World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Review Article)

Air quality analysis and modeling in urban area: A review study

Toral Vyas [1,*] and H. R. Varia [2]

[1] *Department of Civil Engineering, L.D. College of Engineering, Ahmedabad, India.*
[2] *Civil and Infrastructure Engineering, Adani Institute of Infrastructure Engineering, Ahmedabad, India.*

World Journal of Advanced Research and Reviews, 2023, 20(01), 660–669

Publication history: Received on 03 September 2023; revised on 13 October 2023; accepted on 16 October 2023

Article DOI: https://doi.org/10.30574/wjarr.2023.20.1.2096

Abstract

Urban areas across the world are experiencing significant challenges related to air quality, with adverse effects on public health, the environment, and overall quality of life. This thesis aims to investigate and model air quality in urban environments, focusing on the identification of pollution sources and the evaluation of potential mitigation strategies.

The research begins by analyzing the complex interplay of factors influencing urban air quality, including emissions from vehicular traffic, industrial activities, and meteorological conditions. Various modeling techniques, such as numerical simulations, statistical analyses, and machine learning algorithms, are employed to assess the spatiotemporal distribution of air pollutants within urban areas. The overview is carried out to focus on various parameters such as emission sources, meteorological parameters, and topographical features to predict pollutant concentrations.

The study also explores the effectiveness of different mitigation strategies to improve urban air quality. These strategies may include urban planning measures, such as the design of green spaces and pedestrian-friendly zones, as well as transportation-related interventions like the promotion of electric vehicles and the enhancement of public transportation systems. The impact of these strategies on reducing pollutant concentrations is quantitatively assessed using the developed air quality models.

Furthermore, the study considers the implications of climate change on urban air quality, acknowledging that changing climate patterns can exacerbate air pollution issues. Potential adaptation strategies to address these challenges are discussed.

In conclusion, this thesis offers a comprehensive analysis of air quality modeling in urban areas, providing insights into the sources of pollution and the effectiveness of mitigation measures. The research aims to inform policymakers, urban planners, and environmental stakeholders in their efforts to create healthier and more sustainable urban environments.

Keywords: Urban area; Air quality; Particulate matter; NOx

1. Introduction

Urbanization is an inexorable global trend, with more than half of the world's population now residing in urban areas. While cities offer numerous opportunities for economic growth, cultural exchange, and improved quality of life, they also bring about significant environmental challenges, with one of the most pressing being air quality. The impact of urbanization on air quality has raised concerns about the health and well-being of urban residents and the sustainability of these increasingly dense and complex environments.

---

[*] Corresponding author: Toral Vyas

Copyright © 2023 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution Liscense 4.0.

Air quality in urban areas is a multifaceted issue influenced by a myriad of factors, including emissions from vehicular traffic, industrial activities, construction, and residential heating, among others. These emissions release a cocktail of pollutants into the atmosphere, including particulate matter (PM), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), and volatile organic compounds (VOCs). Prolonged exposure to these pollutants has been linked to a range of adverse health effects, including respiratory diseases, cardiovascular problems, and even premature death.

To address the challenges posed by deteriorating air quality in urban areas, it is essential to employ robust analytical techniques and sophisticated modeling approaches. These tools enable scientists, policymakers, and urban planners to gain a comprehensive understanding of the sources, distribution, and dynamics of air pollutants within cities. Moreover, they facilitate the evaluation of potential mitigation strategies, policy interventions, and urban planning initiatives aimed at improving air quality and promoting sustainable urban development.

This paper embarks on a journey to explore the intricate field of air quality analysis and modeling in urban areas. We will delve into the key components of this discipline, including the collection and analysis of air quality data, the development of predictive models, and the integration of interdisciplinary approaches to address the multifaceted nature of urban air pollution. We will also investigate the various challenges and complexities associated with modeling air quality in urban settings, such as the role of meteorological conditions, topographical features, and emerging technologies.

By the end of this exploration, it is our aspiration that readers will have a deeper appreciation for the importance of studying and managing air quality in urban environments. Through rigorous analysis, modeling, and informed decision-making, we can aspire to mitigate the adverse effects of air pollution, foster healthier cities, and ultimately create urban spaces that are both vibrant and sustainable for present and future generations.

2. Literature Review

The foundation of any comprehensive research endeavor lies in understanding the existing body of knowledge that surrounds the chosen subject. In the case of air quality analysis and modeling in urban areas, a rich tapestry of research and scholarship has evolved over the years. This literature review aims to navigate this extensive terrain, examining key studies, methodologies, and findings that have contributed to our understanding of urban air quality.

The concerns over urban air quality can be traced back to the early days of the Industrial Revolution when the rapid growth of cities brought with it the first signs of pollution-related health issues. Since then, a wealth of scientific investigation has explored the sources, distribution, and consequences of air pollution in urban environments. This review embarks on a journey through this historical evolution, tracing the trajectory of urban air quality research from its origins to the present day.

Hag yeol kim (1996) Statistical regression models are presented, that explain the observed variations, across urban areas, in the concentrations of two major pollutants, ozone and carbon monoxide. Model specification and estimation are based on an explicit and new spatial framework derived from the theoretical concept of well-mixed Hag yeol kim (1996) Statistical regression models are presented, that explain the observed variations, across urban areas, in the concentrations of two major pollutants, ozone and carbon monoxide. Model specification and estimation are based on an explicit and new spatial framework derived from the theoretical concept of well-mixed cells, whereby the basic Fickian system of diffusion equations is integrated over the regional space partitioned into a grid of large cells. The concentration in each cell results from the balance of pollutant flows into and out of this cell and of pollutant emissions and removal within that cell and is expressed as the sum of two concentration contributions: (1) the local effect, dependent upon pollution-related factors around the measuring station, and (2) the regional effect, dependent upon pollutant flows originating outside the local area. A large data base is developed, making extensive use of GIS technology, to spatially relate such data as pollution measurements, meteorological factors, land-use characteristics, Census socio-economic data, and major highway network characteristics. The results confirm the appropriateness of the well-mixed cell framework, are in line with general knowledge regarding the determinants of ozone and carbon monoxide concentrations, and clarify the role of transportation, residential fuel-use, economic activities, natural environments, and meteorological factors such as temperature and solar radiation. About 50% of the variations in concentrations are explained by these models. Several areas of further research are outlined [1].

