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Review

Exposure to Air Pollution in Transport Microenvironments

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Abstract: People spend approximately 90% of their day in confined spaces (at home, work, school or in transit). During these periods, exposure to high concentrations of atmospheric pollutants can pose serious health risks, particularly to the respiratory system. The objective of this paper is to define a framework of the existing literature on the assessment of air quality in various transport microenvironments. A total of 297 papers, published from 2002 to 2021, were analyzed with respect to the type of transport microenvironments, the pollutants monitored, the concentrations measured and the sampling methods adopted. The analysis emphasizes the increasing interest in this topic, particularly regarding the evaluation of exposure in moving cars and buses. It specifically focuses on the exposure of occupants to atmospheric particulate matter (PM) and total volatile organic compounds (TVOCs). Concentrations of these pollutants can reach several hundreds of $\mu g/m^3$ in some cases, significantly exceeding the recommended levels. The findings presented in this paper serve as a valuable resource for urban planners and decision-makers in formulating effective urban policies.

Keywords: indoor air pollution; microenvironnement; transport mode; in-vehicle exposure; cabin

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1. Introduction

People spend approximately 90% of their day in confined spaces (at home, work, school or in transit) [1–3].

Even in comfortable and safe indoor environments, there are significant risks associated with exposure to air pollutants. Indoor air pollution contributes to approximately 3.8 million deaths annually, while outdoor exposure causes 4.2 million deaths, resulting in a total of 8 million deaths caused by air pollution [4,5]. One of the main reasons behind these deaths is the poor air quality in urban areas, where approximately 90% of the population does not have access to air that meets the air quality guideline values set by the World Health Organization (WHO) [6–8]. Due to its impact on public health, air pollutants are among the main environmental health risks [7,9,10] While travelers and commuters spend a relatively short amount of time each day in transit (approximately 6% according to [11], and around 5.5% according to [12]), professional drivers spend a considerable portion of their day inside their vehicles (around 25% to 35%). Regardless, the time spent in transportation significantly influences air pollution exposure, contributing up to approximately 30% of the total daily cumulative exposure to certain air pollutants [13–19].

According to [14], pollutant exposures in transport microenvironments are often substantially higher compared to other settings due to the lack of adequate pollutant dispersion, resulting in the accumulation of pollutants in confined spaces [20–22].

Vehicle cabins, in particular, are complex microenvironments where atmospheric pollutants tend to accumulate, including emissions from materials, exhaust emissions from nearby vehicles, evaporative emissions from the fuel system, and abrasion emissions from tires, brakes, and clutches [23]. Therefore, these microenvironments become significant sources of exposure to various air pollutants, such as Volatile Organic Compounds (VOCs), carbon monoxide (CO), nitrogen oxides (NO_x), and particulate matter (PM) [19,24,25]. As reported by Lexen et al., 2021 [12], "concentrations of these pollutants can be particularly high in hot, non-ventilated transport microenvironments; however, concentrations are expected to decrease rapidly with ventilation". As reported in [23], concentrations of different compounds in the passenger compartment are typically higher (even 2–3 times higher) compared to concentrations in other closed environments where people spend their time, such as residential areas, workplaces, public buildings, and hospitals. This condition is further aggravated, especially along busy roads in urban transport environments, where peak concentrations occur during morning commute hours [26–28].

The exposure in transport microenvironments has been well-documented in previous studies and literature reviews, which have described numerous monitoring and evaluation experiences for various modes of transportation, including taxis, buses, private automobiles, motorcycles, bicycles, trains, light rail, and metros. Table 1 provides a summary of the main literature reviews available. Among the types of microenvironments investigated in the review articles, cars and buses have received the most attention. Ref. [29] analyzed air pollution exposures during car and bus travel in Europe, synthesizing findings from 21 papers published between 2000 and 2016. The results generally showed higher exposures for car riders and lower exposures for pedestrians to particulate matter PM2.5, ultrafine particles, carbon monoxide, and black carbon. In addition to cars and buses, Ref. [14] also considered taxis to summarize personal exposure to fine particulate matter and carbon monoxide based on approximately 50 papers published between 1991 and 2005. Ref. [26] examined subway, car, and bus microenvironments to better understand personal exposure during commuting, focusing solely on European studies (48 papers published between 1998 and 2013). The study demonstrated that traveling by car resulted in higher exposure to PM and Black Carbon (BC) compared to cycling. The widespread reliance on private car transport has become a significant daily health threat for urban commuters. Ref. [30] compared exposure to PM2.5, ultrafine particles (UFPs), and BC in cars, buses, bicycles, motorcycles, auto-rickshaws, and on/near-road walking, considering only studies from the Asian region to facilitate comparisons with findings from Europe and the United States of America (USA). The results showed that average PM2.5 concentrations in cars (74 $\mu g/m^3$) and buses (76 $\mu g/m^3$) in Asian cities were approximately two to three times higher than those in Europe and American cities. UFP exposures in Asian cities were twice as high for pedestrians and up to approximately nine times high in cars compared to cities in Europe or the USA. Asian pedestrians were exposed to approximately seven times higher BC concentrations than pedestrians in the USA. Ref. [11] collected papers that provided measurements of pollutants (particulate matter and gases) and evaluations of exposures in passengers of rail, bus, car, motorcycle, published until 2020. Finally, Ref. [31] focused on 'in-transit' UFP exposure studies specific to cars, buses, ferries, and rail, based on 47 papers published up to 2010.

Cars were the primary focus of [23] (approximately 50 papers between 1991 and 2016), Ref. [32] (25 papers between 1999 and 2014), Ref. [12] (64 papers between 2004 and 2021), Ref. [25] (90 papers), and Ref. [33]. Ref. [19] concentrated solely on taxis, highlighting that taxi drivers are exposed to numerous particulate and gas air pollutants inside their vehicles, mainly due to exhaust infiltration emitted from surrounding vehicles and smoking in cabs. Ref. [34] analyzed 31 articles (2004–2020) evaluating schoolchildren's exposure to various air pollutants during their daily commute, while [35] identified recent advances in addressing the spatiotemporal dynamics of exposure during travels based on the 104 studies that they selected.

Lastly, Ref. [36] reviewed the literature (138 papers published between 1990 and 2021) related to chemical and other exposures inside an aircraft cabin.

Table 1. Main review papers available in the literature.

Authors	Transport Microenvironments	Pollutants Considered	Papers Reviewed and Years Considered	Major Findings
[29]	Car and bus	PM2.5, UFP, CO and BC	21 (2000–2016)	"Results show greatest exposures in car riders and lowest exposure in pedestrians"
[23]	Car	VOC	About 50 (1991–2016)	"Elevated concentrations of various VOCs in vehicle cabin, compared with ambient air or other indoor environments, and their impact on human health has been paid a risen attention of the researches. Multiplicity of synthetic materials placed in vehicle interior emit even hundreds of volatile organic compounds. For that reason, concentrations of different organic compounds are probably the highest in new vehicles and decrease with vehicle age increase, along with decreased with time emission of VOCs from materials"
[19]	Taxi	PM2.5, PM10, organic carbon/elemental carbon (OC/EC) and NO_2	21 (1998–2018)	"Results show that taxi drivers are exposed inside their vehicle to numerous particulate and gas air pollutants mainly issued from exhaust infiltration emitted from surrounding vehicles and from smoking in cabs. Concentrations inside taxicabs varied considerably between the studies according to the territorial and the topographical features"
[36]	Aircraft cabin	Oil fumes, organophosphates, and halogenated flame retardants	138 (1990–2021)	"The results show that those who work in the aircraft cabin are at an increased risk of neurological injury or disease due to their profession"
[26]	Car, bus and subway	PM and BC	48 (1998–2013)	"Compared to other transport methods, travelling by car has been shown to involve exposure both to higher PM and BC as compared with cycling"
[14]	Bus, car and taxi	UFPs and CO	About 50 (1991–2005)	"The exposure studies examined revealed pedestrians and cyclists to experience lower fine particulate matter and CO exposure concentrations in comparison to those inside vehicles—the vehicle shell provided no protection to the passengers. Proximity to the pollutant sources had a significant impact on exposure concentration levels experienced, consequently individuals should be encouraged to use back street routes"
[32]	Car	UFPs, PM2.5, PM10, CO, CO_2, BC, and Polycyclic aromatic hydrocarbons (PAHs)	25 (1999–2014)	"In-vehicle panel studies provide additional evidence that traffic PM exposures at commonly experienced concentrations among car commuters can be associated with a cardiorespiratory response"

