sustainability

MDPI

Article

Air Quality and Active Transportation Modes: A Spatiotemporal Concurrence Analysis in Guadalajara, Mexico

Gabriela Ochoa-Covarrubias [1,*], Carlos González-Figueredo [2], Hugo DeAlba-Martínez [2] and Alejandro L. Grindlay [3]

[1] Department of Habitat and Urban Development, ITESO, The Jesuit University of Guadalajara, Tlaquepaque 45604, Mexico
[2] Department of Technological and Industrial Processes, ITESO, The Jesuit University of Guadalajara, Tlaquepaque 45604, Mexico; figueredo@iteso.mx (C.G.-F.); hdealba@iteso.mx (H.D.-M.)
[3] Department of Urban and Regional Planning, University of Granada, 18071 Granada, Spain; grindlay@ugr.es
* Correspondence: ochoagabriela@iteso.mx

Abstract: The protection of pedestrians, cyclists, and public transportation passengers from environmental pollution is a global concern. This study fills the gap in the existing knowledge of temporal exposure to air pollution in Latin American metropolises. The paper proposes a methodology addressing the relationship between two objects of study, i.e., the users of active modes of transport and air quality. This new methodology assesses the spatiotemporal concurrence of both objects with statistical analysis of large open-access databases, to promote healthy and sustainable urban mobility. The application of the empirical methodology estimated the number of users of active transportation modes exposed to poor air quality episodes in the Guadalajara metropolitan area (Mexico) in 2019. The study considered two pollutants, ozone (O_3) and particulate matter (PM_{10}), and two active modes, cycling and bus rapid transit (BRT). Spatiotemporal analyses were carried out with geographic information systems, as well as with numeric computing platforms. First, big data were used to count the number of users for each mode within the area of influence of the air quality monitoring stations. Second, the number of air pollution episodes was obtained using the air quality index proposed by the Environmental Protection Agency (USA) on an hourly basis. Third, the spatiotemporal concurrence between air quality episodes and active mode users was calculated. In particular, the air quality monitoring data from the Jalisco Atmospheric Monitoring System were compared to users of the public bicycle share system, known as MiBici, and of a bus rapid transit line, known as Mi Macro Calzada. The results showed that the number of cyclists and BRT passengers exposed to poor air quality episodes was considerable in absolute terms, that is, 208,660 users, while it was marginal when compared to the total number of users exposed to better air quality categories in the study area, who represented only 10%. To apply the results at the metropolitan scale, the spatial distribution of the air quality monitoring system should be improved, as well as the availability of data on pedestrians and conventional bus passengers.

Keywords: pedestrian; bicycle; active transportation modes; air quality; risk; health; mass transport system; bus rapid transit; GIS; big data

Citation: Ochoa-Covarrubias, G.; González-Figueredo, C.; DeAlba-Martínez, H.; Grindlay, A.L. Air Quality and Active Transportation Modes: A Spatiotemporal Concurrence Analysis in Guadalajara, Mexico. *Sustainability* **2021**, *13*, 13904. https://doi.org/10.3390/su132413904

Academic Editors: Oriol Marquet and Monika Wiktoria Maciejewska

Received: 29 October 2021
Accepted: 3 December 2021
Published: 16 December 2021

1. Introduction

Air quality is a big concern in cities. Since 2016, 90% of worldwide city dwellers living in low- and middle-income countries have breathed air that did not meet the safety standards set by the World Health Organization (WHO), causing 4.2 million premature deaths due to air pollution [1,2].

Air pollution is the presence in the air of matter (solid particles and gases) or forms of energy that cause risk, damage, or serious annoyance for people and other living organisms. According to the WHO [2], PM, carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) are the pollutants with the strongest evidence for being public health concerns.

The Environmental Protection Agency (EPA) proposed the universally recognized air quality index (AQI) [3] to assess air pollution. The EPA defined six categories according to pollutant concentrations. The categories were labeled corresponding to the level of concern, that is, 1, 2, 3, 4, 5, or 6 for good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and hazardous concern, respectively.

Specifically, O_3 and PM pollution at ground level poses a high risk to health [4,5] and have multiscale temporal patterns. The concentrations may vary according to the hour of the day and the season, e.g., O_3 concentrations are higher during the daytime than at night, and particulate matter, such as PM_{10}, is more concentrated in the winter than in the summer. Precipitations also affect PM concentrations [6].

Exposure to excessive O_3 can cause breathing problems, trigger asthma, and reduce lung function, leading to lung disease. Additionally, breathing air with high concentrations of PM is considered the leading environmental cause of death and disease. Both long-term and short-term exposure to PM are associated with morbidity and mortality from cardiovascular and respiratory diseases [2].

Different modes of transport are associated with specific effects of bad air conditions on health [7,8], for instance, the private car is recognized as the most polluting mode of transport [9–11]. Recently, urban policies in large metropolises have promoted active transportation modes through investments in infrastructure, in particular, for improvements for pedestrians, cyclists, and users of mass transport systems. However, active modes, such as walking, cycling, and accessing public transport stations or bus stops, involve a physical effort [12,13]. Thus, the activity involved for these modes requires more inhalation and, consequently, users are more sensitive to air quality [14,15]. The integration of public and nonmotorized transport networks in cities, as well as the reduction of the use of private cars, will contribute to minimizing the health risks to pedestrians, cyclists, and mass public transport users and promote sustainable cities [16].

This study proposes a novel methodology to estimate the exposure of users of active modes to air pollution. It also seeks to give information to these users on healthier threshold hours for walking or cycling. This new methodology involves addressing the relationship between two objects of study, i.e., the users of active modes and air quality, assessing the spatiotemporal concurrence of both objects with the statistical analysis of large open access databases, to support healthy and sustainable urban mobility. This study carried out an empirical analysis in the Guadalajara metropolitan area (GMA), Mexico.

This metropolis is one of the most polluted in the country and in Latin America [17]. Moreover, the city is susceptible to pollution impacts, since nonmotorized and public transport journeys predominate in the city's modal split by 40% and 37%, respectively. This suggests that at least two-thirds of the population, the active mode users, may be vulnerable to poor air quality conditions.

This fact shows the importance of cross-temporal and spatial studies to identify the pollution impacts on city inhabitants. This is also recognized in existing literature [6,7,18–24]. Despite studies in Europe [7,25–27], there is a lack of analysis of large databases of temporal exposure to air pollution concerning active mode users in Latin American metropolises.

A great number of users were expected to be exposed due to the historical poor air quality episodes in the city and the high number of active mode users. Nevertheless, the results showed that this number was smaller than initially assumed. Even though the relative figures were low, the absolute number of users exposed should prompt the adoption of public policies to protect them, such as the reduction of automobile dependency and the promotion of active transportation modes in the city, benefiting the entire population.

This article is structured as follows. The study area is defined in Section 2, with a focus on the air quality monitoring system's areas of influence, the bicycle share system, and the bus rapid transit (BRT) system. The materials and methods are presented in Section 3, followed by the results in Section 4. The discussion and conclusions are included in Sections 4 and 5, respectively.

2. Study Area

The study area was defined by the overlap between the active mode stations where data were available and the area of influence of the air quality monitoring stations (AQSs) of the Jalisco Atmospheric Monitoring System (SIMAJ, by its initials in Spanish) in the GMA.

2.1. The Guadalajara Metropolitan Area: Geographical and Mobility Context

The GMA is the capital of the Jalisco province. It is an urban area of 5.2 million inhabitants in western Mexico [28], comprising nine municipalities: Guadalajara, Zapopan, San Pedro Tlaquepaque, Tonalá, El Salto, Tlajomulco de Zúñiga, Juanacatlán, Ixtlahuacán de los Membrillos, and Zapotlanejo. As shown in Figure 1, the city is surrounded by mountains to the northwest, west, and southeast. The prevailing wind circulates west-southwest, combined with a "chimney effect" caused by north-northeast winds [29], increasing the pollutant concentrations in the south-southeast sector of the city.

