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Health impacts of bike sharing system – A case study of Shanghai

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ABSTRACT

Background: Bike sharing systems have been promoted in many countries. Bike sharing can alleviate urban air pollution and reduce road congestion during peak hours in the morning and evening. In addition, using shared bicycles as a daily commuting tool can help users increase their daily exercise volume. This study evaluates the health effects of shared bicycle use. The evaluation of health is prospective, and we utilize current data to evaluate and analyze the health of future users. The primary health considerations for users include physical activity, PM2.5 levels, and collision rates. Physical exercise might be hindered by high concentrations of PM2.5. Thus, while riding in conditions of very high PM2.5 concentration, the pollutants taken by the traveler will hurt the body and counteract the advantages of physical exercise. This research demonstrates that cycling during periods of low or moderate PM2.5 concentrations should lead to an overall reduction premature mortality.

Data and methods: We perform a health assessment study to quantify the health risks and benefits of car trip substitution by bike trip. We collected the cycling data from Mobike shared bicycles operator in Shanghai established in August 2016. From August 1st to August 31st, 2018, there were 1,023,603 orders and 3,036,936 cycling users. During the computational analysis, we examined three factors: physical activity, PM2.5 pollution, and bicycle collision rate, and then summed the results to determine the cyclist's risk of early death. Three scenarios are created to estimate the annual expected number of deaths (increasing or reduced) due to physical activity, road traffic fatalities, and air pollution.

Results: Air pollution exposure was assessed using variations in the background fine particulate matter (PM2.5) concentration, which was 45 μg/m^3 on average in August 2016 in Shanghai. Cycling under these settings, the advantages of physical exercise exceeded the hazards posed by pollution. When PM2.5 concentrations exceed 45 μg/m^3, seven to eight people will avert early mortality for every 306,936 users. It means 23–26 per million cyclists would avoid premature death. When PM2.5 concentrations exceed 68 μg/m^3, 1 to 2 people will be significantly harmed by air pollution and 4–7 out of every million cyclists are negatively affected by high PM2.5 concentrations.

Conclusions: These results demonstrate that shared cycling can avoid premature mortality. In addition, from the perspective of urban pollution, commuters choosing bicycles instead of cars to travel can reduce urban air pollution, improve air quality, and reduce traffic jams in the morning

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and evening peaks. Further research on the co-benefits of shared bicycles would be helpful to planners.

1. Introduction

The efficiency of the transport network is a matter of concern to national and local governments, including urban planners and those tasked with lowering energy consumption in the transport sector, whether for economic or environmental reasons. Particularly, increased energy use and air pollution are subjects of global concern (Coelho and Almeida, 2015). In China, vehicle ownership has increased at a pace of 30%–40% every year (Cherry et al., 2009). Simultaneously, vehicles, buses, bicycles, motorcycles, and, more recently, electric two-wheelers (hereinafter referred to as electric bikes) have crowded urban roads. The urban planners and transportation specialists that support micro-mobility initiatives value the contributions of a number of sustainable travel alternatives, including as public transit and cycling, as cheap means of transportation to offset the negative consequences of extensive vehicle use (Bachand-Marleau et al., 2012; Shaheen et al., 2013). As a result, bike sharing systems (BSS), as one kind of shared transport option, have drawn an increasing number of participants due to the BSS's low energy consumption, enhanced public health, decreased traffic congestion, and noise reduction (Luo et al., 2019; Qiu and He, 2018). Today, there is a greater interest in shared bicycling, and efforts are being made to provide more appealing bicycles to the market, particularly via the use of more sustainable materials, with the goal of improving well-being and protecting the environment. A study by Woodcock et al. (2014) highlighted the advantages to stakeholders of switching automobile travels for bicycle journeys using BSS in London.

Bike sharing systems have garnered broad attention because to the significant physical advantages they provide to users (Lee et al., 2012; Götschi et al., 2016). The development of this system expands passengers' options and results in healthier travel. Simultaneously, scientists have examined the health advantages and dangers associated with active transportation (Xia et al., 2015). Indirectly, the absence of organized sport leads to premature sickness and death, whereas the shared bicycle system as an active mode of transportation gives possibilities for exercise (Lee et al., 2012; Rydin et al., 2012). Participating in sporting activities on a regular basis may help avoid the onset of chronic illnesses, increase physical fitness, and enhance overall quality of life (Dishman et al., 2004). According to Bauman et al. (2012) and others, working individuals may utilize their daily commute time for exercise. Using shared bicycles as a mode of transportation may help users conserve energy and decrease emissions while also increasing their regular physical activity. The shared bicycle program intends to offer a healthier method of transportation that is easy and quick, does not need particular training, and is adaptable to a broad variety of demographics (Babagoli et al., 2019). Although cycling increases the amount of activity for individuals and promotes human health (Kargarfard et al., 2011), as the human breathing rate increases while riding, riders may absorb more pollutants. This is especially true when the cyclist is in an area with high levels of air pollution, such as city centers. There the carbon monoxide from car exhaust can have a negative impact on cyclists (Marshall et al., 2009). In support of this view, research has shown prolonged exposure to carbon monoxide in healthy adults results in decreased lung function in healthy adults and may lead to more serious adverse effects (myocardial infarction) (De Hartog et al., 2010). Another study showed that even relatively short times spent in traffic may contribute significantly to daily exposures (Beckx et al., 2009a).

The purpose of this research is to examine the health advantages of individuals who ride shared bicycles in Shanghai and to determine the physical benefits of long-term use. Three criteria are used to assess health advantages or health dangers. The participants in this research are everyday users who commute to work or ride for recreation and fitness, as opposed to competitive riders. The objective of the study is to provide empirical support for shared biking, which saves commuting times, decreases urban carbon emissions, and allows for physical activity during transit time.

The remainder of the article is structured as follows: Section 2 provides an overview of the physical and health advantages of riding, the exposure and air pollution associated with cycling, and the risk associated with cycling and crashes. Section 3 details the survey area and data gathering. The methodological approach is detailed in full in Section 3.2. Section 4 contains the experimental findings and comments. Finally, Section 5 concludes the discussion.