Table 1. *Cont.*

Authors	Transport Microenvironments	Pollutants Considered	Papers Reviewed and Years Considered	Major Findings
[31]	Car, bus, ferry, rail	UFPs	47 (until 2010)	"Mean concentrations in bus, automobile (non-tunnel travel), rail, and walk modes were generally comparable. However, UFP exposure (and dose) during time spent in-transit is strongly dependent on a range of mode-specific and more general determinants, including, but not limited to, the effects of: meteorology, traffic parameters, cabin ventilation, filtration, deposition, UFP penetration, fuel type, exhaust treatment technologies, respiratory minute ventilation, route and microscale phenomena"
[30]	Car, bus, motorcycles	PM2.5, UFPs and BC	n.a. (1997–2017)	"PM2.5 concentrations while walking were 1.6 and 1.2 times higher in Asian cities (average 42 $\mu g/m^3$) compared to cities in Europe (26 $\mu g/m^3$) and the USA (35 $\mu g/m^3$, respectively. Likewise, average PM2.5 concentrations in car (74 $\mu g/m^3$) and bus (76 $\mu g/m^3$) modes in Asian cities were approximately two to three times higher than in Europe and American cities. UFP exposures in Asian cities were twice as high for pedestrians and up to ~9-times as high in cars than in cities in Europe or the USA. Asian pedestrians were exposed to ~7-times higher BC concentrations compared with pedestrians in the USA"
[12]	Car	Volatile Organic Compounds (VOCs)	64 (2004–2021)	"Car cabins are complex environments, including a large range of materials and products such as plastics, textiles, leather, and electronics. Chemicals are emitted from these materials over time, and it is possible to quantify these chemicals in dust particles, air and on surfaces in car cabins. Levels of flame retardants, such as PBDEs and OPFRs, have been studied extensively in car cabins, but for other SVOCs knowledge about levels is either still limited or unknown for some chemical classes"
[34]	Schoolchildren commuter	12 different air pollutants	31 (2004–2020)	"Commuter microenvironment plays a vital role in schoolchildren's total daily exposure, although they only spend a small proportion of time on commuting"
[11]	Rail, bus, car, motorcycle	PM10, PM2.5, UFPs, BC, NO_2, and NO_x	40 (2016–2020)	"Higher concentrations of air pollutants were often experienced in motorised transport compared to cycling and walking. However, closing car windows and operating ventilation in recirculation mode was found to lower particulate pollution concentrations inside cars"

Table 1. *Cont.*

Authors	Transport Microenvironments	Pollutants Considered	Papers Reviewed and Years Considered	Major Findings
[35]	Rail, bus, car, motorcycle	n.a.	104 (until 2020)	"The findings show that (a) air pollution exposure is higher in open than close transport modes, (b) pedestrians and cyclists suffer the most due to higher respiration rates and proximity to the streets, (c) air pollution exposure causes both short and long-term changes in travel behaviour (d) despite the poor air quality, many developing nations lack adequate work on exposure"
[25]	Car	PM and VOCs	90	"Particulate matters, aromatic hydrocarbons, carbonyls and airborne bacteria have been identified as the primary air pollutants inside metro system"
[33]	Car	VOCs, CO_x, PMs, and NO_x	n.a.	"Depending on numerous external factors, window-opening, correct usage of automated air conditioning systems, and indoor air filters could be useful air quality improvement tools and recommendations for optimizing the interior air hygiene"

Previous literature reviews on travel microenvironments have been limited in several aspects, including the following:

- Few transport microenvironments considered for each study;
- Small sample size (number of papers), despite a large research timeframe;
- Limited treatment of the number of pollutants;
- Few studies reported on pollutant concentration values.

To overcome these limitations, this study extends the research to include various transport microenvironments, providing a comprehensive overview of scientific activity dedicated to the study of indoor air quality and population exposure during different transportation phases. This paper specifically focuses on the growing interest in finer particles (PM1 and UFPs), which have not always been covered in previous reviews. This study aims to summarize the state of knowledge and provide quantitative information on relative exposures for different transportation modes.

The paper is organized as follows: Section 2 describes the methodological approach adopted for the research and evaluation of the scientific articles. Section 3 presents the research results and their discussion, structured into paragraphs dedicated to specific aspects. Section 4 contains the summary, conclusions, and suggestions for future research.

2. Methodology

2.1. Scope of the Review

To ensure a comprehensive literature review, it is necessary to adopt a meticulous approach for collecting and analyzing bibliographic reference materials. In this paper, a search protocol (Table 2) has been defined, along with an evaluation and selection method for the identified papers (Figure 1). Furthermore, the analysis protocol (Table 3) was applied to critically examine the contents of the collected material and present it in a structured manner. The research questions that this work aims to address are as follows:

Q1: What are the concentrations of pollutants inside means of transport?
Q2: Are high pollutant concentrations associated with specific areas (e.g., large cities) or moving vehicles?
Q3: How are indoor transportation environments monitored?

Table 2. Search protocol for the material collection.

A	**Research Questions**							
	A1.	Q1—What is the concentration of pollutants inside means of transport?						
	A2.	Q2—Are high concentrations connected to specific areas (e.g., large cities) or to moving vehicles?						
	A3.	Q3—How are indoor transportation environments monitored?						
B	**Database**							
	B1.	ScienceDirect						
	B2.	PubMed						
	B3.	Scopus						
C	**Search Criteria**							
	C1.	Journal		All				
	C2.	Year		2002–2021				
	C3.	Article type		Research and Review				
	C4.	Date of search		24 December 2021				
D	**Keywords Used in Documentary Research**							
		Group A		**Group B**	**ScienceDirect**	**Scopus**	**Pubmed**	**Total**
	D1.	*Air quality*	AND	*Microenvironment*	17.793	707	676	19.176
	D2.			*Transport*	389.310	17.855	10.719	67.505
	D3.			*In-Vehicle*	150.797	611	214	151.622
	D4.			*Cabin*	9.990	1.061	399	2.459
	D5.			*Commuter*	7.074	357	5.577	13.008
	D6.			*Driver*	91.320	2.049	984	12.165
	D7.			*Passenger*	36.738	2.563	561	39.862
	D8.	*Indoor air pollutant*	AND	*Microenvironment*	2.308	500	450	3.258
	D9.			*Transport*	16.739	1.014	1.250	17.878
	D10.			*In-Vehicle*	9.900	91	66	256
	D11.			*Cabin*	1.142	209	225	1.576
	D12.			*Commuter*	621	62	741	1.424
	D13.			*Driver*	3.573	109	133	3.815
	D14.			*Passenger*	1.868	177	164	2.209
	D15.	Exposure	AND	*Microenvironment*	90.174	7.242	5.225	102.641
	D16.			*Transport*	661.322	63.783	69.824	794.929
	D17.			*In-Vehicle*	282.770	1.266	685	30.228
	D18.			*Cabin*	9.025	1.399	704	11.128
	D19.			*Commuter*	4.723	602	12.073	17.398
	D20.			*Driver*	135.377	10.108	20.723	166.208
	D21.			*Passenger*	27.317	2.099	883	30.299
E	**Inclusion Criteria**							
	E1.	Analyzes the air quality inside means of transport						OR
	E2.	Reports the concentrations of pollutants measured						OR

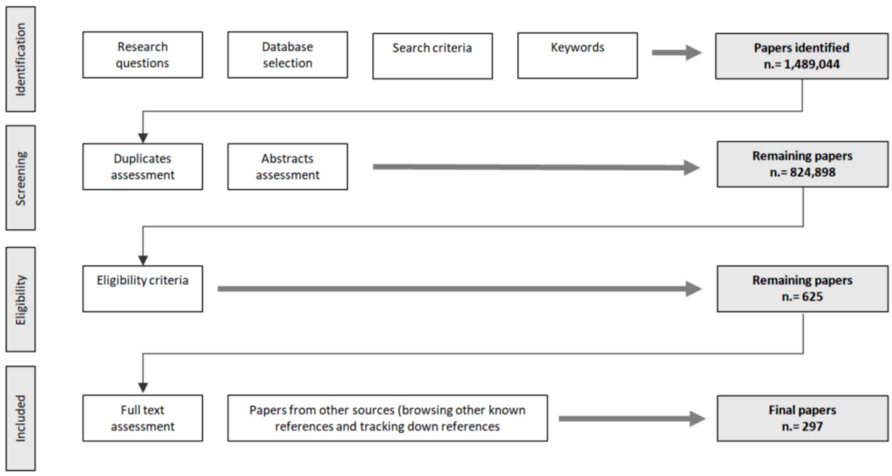

Figure 1. Material selection approach.