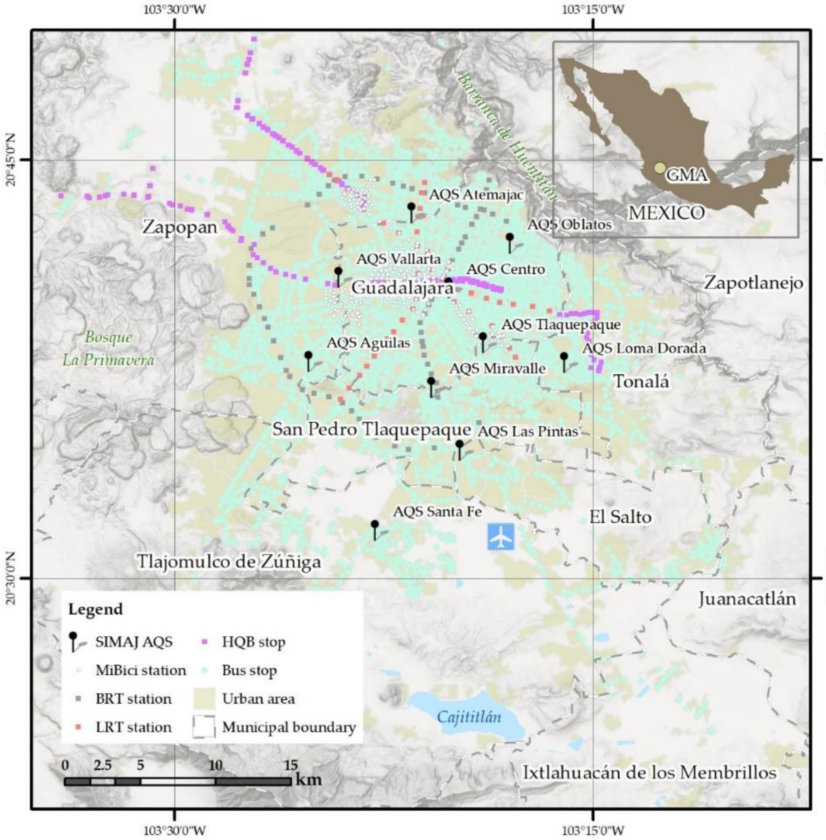


Figure 1. Air quality monitoring stations and active modes stations in the Guadalajara metropolitan area, Mexico. The Figure shows air quality monitoring stations (AQSs) of the Jalisco Atmospheric Monitoring System (SIMAJ, from its initials in Spanish) and their area of influence (AI), the stations of the bicycle share system (MiBici), conventional bus stops, and stations of the Urban Electric Train System (SITEUR, from its initials in Spanish), i.e., light rail transit (LRT), bus rapid transit (BRT), and high-quality buses (HQB). Source: authors based on [30–35].

The metropolitan area has a semiwarm climate, with some heat island episodes. There are temperature inversions in the city on 78% of the days of the year, mainly between November and June. This phenomenon favors the formation of O_3 and makes it difficult for volatile compounds such as PM_{10} to disperse. However, the situation improves in the rainy season (June–August) as the pollutants, mainly the PM_{10}, suspended in the atmosphere precipitate [29].

Air quality is a growing concern in the GMA. Quantifying and monitoring air pollution is the first step to reduce exposure to air pollution [2]. The local government monitors the air quality through the SIMAJ [36] and offers real-time air pollution measurements. Figure 1 shows the ten fixed AQSs. The AQSs measure the concentration of five pollutants (CO, PM_{10}, O_3, SO_2, NO_2) as well as meteorological variables (ambient temperature, relative humidity, and wind speed and direction). The data are used as the input for the announcement of environmental alerts in the city.

Figure 1 shows the heterogenous spatial pattern of the AQSs that partially assess the ambient pollution in the metropolis. Juanacatlán, Ixtlahuacán de los Membrillos, Tlajomulco de Zúñiga, and Zapotlanejo are mostly outside the SIMAJ's area of influence, while El Salto, Tonalá, Tlaquepaque, and Zapopan are only partly inside this area. Only the Guadalajara municipality has acceptable coverage by the SIMAJ.

According to the National Institute of Ecology and Climate Change (Mexico) [10], in 2019, the number of days on which the maximum recommended thresholds were exceeded, in at least one parameter, for any pollutant in the GMA was 267 days. This is 6% more than the number registered in 2018 and represents two thirds of the year with excessive levels of air pollution. The figures in Table 1 reveal that PM_{10} and O_3 are the pollutants that most frequently exceed the standards. Given these figures, this study focused on PM_{10} and O_3 as the pollutants to be analyzed.

Table 1. Ambient pollutants in the Guadalajara metropolitan area in 2019. Source: authors, based on [10].

Pollutant	Assessment	Unit	Value	Standard [NOM-Mexico]	Number of Days above Standard
O_3	8 h	ppm	0.146	0.070	39.50%
PM_{10}	24 h	$\mu g/m^3$	261	75	41.10%
CO	8 h	ppm	3.6	11	N/A
NO_2	1 h	ppm	0.203	0.210	N/A
SO_2	8 h	ppm	0.013	0.2	N/A

N/A: Nonapplicable; ppm = parts per million.

Private vehicles are recognized as the main source of ambient air pollution in cities [37], and the GMA is no exception [38,39]. Between 1980 and 2010, the low-density urban development paradigm in the city increased individual motorized trips by more than 942% [17].

Mass transport systems are recognized as a solution for sustainable transport development [26] and a catalyst for better air quality, despite the negative impacts during their construction [27]. Nevertheless, their contribution to the GMA modal share is very limited. According to the Jalisco State Government [17], 37% of the trips in the GMA are made on foot, 3% by bicycle, 37% by public transportation, and 23% by private vehicles. The mass transport systems barely contribute, with only 3% of the modal share. It is recognized that commuting on foot and by bicycle can significantly reduce urban pollutant emissions [40,41]. According to the National Institute of Statistics and Geography (INEGI, from its initials in Spanish) [28], 25% of dwellings in the GMA have a bicycle as a potential means of transportation. This figure contrasts with the contribution of cycling to the modal split in the city [42].

Historically, cars have been favored in the GMA with large infrastructure investments. Recently, the government, motivated by community associations and academic institutions, has promoted a sustainable mobility paradigm, particularly through active modes, e.g., improvements to the network of bike lanes, the expansion of the bicycle share system (known as MiBici), as well as the enhancement of the Urban Electric Train System (SITEUR, from its initials in Spanish).

MiBici is the public bicycle share system in the city, established in 2014 and recognized as one of the best bicycle share systems in the country in 2019 [43]. The system serves more than 86,000 cyclists through 3200 bicycles and 300 stations [44]. Balderas et al. [16]

state that one of the main reasons users choose MiBici is the low cost compared with other transportation modes. The Ciclocities Ranking 2019 [43] states that the local governments of Guadalajara, Zapopan, and Tlaquepaque have enhanced the cycling infrastructure by deploying public specialists in mobility and by giving it priority in planning bodies.

Figure 1 shows that the spatial distribution of MiBici is located mainly in Guadalajara, to a certain extent in Zapopan, and very little in Tlaquepaque. This network is nonexistent in the rest of the GMA municipalities. Cycling represents around 2% of the total modal split in the GMA [42]. The peak hours of use of the MiBici system are 8:00 a.m. and 6:00 p.m. According to Jalisco Cómo Vamos [45], MiBici registered an average of more than 2.8 million annual cycling trips in the period 2014–2020. The same source reports that the kilometers of bicycle lanes increased five-fold between 2015 and 2020, totaling 182 km. The highest number of trips since the operation began was in 2019, with 4,660,470 trips taken by more than 27 thousand users, with an average travel time of 12:32 min [44]. The heterogeneous spatial distribution of MiBici shows a west–east pattern limited to the core of the city (Figure 1).

The SITEUR has operated since 1989. The public carrier serves more than 98.5 million passengers a year through 121 stations, i.e., 3.23% of the total modal split in the city, mainly with light rail train and BRT [17]. This study counted the BRT Line 1 passengers, due to the data availability when this research was conducted. The BRT Line 1, known as Mi Macro Calzada, is 16.6 km long with 27 stations, and has been in operation since 2009. It accounts for 30.3% of SITEUR trips. The main line plus the 15 feeding lines served 44.2 million passengers in 2020, [46] with a five-minute frequency (morning peak hour) [47]. As shown in Figure 1, the BRT is north–south oriented and only serves the Guadalajara municipality up to the Tlaquepaque boundary.

2.2. The Jalisco Atmospheric Monitoring System's Area of Influence

The study area was determined by the SIMAJ's coverage and the data availability on an hourly basis. The spatial distribution of the AQSs does not cover the GMA's entire urban footprint, as shown in Figure 1. Moreover, according to the SIMAJ [48], the AQSs have a two-kilometer area of influence, for which real-time hourly measurements for PM_{10} concentrations in micrograms per cubic meter and O_3 in parts per million are recorded; these concentrations are used to calculate their related AQIs.