Construction of infrastructure facilities such as buildings and roads are very useful for society. Gerila P. et al (2000) considered in the construction of these facilities. The environmental evaluation of the construction system is studied in this paper. It focuses on the assessment of the environmental impacts of the road and building construction industry in

Japan. Moreover, the Input-Output Approach is used to analyze the impacts of road and building construction to the environment. Results show that significant amounts of nitrogen oxide, sulfur dioxide and carbon dioxide pollutants are emitted from construction alone. Compared to road construction, the building construction industry spewed off lower pollutant emissions. With the detrimental effects of pollutants to urban areas, tradeoffs are necessary to balance the number of emissions and construction of new facilities [2].

Air pollution forecasts in major urban areas are becoming a problem concerning the day-to-day environmental management for city authorities. Slini T. et al.(2002) describes the development of an application to forecast the peak ozone levels with the aid of meteorological and air quality variables, in the Greater Athens Area. For this purpose, several regression models were considered, while the selection of the final model was based on extensive analysis and on literature. The model adapted includes variables that are available on a daily basis, so as daily operational maximum ozone concentration level forecast can be achieve [3].

A large dataset for PM2.5 and PMcoarse (PM2.5-10) concentrations monitored near a busy London highway (Marylebone Road) has been analyzed to define the factors that lead to high concentrations. Charron A. et al. (2005) have highlighted major influencing parameters: wind speed, prevailing wind direction (because of its role on the microscale dispersion within the street), the daily cycle of the atmospheric boundary layer (stable during the night/ convective and mixed during the day), and traffic density. The mainly diesel heavy-duty vehicles are the main source of fine particulate matter at Marylebone Road. In particular, lorries (trucks) dominate PM10 exhaust emissions which are mainly in the fine (<2.5 μm) size range. A strong correlation with PMcoarse suggests that the heavyduty traffic is largely responsible for this component also. Substantial local increments in PM2.5 and PMcoarse due to traffic have been estimated and a large part of the increment in PMcoarse concentrations is inferred to arise from resuspended road dust emissions since the contribution of abrasion processes estimated from emission factors is modest. Despite the strong influence of traffic on PM concentrations measured at Marylebone Road the analysis of factors leading to the highest 5% of hourly concentrations of PM10 at Marylebone Road reveals that almost half of these events were due to building works. The other events occurred when all or most of the key factors occurred simultaneously (heavy traffic, poor dispersion, etc.). Some episodes of high PM2.5 concentrations were associated with long-range transport in which the regional PM2.5 Constituted most of the local concentrations [4].

Wang G. et al. (2008) focused to support decision making, e.g., air quality impact analysis, human health assessment, through spatially modelling traffic-induced air pollution dispersion in urban areas at street level. Based on the information needed in decision making, a framework for a street level air quality decision support system is established, which is composed of basically three parts: an urban base data model, a dispersion model with a spatial database and a 3D GIS environment for visualization. The database is used to provide input for executing the dispersion model. The dispersion model called OSPM is adapted to determine the pollution level based on traffic, meteorology, and street configuration data. The framework for assessing and visualizing pollution levels was implemented for four pilot-study spots in The Hague, The Netherlands. Those spots are representative for the main configuration of roads across the city. NO_2 and PM10 were selected to be modelled pollutants for the reference year of 2006. Parameters considered for the dispersion model were street width and length, building height, wind velocity and direction, ambient air temperature, background pollution, traffic volume, vehicle type and speed. The pollutants concentrations were visualized in planar and non-planar view with buildings represented by cubic volumes. The visualized result has potential to provided valuable information for pollution impact analysis, by also including the vertical dimension of the influenced area and population. Moreover, it provides important information to decision makers for air quality assessment and management [5].

Road widening schemes in urban areas are often proposed as a solution to traffic congestion and as a means of stimulating economic growth. There is however clear evidence that new or expanded roads rapidly fill with either displaced or induced traffic, offsetting any short-term gains in eased traffic flows. What has not been addressed in any detail is the impact of such schemes on air quality, with modelled impact predictions seldom validated by measurements after the expansion of road capacity. Font A. et al. (2014) made use of a road widening project in London to investigate the impact on ambient air quality (particulate matter, NOX, NO_2) during and after the completion of the road works. PM10 increased during the construction period up to 15 μg m−3 during working hours compared to concentrations before the road works. A box modelling approach was used to determine a median emission factor of 0.0022 kg PM10 m−2 month−1, three times larger than that used in the UK emission inventory (0.0007 kg PM10 m−2 month−1). Peaks of activity released 0.0130 kg PM10 m−2 month−1 , three and eight times smaller than the peak values used in the European and US inventories. After the completion of the widening there was an increase in all pollutants from the road during rush hour: 2–4 μg m−3 for PM10; 1 μg m−3 for PM2.5; 40 and 8 μg m−3 for NOX and NO_2, respectively. NO_2 EU Limit Value was breached after the road development illustrating a notable deterioration in residential air quality.