Table 3. Categories for the analysis.

I	**Descriptive Analysis** Year Journal Location (country and city)
II	**Material Collection** PD—Protocol-driven IA—Informal approaches SB—Snowball methods
III	**Transport Microenvironments** Transport microenvironments Fuel Vehicle in motion during measurements
IV	**Pollutant** Measured pollutant Average concentration
V	**Period of Measurement** Sampling period
VI	**Measurement Typology** Active and/or passive instrumentation

2.2. Material Collection and Selection

The search was conducted on 24 December 2021, using ScienceDirect, PubMed, and Scopus as the databases, without any restrictions. Two sets of keywords, referred to as "group A" and "group B", were utilized. Group A consisted of keywords that addressed the main focus of the paper, while group B represented the specific area of study. These two groups were combined, resulting in a list of 21 keywords that were used to search the selected databases.

The search yielded a significant number of articles, particularly in the ScienceDirect database, and specifically for the combination of keywords "Exposure" and "Transport".

The collected papers were selected through a hierarchical analysis of their content, progressing from a preliminary level to a more in-depth assessment. The screening process began with the identification phase, which involved eliminating duplicates and reviewing the abstracts of the papers to determine their relevance to the objective of this study. The remaining papers underwent further evaluation based on content criteria, specifically assessing the use of evaluation indicators for sustainability in tourist destinations.

The final step involved assessing the full text of the remaining papers, which completed the selection process. In total, 282 research papers and 15 review papers were identified and included in the analysis.

2.3. Material Analysis

Table 3 provides a comprehensive framework for analyzing the selected papers and structuring the description of the obtained results. Here is a breakdown of the categories of aspects outlined in Table 3.

- Group I: descriptive analysis.
    - Year of Publication: This aspect focuses on the distribution of papers across different publication years, providing a temporal perspective on the research in the field;
    - Journal: It identifies the journals where the selected papers were published, indicating the scholarly outlets for this topic;
    - Country of Corresponding Author: This aspect highlights the geographical distribution of the corresponding authors, providing insights into the global representation of research on exposure to air pollution in transport microenvironments.
- Group II: Paper Collection Method. This category describes the approach or method used for collecting the papers included in the analysis. It could involve specific search protocols, databases used, and any additional criteria applied during the paper selection process.
- Group III: Means of Transport.
    - Types of Means of Transport: This aspect focuses on identifying and categorizing the various means of transport that were studied by the authors in the selected papers;
    - Type of Fuel: It indicates the type of fuel used by the transport vehicles examined in the studies;
    - Gear During Measurements: This aspect highlights the gear or equipment used during the measurement process, which could vary depending on the specific means of transport.
- Group IV: Pollutants Measured and Concentrations. This category identifies the pollutants that were measured and quantified in the selected papers. It also provides information on the average concentrations of these pollutants reported in the studies.
- Group V: Sampling Period. This aspect describes the duration or period over which the sampling and measurement of air pollutants took place in the selected studies.
- Group VI: Instrumentation Used. This category specifies the type of instrumentation or devices employed for measuring air pollutants in the transport microenvironments studied by the authors.

By considering these different aspects across the groups outlined in Table 3, this research can provide a comprehensive analysis of the selected papers and present a structured description of the obtained results.

3. Results

Table 3 shows the list of the categories of aspects used to analyze the selected papers and to structure the description of the results obtained trying to answer the research questions.

3.1. Descriptive Analysis

Figure 2 illustrates the temporal distribution of the selected articles published from 2002 to 2021. The analysis reveals a steady increase in publications over time, with the highest number of studies published in 2020 and 2021 (33 articles each). Years 2017 and 2013 also saw a significant number of publications (28 and 23 articles, respectively), indicating a growing scientific interest in indoor pollution and exposure assessment during travel in transport microenvironments.

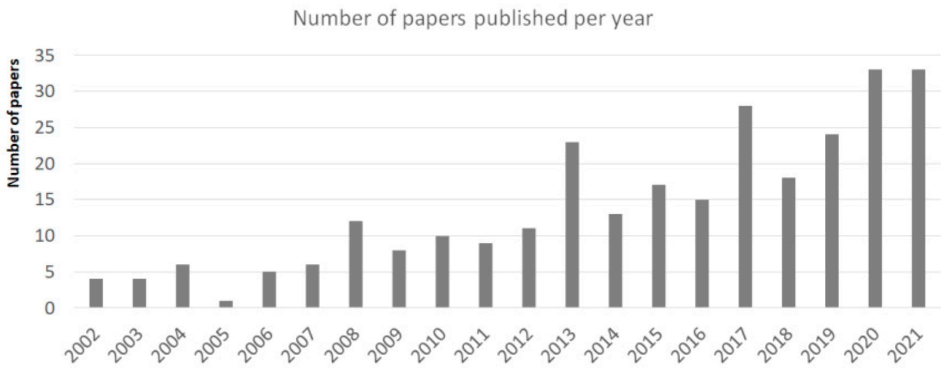

Figure 2. Number of papers published per year.

The journals that most frequently published papers on air quality in transport microenvironments were "*Atmospheric Environment*" with 63 papers and "*Science of the Total Environment*" with 27 papers. Together, they represent 32% of the articles analyzed. The other journals divide the other papers evenly. The "Others" category includes a large number of journals (over 63) that have published no more than three papers each. Figure 3 provides an overview of this situation.

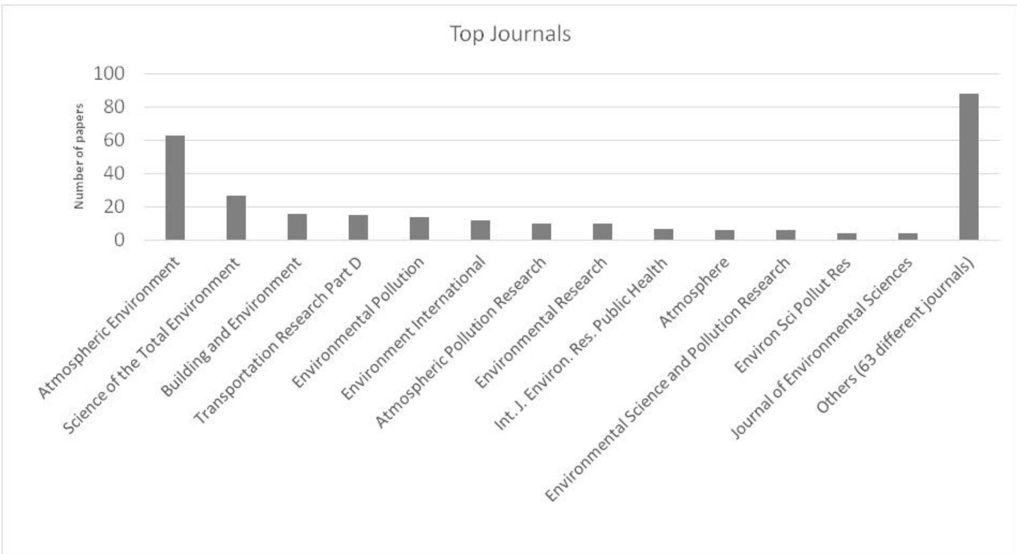

Figure 3. Number of papers published per journal.

The selected studies are concentrated in particular in Asia (43%), Europe (32%) and North America (18%) which, together, represent 93% of the studies analyzed. These works are distributed over the entire time frame analyzed (2002–2021). The remainder is equally distributed in the Southern Hemisphere, with articles available only in a few years. No nationality has been assigned to the studies involving air or sea travel and papers that have not identified the location of their case study are not included. A representation of the geographical distribution of the papers is shown in Figure 4.