The spatial concurrence between the AQSs' areas of influence and the active modes of transport stops/stations was identified through a geographic information system (ArcGis Pro, ESRI®, Redlands, CA, USA). The calculations included 10 AQSs, 287 bike share stations, 9073 conventional bus stops, 77 BRT stations, and 48 light rail transit stations [30,35].

Air quality monitoring data affecting most of the active mode users were not available. Figure 2 highlights the narrow coverage of the AQSs with respect to the active mode stops/stations. Thirty-seven percent of the MiBici stations, 28% of the conventional bus stops, 44% of the BRT stations, 22% of the high-quality bus stops, and 38% of the light rail train stations were outside the area of influence of the AQSs in the city. Only 107 of the MiBici stations were included in the area of influence of four AQSs: Atemajac, Centro, Tlaquepaque, and Vallarta. Similarly, only twelve BRT stations were considered for this study, as they fell inside of the AQSs' areas of influence. Specifically, the BRT stations located within the area of influence of the Centro AQS were Ciencias de la Salud (10), Juan Álvarez (11), Alameda (12), San Juan de Dios (13), Bicentenario (14), La Paz (15), and Niños Héroes (16). The stations in the area of influence of the Miravalle AQS were López de Legazpi (23), Clemente Orozco (24), Artes Plásticas (25), Esculturas (26), and Fray Angélico (27).

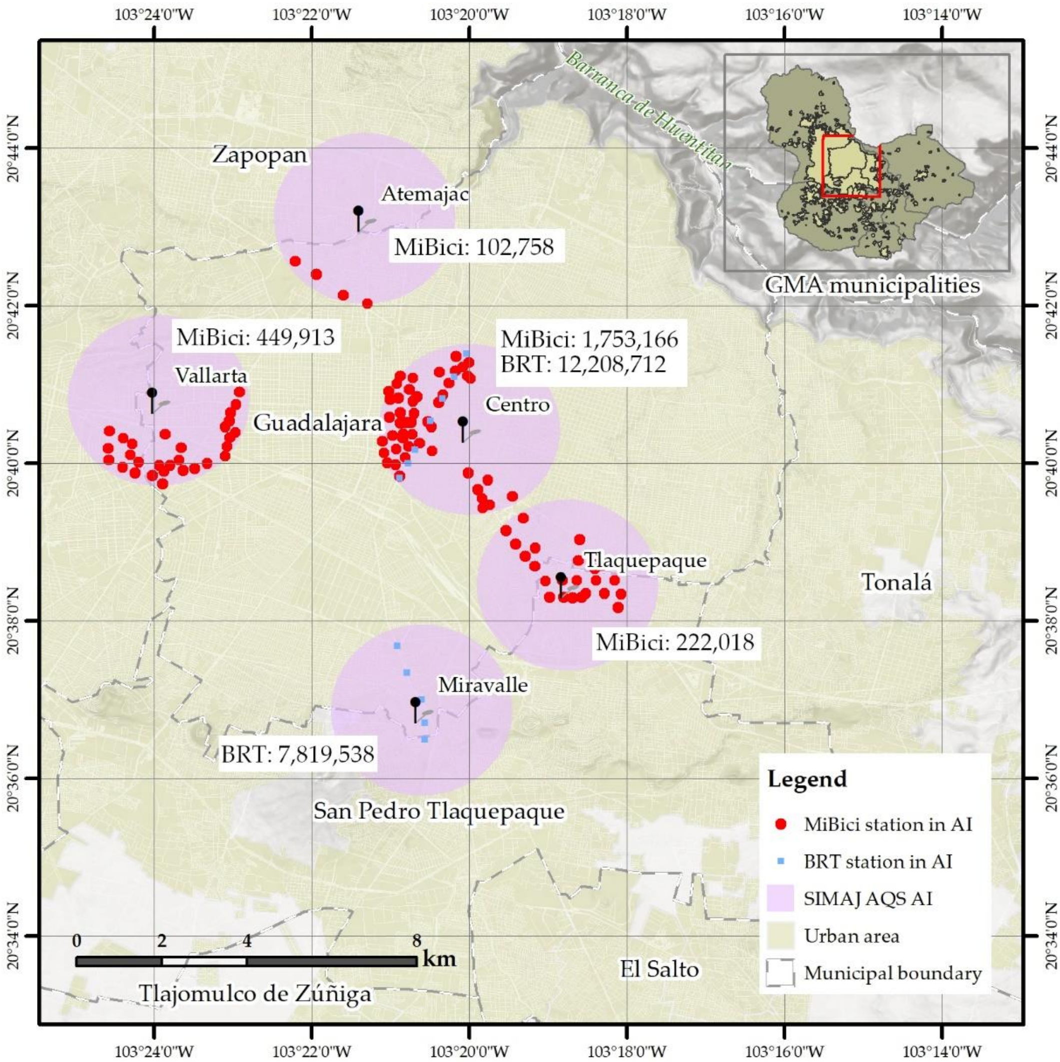


Figure 2. Study area. The figure shows the area of influence (AI) of the air quality monitoring stations (AQSs) managed by the Jalisco Atmospheric Monitoring System (SIMAJ, from its initials in Spanish). The map highlights the active mode stations considered in the study, i.e., 107 stations of the MiBici bicycle share system and 12 bus rapid transit (BRT) stations. Source: authors based on [30–34].

Unfortunately, no data for the conventional and high-quality buses or the light rail trains were available on an hourly basis. Thus, due to the SIMAJ's spatial pattern, together with the data availability, five AQSs, 107 MiBici stations, and 12 BRT stations were considered for the computations.

3. Data Sources and Methods

The WHO states that using large yearly databases allows outcomes to be refined, taking into account seasonal variations [8]. The analysis assessed data from the selected stations in 2019. This year was chosen as the reference year to prevent misrepresentation due to changes in travel behaviors caused by the COVID-19 pandemic in 2020 and 2021. An hourly time scale was selected due to the O_3 and PM_{10} temporal behavior, and data availability. This study benefited from open data availability for all AQSs [48], particularly for O_3 and PM_{10}.

Nonmotorized modes and public transport account for 77% of trips in the city [17]. Disappointingly, no data on pedestrian trips were available, nor trips made by privately owned bicycles. The MiBici open data system [49] was accessed to obtain the total trip registers to or from any of its anchoring stations for 2019. The SITEUR reported the number of passengers entering the BRT stations hourly [50]. No data for light rail trains were available at the required accuracy.

As a consequence of data availability, hereinafter, the term “active mode users” refers to trips via MiBici and pedestrians accessing BRT stations in the areas of influence of AQSs. Table 2 shows data sources and recording frequency for each kind of station computed in this study, i.e., AQS, MiBici, and BRT.

Table 2. Sources of data on air quality monitoring and active transportation modes in the Guadalajara metropolitan area in 2019.

Station	Data	Temporal Basis *	Number of Records	Source
Air quality	O_3 and PM_{10} concentration	Hour	87,600	Ministry of the Environment and Territorial Development (Semadet, Jalisco, Mexico) SIMAJ [36,48]
Active transportation mode	Bicycle in–out anchors	Minute	2,388,884	Government of the State of Jalisco, Mexico: MiBici [49]
	Passengers coming into the BRT station	Hour	105,120	Urban Electric Train System, Guadalajara [50]

* For the year 2019.

A statistical spatiotemporal approach was used. The year 2019 was chosen as the most recent year without potential changes to travel behaviors due to the COVID-19 pandemic [7]. Figure 3 shows the conceptual model used to identify the number of active mode users exposed to poor air quality episodes in the reference year. First, the active mode database was organized to identify the number of active mode users in the AQSs’ areas of influence, on an hourly basis. Then, the number of episodes per hour in each AQS area was assessed using the air quality index [3]. Finally, the concurrence between pollutants and users of active transportation modes was assessed.

