Research article

Association between meteorological factors and elderly falls in injury surveillance from 2014 to 2018 in Guangzhou, China

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HIGHLIGHTS

- Association of elderly falls injury cases and meteorological variables was studied.
- Falls are the primary cause of injury among elderly people in Guangzhou.
- Monthly mean wind speed is associated with monthly elderly falls injuries.
- Monthly mean atmospheric pressure is associated with monthly elderly falls injuries.

GRAPHICAL ABSTRACT
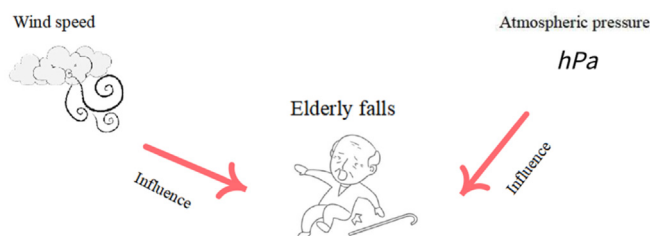
ARTICLE INFO

ABSTRACT

Introduction: With rapid increase in the aging population, falls injuries have become an important public health problem. However, limited data have been reported on the associations between meteorological factors and falls injuries in the elderly. This study assessed the epidemiology of falls injuries and explored this association in the elderly in Guangzhou, China.

Methods: Data on elderly falls injury cases and meteorological variables from 2014 to 2018 in Guangzhou were collected from the Guangzhou Injury Monitoring System and Guangzhou Meteorological Bureau, respectively. The monthly average data on falls injuries and meteorological factors were applied to the data analysis. These correlations were conducted using Pearson correlation analysis. A multiple linear regression model was used to estimate the effects of meteorological factors on falls injuries in the elderly in Guangzhou, China.

Results: Accounting for 49.41% of causes of elderly injury were falls in the Guangzhou Injury Monitoring System from 2014 to 2018, which occupied first place for five consecutive years. The monthly number of elderly falls injury cases was lowest in April and highest in December, and had a positive correlation with monthly mean wind speed ($r = 0.187$, $P < 0.01$) and a negative correlation with monthly atmospheric pressure ($r = -0.142$, $P < 0.05$). A multiple linear regression model was constructed ($F = 10.176$, $P < 0.01$), which explained 23.7% of the

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variances ($R^2 = 0.237$). Monthly mean wind speed ($\beta = 76.85$, $P < 0.01$) and monthly mean atmospheric pressure ($\beta = -3.162$, $P < 0.01$) were independent factors affecting monthly elderly falls injuries.

Conclusions: Falls are the primary cause of injury among elderly people in Guangzhou, China. Meteorological factors are related to falls injuries in the elderly population. Decreasing activity during high wind and low atmospheric pressure weather may help reduce the number of elderly falls injury cases.

1. Introduction

Data from the seventh national Chinese census showed that the elderly population aged ≥60 years reached 264 million by the end of 2020, accounting for 18.7% of the total population (The National Bureau of Statistics. Interpretation of the Communique of the Seventh National Census, 2021). It is predicted that by 2050, China's population >60 years of age will reach 498 million (Zhang et al., 2021). With a rapidly growing elderly population, falls injury has become an important public health problem that seriously threatens the health of the elderly. Falls are defined as a person descending because of the force of gravity and striking a surface at the same or lower level (CDC, 2004). Falls not only reduce the quality of life, but also increase the economic burden on families and society (Bjerk et al., 2017; Zhang and Zhang, 2016). According to the World Health Organization, there were 28%–35% of elderly people suffering injuries annually. At least 20 million elderly people falls every year in China, with medical expenses of more than 5 billion RMB and social costs of RMB 16–80 billion (Zhang and Zhang, 2016). Falls are the leading cause of death among the elderly people (China Death Surveillance Dataset in 2020, 2021). The China Death Surveillance Data of 2020 showed that the injury mortality rate of the elderly (≥65 years) was 163.90/10 million; the death rate caused by accidental falls was 69.41/10 million, representing the most common cause of death in the elderly (China Death Surveillance Dataset in 2020, 2021). The number of fatal falls increases sharply with increasing age (Hemenway and Colditz, 1990; Stevens et al., 2007). Therefore, falls are an important public health issue that requires more studies to fully understand falls and their risk factors.

These risk factors for elderly falls injury cases (EFIC) can be classified as either intrinsic or extrinsic factors. Intrinsic factors depend on individual characteristics such as age, physical resilience, and risk-taking behavior. Many studies have shown that the occurrence of falls increases with age (Mondor et al., 2015; Vikman et al., 2011). Frailty is also associated with falls in the elderly because the risk of frailty increases with age due to a gradual decreases in functional capacity and increases in functional dependence (Nguyen et al., 2019). Falls are more likely to be associated with muscle weakness, balance disturbances, and geriatric syndromes including depression, cognitive impairment, polypharmacy, orthostatic hypotension, gait abnormality, sensory impairment, and social isolation (Inouye et al., 2007; López-Soto et al., 2016; Mertz et al., 2010). Extrinsic factors, such as environmental characteristics, are also important risk factors for elderly falls injury cases (Gyllencreutz et al., 2015; You et al., 2001).