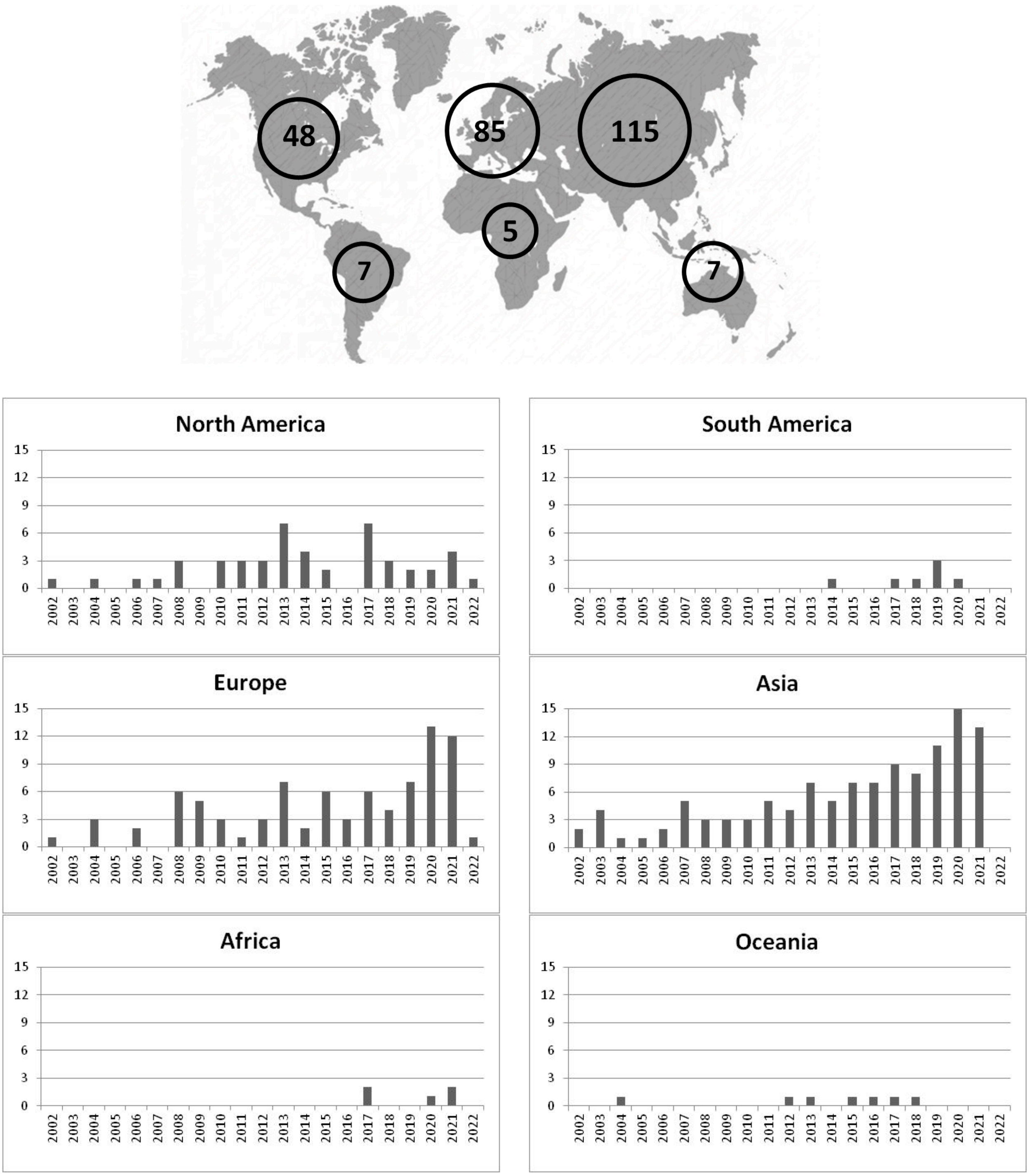

Figure 4. Geographical distribution of the papers analyzed and year of publication.

Figure 5 highlights the most analyzed cities in the selected articles. Beijing and Los Angeles are the prominent areas of study. Beijing has been extensively studied from 2011 to 2021, with taxis and cars being the most investigated means of transport [37–41]. Buses [41,42], metro [42], and trains [37] received less attention. In Los Angeles, which was discussed in articles published between 2012 and 2022, cars were the primary focus [43–47]. Few studies have analyzed buses [44,48] and metro [46]. There is greater balance in the means studied: car [49,50], bus [42,51,52], taxi [51], train [51], ferry [51], and metro [53].

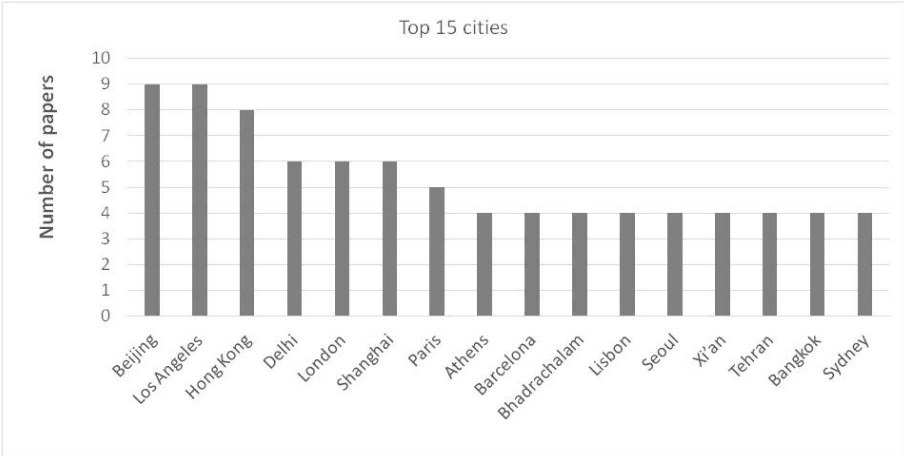

Figure 5. Top 15 cities analyzed.

Other studied areas mainly include cities in Europe (London, Paris, Barcelona, etc.) and in Asia (Delhi, Seoul, etc.). The only city in the Southern Hemisphere present in the top 15 is Sydney, described in [54–56].

Figure 6 shows the extension of the case studies analyzed by the authors. Mega (more than 10 million inhabitants) and big (500,000–1,000,000 inhabitants) cities are more frequent in the studies analyzed (36% and 40%, respectively). Medium cities (100,000–500,000 inhabitants) were analyzed by 14% of the authors with an equivalent distribution between Asia and Europe. The only exceptions to these areas are Ref. [57] which analyzes children's exposure due to aerosol particles generated by diesel-powered school buses in Cincinnati (USA) and [58] which assessed the comparative risk associated with exposure to traffic pollution when traveling via different transport modes in Christchurch, New Zealand. Less interest is associated with small cities (less than 100,000 inhabitants), with such cities being investigated by 10% of the authors. In Europe, Guildford (UK) and Ispra (Italy) are the cities with the largest studies, described by [20,59–62]. In Asia, the city of Bhadrachalam (India) is the subject of four papers [63–66]. In North America, Statesboro (USA) is the subject of the study on VOCs and PM concentrations in new and old model automobiles in [67], while in [68], they evaluated UFPs exposures while walking, cycling, and driving along an urban residential roadways.

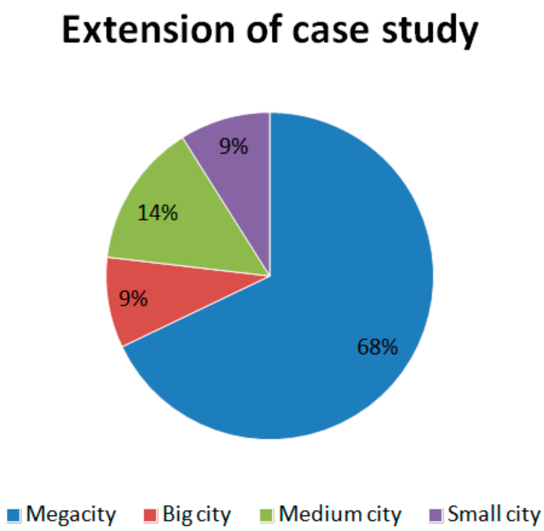

Figure 6. Extension of the cities investigated.