Additionally, PM10, but not PM2.5, glutathione dependent oxidative potential increased after the road was widened consistent with an increase in pro-oxidant components in the coarse particle mode, related to vehicle abrasion [6].

Development and urbanization over the past decade have led to rapid increase in the population of Delhi, the metropolitan city of India. Consequently, there has been a tremendous increase in the number of vehicles, which are causing very high levels of air pollution. Vehicular emissions are becoming most predominant source of air pollution in Delhi. Sindhwani and Goyal (2014) developed an annual emission inventory of road transport emissions of pollutants including carbon monoxide (CO), methane (CH4), nitrogen oxides (NOX), sulfur dioxide (SO_2), volatile organic compounds (VOCs), particulate matter (PM10), lead (Pb) and hydrocarbon (HC), organic carbon (OC) and black carbon (BC) developed (for the period 2000–2010), for the Delhi region. Emissions have been estimated using emission factor and activity–based approach recommended by IPCC. The emissions of CO and NOX have increased nearly 77% and 29% respectively over 2000 to 2010, whereas contribution of SO2 has greatly reduced (a21%) due to phasing out of diesel driven buses and implementation of Bharat Stage–III norms to commercial vehicles. An appreciable increase in NOX emissions has been observed after 2005, which might be due to the use of CNG fuel. Emissions of PM10, OC and BC have decreased in 2001 and 2002, however these are continuously increasing after 2002 due to rapid rise in the annual rate of growth of registered vehicles in Delhi. Two wheelers (2Ws), which constitute 60% of total registered vehicles, have been found to be major contributors towards emissions of the pollutants considered in the present study [7].

Rathi B et al. (2016) did a statistical analysis of ambient air in Aurangabad City (M.S.) during the year 2005-2010 and its concentration of SO_2, NOX, RSPM and SPM are monitored at selected three residential site during rainy, winter and summer season. Results shows that SO_2, NOX, RSPM are well below the permissible limit and SPM is above the permissible limits. The sampling sites are a heavy traffic intersection cum residential area located within the Aurangabad City. It is observed that pollutant values always exceed the NAAQS value throughout the sampling. The annual mean values for all sampling sites and the statistical calculations made on data shows SO_2 , NOX year wise and sidewise significant and RSPM and SPM year wise non-significant and sidewise significant. This study is that the data collected year wise for all parameters on different sites and concentration is also discussed. One of the major sources of air pollution in Aurangabad (M.S.) is the area pollutions from dense residential, heavy vehicles, industries etc [8].

Borrego C. et al. (2016) simulated the atmospheric dispersion of NOx 18 and PM10 with a second-generation Gaussian model 19 over a medium-size south-European city. Microscopic traffic models calibrated with GPS data were used 20 to derive typical driving cycles for each road link, while instantaneous emissions were estimated 21 applying a combined Vehicle Specific Power/Co-operative Program for Monitoring and Evaluation of 22 the Long-range Transmission of Air Pollutants in Europe (VSP/EMEP) methodology. Site-specific 23 background concentrations were estimated using time series analysis and a low-pass filter applied to 24 local observations. Air quality modelling results are compared against measurements at two locations 25 for a 1-week period. 78% of the results are within a factor of two of the observations for 1-h average 26 concentrations, increasing to 94% for daily averages. Correlation significantly improves when 27 background is added, with an average of 0.89 for the 24 hours record. The results highlight the potential 28 of detailed traffic and instantaneous exhaust emissions estimates, together with filtered urban 29 background, to provide accurate input data to Gaussian models applied at the urban scale [9].

Indoor air quality in subterranean train stations is a concern in many places around the globe. However, due to the specificity of each case, numerous parameters of the problem remain unknown, such as the braking discs particle emission rate, the ventilation rate of the station or the complete particle size distribution of the emitted particles. Walther E. et al. (2017) addressed the problem of modelling PM10 concentration evolution in relation with train traffic with a particle mass conservation model which parameters are fitted using a genetic algorithm. The parameters of the model allow to reproduce the dynamics and amplitude of four field data sets from the French and Swedish underground contexts and comply with realistic bounds in terms of emissions, deposition, and ventilation rate [10].

The United States federal government establishes National Ambient Air Quality Standards (NAAQS) for six pollutants, including ozone. States with areas designated in nonattainment of the standards are required to develop State Implementation Plans (SIPs) to demonstrate how pollution levels will be reduced to meet the standards. Historically, most states have developed SIPs independently. However, for ozone and other air pollutants, some states have agreed to cooperate to address regional pollution problems. These types of cooperative efforts have the potential to improve pollution control efficiency. Macpherson A. et al. (2017) presented a mathematical programming model that can help identify potential minimum-cost emissions control strategies that employ regional strategies. We present a series of national-level applications using information from a set of air quality simulations along with spatially and technologically detailed emissions control information. The model quickly evaluates alternative attainment planning scenarios, tests regional strategies, and identifies monitors that potentially have significant influence on attainment strategies [11].

Pisoni E. et al. (2017) used an integrated assessment application to cope with computing power limitations, air quality models which are generally approximated by simpler expressions referred to as "source-receptor relationships (SRR)". In addition to speed, it is desirable for the SRR also to be spatially flexible (application over a wide range of situations) and to require a "light setup" (based on a limited number of full Air Quality Models - AQM simulations). But "speed", "flexibility" and "light setup" do not naturally come together, and a good compromise must be ensured that preserves "accuracy", i.e. a good comparability between SRR results and AQM. In this work we further develop a SRR methodology to better capture spatial flexibility. The updated methodology is based on a cell-to-cell relationship, in which a bell-shape function links emissions to concentrations. Maintaining a cell-to-cell relationship is shown to be the key element needed to ensure spatial flexibility, while at the same time the proposed approach to link emissions and concentrations guarantees a "light set-up" phase. Validation has been repeated on different areas and domain sizes (countries, regions, province throughout Europe) for precursors reduced independently or contemporarily. All runs showed a bias around 10% between the full AQM and the SRR. This methodology allows assessing the impact on air quality of emission scenarios applied over any given area in Europe (regions, set of regions, countries), provided that a limited number of AQM simulations are performed for training [12].