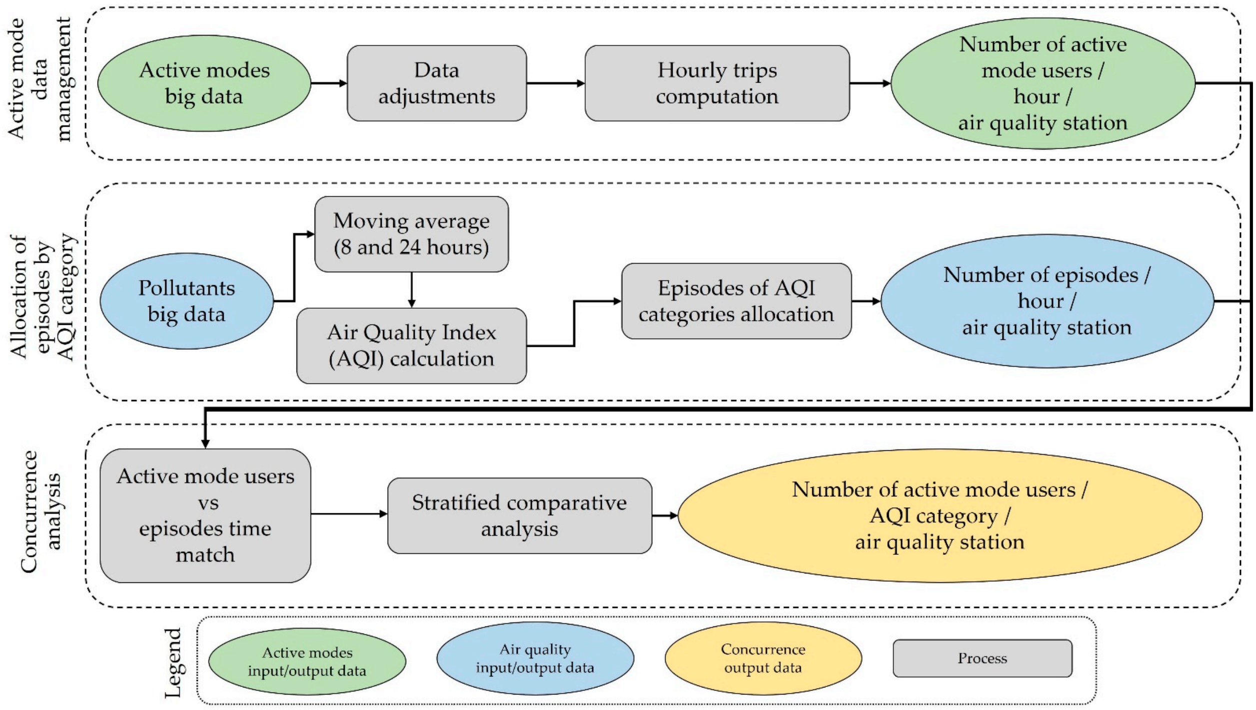


Figure 3. Conceptual model. Active modes analyzed were bicycle share system and bus rapid transit (BRT). Pollutants computed were ozone (O_3) and particulate matter (PM_{10}). Air quality index (AQI) refers to the Environmental Protection Agency index [3]. The word “users” refers to both bicycle trips and BRT passengers.

3.1. Active Mode Data Management

Data from the 107 MiBici stations were used to calculate the number of trips per hour linked to each AQS. The data were managed using Python programming language and Pandas, among other libraries. The following assumptions were made to compute bicycle trips and create a database that would be compatible with AQS data. First, one hour was added to the temporal data. Second, bicycle trips traveling at least one minute inside the AQS's area of influence were quantified as one trip in the corresponding hour. Third, the cyclists were exposed to air quality episodes both when starting and ending the trip at the station, and thus counted twice. However, if a cyclist started and finished the trip at stations linked to the same AQS, it was counted as only one trip.

The SITEUR also provided hourly data on people accessing the 12 selected BRT stations. There were no data for passengers leaving the stations; these results were underestimated, since BRT users were only counted as passengers accessing the BRT and not as pedestrians after their transit journey.

3.2. Allocation of Episodes by AQI Category

AQI was assessed to allocate a category of O_3 and PM_{10} pollution in the five AQSs studied. The AQI was designed by the EPA [51], and calculations were performed using the MATLAB programming language.

First, moving averages of pollutant concentrations were calculated for 8 and 24 h time windows, for O_3 and $PM_{10,}$ respectively. The AQI was calculated by substituting the moving averages directly in Equation (1). Next, the AQI was classified according to the established categories described in the introduction (Section 1). Finally, the number of episodes in AQI categories 3, 4, and 5 were linked to AQSs for each hour of the year; these three categories correspond to poor air quality episodes.

$$AQI = [(AQI_{Hi} - AQI_{Lo})/(Conc_{Hi} - Conc_{Lo})] \times (Conc_i - conc_{Lo}) + (AQI_{Lo}) \quad (1)$$

where

$Conc_i$ = Input concentrations for a given pollutant;
$Conc_{Lo}$ = The concentration breakpoint that is less than or equal to $Conc_i$;
$Conc_{Hi}$ = The concentration breakpoint that is greater than or equal to $Conc_i$;
AQI_{Lo} = The AQI value/breakpoint corresponding to $Conc_{Lo}$;
AQI_{Hi} = The AQI value/breakpoint corresponding to $Conc_{Hi}$.

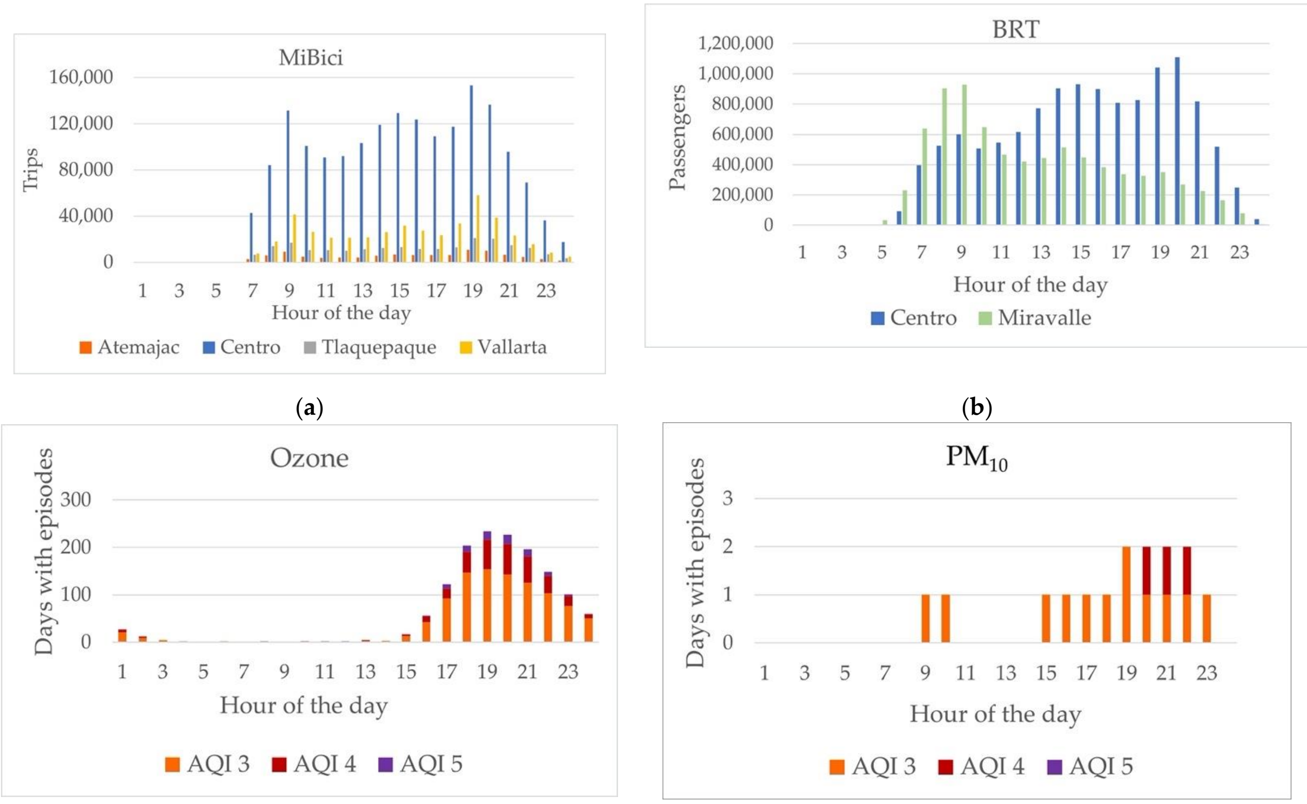
3.3. Concurrence Analysis

The concurrence analysis implied stratified computations of two inputs: first, for the number of MiBici trips and BRT passengers per hour in the five AQSs' areas of influence; then, for the number of poor air quality episodes falling into categories 3, 4, or 5. It was assumed that the entire study area had the same compensation to calculate exposure to pollutants. The concurrence analysis was computed with dynamic tables on a spreadsheet (Excel, MSOffice®, Redmond, WA, USA), associating spatiotemporal correspondence. As a result, the number of active mode users exposed to category 3, 4, or 5 episodes was estimated, both for O_3 and PM_{10}.

