The air we breathe has a myriad of particulate matter from tobacco smoking, industrial fumes, and firewood exposure. Environmental influence of respiratory diseases has been extensively studied since the “Great Smog of London.”

**Background:** Chronic obstructive pulmonary disease (COPD) is the second leading cause of death in India. The objective of this study was to map COPD cases and its risk factors and to determine the association between them using geographic information system (GIS) in a semi-urban area of Trivandrum, South India.

**Materials and Methods:** This community-based cross-sectional, descriptive study (n = 494) was conducted in a subcenter area of a primary health center. Location was mapped and COPD population screener questionnaire was administered to all the study subjects enrolled by census method. Lifetime firewood exposure (person-hours) and tobacco smoking were enquired and distance from road was mapped using portable differential global positioning system. The association with COPD was assessed by kriging and hotspot analysis using ArcGIS software.

**Results:** The prevalence of COPD (6.5%) was comparable to national prevalence estimates. Spatial maps showed COPD case clustering in areas with higher firewood exposure, greater smoking exposure, and in households with closer proximity to local roads. A particular high-risk cluster was obtained which had a significant association with all the risk factors.

**Conclusion:** GIS technology is useful in identification of spatial clustering of COPD cases and its environmental risk factors, making it an important tool for targeted interventions for COPD.

**KEY WORDS:** Chronic obstructive pulmonary disease, geographic information system, India, risk factors, spatial analysis

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**INTRODUCTION**

Environmental influence of respiratory diseases has been extensively studied since the “Great Smog of London.”

The air we breathe has a myriad of particulate matter from tobacco smoking, industrial fumes, and firewood exposure. Environmental influence of respiratory diseases has been extensively studied since the “Great Smog of London.”

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and vehicular exhausts.\textsuperscript{[1]} Chronic obstructive pulmonary disease (COPD) is a common, preventable, and treatable disease, characterized by persistent respiratory symptoms and airflow limitation, due to airway and/or alveolar abnormalities usually caused by significant exposure to noxious particles or gases.\textsuperscript{[2]} COPD is the fourth leading cause of death globally and second in India (global burden of disease [GBD] estimates). It is projected to become the second leading cause of global mortality by 2030.\textsuperscript{[3]} It affects 5\%–19\% of adults over 40 years of age, making it the fourth most common cause of hospitalization in males and the seventh in females.\textsuperscript{[4]} As per the INSEARCH study, the prevalence of COPD (as measured by chronic bronchitis) is 3.49\% in the population above 35 years, whereas in the southern state of Kerala, it is 10\%.\textsuperscript{[5]} Global Burden of Disease (GBD) study had estimated the prevalence of COPD in India at national level to be 2.7\%, while it was found to be 4.0\% for the state of Kerala.\textsuperscript{[6]} A high proportion of COPD remains undiagnosed and there is also poor recognition of COPD by treating doctors. COPD patients often are not even told the name of their disease and are not aware about their own illness. Patients are often inadequately evaluated, pulmonary function test, an essential investigation done only in a minority and are also suboptimally managed.\textsuperscript{[7]} Treatment cost of COPD is high, and it also predisposes to other major diseases such as ischemic heart disease, pneumonia, and malignancies and morbidities that significantly affect human productivity and quality of life.

Cigarette smoking, be it direct or indirect, as a risk factor of COPD has been widely substantiated with extensive evidence. While smoking is the major risk factor for COPD in developed countries, 55\% of COPD patients in India are nonsmokers, thus emphasizing the importance of poor air quality as a major risk factor in India.\textsuperscript{[8]} With rapid urbanization throughout the world, other factors such as burning biomass, industrial fumes, and vehicular exhausts have drawn more attention as risk factors in COPD. These include particulate matters formed by the combination of fine solids such as dust, pollen, soot, and aerosols with gaseous substances of combustion.\textsuperscript{[9]} Carbon monoxide, sulfur dioxides, and nitrogen oxides constitute the substances of combustion, mainly from automobiles and firewood.\textsuperscript{[10]} Literature reveals that chronic exposure to these particulate matter results in COPD and short-term exposure can cause bronchitis and allergic manifestations in those exposed. A study conducted in Mysore explains that a threshold of biomass fuel exposure of 60 was significantly associated with the development of chronic bronchitis.\textsuperscript{[11]} Biomass exposure index has been reported utilizing the average hours spent on cooking per day multiplied by the number of years of cooking.\textsuperscript{[12]}