3.2. Material Collection and Paper Type

Most of the papers were selected through the "Protocol-driven" approach (about 88%), while the remaining were chosen using the "browse" approaches and "Snowball" methods (3% and 9%, respectively). This is due to the fact that the use of an operative protocol for research has allowed the selection of a significant number of articles well representative of the reference literature.

A total of 282 papers were selected via these approaches, to which another 15 reviews, described in Section 1, were added. Therefore, according to the type of paper, most are research works (about 95%), while 5% are review articles.

The summary of these results is reported in Table 4.

Table 4. Final articles selected.

Research Papers	
From search and selection protocol	
	249
From browse approach	
	9
From snowball methods	
	24
Total	
	282
Review papers	
From search and selection protocol	
	14
From browse approach	
	1
From snowball methods	
	0
Total	
	15

3.3. Transport Microenvironments

There have been numerous studies analyzing various transport microenvironments to assess indoor pollutant concentrations and evaluate people's exposure during travel. Figure 7 displays the frequency distribution of the analyzed transport microenvironments. Cars have received the most attention, comprising approximately 35% of the studies. For instance, Ref. [69] found that in-vehicle exposure is highly dynamic and related to local traffic dynamics. A fitted diurnal pattern indirectly explains the complex diurnal variability of the exposure due to the non-linear interaction between traffic density and distance to the preceding vehicles. Refs. [70–72] are other examples of studies in this category. Many studies focusing on cars have examined pollutant concentrations in different ventilation modes, such as open windows, closed windows, and AC On. These studies demonstrated that the different ventilation modes (open window, closed window, and AC On) had a significant effect on the pollutant's concentrations and on indoor comfort (e.g., temperature and humidity). Ref. [73] identified a direct relationship between open windows and high pollutant concentrations, while [74] demonstrated that driving with open windows resulted in the highest PM10 and PM2.5 concentrations. Ref. [75] highlighted that vehicle barrier effects are the primary determinants of in-vehicle ultrafine particle (UFP) exposure concentrations. Other studies in this domain were conducted in [76–85]. The influence of automobile construction materials and temperature on in-cabin pollutant concentrations has also been evaluated in the literature. Ref. [86] found that high temperatures can lead to increased formaldehyde emissions due to the melting process of interior materials. Ref. [87] observed higher concentrations of PM2.5 and CO in new cars compared to old cars. Ref. [88] analyzed the diffusion of organic compounds from interior materials in new cars using TVOCs (excluding formaldehyde) as tracers. The interior temperature and days lapsed after delivery were the main factors affecting the interior concentrations of most compounds according to a multiple linear regression analysis. Ref. [89] investigated inter-brand, intra-brand, and intra-model variations in VOC levels and the effect of temperature. The study reveals that butylated hydroxytoluene (BHT), a common anti-oxidant, was the most common chemical and that a reduction in cabin temperature reduced most VOC levels, but the impact was not statistically significant. Refs. [90–93] are other examples of this type of assessment. The effects of the pollutants on health and the possible consequences for driving and safety were also evaluated. In [94], the authors conducted a study on CO_2 exposure in cars to assess whether reducing CO_2 levels can alleviate unpleasant feelings, fatigue, drowsiness, or lethargy among drivers and passengers. The study found that increased levels of in-vehicle CO_2 were associated with decreased heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), and increased drowsiness. Ref. [95] described a new sensing method representing a novel approach for unobstructive assessment of driver metabolic rate while maintaining indoor air quality within the vehicle cabin. About 27% of the papers analyzed describe studies on air quality inside buses. In [96], the authors evaluated exposure to particulate matter, BC, CO, CO_2, VOCs, formaldehyde (CH2O), total airborne bacteria and fungi pollutants in vehicle cabins, highlighting that the type of ventilation is the main factor affecting the IAQ in vehicle cabins. In [97,98], the influence of varying ventilation scenarios over in-cabin particle concentrations in different school buses during parked and realistic driving (occupied and unoccupied) conditions were analyzed. Other authors adopting a similar study approach are Refs. [99–103].

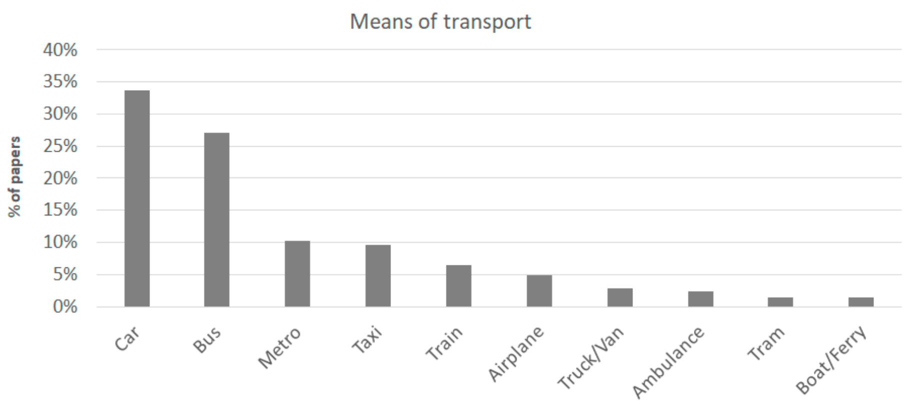

Figure 7. Means of transport.

Other authors have analyzed various factors that can influence in-cabin pollutant concentrations: temperature, humidity, age of the vehicle, and route. Ref. [104] analyzes the benzene, toluene, ethylbenzene and xylenes (BTEX) pollution levels in 22 public buses in Changsha, China. An increase in BTEX levels was observed when in-car temperature or relative humidity increased, while they decreased when car age or travel distance increased. The BTEX concentrations were higher in leather trims buses than in non-leather trims ones. Ref. [105] quantitatively estimated the excess mortality for driver/passenger in long-distance buses in terms of long driving time and inhaled PM concentrations. Several authors have also analyzed the specific case of school buses to evaluate the exposure of students during the journey to/from schools. The evaluations mainly concerned the bus's own exhaust penetrations, the effect of the air conditioning and the opening/closing of doors and windows, and the use of green fuels [106–108]. About 10% of the papers have analyzed the specific microenvironment of taxis and metros. Vehicle's age, model, size, fuel, air conditioning and refueling are the main factors considered in the studies [19,109–115]. The other indoor environments were analyzed less frequently: 6% trains [116–121], 5% airplane [122–126], 5% truck/van/ambulance [47,127–129] and 1% (each) for trams [130–134] and boat/ferry [51,135]. Many studies consider different transport modalities at the same time, providing a comparison of pollutant concentrations and evaluating the possible exposure when using one transportation mode compared to the others. About 30% of the papers collected provide indications of this type [136–140].

Figure 8 shows the frequency distribution of the state of the vehicle during the measurements. The analyses on the pollutant concentrations inside a means of transport were conducted in most of the papers with moving vehicles (89%). In [107], the authors examined particle concentrations and exhaled nitric oxide before and after a group bus trip, collecting data on heart rate variability as well. The study found positive associations between pre-trip samples of fine particles and ambient exposures with exhaled nitric oxide (FENO). After the trips, FENO concentrations were primarily associated with microenvironmental exposures. Ref. [141] investigated the concentrations of PM2.5, black carbon (BC), and CO during Bus Rapid Transit (BRT) trips in Bogotá, Colombia. The study established a strong relationship between vehicle emissions standards and in-vehicle concentrations. In [118], the authors conducted a study on pollutant concentrations during a 26 km fixed route, performing 10 repeated tests during 60 min trips to demonstrate the relationship between emissions from the leading vehicle (LV) and in-cabin PM exposure levels. In [142], a mobile measurement campaign was carried out to investigate the in-vehicle exposure to traffic-related air pollutants in Hangzhou (China). Ref. [143] examined factors such as train air conditioning filters, interior ventilation systems, tunnel environments, and platform air quality that affect airborne particle concentrations inside trains.