Jensen S. et al. (2017) modelled the annual concentrations of NO_2, PM2.5 and PM10 in 2012 for all 2.4 million addresses in Denmark based on a multi-scale air quality modelling approach. All addresses include residential, industrial, institutional, shop, school, restaurant addresses etc. The approach is based on a suite of chemistry-transport models all developed at Aarhus University and includes regional modelling, urban background modelling and street modelling. Information about traffic volumes is based on a newly developed national Danish Transport Model, and national travel speed data have been obtained from a recent dataset based on GPS readings of vehicles. Air quality model results are validated by comparisons with measurements obtained from the fixed site monitoring stations under the Danish Air Quality Monitoring Program. The validation showed that calculated street concentrations of NO_2 for the five available street monitoring stations are within 27% to +12%. The model results were also verified with comparisons with previous model results for NO_2 at 98 selected streets in Copenhagen and 31 streets in Aalborg. The verification showed good correlation in Copenhagen (r2 = 0.70) and good agreement in Aalborg (r2 = 0.60). The target groups for the air quality mapping of all Danish addresses are the general public for information and awareness about air quality, and local and national authorities who may use the information as a screening tool for air quality assessment [13].

Chalabi Z. et al. (2017) presented a decision support system for evaluating UK air quality policies. It combines the output from a chemistry transport model, a health impact model and other impact models within a multi-criteria decision analysis (MCDA) framework. As a proof-of-concept, the MCDA framework is used to evaluate and compare idealized emission reduction policies in four sectors (combustion in energy and transformation industries, non-industrial combustion plants, road transport and agriculture) and across six outcomes or criteria (mortality, health inequality, greenhouse gas emissions, biodiversity, crop yield and air quality legal compliance). To illustrate a realistic use of the MCDA framework, the relative importance of the criteria was elicited from a number of stakeholders acting as proxy policy makers. In the prototype decision problem, we show that reducing emissions from industrial combustion (followed very closely by road transport and agriculture) is more advantageous than equivalent reductions from the other sectors when all the criteria are considered. Extensions of the MCDA framework to support policy makers in practice are discussed [14].

Different construction activities may indicate distinct environmental impacts due to their uniqueness. Ability to assess and compare the environmental impacts from different construction activities can aid the process of minimizing emissions at different building construction processes. Sandanyake M. et al. (2018) presented a comparative impact assessment methodology to evaluate environmental impacts at different activities during the building construction stage. Significant impact related construction activities for five major impact categories namely global warming potential (GWP 100), acidification potential (AP), Eutrophication potential (EP), Photochemical oxidation formation potential (POFP) and Human toxicity potential (HTP) are compared from the global, regional, and local perspectives. A case study of a residential building in Australia is used to demonstrate the application of the functions of the developed method. The results of the case study indicated that the method can be effectively used to compare environmental impacts of different construction activities at different geographical perspectives considered. The method can be used by designers and contractors in comparing impacts of various construction activities to identify the most emission effective construction processes [15].

Yeganeh B. et al. (2018) used Statistical modelling successfully to estimate the variations of NO_2 concentration, but employing new modelling techniques can make these estimations far more accurate. To do so, for the first time in application to spatiotemporal air pollution modelling, we employed a soft computing algorithm called adaptive neuro-fuzzy inference system (ANFIS) to estimate the NO_2 variations. Comprehensive data sets were investigated to determine the most effective predictors for the modelling process, including land use, meteorological, satellite, and traffic variables.

We have demonstrated that using selected satellite, traffic, meteorological, and land use predictors in modelling increased the R2 by 21%, and decreased the root mean square error (RMSE) by 47% compared with the model only trained by land use and meteorological predictors. The ANFIS model found to have better performance and higher accuracy than the multiple regression model. Our best model, captures 91% of the spatiotemporal variability of monthly mean NO_2 concentrations at 1 km spatial resolution (RMSE 1.49 ppb) in a selected area of Australia. [16].

Road intersections have the potential to pose an additional exposure risk to surrounding dwellers or commuters; however, knowledge of fine-scale variations of traffic pollutants especially PM2.5 and black carbon (BC) remains limited. To investigate them, Wang Z. et al. (2018) conducted a three-point synchronous observation at an intersection in Shanghai in winter and spring. Real-time monitors with one-minute intervals were used to obtain the pollutant and meteorological data while gasoline and diesel vehicle volumes were manually collected every five minutes. Observational results showed that the average PM2.5 on the downwind roadside increased by approximately 9% in both seasons and that the average BC increased by 70% in winter and 97% in spring compared to those of the local background site. PM2.5 displayed a similar diurnal variation among the three sites at the intersection, but in contrast to PM2.5, the BC variation was more strongly correlated to the diurnal traffic cycle. Generalized additive models further identified the background variation as the major contributor to the variations in both pollutants at the intersection, explaining 77–99% and 33–43% of the variance in ln( ) PM2.5 and ln(BC), respectively. Air pressure and solar radiation were the next top determinants of pollutant variations. Relative humidity combined with air temperature in winter and with dew-point temperature in spring also had a significant impact. Roadside BC was sensitive to traffic from the windward direction, while PM2.5 was mostly influenced by the external pollution driven by westerly winds. In contrast to gasoline vehicles, diesel vehicles were verified to provide an appreciable contribution of approximately 9% to roadside BC variations in spring [17].