2. Literature review

2.1. Relationship between cycling-related physical and health benefits

The scientific literature consists of numerous well-conducted studies demonstrating that those who exercise frequently have improved health advantages. They have a stronger immune system and a reduced risk of chronic illnesses and rates of various chronic diseases than sedentary individuals (Physical Activity Guidelines Advisory Committee Report, 2008). Furthermore, researchers have determined that, at least in the context of active transportation, the health benefits of exercise exceed the hazards posed by air pollution. However, for poor and middle-income countries, for vulnerable subpopulations (children, the elderly, pregnant women, and those with preexisting diseases), and for indoor air pollution, the evidence for all assessed associations is inadequate (Tainio et al., 2021). The now somewhat dated 'Global guidelines on physical activity and health' study highlights the link between various forms of sports exposure and health outcomes. According to this data, a person who exercises 150 min each week will be healthier than a sedentary person. Inactivity may contribute to the development of non-communicable illnesses. Without exercise, you may have a 25% risk of developing colon cancer and a 27% chance of developing diabetes or heart disease (Stevens et al., 2009). Additionally, physical activity is associated with a continuous dose-response association for the majority of health outcomes. In other words, each extra minute of physical activity provides more health advantages. Epidemiological studies document associations between various exposure categories or levels and health consequences. For instance, a comparison of sedentary persons to those who exceed a specified threshold of exercise (such as 150 min per week) may demonstrate that active people are healthier. However, there is a general agreement that physical activity has a continuous dose–response connection with the majority of health outcomes: that is, each increase in physical activity results in further health benefits (World Health Organization, 2010). This has also been shown in research exploring the benefits of walking or cycling (Oja et al., 2011; Hamer and Chida, 2008). Choosing to ride a shared bicycle is an attractive leisure activity for inhabitants of a city and visitors alike. Travelers may be encouraged to ride their bicycles rather than choose other modes of transportation. More importantly, cycling helps prevent cancer, cardiovascular disease, and obesity (Shaker et al., 2021). Table 1 summarizes the research on the physical and health advantages of riding.

Regular moderate-intensity physical activity contributes significantly to population fitness (Garrard et al., 2012). The American Heart Association said that those who do not exercise regularly have a significant risk of developing atherosclerotic heart disease (Physical activity guidelines advisory committee report, 2008). In certain studies of physical activity, metabolic equivalent of task (MET) is used as a proxy for physical fitness, with the lowest objective set at 500–1000 MET min/week (De Hartog et al., 2010). Almost all commuter cycling falls into the 'moderate intensity' category of exercise, with an energy expenditure of roughly 4 MET, or 5–8 times the energy expenditure at rest (De Hartog et al., 2010; Garrard et al., 2012). This level is about twice as intensive as walking and offers near-continuous activity. Oja et al. (2011) provide data on the health benefits of biking. Cross-sectional and longitudinal studies established a strong link between cycling and cardiorespiratory fitness in adolescents (Oja et al., 2011). According to Agarwal (2020), cycling for 3 h per week results in a relative risk of 0.72. In other words, riding for 3 h per week results in a 28% reduction in all-cause mortality compared to non-cyclists. According to Kelly et al. (2014), cycling has been demonstrated to reduce the risk of all-cause death in the general population. Kelly et al. (2014) uses random effects meta-analysis as a research method to explore physical benefits (all-cause mortality) in cycling populations, who are found to expend 11.25 metabolic equivalents of task hours per week as a consequence of cycling. In comparison to persons who do not ride bicycles, the risk of death from any cause will be lowered by 10%. Otero et al. (2018) conducted a health impact evaluation to determine the health benefits associated with bike sharing system rides across Europe. They examined cyclists in 12 cities and discovered that when passengers are willing to utilize shared bicycles rather than vehicles as a mode of transportation, 73.25 fatalities per year may be averted across the twelve cities.

2.2. Relationship between cycling-related exposure and air pollution

Cycling as a kind of physical exercise is beneficial to human health. Long-term exposure to locations with high levels of air pollution, on the other hand, presents a significant danger to human health. Premature mortality, respiratory disorders, and cardiovascular diseases are all examples of these (Götschi et al., 2016; Kim et al., 2015). Table 2 summarizes the research on cycling-related exposure and air pollution. Each year, almost two million individuals die as a result of damage to the lung tissues and respiratory system caused by air pollution (Shah et al., 2013). There is a positive correlation between long-term exposure to high levels of carbon monoxide, carbon dioxide, and PM2.5 in regions prone to lung cancer. This viewpoint has been substantiated by other work (Parent et al., 2013). Higher rates of inhalation and longer commutes result in higher inhaled doses among physically active commuters. Physical activity gained by active commuting outweighs the danger of an increased dosage of fine particles breathed (Cepeda et al., 2017). Tainio et al. (2016) assessed the health benefits and risks associated with commuters exposed to air pollution. When a cyclist rides for an hour and a half in an area with a PM2.5 concentration of 100 μg/m^3, the harm caused by PM2.5 inhalation to the body will exceed the benefits of cycling and exercise. The health consequences of active travel and air pollution were quantified by examining increases in all-cause mortality at various levels of active travel and air pollution. Assuming a cyclist cycles for one and a half hours per day in a region with a PM2.5 concentration of 100 μg/m3, the cyclist suffers more bodily injury than the rider gains from strenuous exercise. Sun and Mobasheri (2017) conducted a research in which they examined riding activity in Glasgow, England using Strava Metro information. Additionally, some studies found surprising impacts of air pollution exposure on human health. Cyclists who ride for recreational reasons are more exposed to the detrimental impacts of ambient air pollution than those who ride for commuting purposes. Jeroen et al. (2010) measured the all-cause death rate of passengers in the Netherlands who do daily short excursions by bicycle rather than automobile. In comparison to driving, bikers will lose between 0.8 and 40 days of life to air pollution.

It is deemed high-exposure and high-risk to select active commuting in densely populated urban regions (Karanasiou et al., 2014). Even on the same journey, cyclists inhale four to seven times the amount of particles as automobile passengers (Panis et al., 2010).

Table 1
Summary of the available studies on the physical and health benefits of cycling.

Author(s)	Year	Research focus	Parameter type	Method(s)	Application	
					Country	Type
Hamer and Chida	2008	Walking and primary prevention	Deterministic	Statistical analysis	–	Real life
Stevens	2009	Global health risks	–	Framework	–	–
De Hartog et al.	2010	Health benefits and risks of modal shift	Deterministic	Statistical analysis	–	Real life
Oja et al.	2011	Health benefits of cycling	–	Systematic review	–	–
Garrard et al.	2012	Health benefits of cycling	–	Framework	–	–
Kelly et al.	2014	All-cause mortality from walking and cycling	Deterministic	Statistical analysis	–	Real life
Agarwal	2020	Health & economic benefits of bicycle	Deterministic	Simulation model	India	Hypothetical

Table 2
Summary of the available studies on the cycling-related exposure and air pollution.