4. Results

4.1. Active Mode Data Management

As expected, the number of passengers who walked to access the 12 mass transport BRT stations was higher than the number of trips logged at the 104 MiBici stations, that is, 20,028,250 and 2,388,884, respectively. Figure 4 displays the number of annual active mode users studied on an hourly basis. Figure 4a shows that most of the MiBici trips were in the area of influence of the Centro AQS. All stations registered two peak hours, i.e., 9:00 and 19:00. At 9:00, there were 131,608, 17,005, and 41,602 trips in the area of influence of AQS Centro, Tlaquepaque, and Vallarta, respectively. These figures increased at 19:00 in the same areas of influence, that is, 153,314, 21,062, and 58,179 trips, respectively This was concurrent with the standard working hours in the city. In addition, the trips linked to the Centro station also showed a peak hour at 14:00 (lunch time), i.e., 129,274 trips.



(**a**) (**b**)

(**c**) (**d**)

Figure 4. Active mode users and poor ozone (O_3) or particulate matter (PM_{10}) episodes in the study area on an hourly basis. The order of magnitude between figures must be considered to properly compare them. (**a**,**b**) refer to the annual number of MiBici trips and bus rapid transit (BRT) passengers, respectively. (**c**,**d**) show the number of days with episodes within the worst air quality index (AQI) categories for O_3 and PM_{10}, respectively.

The spatial pattern of the BRT passengers was similar, although the stations that contributed to the peak hours were clearly distinguished. Figure 4b shows the three peak hours at the BRT stations in the area of influence of the Centro and Miravalle AQSs, that is, between 8:00 and 9:00, between 14:00 and 15:00, and between 19:00 and 20:00. Of the 20 million passengers using these stations, 60% were in the area of influence of the Centro AQS and 40% in that of the Miravalle station, i.e., 12,208,712 and 7,819,538, respectively. Moreover, it was shown that 1,832,788 passengers walked to reach BRT stations in the vicinity of the Miravalle AQS between 8:00 and 9:00, and 2,152,791 passengers accessed BRT stations around the Centro AQS between 19:00 and 20:00. This can be explained by the fact that the former AQS serves a mostly residential area, while the latter serves areas with a high density of workplaces, particularly retail trade and public services.

4.2. Allocation of Episodes by AQI Category

The AQI calculations emphasized categories three, four, and five. According to the EPA, categories four and five strongly affected users in active modes. No consensus was found regarding the impact of category three episodes on active mode users. Even though the Environmental Protection Agency does not explicitly include cyclists as a sensitive group, some organizations promote the use of face masks for cyclists riding within areas in AQI category three. Thus, this category was computed to account for cyclists' exposure to pollutants.

For the studied area, only the Tlaquepaque AQS recorded PM_{10} data in 2019. Thus, the PM_{10} results are not included in this section, since the calculations were not representative of the phenomenon in the study area. However, it is important to note that in the south-southeastern AQSs of the city (Santa Fe, Las Pintas, and Tonalá), more high-PM_{10}-concentration episodes are usually recorded but there were no available records of users of active modes of transport for their areas of influence. Figure 4c shows the temporal pattern of the AQI on an hourly basis. The results showed that the worst O_3 concentrations were between 17:00 and 23:00, as expected for O_3 behavior. The worst air quality episodes, adding the three AQI categories together, were recorded at 19:00 on 227 days. Table 3 shows the total number of episodes in the three AQI categories and the percentage of episodes accounted for by the five SIMAJ stations in the study area with respect to the entire GMA. PM_{10} was not representative of the phenomenon, due to the scarce data assessed, and hence was dismissed.

Table 3. Days with poor air quality episodes in 2019 on an hourly basis.

Pollutant	**AQI 3** [1]		**AQI 4** [1]		**AQI 5** [1]	
	[Episodes [2]**]**	**[%** [3]**]**	**[Episodes** [2]**]**	**[%** [3]**]**	**[Episodes** [2]**]**	**[%** [3]**]**
O_3	993	55.19	342	52.31	96	59.26
PM_{10}	1	7.14	3	100	0	0

[1] Air quality index (AQI) category according to EPA; [2] number of episodes in the corresponding AQI category, on an hourly basis in 2019; [3] percentage of episodes in the corresponding AQI category accounted for by the 5 AQSs, on an hourly basis at the metropolitan scale.

4.3. Concurrence Analysis

Few MiBici and BRT users within the study area were exposed to O_3 and PM_{10} episodes in categories three, four or five of the AQI during 2019, that is, less than 1.48% and 0.87%, respectively. Table 4 shows the spatiotemporal match between the pollutant episodes and the active mode users. The difference between the two modes in the order of magnitude of the figures is explained by the modes' attributes: MiBici is unipersonal and BRT is mass transport.

Table 4. Active transportation users exposed to O_3 and PM_{10} in the study area.

		MiBici		**BRT**		**MiBici + BRT**	
Total users	AQI [1]	2,388,884		20,028,250		22,417,134	
O_3	3	28,469	1.19%	145,468	0.73%	173,937	0.78%
	4	6467	0.27%	27,761	0.14%	34,228	0.15%
	5	43	0.00%	18	0.00%	61	0.00%
	Total	34,979	1.48%	173,247	0.87%	208,226	0.93%
PM_{10}	3	431	0.02%	0	0.00%	431	0.00%
	4	69	0.00%	0	0.00%	69	0.00%
	5	0	0.00%	0	0.00%	0	0.00%
	Total	*500*	0.02%	*0*	0.00%	*500*	0.00%
O_3 + PM_{10}	All categories	35,479	1.50%	173,247	0.87%	208,726	0.93%

[1] Air quality index (AQI) category according to EPA.

The results show that only 0.24% and 0.14% of MiBici and BRT users in the study area were exposed to unhealthy or very unhealthy levels of concern, i.e., categories four and five. However, the figures become relevant when analyzed in absolute terms. More than 200,000 active users were exposed; this is almost 35,000 and 173,000 MiBici and BRT users, respectively. Only 22 cyclists were riding and 18 pedestrians were accessing BRT stations while category five O_3 episodes occurred, and this occurred only in the area of influence of the Miravalle AQS, as shown in Figure 5. Nevertheless, more than 30,000 active mode users were exposed to category four O_3 episodes.