Atmospheric dispersion models are widely applied to simulate pollutant concentrations such as PM2.5 for use in long- and short-term health studies. A significant proportion of PM2.5 originates outside urban areas in which many people live. It is important to reflect this 'background' component in the modelling process in order to provide an accurate representation of the total pollution load experienced by human populations. To be credible, model outputs must be verified against available monitoring data, which, in the case of PM2.5, may be limited to a small number of monitoring sites across a large urban area. Draper E. et al. (2023) evaluated four different approaches to representing background PM2.5 in an atmospheric dispersion model (ADMS-Urban) for Nottingham, UK. A directional approach, based on multiple urban background monitoring sites located outside the study area provides the most robust estimates. Our adopted approach allows us to model both short- and long-term air quality conditions, whilst accounting for local- and regional-scale variations in the pollution burden and will ultimately enable us to assess short- and long-term effects of air pollution on health [18].

Air pollution is an important issue facing the sustainable development of cities. In the context of rapid urbanization in China, a considerable number of cities show the coexistence of external morphological expansion and internal functional shrinkage, as well as obvious spatial heterogeneity in a large-scale region. The systematic construction of their interaction mechanisms is of great significance for air pollution remediation. Therefore, Rao Y. et al. (2023) studied attempts to apply geographically weighted regression (GWR) to analyze the effect of urban growth patterns and urban shrinkage on air quality based on 10-year PM2.5 concentration change data from 174 prefecture-level cities in China. The results of the study indicate that: (1) The relationship between urban growth pattern and air quality has spatial heterogeneity. (2) The impact of shrinking cities on air quality is greater in colder regions and highly industrialized areas. (3) Urban growth pattern and shrinking cities show significant antagonistic effects on air quality, and the infilling growth of shrinking cities can cause serious deterioration of air quality. Considering the different urban evolutionary paths in developed and developing countries, this study provides different suggestions for city managers to promote sustainable urban development [19].

Urban air quality is a global concern, and while numerous studies have examined the impact of geography, climate, and urban development on air quality, few have considered the role of electric vehicles (EVs) in predictive models. Furthermore, little attention has been paid to the spatial heterogeneity of EVs. Given the rapid growth of the EV industry, it is crucial to understand the increasing significance of EVs and electric vehicle charging stations (EVCS) on air quality. Xie D et al. (2024) focused on Wuhan, a representative polycentric city, to investigate the combined effects of EVs and EVCS on air quality, alongside other urban factors. The study employs Markov chains (MC) to process air quality data and utilizes Ordinary Least Squares (OLS) and Multiscale Geographically Weighted Regression (MGWR) for data modeling. The results highlight that incorporating EV and EVCS variables enhances the model's fit. Notably, EVCS demonstrates a pronounced influence on improving air quality in areas with high plot ratios and building densities along the north bank of the Yangtze River. The study identifies spatial variations in the geographic distribution of both EVs and EVCS, as well as the distribution of MGWR coefficients. Three distinct regional centers in Wuhan exhibit high concentrations of EVCS per unit area. Moreover, the projected outcomes suggest that these three regions can anticipate significant improvements in air quality, with probabilities ranging from 3.93 % to 10.06 %, 4.40 % to 11.43 %, and 2.55 % to 6.52 % in achieving an Excellent Status (S1) for future air quality, under the assumption of maintaining current EV policies. This study advances our understanding of the contribution of EVs and EVCS to air quality within polycentric cities. It introduces novel research perspectives and methodologies, enriching related fields of study. The findings can inform policymakers and urban planners in developing strategies for creating cleaner and more efficient cities [20].

The North China Plain (NCP) is one of the areas with a fast urbanization rate. Jiang Q. et al (2023) showed the proportion of urban areas has increased from 1.78% in 2000 to 6.70% in 2015 in the NCP. Urban expansion induce variations in air pollutants are mainly determined by changes in meteorological conditions and atmospheric physicochemical processes. A persistent severe wintertime particulate pollution episode is simulated using the WRF-Chem model to investigate the impacts of land use/cover change on air quality in the NCP. Sensitivity simulations demonstrated that the urban expansion increases the near-surface temperature by approximately 0.2 °C, and further the development of the planetary boundary layer height by approximately 1.6%, but decreases the relative humidity by 0.4% on average. The near-surface O_3 concentrations are increased by 2.2%, but the PM2.5 concentrations are decreased by 2.4% on average in the NCP. The near-surface concentration of NO_2, SO_2, and CO decrease by 4.5%, 2.2%, and 2.7%, respectively. The decrease in PM2.5 concentrations is approximately 8.9% in urban areas. Although urban expansion increases anthropogenic emissions of air pollutants, it alleviates particulate pollution to some degree, particularly in urban areas [21].