Author(s)	Year	Research focus	Parameter type	Method(s)	Application	
					Country	Type
Zhu et al.	2002	Concentration and size distribution of particles	Deterministic	Statistical analysis	USA	Real life
McNabola et al.	2008	Personal exposure to fine particulate matter	Deterministic	Statistical analysis	Ireland	Real life
Jeroen et al.	2010	The health benefits of cycling and risks	Deterministic	Statistical analysis	Netherlands	Real life
Panis et al.	2010	Exposure to particulate matter in traffic	Deterministic	Statistical analysis	Belgium	Real life
Shah et al.	2013	Global association of air pollution and heart failure	–	Systematic review	–	–
Parent et al.	2013	Traffic-related air pollution and prostate cancer risk	Deterministic	Logistic regression	Canada	Real life
Karanasiou et al.	2014	Exposure during cycling	Deterministic	Policy regulations	European cities	Real life
Kim et al.	2015	Human health impact of airborne particulate matter	–	Review	–	–
Götschi et al.	2016	Cycling as a part of daily life	–	Review	–	–
Tainio et al.	2016	The health benefits of cycling and walking	Deterministic	Statistical analysis	–	Hypothetical
Götsch et al.	2016	Cycling as a part of daily life	–	Review	–	–
Cepeda et al.	2017	Systematic review of levels of air pollution by transport mode	–	Systematic Review	–	–
Sun et al.	2017	Cycling and air pollution exposure	Deterministic	Spatial analysis	USA	Real life
Tainio et al	2021	Systematic review of air pollution, physical activity and health	–	Systematic Review	–	–
Schmitz et al	2021	Use of smart sensors to monitor pollution in newly established bike lanes in Berlin	–	Case Study	Germany	Real Life

McNabola et al. (2008) concluded that biking increases energy expenditure and respiratory rate. As a result, the rate of pollutant particle inhalation is quicker than that of automobile passengers, and the quantity of PM2.5 deposited in the rider's lung is greater. Panis et al. (2010) verified the same point of view, stating that increased physical activity while cycling results in an increase in respiration rate. Likewise, Singh et al. (2021) conducted a comprehensive evaluation of the effects of exposure to air pollution on travel behavior. Even if cyclists and motorcyclists are in the same area at the same time, the cyclist will absorb more PM2.5 due to their greater breathing rate. Consequently, it is more hazardous for bicycles. There is more TRAP ('traffic-related air pollution') caused by dust contaminated by traffic elements on bike routes near the busiest crossings, which may easily be re-suspended, putting the health of bikers and pedestrians in jeopardy. Wet sweeping should be used to remove dust from the road to prevent it from re-emerging, as well as avoid riding near busy roads (Adamiec et al., 2022). Motor vehicle emissions are a significant source of ultrafine particles with a diameter of 0.1 m in metropolitan areas. However, it is difficult to pinpoint the source of this contaminant near a major roadway (Zhu et al., 2002). As a result, visitors may opt for less polluting routes or avoid riding during busy hours (Hertel et al., 2008). In a recent case study of bicycle lanes in Berlin, Schmitz et al. (2021) demonstrate the value of low-cost smart sensors to collect localized air quality readings in order to monitor exposure on an ongoing basis; this approach promises much higher data quality if widely implemented. Saatchian et al. (2021) using structural equation modeling found that participation in the shared bicycle program had health, environmental, social, economic, and geographical benefits. Additionally, engaging in a bike-sharing program during this pandemic can help minimize viral transmission and keep users physically active.

Table 3
Summary of the available studies on the cycling and crash risk.

Author(s)	Year	Research focus	Parameter type	Method(s)	Application	
					Country	Type
Mindell et al.	2012	Assessment of road safety by travel mode	Deterministic	Statistical analysis	UK	Real life
Asbridge et al.	2014	Cycling-related crash risk	Deterministic	Statistical analysis	Canada	Real life
Vanparijs et al.	2015	Exposure measurement in bicycle safety	–	Review	–	–
Sanders	2015	Perceived traffic risk for cyclists	Deterministic	Statistical analysis	USA	Real life
Götsch et al.	2016	Cycling as a part of daily life	–	Review	–	–
Dozza et al.	2017	Bicycle crashes and risks	Deterministic	Statistical analysis	Sweden	Real life
Scholes et al.	2018	Fatality rates associated with driving and cycling	Deterministic	Statistical analysis	UK	Real life
Ewing and Dumbaugh	2019	Built environment and traffic safety	–	Review	–	–
Branion-Calles et al.	2020	Cyclist crash rates and risk factors	Deterministic	Statistical analysis	European cities	Real life
Branion-Calles et al.	2020	Cyclist crash rates and risk factors	Deterministic	Binomial regression	European cities	Real life

2.3. Relationship between cycling and crash risk

Table 3 summarizes the research on cycling and collision risk. It is critical to understand crash risk in order to enhance safety (Branion-Calles et al., 2020). The crash risk factor comprises the possibility of death, the severity of collisions, injuries, and equipment failure (Götschi et al., 2016). The built environment itself has an effect on cycling safety (Ewing and Dumbaugh, 2009). This covers the physical surroundings, as well as the movement, speed, and density of other vehicles (Vanparijs et al., 2015). In densely populated areas, bikers have a greater danger of death or collision than users of other forms of transport (Scholes et al., 2018). Mindell et al. (2012) quantified collisions based on commuter time and distance travelled. In the United Kingdom, for example, 25 bikers will die every billion kilometers, whereas 25 motorists would perish every 2.3 billion kilometers. Additionally, Dozza (2017) collected data from 11 roadside bicycle stations to assist in assessing the risk of a collision while riding. This conclusion implies that the group of night-cyclists on weekend nights is predisposed to crash modes, which might be a result of particular circumstances such as drunkenness. Similarly, Asbridge et al. discovered in 2014 that roughly 14.5% of cyclists collided as a result of alcohol intake and approximately 15% of cyclists wrecked as a result of marijuana usage in Canada. As a result, commuters who consume alcohol or marijuana may significantly increase the likelihood of crashes and the danger of non-fatal injuries when riding. Additionally, the usage of cellphones while riding a bicycle has a reflective link with collision risk, which De Hartog et al. have widely established (2010).

It is critical to record small collisions or non-injury events since focusing on these encounters may result in quantifiable economic losses. A clear example is the expense of automobile maintenance and missed travel time. Additionally, even if the incident or collision is minimal, the individual involved will have unfavorable feelings about how others view riding safety (Sanders, 2015). This might result in a drop in cycling orders, decreasing the possible health advantages of riding for people (Branion-Calles et al., 2020).