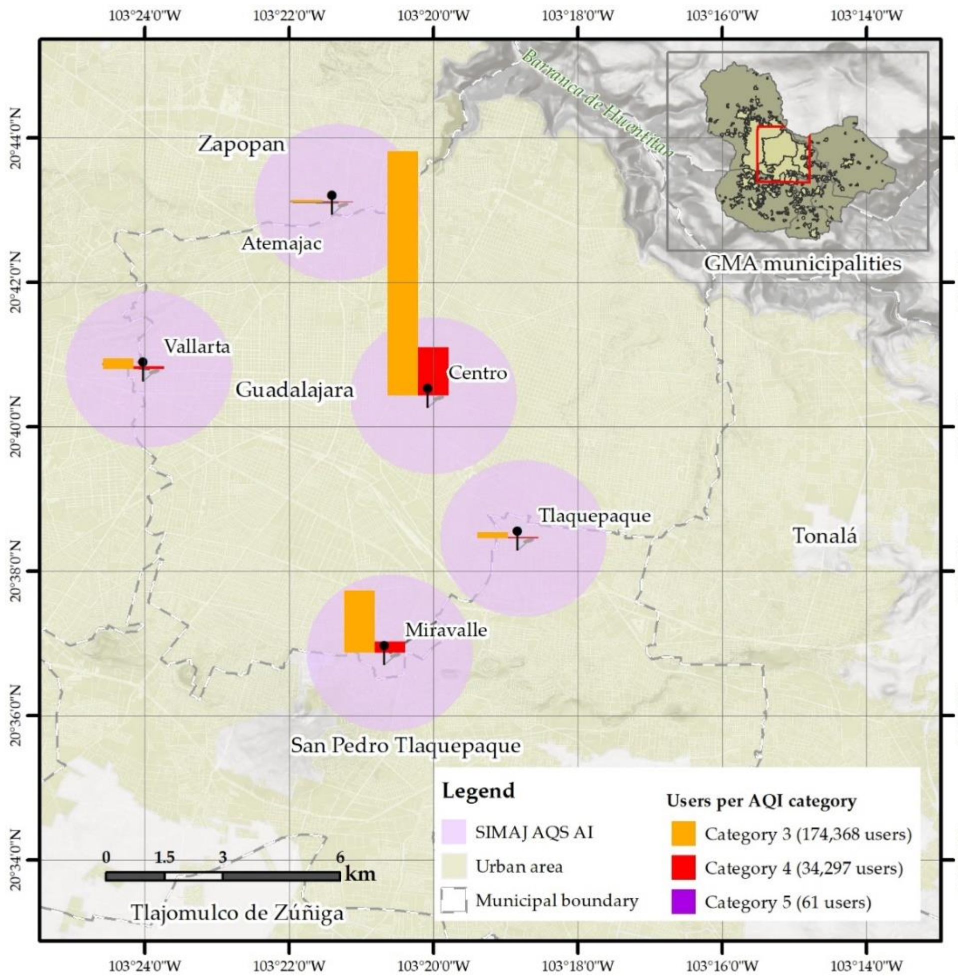


Figure 5. Spatiotemporal concurrence of air quality episodes and active mode users in 2019. Figures summarize ozone (O_3) and particulate matter (PM_{10}). Source: authors based on [30–34].

Although these figures are modest in the context of the metropolitan area's overall trips, it should be considered that, in this study, active transportation modes only served a small fraction of the urban area in the metropolis, due to the limited area of influence of the AQSs in the city (Figure 5).

More than two hundred thousand active users were exposed to O_3. In contrast, the exposure to PM_{10} affected fewer than 500 passengers, due to the lack of data for this pollutant in most of the AQSs. According to the daily temporal pattern, most of the exposure occurred in the afternoon. Fewer than 10% of the total users were exposed to pollutant episodes in categories three, four, or five.

5. Discussion

According to the novel methodology proposed, the data availability determined the estimation of the exposure of active mode users to air pollution. In the case of the GMA, the spatial and temporal data accuracy of active modes and air quality was limited. On the one hand, MiBici data were accessible and well structured. Thus, the spatiotemporal data precision allowed deep analyses of this active mode. In contrast, no data on pedestrian flows were available at all. Additionally, regardless of the great potential of data analysis from smart cards already proved in other cities [52], neither bus nor light rail train data were available at the required accuracy. Only data on passengers accessing BRT stations were obtained on an hourly basis. All these active modes data limitations led to an underestimation of the real situation.

On the other hand, the gaps in the air quality data were a consequence of the heterogeneous spatial distribution, the small number of AQSs, and their temporal lack of operation [17]. First, the spatial distribution and the 2 km area of influence of the AQSs resulted in the assessment of only 18.63% of the GMA urban fabric. This spatial restriction dismissed most of the MiBici and BRT stations. Second, PM_{10} was assessed only by the Tlaquepaque AQS; thus, the results of this pollutant were underestimated.

Despite the data availability limitations in the GMA, the results allowed the trends of the mobility and the temporal exposure of cyclist and BRT users to air pollution to be successfully identified. Concerning the mobility patterns, two tendencies were identified. First, the BRT stations located in residential areas were largely used in the morning, while the downtown stations were predominantly used at lunchtime and in the evenings. The trips are generated by the concentration of economic activity [53]. This trend confirms other studies' results showing that cycling and BRT trips are mainly used for commuting to work [54]. Second, results showed that active mobility was concentrated around the central AQSs, confirming that a high centrality in cities promotes mobility concentration in the downtown area where the main economic activity is concentrated [55], as in other metropolises in Latin America [56,57].

The results for the temporal exposure of cyclists and BRT users to air pollution showed that users traveling in the evenings, i.e., from 18:00 to 21:00, were more exposed to air pollution than users travelling at other hours of the day, similar to other empirical cases in Latin America [58,59].

6. Conclusions

The link between air quality and active transportation modes assessed in this study is recognized locally and worldwide [7,26]. When using active transportation mode systems, such as MiBici and SITEUR, people perform physical activity, contributing to their health [41]. However, cyclists, pedestrians, and transit users are susceptible to traffic injuries [60,61] and environmental pollution [62]. This research focused on the latter.

The study estimated the exposure of active mode users to air pollution and identified the healthier threshold hours for walking or cycling in the GMA. It is extremely important to protect pedestrians, cyclists, and passengers of public transport from ambient pollution in a context such as the GMA, where more than 70% of trips are made on foot or by nonmotorized vehicles, buses, or mass transport systems.

The number of exposed users was small, since the results revealed that 208,660 users of MiBici or BRT, i.e., less than 10%, were exposed to the worst categories of the AQI in the study area, mainly within category three. Furthermore, according to the results, cyclists and pedestrians may reduce their exposure to poor air quality episodes when traveling before 18:00 and after 21:00.

The 13th Sustainable Development Goal (SDG) seeks to bring down the levels of atmospheric pollution by shifting from private motorized modes to active transportation [26,63]. The proposed methodology can be applied in other metropolitan areas to provide key information for sustainable mobility and air quality contingency plans in the context of this SDG [64].

The empirical application of the methodology led to three general suggestions for cities seeking to reach SDGs. First, spatiotemporal data of active mode users should be recorded and made available as open access data, according to worldwide trends [65,66]. Next, air quality monitoring systems should properly assess the air quality in the metropolis. Finally, urban planning, mobility, and environmental and public health policies should be coordinated and should fully adopt the current urban sustainability paradigm [37,67].

The results did not apply to the whole metropolitan area due to methodological and data deficiencies: The limited area of air quality monitoring due to the spatial distribution of the AQSs; the lack of active mode users' data; the underestimated calculations as a consequence of the gaps in the PM_{10} data; and the lack of data from pedestrians, conventional buses, and light rail train users. Despite the limitations in the data availability for the study area, this methodology can be replicated in other urban areas to support decision making in the generation of public policies for the benefit of active mode users and to promote safe and healthy active mode trips, thus contributing to sustainable mobility in cities.

Author Contributions: Conceptualization, G.O.-C., C.G.-F., H.D.-M. and A.L.G.; methodology, G.O.-C., C.G.-F. and H.D.-M.; software, C.G.-F. and H.D.-M.; formal analysis, C.G.-F. and H.D.-M.; investigation, G.O.-C., C.G.-F. and H.D.-M.; resources, G.O.-C., C.G.-F., H.D.-M. and A.L.G.; data curation, G.O.-C., C.G.-F. and H.D.-M.; writing—original draft preparation, G.O.-C.; writing—review and editing, C.G.-F., H.D.-M. and A.L.G.; visualization, G.O.-C., C.G.-F. and H.D.-M.; supervision, A.L.G.; project administration, G.O.-C.; funding acquisition, G.O.-C. and A.L.G. All authors have read and agreed to the published version of the manuscript.

Funding: The article processing charge was funded by the Ministry of Science, Innovations and Universities (Spain), reference REDES2018-102320-T.

Data Availability Statement: Not applicable.