Alencia V. et al. (2023) analyzed the impact of urban form on air pollution for two urban growth scenarios in 2040 for Quito, Ecuador: Urban sprawl (low-density outward expansion) and densification (the population increase occurs within the 2017 city boundaries). We estimate concentrations of carbon monoxide (CO), nitrogen oxides (NOx), nitrogen dioxide (NO_2), ozone (O_3), and particulate matter with an aerodynamic diameter equal to or less than 2.5 μm (PM2.5). Two downscaled global emission pathways (ECLIPSE) that present a lower/upper range are applied: 1) Current legislation emissions, CLE, and 2) Maximum technically feasible reductions, MTFR. The population is expected to increase by 50%, from 3 million in 2017 to 4.5 million in 2040. The sprawl scenario considerably increases the urban area by 52%. However, these new areas hold only 9% of the population. Both pathways present considerably lower emissions for 2040 than in 2017. Emissions for all sectors, except transportation, are the same for both scenarios. Transport emissions for the densification scenario are 32% lower than for urban sprawl. Due to reduced emissions, the 2040 scenarios result in lower CO, NOx, and PM2.5 concentrations for both pathways compared to 2017. This drop is more marked for the MTFR pathway compared to CLE. Contrary to our expectations, the two scenarios result in similar annual concentrations at the metropolitan level. Even when emission variations are considerable, differences between the scenarios are relatively small, particularly for CO, O_3, and PM2.5, due to high regional contributions. However, the spatial distribution of concentrations within urban areas differs significantly; thus, the sprawl scenario results in a larger surface with higher CO, NOx, NO_2, and PM2.5 levels and the opposite for O_3. Still, due to the population distribution, the densification scenario exposes more residents to higher CO, O_3, and PM2.5 values, and the sprawl scenario exposes more inhabitants to higher concentrations of NO_2 and NOx. We find an improvement in air quality for both scenarios in 2040 compared to 2017. The annual average NO_2 concentrations exceed local regulations in a small urban area only for the CLE pathway. In contrast, for PM2.5, the area and population exposed to levels that exceed the local regulation are higher than that for NO_2 and more significant for the densification than the sprawl scenario and for the CLE than the MTFR pathway. [22]

The environmental impacts of transportation network companies (TNCs) have been under intense debate with conflicting claims. However, there are limited empirical studies that quantify TNCs' environmental impacts. Kong H. et al. (2023) examined the impact of TNCs on urban air quality in 388 metropolitan statistical areas (MSAs) in the U.S. over the period from 2010 to 2018. Based on difference-in-differences and yearly regression models, we generate three major findings: (1) The entry of TNCs has a positive impact on the overall urban air quality measured by AQI; (2) despite the positive impact on the overall air quality, TNC entry increases CO and NO_2 pollution; and (3) TNC entry reduces PM10 pollution but has no statistically significant impact on PM2.5 pollution, and the effect on PM10 reduction takes 2 years to appear. The findings provide useful insights into the management and design of shared mobility and urban transport systems [23].

Air pollution is a prevailing environmental problem in cities worldwide. The future vehicle electrification (VE), which in Europe will be importantly fostered by the ban of thermal engines from 2035, is expected to have an important effect on urban air quality. Calatayud V. et al. (2023) represented Machine learning models as an optimal tool for predicting changes in air pollutants concentrations in the context of future VE. For the city of Valencia (Spain), a XGBoost (eXtreme Gradient Boosting package) model was used in combination with SHAP (SHapley Additive exPlanations) analysis, both to investigate the importance of different factors explaining air pollution concentrations and predicting the effect of different levels of VE. The model was trained with 5 years of data including the COVID-19 lockdown period in 2020, in which mobility was strongly reduced resulting in unprecedent changes in air pollution concentrations. The interannual meteorological variability of 10 years was also considered in the analyses. For a 70% VE, the model predicted: 1) improvements in nitrogen dioxide pollution (−34% to −55% change in annual mean concentrations, for the different air quality stations), 2) a very limited effect on particulate matter concentrations (−1 to −4% change in annual means of PM2.5 and PM10), 3) heterogeneous responses in ground-level ozone concentrations (−2% to +12% change in the annual means of the daily maximum 8-h average concentrations). Even at a high VE increase of 70%, the 2021 World Health Organization Air Quality Guidelines will be exceeded for all pollutants in some stations. VE has a potentially important impact in terms of reducing NO_2-associated premature mortality, but complementary strategies for reducing traffic and controlling all different air pollution sources should also be implemented to protect human health [24].

Urban air pollution has emerged as a prominent public health concern in megacities and highly developed city clusters. Accurate modelling of urban air quality over complex terrain is challenging due to heterogeneous urban landscapes and multiscale land-atmosphere interactions. Wang H. et al. (2021) investigated the applicability of urban canopy models in the Weather Research and Forecast (WRF) model and assessed the impacts of implementing these models on the urban air quality simulation in the Community Multiscale Air Quality (CMAQ) model over the megacity Chengdu, southwestern China. The land use and land cover of Chengdu were updated in WRF by using the land-use products in 2017 from the Moderate-resolution Imaging Spectroradiometer (MODIS). Sensitivity experiments with various urban canopy models were conducted to investigate the feasibility of different urban canopy models on WRF-CMAQ simulations. We found that the SLAB model significantly underestimates NO_2 and PM2.5 concentrations, with mean fractional bias in winter (summer) reaching 52.93% (−50.34%) and −102.82% (−23.12%), respectively. Such large biases are mainly attributed to overpredicted wind speeds resulting from the flat structure in the SLAB model. In contrast, the BEM (a multilayer urban canopy model coupled with air-conditioning systems) model yields the best model performance in both winter and summer, with mean fractional errors of 33.15% (38.96%) and 34.10% (33.15%) for NO_2 and PM2.5 in winter (summer), respectively. The UCM (a single-layer urban canopy model) model illustrates good performance in summer, with MFBs of 25.61% for NO_2 and 19.03% for PM2.5, while NO_2 and PM2.5 concentrations are overestimated in winter, with MFBs of 62.58% and 38.19%, respectively. In contrast, BEP (a multilevel urban canopy model)-modelled NO_2 (MFB: 37.18%) and PM2.5 (MFB: 18.72%) correlate well with observations in winter, while significantly overestimated air pollutant concentrations in summer with MFBs of NO_2 and PM2.5 of 49.70% and 44.50%, respectively. In general, the BEP model and the BEM model are well suited for air quality simulations over Chengdu in winter, and the BEM model could be considered for air quality simulations in summer. Furthermore, we assessed the effects of extensive usage of air conditioning systems in Chengdu during summertime, and the results suggest that using air conditioning systems facilitates the dispersion of air pollutants over Chengdu. This study pinpoints the limitations of default WRF configurations and tests the applicability of urban canopy models in the WRF-CMAQ model over Chengdu, in addition highlighting the crucial role of urban canopy models in urban meteorological-air quality simulations [25].