Location-based analytical techniques are now increasingly being used by epidemiologists as a tool for ascertaining the spatial and environmental determinants for diseases.\textsuperscript{[13]} It tries to incorporate the contribution of the third component of the epidemiologic triad, the environment, which is often underestimated in conventional research. Geographic information system (GIS) acts as a common platform that shares data related to epidemiologic and geographic aspects consolidating their spatial data. The integrated data permit spatial analysis and can also be depicted visually as various layers on maps, which serve as a powerful tool, enabling the presentation of information that is difficult to show by other means.\textsuperscript{[14]} COPD is a disease that has a high association with environmental risk factors; hence, GIS is a useful tool to measure the spatial association of determinants such as tobacco smoke, firewood and vehicular exhaust exposure, and clustering of cases, to aid in disease control and etch out location-specific preventive strategies.

In this context, we attempted to study the spatial association between COPD and its risk factors in an urban area of Trivandrum, the capital city of Kerala, a state in the extreme south of India, with the technical assistance from the Inter-University Centre for Geospatial Information Science and Technology, University of Kerala.

**MATERIALS AND METHODS**

A community-based cross-sectional study was conducted in the smallest defined health-care unit in the community known as “subcenter.” A subcenter usually caters to a population of about 5000 and is a subunit of the primary health center. The present study was conducted in a subcenter area, catering to the field practice area of the Government Medical College at Trivandrum, India, that was selected randomly from a total of 11 subcenters under the field practice area. Ethical clearance for the study was obtained from the Human Ethics Committee (No. 02/07/2016/MCT) of the Government Medical College, Trivandrum. The study area had 540 individual houses and 274 apartments in 4 multistoried buildings. It covered an area of 1.05 square km. All the individual houses were recruited in the study and hence no sampling technique was to be adopted.

After taking informed consent, data were collected from February 1 to April 30, 2016, jointly by a team of postgraduates from the Department of Community Medicine of the Government Medical College, Trivandrum, and technicians from the Centre for Geospatial Information Science and Technology of the Kerala University. Data collection and geospatial mapping were done simultaneously. Study population comprised all the individuals above the age of 35 years residing in the area, enrolled by census method. Details regarding individuals were obtained from an adult member of the household present at the time of data collection. Dwellings found closed/uninhabited were visited on 3 separate days at different times of the day. Those houses, still found to be locked, were excluded from the study. Those residents who have not been residing in this particular location at least for the past 2 years were also excluded, which ultimately gave a study size of 494 individuals.
A structured questionnaire was used to gauge information on the sociodemographic profile of the subjects, past and present self-reported respiratory disease profile, and aspects on exposure to pollutants such as tobacco smoke, firewood exposure, and other risk factors, if any. COPD population screener tool\cite{15} was incorporated in the questionnaire to pick up subjects that were at high risk of developing COPD in the near future. The screening tool included five questions targeted to adults above 35 years of age. Those individuals who fell in the high-risk category were operationally defined as COPD cases, which were later confirmed by spirometry. All the households in the study area were mapped using differential global positioning system (DGPS), and coordinates of houses, COPD cases, tobacco smoking exposure, firewood exposure, and distance of house from the main road were mapped.

Biomass fuel exposure was estimated in person-hours to assess the lifetime firewood exposure load in study subjects. The “traffic exposure” is defined as the proximity of the residential settlements with the major roadways. The “major roadways” in the current study refer to the outer boundary of the study area formed by surrounding road, National Highway 66, which is one of the most important highways through the state with heavy vehicular traffic at all times.\cite{16} Due to the lack of resources in accurately assessing the particulate contaminants at various times at various locations in the study area, distance from the nearest major roadway was considered as a surrogate marker of exposure to vehicular emissions as was done previously.\cite{17}

The spatial coordinates of COPD risk cases were overlaid on the firewood exposure pattern in the study area, and significant COPD hotspots were identified by kriging, a geospatial analytic method. Kriging is an advanced geostatistical procedure which generates an estimated surface from a set of points with z values, assuming that the distance or direction between sample points reflects a spatial correlation that can be used to explain the variation in the surface. It helps in creating a prediction surface with measure of certainty of the predictions. The effect of population density was accounted for by measuring the distance from the main road was considered as a surrogate marker of exposure to vehicular emissions as was done previously.\cite{17}

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Data were also entered in MS Excel and analyzed using SPSS 16.0 (SPSS Inc. Released 2007. SPSS for Windows, Trial Version 16.0. Chicago, SPSS Inc). Chi-square and Mann-Whitney U tests were performed.