Acknowledgments: The authors recognize the financial support of the National Council of Science and Technology (CONACYT), of the Development Trust of Mexico (FIIDEM), and of the ITESO, the Jesuit University of Guadalajara. The authors also acknowledge the Urban Electric Train System (SITEUR, Jalisco, Mexico), the MiBici system, and the Ministry of the Environment and Territorial Development (Semadet, Jalisco, Mexico) for the helpful data provided. Thanks also to English reviewers, William Quinn and Rosie Dibb, and to the anonymous reviewers for their helpful comments to improve the paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. UN-Habitat. Sustainable Development Goals Cities. Available online: https://unhabitat.org/programme/sustainable-development-goals-cities (accessed on 14 January 2021).
2. World Health Organization. Air Pollution. Available online: https://www.who.int/westernpacific/health-topics/air-pollution (accessed on 28 June 2021).
3. Environmental Protection Agency, (EPA). Air Quality Index Basics. Available online: https://www.airnow.gov/aqi/aqi-basics (accessed on 8 September 2021).
4. Environmental Protection Agency, (EPA). Health Effects of Ozone Pollution. Available online: https://www.epa.gov/ground-level-ozone-pollution/health-effects-ozone-pollution (accessed on 25 August 2021).
5. Environmental Protection Agency, (EPA). Health and Environmental Effects of Particulate Matter (PM). Available online: https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm (accessed on 25 August 2021).
6. De Jesus, A.L.; Thompson, H.; Knibbs, L.D.; Hanigan, I.; De Torres, L.; Fisher, G.; Berko, H.; Morawska, L. Two decades of trends in urban particulate matter concentrations across Australia. *Environ. Res.* **2020**, *190*, 110021. [CrossRef]
7. Alemdar, K.D.; Kaya, Ö.; Canale, A.; Çodur, M.Y.; Campisi, T. Evaluation of air quality index by spatial analysis depending on vehicle traffic during the COVID-19 outbreak in Turkey. *Energies* **2021**, *14*, 5729. [CrossRef]
8. Kahlmeier, S.; Götschi, T.; Cavill, N.; Castro Fernandez, A.; Brand, C.; Rojas-Rueda, D.; Woodcock, J.; Kelly, P.; Lieb, C.; Oja, P.; et al. *Health Economic Assessment Tool (HEAT) for Walking and for Cycling*, 2017th ed.; WHO Regional Office for Europe: Copenhagen, Denmark, 2017; ISBN 978-92-890-5278-8.
9. Saeidizand, P.; Fransen, K.; Boussauw, K. Revisiting Car dependency: A worldwide analysis of car travel in global metropolitan areas. *Cities* **2021**, *120*, 103467. [CrossRef]
10. Instituto Nacional de Ecología y Cambio Climático. *Informe Nacional de la Calidad del Aire 2019, México*; Coordinación General de Contaminación y Salud Ambiental, Dirección de Investigación de Calidad del Aire y Contaminantes Climáticos: Ciudad de Mexico, Mexico, 2020; p. 343.
11. Grindlay, A.L.; Molero, E.; Miralles-Guasch, C.; Lizárraga, C. Environmental impacts for everyday mobility in Andalusia (Spain) towards a sustainable scenario? *WIT Trans. Ecol. Environ. Sustain. City X* **2015**, *194*, 373–384.
12. Morency, C.; Trépanier, M.; Demers, M. Walking to transit: An unexpected source of physical activity. *Transp. Policy* **2011**, *18*, 800–806. [CrossRef]
13. Mageau-Béland, J.; Morency, C. Assessing physical activity achievement by using transit. *Transp. Res. Rec.* **2021**, *2675*, 0361198121999057. [CrossRef]
14. Peng, L.; Shen, Y.; Gao, W.; Zhou, J.; Pan, L.; Kan, H.; Cai, J. Personal exposure to PM2.5 in five commuting modes under hazy and non-hazy conditions. *Environ. Pollut.* **2021**, *289*, 117823. [CrossRef] [PubMed]
15. Adams, M.D.; Yiannakoulias, N.; Kanaroglou, P.S. Air pollution exposure: An activity pattern approach for active transportation. *Atmos. Environ.* **2016**, *140*, 52–59. [CrossRef]

16. Balderas Torres, A.; Zafra Ortega, A.; Sudmant, A.; Gouldson, A. *Sustainable Mobility for Sustainable Cities: Lessons from Cycling Schemes in Mexico City and Guadalajara, Mexico*; Coalition for Urban Transitions: London, UK; Washington, DC, USA, 2021; p. 45.
17. Plan Estatal de Gobernanza y Desarrollo de Jalisco (Government of the State of Jalisco). *Plan Estatal de Gobernanza y Desarrollo de Jalisco 2018–2024. Visión 2030. Diagnóstico*; Gobierno del Estado de Jalisco: Guadalajara, Mexico, 2019; p. 618.
18. Achebak, H.; Petetin, H.; Quijal-Zamorano, M.; Bowdalo, D.; Pérez García-Pando, C.; Ballester, J. Trade-offs between short-term mortality attributable to NO2 and O3 changes during the COVID-19 lockdown across major Spanish cities. *Environ. Pollut.* **2021**, *286*, 117220. [CrossRef]
19. Xia, N.; Du, E.; Guo, Z.; de Vries, W. The diurnal cycle of summer tropospheric ozone concentrations across Chinese cities: Spatial patterns and Main drivers. *Environ. Pollut.* **2021**, *286*, 117547. [CrossRef]
20. Bhat, S.U.; Khanday, S.A.; Islam, S.T.; Sabha, I. Understanding the spatiotemporal pollution dynamics of highly fragile montane watersheds of kashmir Himalaya, India. *Environ. Pollut.* **2021**, *286*, 117335. [CrossRef]
21. Iglesias-Merchan, C.; Laborda-Somolinos, R.; González-Ávila, S.; Elena-Rosselló, R. Spatio-temporal changes of road traffic noise pollution at ecoregional scale. *Environ. Pollut.* **2021**, *286*, 117291. [CrossRef] [PubMed]
22. Jia, H.; Pan, J.; Huo, J.; Fu, Q.; Duan, Y.; Lin, Y.; Hu, X.; Cheng, J. Atmospheric black carbon in urban and traffic areas in Shanghai: Temporal variations, source characteristics, and population exposure. *Environ. Pollut.* **2021**, *289*, 117868. [CrossRef] [PubMed]
23. Shogrkhodaei, S.Z.; Razavi-Termeh, S.V.; Fathnia, A. Spatio-temporal modeling of PM2.5 risk mapping using three machine learning algorithms. *Environ. Pollut.* **2021**, *289*, 117859. [CrossRef]
24. Sullivan, R.C.; Pryor, S.C. Quantifying spatiotemporal variability of fine particles in an urban environment using combined fixed and mobile measurements. *Atmos. Environ.* **2014**, *89*, 664–671. [CrossRef]
25. Cheng, J.; Tong, S.; Su, H.; Xu, Z. Hourly air pollution exposure and emergency department visit for acute myocardial infarction: Vulnerable populations and susceptible time window. *Environ. Pollut.* **2021**, *288*, 117806. [CrossRef]
26. Lejda, K.; Mądziel, M.; Siedlecka, S.; Zielińska, E. The future of public transport in light of solutions for sustainable transport development. *Zesz. Nauk. Transp./Politech. Śląska* **2017**, *95*, 97–108. [CrossRef]
27. Qazi, M.Y.S.; Niazi, M.H.K.; Niazi, A.R.K. Environmental and Social Challenges for Bus Rapid Transit (BRT) Peshawar, Using Culture as a Moderator: An Empirical Study in Peshawar Khyber-Pakhtunkhwa. *J. Manag. Sci.* **2021**, *15*, 170–186.
28. Inegi, Instituto Nacional de Estadística y Geografía (National Institute of Statistics and Geography, Mexico). Population and Housing Census. Available online: https://www.inegi.org.mx/programas/ccpv/2020/default.html#Microdatos (accessed on 9 February 2021).
29. Secretaría de Media Ambiente y Desarrollo Territorial. *ProAire Jalisco 2014–2020*; Secretaría de Media Ambiente y Desarrollo Territorial (SEMADET, Jalisco): Guadalajara, Mexico, 2014; p. 257.
30. IMEPLAN. SIGmetro. Available online: https://sigmetro.imeplan.mx/mapa (accessed on 26 October 2020).
31. Inegi, Instituto Nacional de Estadística y Geografía (National Institute of Statistics and Geography, Mexico). *Topographic Information Vector Data Set F13D55 Tesistán. San Francisco Tesistán Scale 1:50,000 Series III*; INEGI: Aguascalientes, Mexico, 2015.
32. Inegi, Instituto Nacional de Estadística y Geografía (National Institute of Statistics and Geography, Mexico). *Topographic Information Vector Data Set F13D65 Guadalajara Oeste Scale 1:50,000 Serie III*; INEGI: Aguascalientes, Mexico, 2014.
33. Inegi, Instituto Nacional de Estadística y Geografía (National Institute of Statistics and Geography, Mexico). *Topographic Information Vector Data Set F13D75 Jocotepec Scale 1:50,000 Series IIII*; INEGI: Aguascalientes, Mexico, 2015.
34. Inegi, Instituto Nacional de Estadística y Geografía (National Institute of Statistics and Geography, Mexico). *Geostatistical Framework. Population and Housing Census 2020*; INEGI: Aguascalientes, Mexico, 2020.
35. Imeplan, Instituto de Planeación y Gestión Metropolitana de Guadalajara (Guadalajara Metropolitan Planning and Management Institute, Mexico). *Bus Network Geometry in the Guadalajara Metropolitan Area*; Imeplan: Guadalajara, Mexico, 2018.
36. Sistema de Monitoreo Atmosférico de Jalisco. Available online: https://semadet.jalisco.gob.mx/medio-ambiente/calidad-del-aire/sitio-de-sistema-de-monitoreo-atmosferico-de-jalisco (accessed on 23 August 2021).
37. Landrigan, P.J. Air pollution and health. *Lancet Public Health* **2017**, *2*, e4–e5. [CrossRef]
38. De Quevedo García Najar, F.; Asprilla Lara, Y.; González Pérez, M.G. Entropías de la movilidad urbana en el espacio metropolitano de Guadalajara: Transporte privado y calidad del aire. *Tecnura Tecnol. Cult. Afirmando Conoc.* **2017**, *21*, 138–140. [CrossRef]
39. Zuk, M.; Tzintzun Cervantes, M.G.; Rojas Bracho, L. *Tercer Almanaque de Datos y Tendencias del Aire en Nueve Ciudades Mexicanas. Almanaque de Datos y Tendencias del Aire en Ciudades Mexicanas*; Instituto Nacional de Ecología: Mexico City, Mexico, 2007; p. 116.
40. Chen, Y.; Zhang, Y.; Coffman, D.; Mi, Z. An environmental benefit analysis of bike sharing in New York City. *Cities* **2021**, in press. [CrossRef]
41. Rojas-Rueda, D. Health impacts of urban bicycling in Mexico. *Int. J. Environ. Res. Public Health* **2021**, *18*, 2300. [CrossRef]
42. ITDP; Institute for Transportation and Development Policy Mexico; Medina Cardona, S.N.; Pérez Campos, A.B. *Ranking ciclociudades 2020. Desempeño de las Políticas de Movilidad En Bicicleta en Ciudades mexicanas*; ITDP: Mexico City, Mexico, 2021; p. 59.
43. ITDP; Institute for Transportation and Development Policy Mexico; Medina Cardona, S.N.; Pérez Campos, A.B.; Mareike Wegmann, J. *Ranking ciclociudades 2019. Desempeño de las Políticas De Movilidad en Bicicleta en Ciudades Mexicanas*; ITDP: Mexico City, Mexico, 2020; p. 62.
44. Gobierno del Estado de Jalisco (Jalisco State Government, Mexico). MiBici | Sistema de Bicicletas Públicas del AMG. Available online: https://www.mibici.net/ (accessed on 9 September 2021).
45. Vamos, J.C.; Garibaldi, F.; Rodríguez, F.; Soto, E. *Moverse en Guadalajara 2020*; Jalisco Cómo Vamos: Guadalajara, Mexico, 2020; p. 66.