Landscape structure, the spatial characteristic of land cover, is a key factor in air quality. Sohrab S. et al. (2023) investigated the connection between different land-use category areas taken from the 2018 Urban Atlas and the European Environmental Agency's monthly average coarse particulate matter (PM10) concentrations. We identified the main PM10 emission-source land-use categories that restrict the transmission of PM10 and therefore reduce PM10 concentrations in urban and suburban areas. According to our results, water, forest, and urban park areas inside differently sized buffer zones surrounding PM10 monitoring stations have an obvious clearing effect on PM10 concentrations throughout almost all seasons, while there is a positive correlation between areas of vacant land, railways and mine, dump and construction sites and monthly PM10 concentrations. In addition, the strong effect of the correlation between built-up areas, industrial areas and roads and monthly average PM10 concentrations changes seasonally. Air pollution from motor vehicles shows a significant positive statistical relationship with PM10 concentrations only in the summer, but in contrast, during the heating (cold) period, because of motor vehicle driving (secondary) winds, traffic corridors have a significant decreasing effect on PM10 concentrations. By understanding the effect of different land use/land cover patterns on PM10 concentrations and variability, we can derive precise spatial urban planning strategies that are adaptable for health care [26].

Urban ventilation corridors are effective in improving urban air quality and alleviating heat island problems, and are widely used in cities around the world. Han Li et al. (2022) studied typical smog-polluted cities in China to examine whether urban ventilation corridors will worsen air pollution in cities and then proposes countermeasures. First, this paper identifies compensation spaces outside the central urban area of Xi'an and then analyses the prevailing wind direction in these compensation spaces. Based on these findings, this paper identifies potential cold air passages and assesses the air cleanliness in these compensation spaces according to the spatial distributions of PM2.5 and PM10. The study finds that four compensation spaces are found outside the central urban area of Xi'an and seven potential cold air passages, including six expressways and one railway, and the PM10 and PM2.5 concentrations in three of the four compensation spaces are higher than those in the central urban area. From the beginning (located in the compensation space) to the end (located in the action space) of the cold air passages P1 and P2, PM2.5 decreased by 11.88% and 11.82%, and PM10 decreased by 9.40% and 9.76%. This study discovers that if the urban compensation spaces are in areas with high concentrations of pollutants, the polluted cold air will be introduced to the central urban area along the cold air passages due to the prevailing wind. Unlike previous studies which concluded that urban ventilation corridors improve air quality in central urban areas, this study demonstrates that urban ventilation corridors are at risk of exacerbating air pollution in central urban areas. Therefore, when planning urban ventilation corridors, a city should make an assessment of the air cleanliness of the compensation spaces mandatory to avoid worsening air pollution in the central urban area and creating an unsustainable climate environment due to the planning of urban ventilation corridors, which may further lead to economic losses and threats to public health [27].

3. Conclusion

This literature review explores the evolution of urban air quality research, tracing its origins back to the Industrial Revolution. Statistical regression models are presented to explain variations in ozone and carbon monoxide concentrations across urban areas. The model specification and estimation are based on a new spatial framework derived from the theoretical concept of well-mixed cells. A large data base is developed using GIS technology to spatially relate pollution measurements, meteorological factors, land-use characteristics, Census socio-economic data, and major highway network characteristics. The results confirm the appropriateness of the well-mixed cell framework and clarify the role of transportation, residential fuel-use, economic activities, natural environments, and meteorological factors. The review also discusses the environmental impacts of the road and building construction industry in Japan, highlighting the need for tradeoffs between emissions and construction. The review also discusses the development of an application to forecast peak ozone levels in the Greater Athens Area, aiming to support decision-making through spatial modeling of traffic-induced air pollution dispersion in urban areas at street level.

This study investigates the impact of road widening schemes on air quality in urban areas, focusing on London. The study found that PM10 concentration increased during construction and NO_2 EU Limit Value was breached, indicating a significant deterioration in residential air quality. The study also found that two-wheelers, which constitute 60% of registered vehicles, are major contributors to these pollutants. A statistical analysis of ambient air in Aurangabad City (M.S.) during 2005-2010 revealed that dense residential, heavy vehicles, and industries are major sources of air pollution. The study also addressed the problem of modeling PM10 concentration evolution in relation to train traffic using a particlemass conservation model fitted using a genetic algorithm. The study presents national-level applications using air quality simulations and detailed emissions control information. The study emphasizes the need for a cell-to-cell relationship to ensure accurate predictions and validated measurements after road capacity expansion.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] H.Y. Kim, “Modeling Air Quality In Urban Areas: A Cell-Based Statistical Approach,” Department of City and Regional Planning, The Ohio State University , Columbus, Ohio U.S.A, 1996.

[2] G. P. Gerilla, Y. Takeyama and H. Inamur, “Environmental Impacts of the Road and Building Construction Industry in Japan,” in Proceedings of the International Symposium on Lowland Technology, Saga, Japan,, October 4-6, 2000.

[3] T. Slini, K. Karatzas and A. Papadopoulos, “Regression Analysis and Urbam Air Quality Forecasting: An Application for The City of Athence,” Global Nest: the International Journal, pp. 153-162, 2002.

