari, and T. Maharajan, "Feasibility Study Of Metro Transport: Case Study Madurai," *Int. J. Civ. Eng. Technol.*, vol. 4, no. 4, pp. 976–6308, 2013.
[5] J. S. Smith, "Madurai, India: The Architecture of a City," 1976. Accessed: Sep. 19, 2022. [Online]. Available: https://dspace.mit.edu/bitstream/handle/1721.1/34289/02639082-MIT.pdf?sequence=2.
[6] D. H. Stanley, M. R. Binford, M. Camerini, and J. W. Elder, "Wedding of the Goddess," *J. Am. Folk.*, vol. 92, no. 365, 1979, doi: 10.2307/539437.
[7] "மதுரை மாநகராட்சி." https://www.maduraicorporation.co.in/ (accessed Aug. 14, 2021).
[8] S. L.-M. A. Studies and undefined 1977, "Changing form and function in the ceremonial and the colonial port city in India: an historical analysis of Madurai and Madras," *cambridge.org*, Accessed: Sep. 19, 2022. [Online]. Available: https://www.cambridge.org/core/journals/modern-asian-studies/article/changing-form-and-function-in-the-ceremonial-and-the-colonial-port-city-in-india-an-historical-analysis-of-madurai-and-madras/00A33B4F85CDE0B741B7EE5FB9F8BB20.
[9] Census, "District CENSUS Handbook 2011," 2011.
[10] S. Tamilenthi, P. Arul, and K. Chandramohan, "Detection of Urban Change and Urban Sprawl of Madurai City , Tamilnadu Using GIS and RS," vol. 1, no. 3, pp. 107–120, 2015.
[11] N. Y. City, "Issues in sustainable transportation Todd Litman*," *Transp. Res.*, vol. 6, no. 4, 2006.
[12] K. S. Sridhar, "Urbanization and Carbon Emissions in India and China," *Environ. Urban. ASIA*, vol. 9, no. 2, pp. 113–126, 2018, doi: 10.1177/0975425318783544.
[13] B. A. Anand, A. Sreevatsan, and P. Taraporevala, "SCM POLICY 28Aug2018," *SCM Policy Brief, Cent. Policy Res.*, no. August, 2018, [Online]. Available: http://cprindia.org/system/tdf/policy-briefs/SCM POLICY BRIEF 28th Aug.pdf?file=1&type=node&id=7162.
[14] C. L. Glaser, "The causes and consequences," 2000.
[15] J. Rychlewski, "Street Network Design for a Sustainable Mobility System," in