46. Siteur, Sistema de Tren Eléctrico Urbano (Urban Electric Train System, Guadalajara). *BRT Ficha del Indicador 2020*; SEPLAN: Guadalajara, Mexico, 2020.
47. Siteur, Sistema de Tren Eléctrico Urbano (Urban Electric Train System, Guadalajara). BRT Mi Macro. Available online: http://www.siteur.gob.mx/index.php/sistemas-de-transporte/mi-macro (accessed on 23 August 2021).
48. Secretaría del Medio Ambiente y Desarrollo Territorial del Estado de Jalisco (Ministry of the Environment and Territorial Development of the State of Jalisco, Mexico). Datos Abiertos: Estaciones SIMAJ. Available online: https://datos.jalisco.gob.mx/dataset/bases-de-datos-historicas-de-la-calidad-del-aire/resource/5b68f6ee-b8bf-4d96-865b (accessed on 9 September 2021).
49. Gobierno del Estado de Jalisco (Jalisco State Government, Mexico). MiBici | Datos Abiertos. Available online: https://www.mibici.net/es/datos-abiertos/ (accessed on 13 September 2021).
50. SITEUR, Sistema de Tren Eléctrico Urbano. (Urban Electric Train System, Guadalajara) INFOMEX 2782021. In *Datos Técnicos de Transporte. BRT, Ingresos Totales Franja Horaria 2019*; SITEUR: Guadalajara, Mexico, 2021.
51. EPA, Environmental Protection Agency. The AQI Equation. Available online: https://forum.airnowtech.org/t/the-aqi-equation/169 (accessed on 22 September 2021).
52. Pelletier, M.-P.; Trépanier, M.; Morency, C. Smart card data use in public transit: A literature review. *Transp. Res. Part C Emerg. Technol.* **2011**, *19*, 557–568. [CrossRef]
53. Inegi, Instituto Nacional de Estadística y Geografía (National Institute of Statistics and Geography, Mexico). National Statistical Directory of Economic Units (DENUE, from Its Initials in Spanish). Available online: https://www.inegi.org.mx/app/descarga/ (accessed on 27 January 2020).
54. Rosas Gutiérrez, J.; Chías Becerril, L.; Rosas Gutiérrez, J.; Chías Becerril, L. Los BRT ¿nuevo paradigma de la movilidad urbana mundial? *Investig. Geográficas* **2020**, *103*, e60045. [CrossRef]
55. Calonge Reillo, F. Viajando por la periferia del Área Metropolitana de Guadalajara, México. Entre la pasividad y la agencia. *Cuad. Antropol. Soc.* **2019**, *50*, 67–84. [CrossRef]
56. Mora, R.; Truffello, R.; Oyarzún, G. Equity and accessibility of cycling infrastructure: An analysis of Santiago de Chile. *J. Transp. Geogr.* **2021**, *91*, 102964. [CrossRef]
57. Rosas-Satizábal, D.; Guzman, L.A.; Oviedo, D. Cycling diversity, accessibility, and equality: An analysis of cycling commuting in Bogotá. *Transp. Res. Part D Transp. Environ.* **2020**, *88*, 102562. [CrossRef]
58. Pinzón, T.M.; Arias, J.J. Contaminación vehicular en la conurbación Pereira-Dosquebradas. *Rev. Luna Azul* **2013**, *37*, 101–129.
59. Beleño Montagut, L.; Colegial Gutierrez, J.D. Análisis de la Contaminación por flujo vehicular en un entorno universitario. *Bistua Rev. Lla Fac. Cienc. Básicas* **2018**, *16*, 28–41. [CrossRef]
60. Xu, P.; Dong, N.; Wong, S.C.; Huang, H. Cyclists injured in traffic crashes in Hong Kong: A call for action. *PLoS ONE* **2019**, *14*, e0220785. [CrossRef]
61. Xu, X.; Xie, S.; Wong, S.C.; Xu, P.; Huang, H.; Pei, X. Severity of pedestrian injuries due to traffic crashes at signalized intersections in Hong Kong: A bayesian spatial logit model. *J. Adv. Transp.* **2016**, *50*, 2015–2028. [CrossRef]
62. Sun, Y.; Mobasheri, A. Utilizing crowdsourced data for studies of cycling and air pollution exposure: A case study using strava data. *Int. J. Environ. Res. Public Health* **2017**, *14*, 274. [CrossRef] [PubMed]
63. United Nations (UN). Sustainable Development Goals. Available online: https://www.un.org/sustainabledevelopment/ (accessed on 7 October 2021).
64. Figueredo, D.C.G.; Martínez, D.A.; Egurrola Hernández, E.A.; De los Reyes Corona, S.A. *Análisis de Riesgo Ante Eventos de Mala Calidad del Aire en el Área Metropolitana de Guadalajara Informe para SEMADET Jalisco*; Instituto Tecnológico y de Estudios Superiores de Occidente (ITESO): Tlaquepaque, Mexico, 2018; p. 37.
65. Leaders. The Promise of Open-Source Intelligence. *The Economist*, 7 August 2021. Available online: https://www.economist.com/leaders/2021/08/07/the-promise-of-open-source-intelligence (accessed on 8 November 2021).
66. Glaeser, E.L.; Kominers, S.D.; Luca, M.; Naik, N. Big data and big cities: The promises and limitations of improved measures of urban life. *Econ. Inq.* **2015**, *41*, 21778.
67. Ochoa-Covarrubias, G.; Molero-Melgarejo, E.; Grindlay-Moreno, A.; Falcon Meraz, J.M. Planeación y movilidad como promotores de ciudades saludables en España y México. In *Proceedings of the Fundamentos y Práctica de la Ciudad Sostenible, Actas del Congreso Iberoamericano para la Fundamentación y Práctica de la Ciudad Sostenible, Valencia, Spain, 16 November 2019*; Poyatos Sebastián, J., García Soriano, L., Baró Zarzo, J.L., Eds.; Universitat Politècnica de Valencia: Valencia, Spain, 2019; pp. 155–172.