[4] A. Charron and R. M. Harrison, “Fine (PM2.5) and Coarse (PM2.5-10) Particulate Matter on A Heavily Trafficked London Highway: Sources and Processes,” Environmental Science & Technology , vol. 39, no. 20, 2005.

[5] G. Wang , F. H. M. van den Bosch and M. K. , “Modeling urban Traffic Air Pollution Dispersion,” The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, pp. 153-158, 2008.

[6] A. Font , . T. Baker, I. S. Mudway, E. Purdie, C. Dunster and . G. W. Fuller, “Degradation in urban air quality from construction activity and increased traffic arising from a road widening scheme,” Science of the Total Environment, vol. 497, pp. 123-132, 2014.

[7] R. Sindhwani and . P. Goyal, “Assessment of traffic–generated gaseous and particulate matter emissions and trends over Delhi (2000–2010),” Atmospheric Pollution Research, vol. 5, p. 438T446, 2014.

[8] D. B. Rathi and S. D. Rathod, “Statistical Analysis of Ambient Air Quality in Aurangabad City, Maharashtra, India,” Modern Chemistry & Applications, vol. 4, no. 3, 2016.

[9] C. Borrego, J. Amorim, O. Tchepel, . D. Dias, S. Rafael and E. Sá, “Urban scale air quality modelling using detailed traffic emissions estimates,” Atmospheric Environment, vol. 131, pp. 341-351, 2016.

[10] E. Walther and . M. Bogdan, “A novel approach for the modelling of air quality dynamics in underground railway stations,” Transportation Research Part-D: Transport and Environment, vol. 56, pp. 33-42, 2017.

[11] A. J. Macpherson, H. Simon, R. Langdon and D. Misenheimer, “A mixed integer programming model for National Ambient Air Quality Standards (NAAQS) attainment strategy analysis,” Environmental Modelling & Software, vol. 91, pp. 13-27, 2017.

[12] E. Pisoni, A. Clappier, B. Degraeuwe and P. Thunis, “Adding spatial flexibility to source-receptor relationships for air quality modeling,” Environmental Modelling & Software, vol. 90, pp. 68-77, 2017.

[13] S. S. Jensen, M. Ketzel, T. Becker, J. Christensen, J. Brandt and M. Plejdrup, “High resolution multi-scale air quality modelling for all streets in Denmark,” Transportation Research Part D, vol. 52, pp. 322-339, 2017.

[14] Z. Chalabi, A. Milojevic, R. M. Doherty, D. S. Stevenson, I. A. MacKenzie, J. Milner and . M. Vieno, “Applying air pollution modelling within a multi-criteria decision analysis framework to evaluate UK air quality policies,” Atmospheric Environment, vol. 167, pp. 466-475, 2017.

[15] M. Sandanayake, G. Zhang and S. Setunge, “A comparative method of air emission impact assessment for building construction activities,” Environmental Impact Assessment Review, vol. 68, pp. 1-9, 2018.

[16] B. Yeganeh, M. G. Hewson, S. Clifford, A. Tavassoli, L. D. Knibbs and . L. Morawska, “Estimating the spatiotemporal variation of NO2 concentration using an adaptive neuro-fuzzy inference system,” Environmental Modelling & Software, vol. 100, pp. 222-235, 2018.

[17] Z. Wang, S. Zhong, H.-d. He, Z.-R. Peng and . M. Cai, “Fine-scale variations in PM2.5 and black carbon concentrations and corresponding influential factors at an urban road intersection,” Building and Environment, vol. 141, pp. 215-225, 2018.

[18] E. L. Draper , . J. D. Whyatt, R. S. Taylor and S. E. Metcalfe, “Estimating background concentrations of PM2.5 for urban air quality modelling in a data poor environment,” Atmospheric Environment, vol. 314, 2023.

[19] Y. Rao, C. Wu and . Q. He, “The antagonistic effect of urban growth pattern and shrinking cities on air quality: Based on the empirical analysis of 174 cities in China,” Sustainable Cities and Society, vol. 97, 2023.

[20] D. Xie, Z. Gou and X. Gui, “How electric vehicles benefit urban air quality improvement: A study in Wuhan,” Science of The Total Environment, vol. 906, 2024.

[21] Q. Jiang, N. Bei, J. Wu, X. Li, R. Wang, J. Yu, Y. Lu and X. Tie, “Impacts of urban expansion on meteorology and air quality in North China Plain during wintertime: A case study,” Urban Climate, vol. 52, 2023.

[22] V. H. V. alencia , G. Levin and M. K, “Densification versus urban sprawl. Modeling the impact of two urban growth scenarios on air quality,” Atmospheric Environment, vol. 310, 2023.

[23] H. Kong, S. T. Jin and . D. Z. Sui , “Can transportation network companies improve urban air quality?,” Transportation Research Part D: Transport and Environment, vol. 119, 2023.

[24] V. Calatayud , J. Diéguez and E. Agathokleous , “Machine learning model to predict vehicle electrification impacts on urban air quality and related human health effects,” Environmental Research, vol. 228, 2023.

[25] H. Wang, Z. Liu, . Y. Zhang and . Z. Yu, “Impact of different urban canopy models on air quality simulation in Chengdu, southwestern China,” Atmospheric Environment, vol. 267, 2021.

[26] S. Sohrab , N. Csikos and P. Szilassi, “Effects of land use patterns on PM10 concentrations in urban and suburban areas. A European scale analysis,” Atmospheric Pollution Research, vol. 14, no. 12, 2023.

[27] L. Han , J. Zhao, . T. Zhang and J. Zhan, “Urban ventilation corridors exacerbate air pollution in central urban areas: Evidence from a Chinese city,” Sustainable Cities and Society, vol. 87, 2022.