**RESULTS**

Four hundred and ninety-four individuals aged over 35 years residing in the 1.05 km² study area were studied after mapping the area and location of households using DGPS and GIS techniques [Figure 1]. The study population had a mean age of 54.1 (17.1) years and 30.4% were male. The proportion of subjects with low economic status (as measured by those in “below poverty line” category) was only 9.3%. The households of all 494 subjects were mapped using DGPS and their coordinates entered into the GIS database to create the baseline map [Figure 1a]. Subsequently, another map showing spatial distributions of COPD cases detected through the screening tool was also made [Figure 1b].

The prevalence of COPD was 6.5% as 32 subjects among the 494 tested fulfilled the operational definition and confirmation criteria for COPD. The previously identified common risk factors included smoking, exposure to biomass smoke, socioeconomic factors such as lower income, and environmental factors such as pollution. Hence, the prevalence of tobacco smoking (passive and active) and proportion of firewood use (among different domestic fuel usage) were also tabulated [Table 1]. Further, maps were created depicting the spatial distribution of risk factors to COPD risk score distribution and risk factors of COPD, namely firewood exposure and tobacco smoking [Figure 1c-e], to examine possible patterns of clustering.

Analysis revealed a significant association between tobacco smoking and firewood exposure with COPD (P < 0.001) and with an odds ratio of 6.86 (confidence interval – 3.20–14.69). Nonparametric test was done to find the association between COPD and pack-years of smoking, which was found to be significant (P < 0.05) [Table 2]. Descriptive analysis of proximity of houses from the major road showed that the mean distance from the road was less in houses habited by COPD cases (median interquartile range [IQR] – 23.43 [7.74–67.95]) than those households which housed non-COPD individuals (median [IQR] – 31.20 [8.87–61.31]). However, it was not statistically significant (P > 0.05) [Table 2].

The spatial coordinates of COPD risk cases were overlaid on the firewood exposure pattern in the study area, to obtain significant COPD hotspots [Figure 2a]. Further, hotspot analysis showed a significant association between COPD and firewood exposure in the northeastern boundary area, whereas the other two clusters showed no significant association [Figure 2b]. Finally, hotspots were determined

| Risk factor | Frequency (%) |
|-------------|---------------|
| Tobacco smoking | 61 (12.3) |
| Active smoking | 42 (8.5) |
| Passive smoking | 270 (54.7) |
| Fuel type | 1 (0.2) |
| LPG | 12 (2.4) |
| Firewood indoor | 4 (0.8) |
| Firewood outdoor | 64 (13) |
| LPG + firewood indoor | 143 (28.9) |

LPG: Liquefied petroleum gas
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for the combined effect of smoking, cumulative firewood exposure, and proximity to road on COPD [Figure 2c]. The analysis indicated a significant hotspot in the northeastern boundary and a few cold spots suggesting strong relation of
COPD with smoking, exposure to firewood, and proximity to dusty roads.

**DISCUSSION**

The present study was conducted to establish the association of common determinants of COPD using GIS technology, a novel method in the setting of an urban area in Trivandrum district, Kerala. Environment plays a major role in the development of COPD, and GIS technology is used here to elucidate environmental determinants of the disease. GIS-based maps were created depicting the spatial distribution of COPD cases, patterns of firewood exposure, tobacco smoking, and distance from main road, separately. The coordinates of COPD cases were then overlaid onto these maps to get the spatial clustering of cases.

The contribution of burning biomass, tobacco smoking, and traffic exposure to the development of COPD is well established independently, showing varying exposure patterns in urban and rural areas. A similar contribution from all these factors together, contributing to the single outcome of COPD, could be visualized from the maps in the present study. The proportion of households who used biomass either exclusively or as a part of cooking fuel was 45.1% in the current study, whereas previous studies show the prevalence of using biomass range from 55% to 70%,[19] with rural areas having greater dependence on biomass. Firewood exposure when mapped in the present study showed a higher person-hour density in the northeastern part of the study area and few other scattered locations. The prevalence of tobacco smoking in the current study was 12.3% and another 8.5% being passive smokers. This is consistent with the Global Adult Tobacco Survey 2 report, which reported that 9.3% of all adults in Kerala were smokers. The spatial map created based on tobacco smoking had clustering in the northeastern part as in line with the firewood exposure. Besides, there are cold spots which indicate disease prevalence significantly lesser in density than in the hotspot areas. The study area in the present research has National Highway 47 as one of its boundaries,[19] which is already overburdened with traffic and is a notorious location for traffic blocks in the city,[19] further adding to the problem statement of particulate matter pollution in the area. COPD cases, when mapped in the current study, however, were more distributed along the local road, which also happens to be the northeastern boundary rather than along the National Highway. This may be due to the construction activities going on around the area, with frequent movement of trucks carrying building materials through the local road. The pollutants arising from these duty roads differ from the particulate matter pollution from vehicular traffic. About 25% of the households were within 8 m of the road in this area. The finding that risk for COPD was greater in the areas adjacent to the dusty local roads rather than in areas with more vehicular emission exposure is a relevant observation from the study.