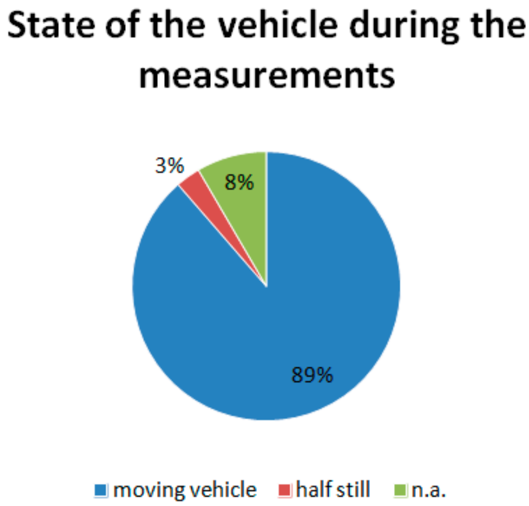

Figure 8. State of the vehicle during the measurements.

In [144], the authors analyzed particle and metal exposure in the Parisian subway, while [145] evaluated VOC concentrations during taxi trips. On the other hand, fewer studies have focused on stationary vehicles, specifically cars. These studies aimed to assess the impact of sources inside the vehicle, such as coatings and materials used in the vehicle interior, emphasizing their significant contribution to indoor air quality. Some authors conducting research in this area include [146–148].

Finally, Figure 9 shows the type of power supply of the means of transport analyzed. It is important to underline that not all studies indicate the type of power supply of the means studied. Most of the works analyze diesel-powered vehicles [149–152] or petrol vehicles [153–157]. Less frequency was detected on vehicles fueled with CNG or LPG [112,158–161], while most recent studies have also analyzed electric or hybrid vehicles [28,162–164].

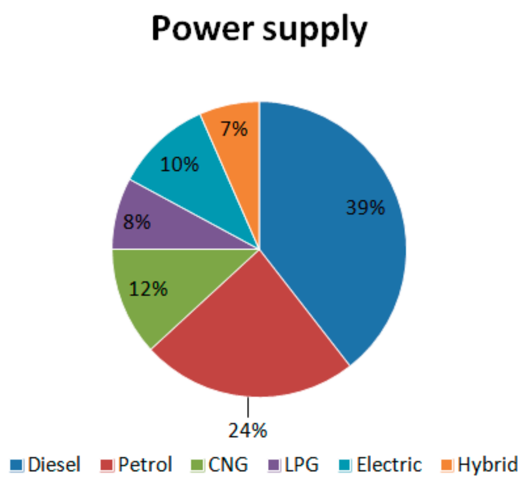

Figure 9. Transportation fuels.

3.4. Pollutants and Concentration

The literature review covers a wide range of pollutants, including both particulate matter and gases. Figure 10 shows the number of papers that analyzed each pollutant. Particulate matter (PM10, PM4, PM2.5, and UFPs) is the most extensively studied pollutant, with 218 papers (approximately 73% of the total) focusing on it. Ref. [165] analyzed in-vehicle exposure to PM10 and UFPs in Athens, observing higher exposures in heavily trafficked areas and during rush hours. Ref. [16] investigated exposures and inhaled doses of BC, UFPs, PM2.5, CO, and CO_2 in different travel modes in Barcelona, with car mode experiencing the highest concentrations of all contaminants. In [166], the authors monitored exposure to PM10, PM2.5, CO, and BTEX inside public transport vehicles in the Kathmandu Valley, finding severe particulate pollution inside the buses. Ref. [167] described a study monitoring daily personal exposure to UFPs in various microenvironments using a GPS logger, while [168] studied PM2.5 exposures for different commuting modes in Salt Lake City, Utah (USA). TVOCs (Total Volatile Organic Compounds) have also been extensively studied, with 55 papers focusing on them. These studies consider the numerous possible sources of TVOCs both outside and inside microenvironments. Examples of such studies include [51,91,159,169–171]. CO and CO_2 in transport environments have also been subjects of frequent investigation, with approximately 40 studies conducted for each pollutant. Examples of such studies include those by [172–176]. Other pollutants, such as NO_2, O_3, SO_2, and metals, have received less attention in the literature, with fewer studies conducted on these substances. Examples of studies on these pollutants include [56,177,178] for NO_2, Refs. [179–181] for 03, Refs. [176,182] for SO_2, and Refs. [144,183] for metals.

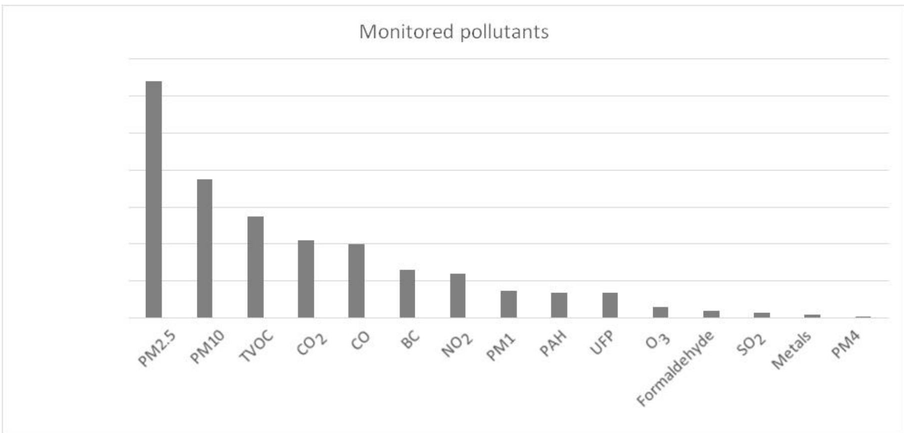

Figure 10. Number of papers analyzing each pollutant.

Table 5 shows the concentration values of air pollutants measured inside the means of transport described in the papers analyzed. In particular, the data shown in the table have been divided according to the geographical scope of the study and the type of means of transport. In cars, the particulate concentrations were also very high. In [71], the authors found high particulate concentrations, with PM10 reaching 844 µg/m^3 and PM2.5 at 458 µg/m^3 in the metropolitan city of Dhanbad, India. The highest concentrations were observed during congestion periods, with PM levels inside auto-rickshaws being 3.3 times higher than the ambient levels. Buses also exhibited noteworthy particulate concentrations. In [166], the authors measured PM10 levels of 275 µg/m^3 inside public transport vehicles in Kathmandu Valley, Nepal, and found that they frequently exceeded critical levels, while [109] studied commuter exposure in Bogota, Colombia, and reported high average concentrations of PM2.5 and BC within the city's Bus Rapid Transit (BRT) system vehicles.

Trains and metros showed significant PM10 concentrations as well. In [121], the authors assessed the indoor environmental quality in train cabins in Athens, Greece, reporting an average PM10 concentration of 238.8 µg/m^3 in old cabins, while [184] found elevated levels during morning rush hours, with PM10 concentrations ranging from 500 to 600 µg/m^3. Ref. [185] analyzed relative contributions of different transport modes in Rome, Italy, and observed PM10 concentrations of 268 µg/m^3. The particulate concentrations (regardless of particle size) are lower in other transport microenvironments. TVOC concentrations were notably high in buses (1313 µg/m^3), cars (2234 µg/m^3), and trains (598 µg/m^3) according to [96]. Additionally, buses exhibited elevated concentrations of BTEX (up to 703 µg/m^3 in [104]), NO_2 (203 µg/m^3 in [186]), and BC (250 µg/m^3 in [109]). These findings emphasize the importance of monitoring and improving air quality within a means of transport to mitigate potential health risks associated with particulate matter and other pollutants.

Table 5. Concentration values of air pollutants.