3. Research methodology

3.1. Survey area and data collection

Shanghai is the central nexus of China's finance, trade, technology and shipping, and is developing rapidly. Administratively it is an autonomous municipality of China (Mou et al., 2020). The population of Shanghai is on the rise, and commuting time and commuting tools have become the focus of attention (Zhang et al., 2018; Lyu et al., 2020). We collected the cycling data form Mobike shared

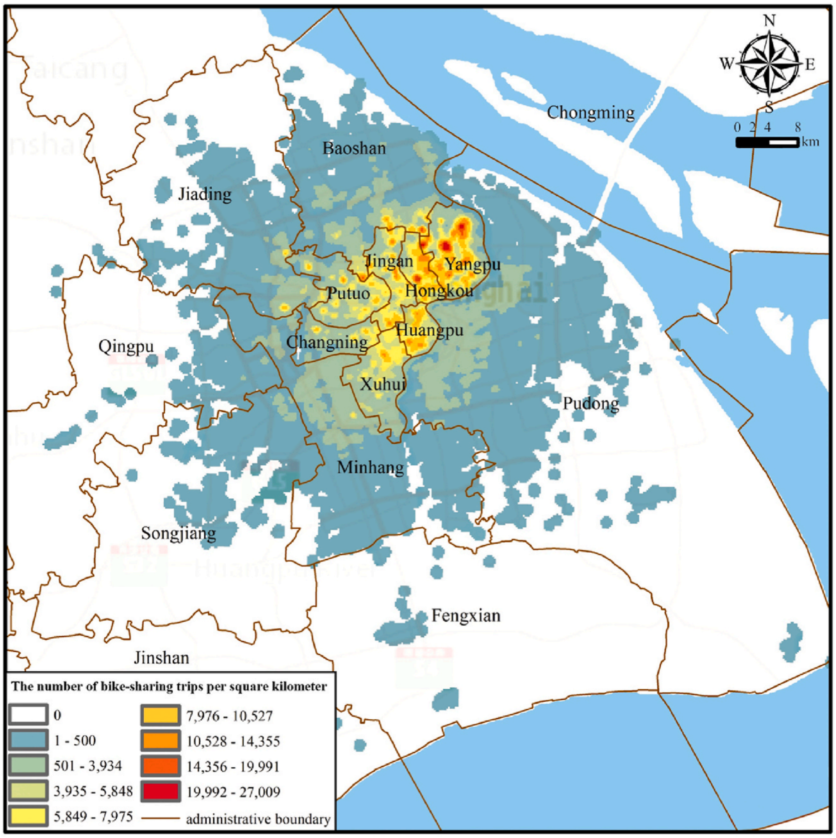

Fig. 1. The destinations of bike sharing system trips.
(a) Travel distribution in morning peak (b) Travel distribution in evening peak.

bicycles operator in Shanghai in August 2016. From August 1st to August 31st, 2018, there were 1,023,603 orders and 306,936 cycling users. The number of trips makes a difference in terms of health advantages. However, the number of travelers that take five, ten, or even fifteen trips every week is small. For this reason, the fewer orders that fulfil the standards for physical activity, the less the health benefit. The raw data contains information on a user's single or numerous riding orders, which we arrange and summaries. Each week, the median number of ride trips taken by users is 2, the average number of ride trips taken by individuals is 2.6, and the modal number of ride trips taken by businesses is 2. The order includes basic information about the trip, order number, user number, bicycle number, travel time, and the latitude and longitude of the start and end of the trip. According to the original data, the shared bicycle system is used at a high frequency in the city center (see Fig. 1), for instance, near subway stations, shopping malls, large companies. Form the travelling time, some users are hiring sharing bikes to take short trips. They may use shared bicycles for shopping trips instead of daily commuting. Users have many different purposes for using shared bicycles. In addition, according to the data, the morning peak hours of attendance are 7am–8 am, and the evening peak hours are 5pm–6 pm. As a result, we demonstrate the use of bicycle stations throughout the morning and evening peak hours in Fig. 2(a) and (b) (b). We get the cyclist's driving trajectory based on the data, and from the cyclist's driving trajectory, we can determine the traveler's driving route and range of activities. It is self-evident that morning and evening travel hours are distinct, as are driving routes and bicycle parking places. As can be observed, commuters commonly utilize the shared bicycles in the Yangpu, Jing'an and Hongkou districts during the morning rush hour. These three regions constitute Shanghai's core business district and are also the primary places for the headquarters of huge corporations. During the nighttime rush hours, visitors regularly use shared bicycles in various retail districts of Shanghai. For instance, the districts of Huangpu and Xuhui are popular due to the fact that these two districts are home to numerous huge retail malls and amusement parks. The Huangpu area, in particular, is adjacent to well-known tourist attractions like as the Bund, and the public may ride shared bicycles in a larger range at night.

3.1.1. The analysis of sample data

August 1st to August 31st, 2016, the cycling data form Mobike shared bicycles operator in Shanghai in August 2016 was analyzed using a geographic information system (GIS)-based inverse distance weighting (IDW) method, and some statistical analysis. This data includes 976,547 orders (306,936users). First of all, the density map of the starting and ending points of the bike sharing stations of 65535 orders taken from this data is shown in Fig. 3(a) and (b) which are starting/ending in the focused region. The density map of bike sharing use in terms of duration (minutes) is shown in Fig. 3(c).

Geographic information system (GIS) is used for density mapping. One of the most widely used deterministic models in spatial interpolation is the inverse distance weighting (IDW) method (Johnston et al., 2001) as defined in Eqs. (1)–(3).

$$\partial(x,y)=\sum_{i=1}^{m}\omega_i\vartheta_i \tag{1}$$

where m is the number of scatter points in the set, ω_i is the weight, and ϑ_i is the function values in the dataset values. The classical form of the weight function is given by:

$$\omega_i=\frac{\beta_i^{-n}}{\sum_{j=1}^{m}\beta_j^{-n}} \tag{2}$$

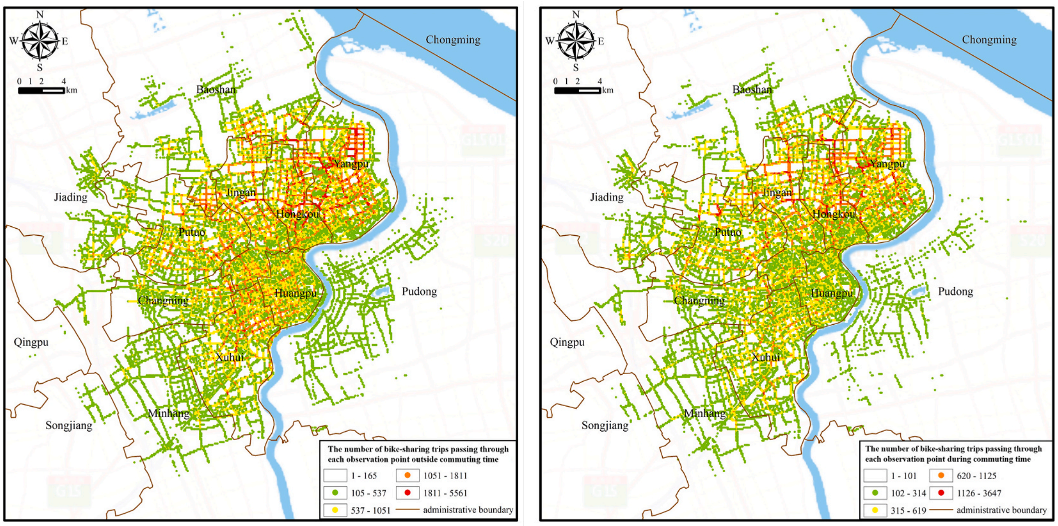

Fig. 2. Travel distribution.

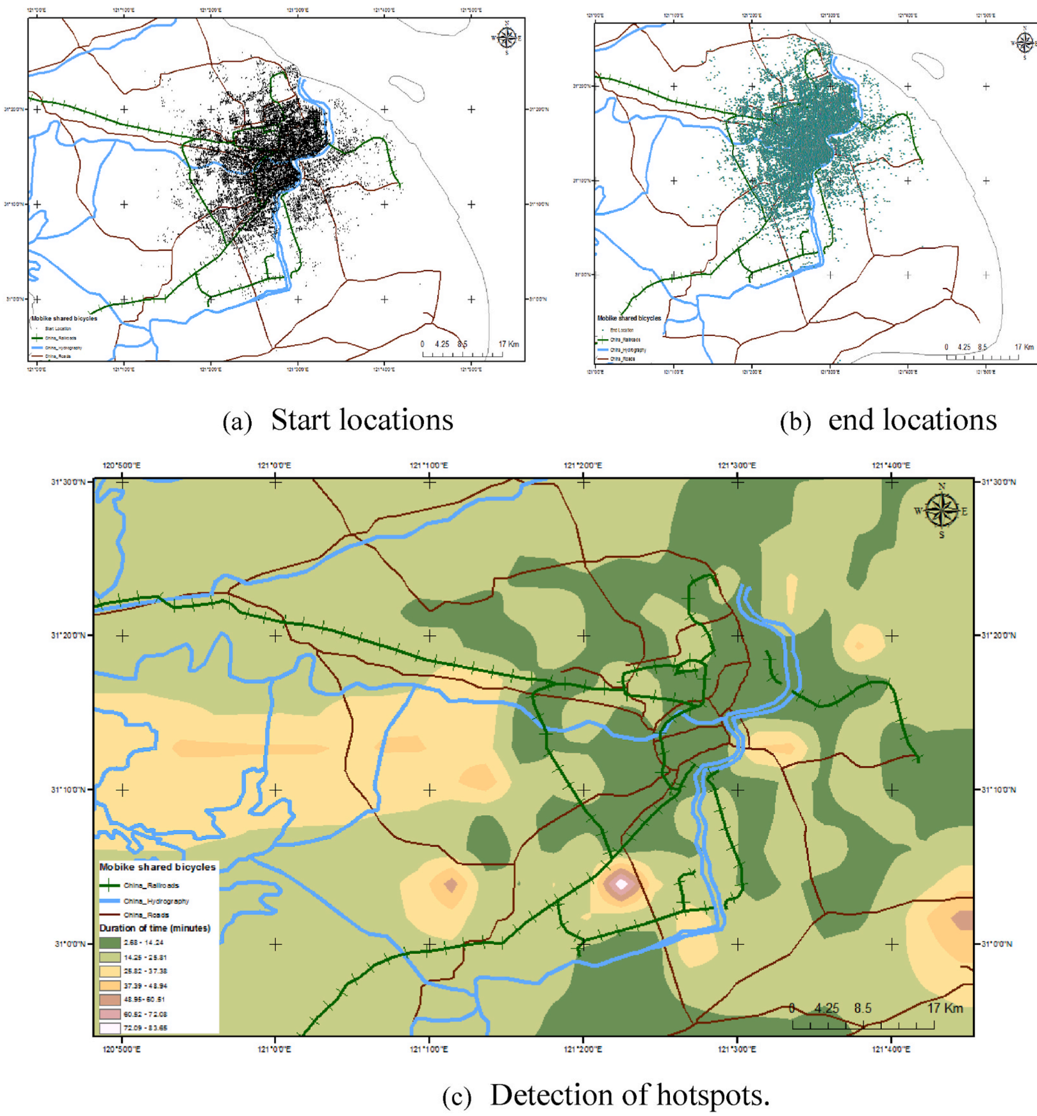

Fig. 3. Density mapping and hotspots.

where n is a positive real number, and β_i is the distance from the scatter point to the interpolation point or:

$$\varphi_i = \sqrt{(x - x_i)^2 + (y - y_i)^2} \tag{3}$$

where φ represents distance between two points, and x and y are the coordinates of the interpolation point.

3.2. Methodology

This research examines the three components of the health benefits of bike sharing systems. To begin, we use a nonlinear analysis as our computational mode. In order to minimize the number of assumptions we needed to make about user behavior, we adopted the most parsimonious modelling approach available rather than the most comprehensive. ITHIM is a collection of models and tools created by CEDAR to undertake an integrated evaluation of the health consequences of urban and national transport scenarios and policies. In this research, however, we used the WHO HEAT to isolate the health advantages that individuals get from choosing bicycles over other forms of transportation. Comparing bike sharing to other forms of public transportation reveals these health advantages. Second, we split the data during processing, analyzing it in two distinct contexts. When the driving distance is less than or equal to 1 km, we assume cycling rather than walking; when the driving distance is higher than 1 km, we assume cycling rather than automobiles. Third, our computational model is capable of calculating regions with elevated PM2.5 concentrations, while the WHO HEAT model calculates areas with PM2.5 concentrations less than 40 μg/m^3. The predicted health outcome was the anticipated yearly number of deaths (increased or averted) as a result of physical activity, road traffic fatalities, and air pollution (particulate matter 2.5 m (PM2.5)) as a result of automobile journeys replacing BSS excursions (see Fig. 4). According to Joachim et al. (2010), when the trip is around 1 km, the majority of commuters are willing to utilize shared bicycles and other modes of transportation (public and private vehicles). When the journey is shorter than 1 km, people choose to stroll. As a result, during the data screening process, we compute user data for users with a driving distance higher than or equivalent to 1 km. Additionally, we examined the study findings showing people prefer to bicycle rather than walk when the distance is less than 1 km.