COPD unlike other noncommunicable diseases does not have an active national control program, even though the disease has a greater mortality and morbidity than other noncommunicable diseases.[20] Technical and financial difficulties associated with mass screening for COPD is challenging in a country like India, if undertaken as a part of any national health program. The benefits of screening the entire population for COPD is an issue that has been repeatedly debated, with the benefit being that early identification and secondary prevention is needed as the forced vital capacity in the first second forced expiratory volume decline is highest in the early phases of COPD, whereas the difficulty being that large-scale screening is not cost-effective and often does not lead to treatment.

Most countries are today striving to attain the sustainable development goals (SDGs) which have been taken up by most states in India. One of the key components to achieve the SDGs is to reduce the mortality and morbidity due to noncommunicable diseases, including COPD. However, in a resource-limited country, large-scale screening for COPD would not be possible. Various techniques have been developed to facilitate the identification of COPD, one successful model being the efforts of using a short questionnaire with a peak flow meter to screen for COPD, but such efforts require the screening of the entire population with a questionnaire as well a peak flow meter, which makes it research intensive and hence may be difficult to roll out.[21]

In this context, GIS technology comes in handy to identify hotspots wherein targeted preventive measures may be instituted. Kerala, as part of the Aardram Mission—Comprehensive Primary Health Care,[22] has started a COPD control program named “SWAAS” in 2016.[23] The e-health component of the mission may incorporate GIS technology to map and thus could facilitate the identification of COPD hotspots in each primary health center area as demonstrated in this study and such hotspots may be prioritized for COPD screening, thus conserving resources. The model may be scaled up for the entire country.

This study is using GIS as a means of facilitating the identification of COPD hotspots for the first time in India. The strength of this study is that it covers a good population in the field and demonstrates that the GIS team can work with the medical team to conserve resources and prioritizing the areas for screening for COPD. The limitation of the study is that other risk factors for COPD have not been incorporated in the model by this study. Furthermore, seasonal trends in diseases as well as risk factor patterns cannot be accounted for unless the study is again carried out in a different time upon the same study population. Financial and technical constraints restrained us from exploring the full potential of further geospatial analyses such as regression analysis and predictor surface model to predict disease occurrence.
CONCLUSION

The prevalence of COPD is higher and that of its determinants such as smoking and firewood exposures is lower in this urban location in Kerala when compared to national figures. This discrepancy shows evident clustering of risk factors in selected geographical areas rather than widespread distribution. It has also been observed that the proximity to the local roads along with smoking and exposure to firewood burning augments the occurrence of the disease. GIS technology is apt in bringing out such spatial clusters, so that targeted interventions for control and prevention of COPD can be taken, as COPD is a disease that has high mortality and morbidity, adversely affecting the quality of life and the productivity of the country.

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Conflicts of interest
There are no conflicts of interest.