Geographic Area	Pollutant (Unit of Measurement)	Pollutant Concentrations by Means of Transport								References
		Car	Bus	Truck/Van	Tram	Train	Metro	Boat/Ferry	Taxi	
ASIA										
Beirut (Lebanon)	PM2.5 (µg/m^3)	93								[87]
	CO (ppm)	10–20								[87,172]
	CO_2 (ppm)	2500								[87]
Teheran (Iran)	PM10 (µg/m^3)	60								[175]
	BTEX (ppb)								35	[145,159]
	CO (ppm)	22								
	Formaldehyde (ppb)								800	
	Acetaldehyde (ppb)								500	
Changsha (China)	PM2.5 (µg/m^3)	6								[94]
	BTEX (µg/m^3)	40	703						1441	
	CO_2 (ppm)	1663								

Table 5. *Cont.*

Geographic Area		Pollutant (Unit of Measurement)	Pollutant Concentrations by Means of Transport								References
			Car	Bus	Truck/Van	Tram	Train	Metro	Boat/Ferry	Taxi	
ASIA	Tianjin (China)	PM2.5 (μg/m^3)	70								[174,187]
		CO_2 (ppm)	1000								
	Beijing (China)	PM10 (μg/m^3)					108				[37]
		PM2.5 (μg/m^3)	15	38			37	75		95	[37,39,42,188]
		PM1 (μg/m^3)					14.7				[37]
		TVOC (ppm)					0.3				[37]
		CO (ppm)								2.8	[189]
		CO_2 (ppm)	17			5	5				[42]
		NO_2 (μg/m^3)						31		47	[39]
		Benzene (μg/m^3)					13.7				[37]
		Toluene (μg/m^3)					12.4				
		Xylene (μg/m^3)					4.1				
	Shanghai (China)	PM2.5 (μg/m^3)	114	159			600	136			[190]
		TVOC (μg/m^3)						84			[114]
		CO_2 (ppm)					430				[191]
	Harbin (China)	PAH (μg/g)		48							[161]
	Hong Kong (China)	PM2.5 (μg/m^3)	331	[63]				18			[192]
		TVOC (ppb)						35	2.1		[50,51]
		CO (ppm)	1.7	5							[49,50]
		CO_2 (ppm)	5000	3000							
		NO_2 (ppm)	0.08								[49]
	Seoul (Republic of Korea)	PM10 (μg/m^3)						78			[193]
		TVOC (ppb)	5								[194]
	Tainan City and Taipei City (Taiwan)	PM10 (μg/m^3)		59.8							[195]
		PM2.5 (μg/m^3)		47.5							
		CO (ppm)		2.3							
		CO_2 (ppm)		1493							
	Ho Chi Minh (Vietnam)	Benzene (μg/m^3)		25						30.5	[137]
	Bangkok (Thailand)	PM2.5 (μg/m^3)		49						77	[196]
		TVOC (μg/m^3)		48			13.2		45.5		[197]
	New Delhi (India)	PM2.5 (μg/m^3)	200	113				72			[79,158,198]
		BC (μg/m^3)	75								

Table 5. *Cont.*

Geographic Area		Pollutant (Unit of Measurement)	Pollutant Concentrations by Means of Transport								References
			Car	Bus	Truck/Van	Tram	Train	Metro	Boat/Ferry	Taxi	
ASIA	Bhadrachalam (India)	PM10 (μg/m^3)	56	107							[63,66]
		PM2.5 (μg/m^3)	85	75							
		PM1 (μg/m^3)	14	16.5							
		CO (ppm)	1.8								
	Dhanbad (India)	PM10 (μg/m^3)	844								[71,98]
		PM2.5 (μg/m^3)	458								
		PM1 (μg/m^3)	302								
		CO_2 (ppm)	600	600							
	Chennai (India)	CO (ppm)	4								[199]
	Salem (India)	PM2.5 (μg/m^3)	44								[200]
		CO_2 (ppm)	261								
	Kathmandu (Nepal)	PM10 (μg/m^3)		275							[166]
		PM2.5 (μg/m^3)		92							
		TVOC (ppb)		3							
		CO (ppm)		180							
	Manila (Philippines)	PM10 (μg/m^3)					15				[117]
		PM2.5 (μg/m^3)					14				
		CO_2 (ppm)					563				
EUROPE											
	Uppsala and Stockholm (Sweden)	PM10 (μg/m^3)					43				[143]
		PM2.5 (μg/m^3)					12				
	Stockholm (Sweden	BC (μg/m^3)		2.7							[131]
	Helsinki (Finland)	PM2.5 (μg/m^3)		15		10					[131]
		BC (μg/m^3)		2		1.7					
	London (UK)	PM10 (μg/m^3)	20	39	8.9			68.4			[76,128,201]
		PM2.5 (μg/m^3)	7.4	13.2	3.8			34.5			
		PM1 (μg/m^3)	6.9	9.2				23.3			
		CO_2 (ppm)			802						[128]
		BC (μg/m^3)	4.4	5.6				9.8		5.2	[76,201]
		NO_2 (ppb)			80					78.5	[128,164]
	Dublin (Ireland)	PM2.5 (μg/m^3)	103.5								[70]
		Benzene (ppb)	3								

Table 5. *Cont.*

Geographic Area		Pollutant (Unit of Measurement)	Pollutant Concentrations by Means of Transport								References
			Car	Bus	Truck/Van	Tram	Train	Metro	Boat/Ferry	Taxi	
EUROPE	Frankfurt (Germany)	PM10 (μg/m^3)	40–70								[202]
		PM2.5 (μg/m^3)	45								
	Paris (France)	PM10 (μg/m^3)						188			[144]
		PM2.5 (μg/m^3)		59				136			[144,186]
		CO (ppm)								0.01	[111]
		NO_2 (μg/m^3)		203						113	[111,186]
	Athens (Greece)	PM10 (μg/m^3)					48–148–350				[120,121,184]
		PM2.5 (μg/m^3)					10–32–50				
		PM1 (μg/m^3)					6.5–7.9–27				
		TVOC (μg/m^3)					0.6				
		CO (ppm)					443				
		CO_2 (ppm)					755				[121]
		Benzene (μg/m^3)					1.2				[120,121]
		NO_2 (μg/m^3)					180				
		SO_2 (μg/m^3)					8				
	Thessaloniki (Greece)	PAH (ng/m^3)	4	6							[203]
	Lisbon (Portugal)	PM10 (μg/m^3)	7	2			4	85			[96,113]
		PM2.5 (μg/m^3)	14	17			15	40			
		TVOC (μg/m^3)	1132	1313			598				[96]
		CO (ppm)	0.6	0.6			0.3				
		CO_2 (ppm)	1132	753			747				
		BC (μg/m^3)	4	4.5			3				
		CH2O (μg/m^3)	0.4	0.7			0.6				
	Oporto (Portugal)	BTEX (μg/m^3)		5.2							[204]
	Milan (Italy)	PM10 (μg/m^3)	15				31				[205,206]
		PM4 (μg/m^3)	12				21				
		PM2.5 (μg/m^3)	10				17				
		PM1 (μg/m^3)	8				11				
		TPS (μg/m^3)	18				38				
		BC (μg/m^3)	3.8				6				
		NO_2 (μg/m^3)	24				73				
		Benzene (μg/m^3)	3.8								
	Ispra (Italy)	PM10 (μg/m^3)	28								[61,62]
		PM2.5 (μg/m^3)	18								
		PM1 (μg/m^3)	15								

Table 5. *Cont.*

Geographic Area		Pollutant (Unit of Measurement)	Pollutant Concentrations by Means of Transport								References
			Car	Bus	Truck/Van	Tram	Train	Metro	Boat/Ferry	Taxi	
EUROPE	Parma (Italy)	Benzene (μg/m^3)								5.85	[207]
	Florence (Italy)	PM2.5 (μg/m^3)		56						39	[152]
	Rome (Italy)	PM10 (μg/m^3)	61					268	268		[185]
		CO (ppm)	0.7								
		CO_2 (ppm)	1271								
	Naples (Italy)	PM10 (μg/m^3)						169			[208]
		PM2.5 (μg/m^3)						46			
	Barcelona (Spain)	PM10 (μg/m^3)								61	[28]
		PM2.5 (μg/m^3)	35	25		29		42			[16,28,132]
		CO (ppm)	6.4	2		0.4		0.9		1.2	
		CO_2 (ppm)	668	886		643		694		802	
		BC (μg/m^3)	17	5.5–7		3.4		7		6.5	
	Istanbul (Turkey)	PM2.5 (μg/m^3)	60	100			28.5	42	16		[135]
		BC (μg/m^3)		10			4.7		4		
America (North and South)											
	Calgary (Canada)	PM2.5 (μg/m^3)			150						[209]
		CO (ppm)			1.8						
		CO_2 (ppm)			600						
		NO_2 (μg/m^3)			0.05						
	North Carolina State University campus (USA)	PM2.5 (μg/m^3)	15	14							[181]
		CO (ppm)	1	0.9							
		O_3 (ppb)	10	9							
	Detroit (USA)	TVOC (μg/m^3)	57.5	65							[210]
	Phoenix (USA)	TVOC (μg/m^3)		1000							[163]
	Los Angeles (USA)	PM2.5 (μg/m^3)		13						26	[211,212]
		PAH(μg/m^3)	148	124			61	77			[44]
	Santa Monica (USA)	PM2.5 (μg/m^3)	8.5								[68]
	Austin (USA)	PM2.5 (μg/m^3)		14							[102]
		NO_2 (ppb)		25							
	Mexico City (USA)	PM2.5 (μg/m^3)	28	50							[213]