3.2.1. Scenario one: distance > 1 km

3.2.1.1. Physical benefits. According to Matthews et al. (2007), the metabolic equivalent (MET) level of cycling is 4 MET. Metabolic Equivalent Task (MET) has been used as an indication of activity in several studies, with a minimum aim of 500-1000 MET minutes per week set. Cycling at a leisurely pace of 15 km per hour has a moderate MET value of 4 (Ainsworth et al., 2000). Taking an automobile is assumed to be 1 MET as passengers remain stationary. For any piece of bike usage data generated routinely by user i, it includes the cycling duration t_i and distance travelled d_i. Thus, MET-hours/day is given by $4 * \widehat{t_i^{bike}}$, where $\widehat{t_i^{bike}}$ is the average time travelled with Mobike by the same user per day. By checking it with the results from Matthews et al. (2007), we could then obtain the improved all Hazard Ratio (HR) of user i, $HR_i^{physical\_bike}$. Comparatively, imagine if the same user has chosen to travel by automobile, we then calculate the MET-hours/day as $1 * \widehat{t_i^{bike}}$ since the user could have remained idle for the same distance to be travelled. Looking up under the non-exercise category, we then obtain $HR_i^{physical\_auto}$. Health benefit $HB_{physical\_auto}$ brought by switching is defined Eqs. (4) and (5).

$$\frac{n^e}{s^e} = \frac{n^c}{c^s} \bullet HR \tag{4}$$

$$HB_{physical\_auto} = \sum \left(HR_i^{physical_{bike}} - HR_i^{physical_{auto}} \right) \forall i \tag{5}$$

Where n^e is the number of deaths in exposed group, s^e is the sample size of exposure group. n^c means the number of deaths in the control group and c^s is used to signify the number of control group sample size.

(1) Air pollution risk

$$C^{simu\_bike} = \frac{t^b \bullet r^b \bullet c^o + (24\ hrs - t^b) \bullet r^i \bullet c^i}{v} \tag{6}$$

Where t^b is cycling time, r^b is the air inhaled while riding, c^o is the average outdoor PM2.5 concentration of Shanghai. c^i is the average

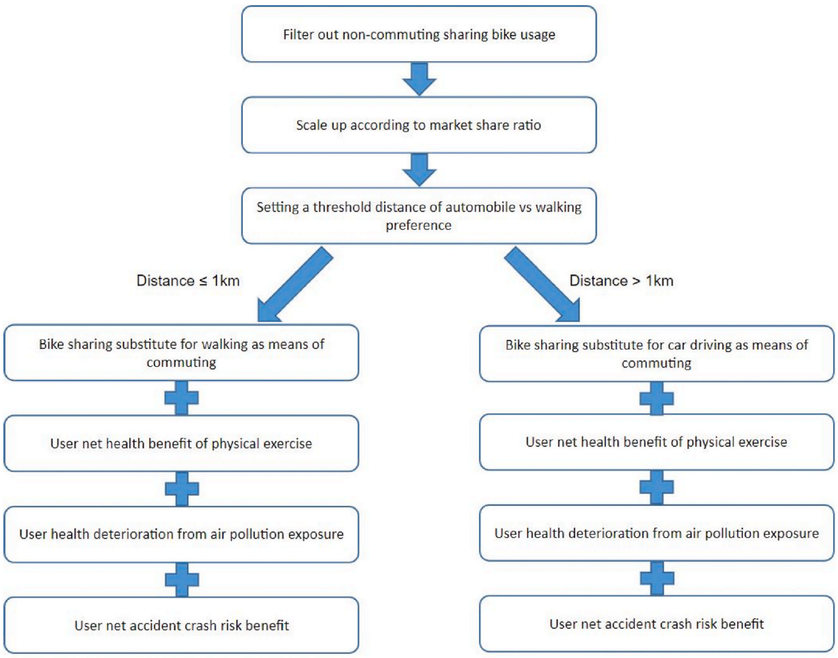

Fig. 4. Conceptual framework of bike sharing systems and health.

indoor PM2.5 concentration. v is the standardized basic air volume inhaled. Having c^{simu}, we could look at Apte et al. (2015) to obtain the relative risk (RR) of the simulated surrounding PM2.5 concentration. Recalling that

$$HR_{c^{simu\_bike}} = RR \bullet HR_{c_{ref}}$$

For the case of one user, active volume is 1. Hence, we can reversely derive $HR_{c^{simu\_bike}}$ for user i. Similarly, we can derive $HR_{c^{simu\_auto}}$.

$$c^{simu\_auto} = \frac{\left(24\ hrs - t_i^{auto}\right) \bullet r^{idle} \bullet c^{indoor}}{v}$$

Hence the net total health benefit HB_{expo_auto} is given in Eq. (7).

$$HB_{expo\_auto} = \sum HR_i^{expo\_bike} - HR_i^{expo\_auto} \forall i \tag{7}$$

(2) Crash risk

$$HR_{crash\_bike} = \frac{c^r}{c^p}$$

$$HR_{crash\_auto} = \frac{a^r}{a^p}$$

Assuming that c^r represents the cycling crash mortality risk and c^p is the cycling active population. Where a^r is the auto crash mortality, a^p is the auto active population. Hazard ratio of car crash of automobile passengers. Let the number of total users in the data set be N. HB_{crash_auto} is defined in Eq. (8).

$$HB_{crash\_auto} = \left(HR^{crash\_bike} - HR^{crash\_auto}\right) \tag{8}$$

3.2.2. *Scenario one: distance $\leq$ 1 km*

3.2.2.1. Physical benefit. MET-hours/day is given by $4 * \widehat{t_i^{bike}}$, where $\widehat{t_i^{bike}}$ is the average time travelled with Mobike by the same user per day. By checking it with the results from Matthews et al. (2007), it could then obtain the improved all Hazard Ratio (HR) of user i, $HR_i^{physical\_bike}$. Comparatively, imagine if the same user has chosen to travel by feet, we then calculate the MET-hours/day as $3.3 * \widehat{t_i^{walk}}$. t_i^{walk} is given by

$$t_i^{walk} = \frac{d_i}{s^{walk}}$$

$$\frac{n^e}{s^e} = \frac{n^c}{c^s} \bullet HR$$

s^{walk} is the average walking speed of an adult. Looking up under the walking category, then obtain $HR_i^{physical\_walk}$. Health benefit $HB_{physical\_walk}$ brought by switching is defined in Eq. (9).