 https://doi.org/10.37896/pd91.5/91548

ISSN: 0369-8963

*Transportation Research Procedia*, 2016, vol. 14, doi: 10.1016/j.trpro.2016.05.108.
[16] L. Zhou, X. Xu, G. Ding, M. Zhou, and X. Cheng, "Diurnal variations of air pollution and atmospheric boundary layer structure in Beijing during winter 2000/2001," *Adv. Atmos. Sci.*, vol. 22, no. 1, pp. 126–132, 2005, doi: 10.1007/bf02930876.
[17] T. V. Ramachandra, B. H. Aithal, and K. Sreejith, "GHG footprint of major cities in India," *Renew. Sustain. Energy Rev.*, vol. 44, pp. 473–495, 2015, doi: 10.1016/j.rser.2014.12.036.
[18] MORTH, "Basic _Road_Statics_of_India.pdf." MORTH, [Online]. Available: https://morth.nic.in/basic-road-statistics-india.
[19] T. V. Ramachandra and Shwetmala, "Emissions from India's transport sector: Statewise synthesis," *Atmos. Environ.*, vol. 43, no. 34, pp. 5510–5517, 2009, doi: 10.1016/j.atmosenv.2009.07.015.
[20] T. Li *et al.*, "Fine particulate matter (PM2.5): The culprit for chronic lung diseases in China," *Chronic Dis. Transl. Med.*, vol. 4, no. 3, pp. 176–186, 2018, doi: 10.1016/j.cdtm.2018.07.002.
[21] *World health statistics 2020*. 2020.
[22] I. S. Kim *et al.*, "Long-term fine particulate matter exposure and cardiovascular mortality in the general population: a nationwide cohort study," *J. Cardiol.*, vol. 75, no. 5, pp. 549–558, 2020, doi: 10.1016/j.jjcc.2019.11.004.
[23] J. Rovira, J. L. Domingo, and M. Schuhmacher, "Air quality, health impacts and burden of disease due to air pollution (PM10, PM2.5, NO2 and O3): Application of AirQ+ model to the Camp de Tarragona County (Catalonia, Spain)," *Sci. Total Environ.*, vol. 703, no. xxxx, p. 135538, 2020, doi: 10.1016/j.scitotenv.2019.135538.
[24] S. Host, E. Chatignoux, C. Leal, and I. Grémy, "Health risk assessment of traffic-related air pollution near busy roads," *Rev. Epidemiol. Sante Publique*, vol. 60, no. 4, pp. 321–330, 2012, doi: 10.1016/j.respe.2012.02.007.
[25] C. Gajjar and A. Sheikh, "India Specific Road Transport Emission Factors," 2015.
[26] S. Baidya and J. Borken-Kleefeld, "Atmospheric emissions from road transportation in India," *Energy Policy*, vol. 37, no. 10, pp. 3812–3822, 2009, doi: 10.1016/j.enpol.2009.07.010.
[27] J. Pucher, Z. R. Peng, N. Mittal, Y. Zhu, and N. Korattyswaroopam, "Urban transport trends and policies in China and India: Impacts of rapid economic growth," *Transp. Rev.*, vol. 27, no. 4, pp. 379–410, 2007, doi: 10.1080/01441640601089988.
[28] E. Arsenio, K. Martens, and F. Di Ciommo, "Sustainable urban mobility plans: Bridging climate change and equity targets?," *Res. Transp. Econ.*, 2016, doi: 10.1016/j.retrec.2016.04.008.
[29] N. Ole Kenneth, "EMEP/EEA air pollutant emission inventory guidebook 2013: Technical guidance to prepare national emission inventories," 2019. [Online]. Available: http://www.eea.europa.eu/publications/emep-eea-guidebook-2013.
[30] Ahmedabad Municipal Corporation, "The Smart City Challenge Stage 2 Smart City Proposal Madurai," *Gov. India*, no. 7, p. 113, 2016.
[31] V. Saravanabavan, D. Balaji, S. P.- GeoJournal, and undefined 2019, "Identification of dengue risk zone: A geo-medical study on Madurai city," *Springer*, vol. 84, no. 4, pp. 1073–1087, Aug. 2019, doi: 10.1007/s10708-018-9909-9.
[32] D. Kundu, P. Sharma, B. Lahiri, and C. Sangtani, "NIUA & Madurai: a shrinking and segregated city," 2020, [Online]. Available: www.centreforsustainablecities.ac.uk.
[33] V. Sreekanth, B. Mahesh, and K. Niranjan, "Gradients in PM2.5 over India: Five city study," *Urban Clim.*, vol. 25, no. January, pp. 99–108, 2018, doi: 10.1016/j.uclim.2018.06.001.
[34] CPCB, "Guidelines for the Measurement of Ambient Air Pollutants (NAAQS)," *Cent.*

 https://doi.org/10.37896/pd91.5/91548

ISSN: 0369-8963

*Pollut. Control Board, Gov. India*, 2009, [Online]. Available: http://www.cpcb.nic.in.

[35] S. P. Sekar and S. Kanchanamala, "An Analysis of Growth Dynamics in Chennai Metropolitan Area," *Inst. T. Planners, India*, vol. 8, no. 4, pp. 31–57, 2011.


https://doi.org/10.37896/pd91.5/91548