Table 5. *Cont.*

Geographic Area	Pollutant (Unit of Measurement)	Pollutant Concentrations by Means of Transport								References
		Car	Bus	Truck/Van	Tram	Train	Metro	Boat/Ferry	Taxi	
America (North and South)										
Bogota (Colombia)	PM2.5 (μg/m^3)		150				167			[141,162]
	CO (ppm)		3.5-5							
	BC (μg/m^3)		250							
Medellin (Colombia)	PM2.5 (μg/m^3)						42.2			[162]
Caxias do Sul (Brazil)	NO_2 (ppb)		48							[214]
Paramaribo (Suriname)	BTEX (μg/m^3)		0.44							[149]
Oceania										
Auckland (New Zealand)	CO (ppm)	1								[154]
Africa										
Cairo (Egypt)	PM10 (μg/m^3)	26–98								[74]
	PM2.5 (μg/m^3)	12–29	200							[99]
Lagos (Nigeria)	CO (ppm)	32	23							[157]
	TVOC (μg/m^3)	0.7	0.2							

3.5. Measurement Period

The authors included in the review have employed diverse measurement periods, resulting in heterogeneity across the studies. The seasons investigated most frequently were winter (30% of the authors) and summer (28%) followed by spring (24%). Some examples include [90,215,216], which conducted measurements during winter, while [182,217,218] focused on summer sampling. Spring measurements were conducted in [219,220], while only 11% of studies carried out sampling in autumn [221,222]. Some authors opted for year-long campaigns (7% of the cases reviewed), such as [17,223,224].

3.6. Instrumental Approach to Measurement

The authors included in the review employed various instrumental approaches for sampling and analyzing the air quality inside the means of transport. These approaches can be categorized into active and passive sampling methods. Active samplers utilize a forced aspiration system with pumps, allowing for accurate measurements even over short sampling times. On the other hand, passive instruments sample air without suction systems and have lower temporal resolution as they require a higher concentration of pollutants to be "accumulated" before detection. The majority of the selected papers (about 87%) utilized active instrumentation. For example, in [225], the authors employed portable Langan analyzers for CO measurements and DustTrak analyzers for particulate matter determinations. In [208], the authors use a portable photometric Aerocet sampler to measure PM concentrations in the Naples metro line: the concentrations of PM10 range between 172 and 262 mg/m^3, while those of PM2.5 are between 45 and 60 mg/m^3. In [226], the authors utilized an aerosol monitor, a temperature-relative humidity monitor, and a mobile phone for analyzing exposure to ambient fine particulate matter (PM) in transit microenvironments in the Guangdong Province (China). In [227], to analyze personal exposure to PM (PM1, PM2.5, and PM10) for multiple transportation modes in Guangzhou (China), they used an unportable battery-operated aerosol spectrometer.

The use of instruments for measuring ultrafine particles has been described by [200] who, to measure the concentrations of particulate matter in private road transport modes in Salem (India), use two real-time portable monitoring devices which follow the principle of the light scattering method.

In [228], they evaluate the commuter PM exposure to severe traffic-related air pollution (TRAP) using a portable Laser Aerosol Spectrometer and a Dust Monitor based on the optical principle. In contrast, a smaller portion of authors (about 13%) employed passive sampling approaches. Ref. [210] used 74 adsorbent tube samples, with 1.5 m height, at the front and other samples to measure VOCs from buses and cars, while [229] evaluated VOC exposure in public buses using passive sampling. In [214], the authors employed passive samplers to measure NO_2 concentrations for bus drivers, and [206] integrated real-time monitors with time-integrated techniques to evaluate personal exposure to selected pollutants in Milan. These examples highlight the diverse range of instrumental approaches adopted by authors in the literature to assess air quality inside a means of transport.

4. Conclusions

This study reports a critical analysis of the main results concerning the assessment of air quality within different types of transport microenvironments. The extensive bibliography available on this topic has been analyzed in relation to specific aspects: (a) descriptive aspects of each paper and collection methods; (b) type of means of transport; (c) monitored pollutants; (d) measurement period; and (e) type of sampling approach. A total of 297 studies were selected and analyzed. The critical analysis of the selected studies on air quality within transport microenvironments leads to draw the following conclusions and limitations:

- Strong Scientific Interest: The exposure of workers and commuters to air pollutants in transport microenvironments is a topic of significant scientific interest, as evidenced by the large number of papers collected. There is an increasing trend of scientific articles, particularly in the years 2020 and 2021, indicating the increasing attention given to this field;
- Geographic Distribution: The majority of studies are concentrated in the Northern Hemisphere, specifically in Asia (Beijing, Hong Kong, and Delhi) and Europe (London, Paris, and Athens). This emphasizes the importance of the topic and the health concerns in densely populated areas, especially in mega and big cities.
- Focus on Cars and Buses: Studies on personal exposure to air pollutants during car and bus commuting are more prevalent compared to other types of transport microenvironments. This is expected since cars and buses are the most commonly used means of transportation globally. The evaluations often occur during the movement of these vehicles, particularly those fueled by diesel or petrol, to assess the impact of internal and external sources and the air exchange between the environments;
- Particulate Matter (PM): Researchers are primarily interested in atmospheric particulate matter, especially PM2.5. Fine PM has effects on health, even at very low concentrations; in fact, a threshold below which no damage to health is observed has not been identified. Concentrations of particulate matter in transport microenvironments are often very high, exceeding several hundred $\mu g/m^3$ and surpassing outdoor levels. These high levels of particulate matter are often linked to particular conditions and, in the studies analyzed, they were found in very busy areas, during peak hours, in old cabins without ventilation and air filtration systems. Tobacco smoke in confined spaces also significantly influences pollutant concentrations;
- Cars, trains and metros are the types of vehicles with higher concentrations of pollutants;

- The World Health Organization (WHO) recognizes the strong relationship between exposure to high concentrations of fine particulate matter and increased mortality and morbidity. The harmful effects on health due to exposure to particulate matter in means of transports have been described and analyzed by various authors, highlighting their criticality;
- Total Volatile Organic Compounds (TVOCs): TVOCs, classified as a class I carcinogen by the International Agency for Research on Cancer (IARC), also exhibit high concentrations in various transport microenvironments;
- Their presence is particularly relevant especially in new vehicles where the internal construction materials (e.g., plastic, rubber, textiles, fibers, and adhesives) have significant emissions of VOCs. Also, in this case, various factors combine to increase the pollutant concentrations: air temperature (maximum level with high temperatures) and relative humidity, air exchange rate, and type of material.
- In particular, the highest concentrations were found in parked new vehicles compared to older vehicles during operating conditions (vehicle moving).
- Seasonal Variation: While there is a clear relationship between pollutant concentrations and seasons (higher concentrations in winter), most studies analyzed focused on individual seasons. Only a few papers included evaluations in both warm and cold periods. This limits our understanding of the seasonal variations in pollutant levels within transport microenvironments.
- Active Instrumentation: Active sampling approaches, employing instruments with forced aspiration systems, are the most commonly used in measuring pollutant concentrations within transport microenvironments.

In conclusion, given the frequent use of transport microenvironments and the significant concentrations of pollutants present, there is a clear need for assessing occupational and personal exposure and their impact on respiratory health. The findings of this paper provide valuable insights for exposure analysis and can assist urban planners and decision-makers in developing policies and interventions to improve and manage air quality, ultimately protecting public health.

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