$$HB_{physical\_walk} = \sum HR_i^{physical\_bike} - HR_i^{physical\_walk} \forall i \tag{9}$$

(1) Air pollution exposure

$HR_{c^{simu\_bike}}$ for user i have been calculated in the previous section. Similarly, the simulated PM2.5 concentration of walking is given as

$$c^{simu\_bike} = \frac{t_i^{bike} * r^{bike} * c^{outdoor} + \left(24\ hrs - t_i^{bi\ ke}\right) * r^{idle} * c^{indoor}}{V}$$

$$c^{simu\_walk} = \frac{t^w * r^{walk} * c^{outdoor} + (24\ hrs - t^w) * r^{idle} * c^{indoor}}{V}$$

$$RR = \frac{HR_{c^{simu\_walk}}}{HR_{c_{ref}}}$$

Similarly, Where t^w is walking time, r^{bw} is the air inhaled while walking. Same as the method used previously, we can derive $HR_i^{expo\_walk}$. Hence the net total health benefit HB_{expo_auto} is defined in Eq. (10).

$$HB_{expo\_walk} = \sum HR_i^{expo\_bike} - HR_i^{expo\_walk} \forall i \tag{10}$$

(2) Crash risk

$$HR_{crash\_bike} = \frac{w^r}{w^p} \tag{11}$$

$$HB_{crash\_walk} = \left(HR^{crash\_bike} - HR^{crash\_walk}\right) \tag{12}$$

By comparing the collision rate of walking, we can get the collision rate of riding. Assuming that w^r represents the walking crash mortality risk and w^p is the walking active population. HB_{crash_walk} is defined by Eqs. (11) and (12).

4. Results and discussion

When the journey distance exceeds 1 km, the health benefit is around 7.7. The health benefit increases by around 0.18 when the trip distance was less than 1 km. Thus, we sum the two values to get the final result. According to the original survey data, the median riding time of each cyclist in a month is 12 min. When commuters use shared bicycles when the outdoor PM2.5 concentration is 45 μg/m^3, around 7 to 8 people will avoid premature death (306,936 users in total). When PM2.5 concentrations reach 55 μg/m3, about 4–5 individuals will avoid early mortality. If the PM2.5 concentration is 65 μg/m3, around 1 person will not die prematurely. We also discovered users who had cycled only once in the original data. This might occur because the user want to try out shared bicycle riding. Exercise for a short period of time or for a tiny quantity offers minimal health benefit. Three other scenarios were presented. First, we examine the user's health benefits, assuming that the user cycles around five times per month. When the number of trips is increased to five or more, three to four persons may avoid dying prematurely. In the second situation, when the health advantages of commuters who ride around 10 times a month are considered, one of them will escape the chance of dying prematurely. Finally, we adjusted the number of rides to a value close to ten. The overall number of riders falls as the number of rides increases. As a consequence, 0.48 riders will escape the chance of dying prematurely (see Table 4).

When PM2.5 concentrations increase, the positive impacts of physical exercise are cancelled out by the harmful consequences of air pollution. Consequently, we questioned how much PM2.5 might have an adverse effect on the rider. We thus compute PM2.5 to be 45 μg/m^3, 46 μg/m^3, 47 μg/m^3 … 68 μg/m^3. We discovered that when PM2.5 levels hit 68 μg/m^3, there would be adverse impacts because the damage caused by air pollution has outweighed the health advantages of riding. By treating PM2.5 as a variable, unambiguous results may be derived. In comparison to the rate at which bicycles collide with other vehicles, air pollution is more hazardous to riders. Additionally, when outdoor PM2.5 concentrations exceed 68 μg/m^3, the amount of PM2.5 breathed by riders is greater than that of the driving populace, owing to the quicker breathing rate associated with cycling. Thus, as comparison with those who drive, the absence of protective shells for cyclists increases the risk of mortality from air pollution when riding a bicycle.

We discovered that when the number of monthly trips increases, the number of eligible users decreases proportionately. According to raw order statistics, the majority of users ride once or twice each week. The number of riders making 3, 4, 5, or even 10 trips each week fell. Therefore, whether we pick 3, 4, or 5 rides each week, the number of people who may match the requirements is restricted, and a restricted number of individuals will have a restricted health effect. In another word, the number of persons who benefit from riding will decline. The purpose of this research is to determine the health advantages of travelling by bicycle rather than vehicle. Cycling is a mode of transportation that may be used to maximize health advantages. In addition, using shared bicycles instead of cars can also reduce sound pollution and air pollution, and reduce traffic collisions. This variability in the health impacts of the same amount of bikes can be explained because each BSS has a different usability ratio (number of daily trips per bike), different trip duration, traffic safety and air quality. If local governments attempt to improve those elements (bike usability, traffic safety, and air quality), the health advantages of present BSSs may be enhanced.

Three factors are used to assess the health advantages of riding. To begin, physical activity benefits human health. Physical activity can avoid cardiovascular disease, diabetes, some malignancies, and death (Rydin et al., 2012). This research considered just all-cause mortality (as a result of physical activity, air pollution, and traffic events) as a health outcome since it was predicted to have the greatest health and economic consequences (Rydin et al., 2012). As can be seen from the data above, cycling may have beneficial effects on the body. Although PM2.5 and automobile collisions may have a detrimental effect on cycling, these effects are minor unless PM2.5 levels are very high.

To assist planners in evaluating the optimal transport mix, this research examined the effect of shared bicycles on human health by examining urban air pollution levels and traffic collisions, as well as the quantity of exercise performed on shared bicycles. According to this research, a 40 percent increase in on-road air pollution exposure each trip for cyclists is anticipated to reduce the benefits of bike

Table 4
The results of the three calculations.

Number of rides	Riding distance (km)	Physical benefit	Air pollution	Crash risk	Health benefits (scenario breakdown and total)	
1	≤1	−9.19	1.57	−0.000013	−7.62	−7.76
1	>1	−0.31	0.17	−0.000018	−0.14	
5	≤1	−3.2	1.03	−0.000012	−2.17	−2.24
5	>1	−0.09	0.017	−1.72E-05	−0.073	
10	≤1	−1.06	0.08	−0.000041	−0.98	0.99
10	>1	−0.012	0.009	−0.000017	−0.019	
15	≤1	−0.57	0.081	−0.000039	−0.48	−0.48
15	>1	−0.04	0.0046	−0.000016	−0.0024	

sharing (Agarwal, 2020). In addition, cyclists are especially susceptible to high breathing rates and close proximity to the road, both of which have an impact on their health. Reduced driving hours are anticipated to lower the exposure of the human body to PM2.5 Singh et al. (2021). The conclusion is self-evident. In comparison to sedentary persons or those who exercise seldom, active transportation may provide significant health advantages to commuters, which are greater if automobile use declines.