REFERENCES
1. Andersen ZJ, Hvidberg M, Jensen SS, Ketzel M, Loft S, Sørensen M, et al. Chronic obstructive pulmonary disease and long-term exposure to traffic-related air pollution: A cohort study. Am J Respir Crit Care Med 2011;183:455-61.
2. GOLD Guidelines for the Management of COPD – 2017 Update | Family Practice News. Available from: http://www.rsedged.com/familypracticenews/article/138605/pulmonology/gold-guidelines-management-copd-2017-update. [Last accessed on 2017 Aug 03].
3. (Anonymous). Available from: http://www.healthdata.org/sites/default/files/files/country_profiles/GBD/ihme_gbd_country_report_india.pdf. [Last accessed on 2017 Jun 18].
4. The Burden of COPD in Canada: Results from the Confronting COPD Survey (PDF Download Available). Available from: https://www.researchgate.net/publication/10846388_The_burden_of_COPD_in_Canada_results_from_the_confronting_COPD_survey. [Last accessed on 2017 Jun 20].
5. Jindal SK, Aggarwal AN, Gupta D, Agarwal R, Kumar R, Kaur T et al. Indian study on epidemiology of asthma, respiratory symptoms and chronic bronchitis in adults (INSEARCH). Int J Tuberc Lung Dis 2012;16:1270-7.
6. GOLD India Compare | IHME Viz Hub. Available from: http://vizhub.healthdata.org/gbd-compare/india. [Last accessed on 2021 Jul 25].
7. Arjun P, Nair S, Jilisha G, Anand J, Babu V, Moosan H, et al. Assessing health-seeking behavior among asthma and COPD patients in urban South India. J Family Med Prim Care 2019;8:2714.
8. Jindal SK, Aggarwal AN, Chaudhry K, Chhabra SK, D’Souza GA, Gupta D, et al. A multicentric study on epidemiology of chronic obstructive pulmonary disease and its relationship with tobacco smoking and environmental tobacco smoke exposure. Indian J Chest Dis Allied Sci 2006;48:23-9.
9. Particulate Matter – American Lung Association Site. Available from: http://www.chemtrails911.com/health_doc/Particulate%20Matter%20-%20American%20Lung%20Association%20Site.htm. [Last accessed on 2017 Jun 20].
10. Lindgren A, Stroh E, Monténéry P, Nihlén U, Jakobsson K, Axmon A. Traffic-related air pollution associated with prevalence of asthma and COPD/chronic bronchitis. A cross-sectional study in Southern Sweden. Int J Health Geogr 2009;8:2.
11. Mahesh PA, Jayaraj BS, Prabhakar AK, Chaya SK, Vijaysimha R. Identification of a threshold for biomass exposure index for chronic bronchitis in rural women of Mysore district, Kamataka, India. Indian J Med Res 2013;137:87-94.
12. Available from: http://icmr.nic.in/ijmr/2013/January/10.pdf. [Last accessed on 2017 Aug 03].
13. Positional Accuracy of Geocoded Addresses in Epidemiologic Research (PDF Download Available). Available from: https://www.researchgate.net/publication/10675667_Positional_Accuracy_of_Geocoded_Addresses_in_Epidemiologic_Research. [Last accessed on 2017 Jun 20].
14. Toubiana L, Richard JB, Landais P. Geographical information system for end-stage renal disease: SIGNe, an aid to public health decision making. Nephrol Dial Transplant 2005;20:273-7.
15. COPD Risk Screener | COPD Foundation. Available from: https://www.copdfoundation.org/screener.aspx. [Last accessed on 2017 Jun 22].
16. Kerala PWD ‑ National Highways. Available from: http://www.keralapwd.gov.in/getPage.php?page=NH%20in%20Kerala & pagetld=301. [Last accessed on 2017 Aug 03].
17. Valamparampil MJ, Mohan A, Jose C, Sadheesan DK, Aby JJ, Vusudevakaimal P, et al. Role of geographic information system in assessing determinants of cardiovascular disease: An experience from a low- and middle-income country. Asia Pac J Public Health 2018;30:351-60.
18. Google Maps. Available from: https://www.google.co.in/maps/place/Sreekariyam,+Thiruvananthapuram,+Kerala/@8.5471434,76.9063512,15z/data=!3m1!4b1!4m5!3m4!1s0x3a797a48b0f6de01:0xda35f0d2a674e359!8m2!3d8.5511071!4d7.7574028?hl=en. [Last accessed on 2017 Jun 20].
19. EIA-NH-47-P1I-EXECUTIVE SUMMARY ENG. Available from: http://www. ntpch.gov.in/pdf/eia_nh47_eng.pdf. [Last accessed on 2017 June 27].
20. Available from: http://www.japi.org/february_2012_special_issue_copd01_editorial_india_needs_a.pdf. [Last accessed on 2017 Aug 10].
21. Thorat YT, Salvi SS, Kogule RR. Peak flow meter with a questionnaire and mini-spirometer to help detect asthma and COPD in real-life clinical practice: A cross-sectional study. NPJ Prim Care Respir Med 2017;27:32.
22. Krishnan GA, Nair AK. Primary Health Care Innovations with Superior Allusion to Family Health Centers. Indian J Community Med 2011;36:149-52.
23. Gopakumar S, Valamparampil MJ, Manu MS, Nair S, Kamala R, Atulya AR, et al. The first state-level public health program for obstructive airway disease in India: An early field-level evaluation. J Family Med Prim Care 2020;9:4998–5003.