It is widely established that prolonged exposure to locations with high levels of air pollution has a detrimental effect on the human body. The primary reason for the elevated level of urban air pollution is the increased number of motor vehicles; even inside, the phenomena of pollutant concentrations above the norm will occur. Urban pollutants come in a variety of forms, including NO, NO_2, CO_2, and others. The greater the air pollution index, the worse the rider's health. Cyclists have the option of travelling at off-peak hours or via a side route off the main road. These two strategies may help minimize exposure risk. Additionally, municipal planners must develop a reasonable bicycle network infrastructure. For instance, separating motor vehicle lanes from bicycle lanes and growing green vegetation next to the cycling lanes may help absorb some of the exhaust gas and air pollutants released by automobiles. When urban concentrations vary, the degree of injury to the human body varies. As a consequence, the variation in trip duration results in varying PM2.5 concentrations breathed by riders, resulting in varying health advantages. Air pollution is a hazard for cyclists in metropolitan environments, however the effect is usually negligible in comparison to the health advantages unless air pollution levels are very high.

Finally, we analyze the chance of cyclists dying in traffic collisions in our research. There are several factors that contribute to cyclists' traffic collisions, the most of which are related to their riding technique, route, surrounding environment, and fundamental transit services. Due to the preservation of the original data, the information we got does not include the rider's age. As a result, no correlation between road collisions and age or gender has been shown. As is the case with any risk assessments, our research was constrained by a lack of data and the requirement of making assumptions in order to predict plausible situations. In terms of the scenarios considered, a conservative scenario was developed using data from trip surveys and an understanding of the present car-bike replacement rate among bike sharing program participants. To demonstrate the system's true potential for health improvement. This is especially relevant given that shared bikes already exist in those cities, and if additional actions were taken to promote car-bike substitution (via media campaigns, education, economic incentives, and improvements to urban infrastructure and transportation planning), shared bikes could achieve even greater health and economic benefits.

5. Conclusion

This research has three limitations. The most important is that we could not undertake PM2.5 detection on particular streets in Shanghai owing to equipment constraints. We calculated the average PM2.5 concentration in Shanghai in August. Second, if we were to conduct the study with more recent data, we would need to investigate other micro-mobility modes of transportation in order to bolster the study findings. For instance, passengers may choose shared bicycles rather than public transportation such as automobiles or subways, or they may choose e-scooters for short trips. Lastly, in our data set, we could determine the distance travelled from the raw data, but we did not map the actual routes taken. However, the actual driving distance is more than the distance in a straight line. Therefore, in the future, we can determine the true distance by exploring the riding paths of users. Greater use of low-cost sensors in cities to monitor air pollution along bicycle lanes coupled with enhanced data collection by bike sharing firms will allow refinement of the research.

This study focuses on the health benefits of shared bicycle excursions rather than automobile trips. At a PM2.5 concentration of 45 $\mu g/m^3$, 7–8 others will benefit from the traveler's health. When PM2.5 concentrations reach 55 $\mu g/m^3$, about 4–5 individuals will prevent early mortality. If the PM2.5 concentration is 65 $\mu g/m^3$, around 1 person will not die prematurely. We predicted that when the PM2.5 concentration reached 68 $\mu g/m^3$, 1 or 2 premature deaths would be prevented. Consequently, when the outside PM2.5 concentration is greater, the danger to bikers increases, despite the fact that the damage caused by bicycle collision rates is far less than the harm caused by pollutants. This study may help planners frame more effective campaigns. If the long-term health advantages of riding are objectively portrayed, more travelers will be motivated to join shared bicycle programs because they recognize they are helping themselves as well as their communities.

In comparison to other modes of transportation, travelling through bike sharing system provides higher health advantages. The findings demonstrate that when cycling is made more accessible to the public, it may help prevent premature death. We evaluated the health advantages of cycling under three scenarios in this research (physical activity, pollution risk, and collision risk). While increased physical activity benefits bikers, cycling in places with high pollution levels (PM2.5) is risky. Additionally, although the likelihood of a cyclist being killed in a collision with another vehicle is remote, the danger of collision cannot be overlooked. Additionally, commuters who choose bicycles over vehicles may help decrease urban air pollution, enhance air quality, and alleviate traffic congestion during morning and evening rush hours. This approach recognizes that people who are already physically active will experience less benefit than those who are more sedentary. This nonlinear method resulted in a more realistic evaluation of the health benefits associated with physical exercise than a linear model gives.

Commuting on communal bicycles will encourage commuters to make the most of their time for physical activity. In comparison to the advantages of physical health, the dangers associated with air pollution and collisions have a smaller influence on health. From a public health standpoint, sharing bicycles should be encouraged. When green travel becomes the preferred mode of transportation for travelers, urban air quality and traveler health will improve significantly. If users continue their riding habits, the advantages to their own health will rise. Fostering the growth of shared bicycle program should involve collaborative efforts from a variety of stakeholders, including health insurers and national health systems.

Although crashes have a negligible harmful effect, they will have a psychological influence on the victims since they will be aware that there is a danger associated with riding. As a result, city planners should establish networks of dedicated bike lanes and optimize the allocation of urban traffic lanes. Bike sharing is not a panacea, as not all users can access it and not all trips can be taken that way. Stakeholders should thus actively encourage green modes of transportation and lessen overall reliance on motor vehicles. Reduced urban air pollution benefits not just passengers, but also the whole urban population.

There are still several unresolved questions about the study on the health consequences of shared bicycle program on users. Cyclists' speed and intensity of riding, as well as the specific design of streets, topography, and traffic flow, all have an effect on fluctuations in air pollution concentrations. A more in-depth examination of the effect of basic transportation infrastructure on population health would be enabled by sensors that collect air pollution levels on a more granulated basis. Additionally, the ease and safety of shared bicycles continue to be a priority. This study lays the groundwork for future research on green modes of transportation and public health. Additionally, our findings may be utilized to aid in the creation of future bike sharing schemes. We have provided suggestions for planners, operators of shared bicycles, and community health organizations.

Author statement

YC – Conceptualisation, Data Curation, Formal Analysis, Investigation, Writing (original draft), Writing (review and editing).
KH – Conceptualisation, Formal Analysis, Methodology, Investigation, Validation, Writing (review and editing).
MD - Investigation, Writing (review and editing).
DC – Supervision, Investigation, Writing (review and editing), Resources

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Data availability

Data will be made available on request.

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