Meteorological factors are important environmental factors. Seasonality is considered to be one of the important factors influencing falls. Most studies have found that the prevalence of falls is significantly higher in winter and autumn. This was also the case in subtropical regions, such as Taiwan (Lin et al., 2015) and Hong Kong (Yeung et al., 2011). However, other studies have found that the prevalence of fall-related injuries did not differ seasonally (Bergström et al., 2008; Mondor et al., 2015). Findings indicating seasonal differences in falls remain controversial. Interestingly, this also exists with regard to temperature, as the impact of temperature on falls remains unclear, and the published evidence is inconsistent. For example, some studies have noted a significant negative association between falls and temperature (Modarres et al., 2012; Morency et al., 2012), contrary to other studies that did not report any significant association (Driedger et al., 2016). Although numerous studies have focused on the risk factors for falls,

few have investigated the meteorological factors affecting falls among elderly people in China.

Based on the findings presented above, we hypothesized that there may be a relationship between meteorological factors and falls in the elderly. Therefore, we aimed to assess the epidemiology of falls injuries and explore the associations between falls injuries and meteorological factors in the elderly in Guangzhou, China.

2. Methods

2.1. Study design

This study consisted of a retrospective review of falls injuries among the elderly and their relationship with meteorological factors between 2014 and 2018 in Guangzhou, China. Fall-related injury data were obtained from the Guangzhou Injury Monitoring System and meteorological data were obtained from the Guangzhou Meteorological Bureau. Guangzhou is the capital of Guangdong Province, located in southern China. It has a total area of 7434.40 km^2, with 18.87 million inhabitants. Guangzhou is situated in the southern subtropical zone and has a typical southern subtropical monsoonal ocean climate. Due to the topography of the location, the marine climate characteristics are particularly significant, with warm and rainy weather, sufficient sunshine, small temperature differences, and long summers.

2.2. Data source

Guangzhou Injury Monitoring System.

2.2.1. Fall-related injury data

According to the National Injury Monitoring Program, Guangzhou established an injury monitoring system in 2014, and by the end of 2019, five sentinel hospitals joined this system. All injury cases of the first visit to the sentinel hospital and diagnosis of injury are reported to the Guangzhou Injury Monitoring System. The reports include general information about patients, basic information about injury events, and clinical injury information (Duan et al., 2015). In this study, the data were from elderly patients (≥60 years old) diagnosed with falls injury in cases reported by the Guangzhou Injury Monitoring System between January 1, 2014, and December 31, 2018.

A three-level supervision system was established to ensure the quality of the monitoring data. The administrative departments of city-level, county-level, and sentinel hospital levels conducted on-site supervision on the monitoring of sentinel hospitals, semi-annually, quarterly, and monthly, respectively. Supervision projects include false and missing report rates (5% and 10% respectively) (Lin et al., 2020). False report rates were <5% and missing report rates were <10% between 2014 and 2018 in Guangzhou, China.

Falls were defined as events that resulted in a person coming to rest inadvertently on the ground, floor, or other lower level (Peng et al., 2019). Monthly falls injury cases were included in the data analysis.

2.2.2. Meteorological data

Meteorological data were obtained from the Guangzhou Meteorological Bureau from January 1, 2014, to December 31, 2018, collected by the Guangzhou Ground Meteorological Observatory. The data included the mean temperature, diurnal temperate range, wind speed, rainfall, mean relative humidity, atmospheric pressure, and sunshine hours.

Weather data were measured at a fixed-site station located in the central district of Guangzhou. Monthly average meteorological data were applied to the data analysis in this study.

2.3. Ethics statement

Ethical approval for this study was obtained from the Ethics Committee of the Center for Disease Control and Prevention of Guangzhou.

2.4. Data analyses

Data were exported from the Guangzhou Injury Monitoring System, followed by statistical analysis using R 4.0.0 and SPSS 21.0 (SPSS Inc., Chicago, IL). A descriptive analysis was applied to analyze the monthly trends and characteristics of elderly falls injury cases and various meteorological factors from 2014 to 2018. Correlation analysis was conducted between the monthly mean number of elderly falls injury cases and monthly mean meteorological factors using Pearson correlation analysis. A multiple linear regression model was established to assess the association between monthly EFIC and meteorological factors. Statistical significance was set at $p \leq 0.05$.

3. Results

From January 1, 2014, to December 31, 2018, a total of 19,234 elderly injury cases were reported in the Guangzhou Injury Monitoring System, and 9,503 (49.41%) cases were elderly falls injury cases. Meanwhile, falls injuries were the primary cause of injury in the elderly in five consecutive years (Table 1). The monthly number of elderly falls injury cases was lowest in April and highest in December (Figure 1). December was the peak period for female patients, whereas male patients had the highest incidence in September.

From 2014 to 2018, the mean monthly number of elderly falls injuries was 158.38 cases, and they ranged from 18 to 256 cases (Table 1). The mean monthly temperature was 22.20 °C, ranging from 12.82 °C to 29.66 °C. The mean monthly diurnal temperature range was 8.20 °C, ranging from 4.71 °C to 15.11 °C. The mean monthly rainfall was 6.01 mm, ranging from 0.01 mm to 25.99 mm. The monthly wind speed ranged from 1.58 m/s to 2.98 m/s, with an average of 2.16 m/s. The monthly atmospheric pressure ranged from 991.79 h Pa to 1019.28 h Pa, with an average of 1005.44 h Pa. Monthly relative humidity ranged from 62.98% to 87.65%, with an average of 79.17%. The monthly sunshine hours ranged from 0.81 h to 7.59 h, with an average of 4.41 h (Table 2).

Figure 2 shows the trends and characteristics of elderly falls injury cases and meteorological factors in a monthly time series between January 2014 and December 2018. Trends in monthly elderly falls injury cases and meteorological factors were observed (Figure 2a-g, Table 3). The Pearson correlation analysis results showed that monthly elderly falls injury cases had a positive correlation with monthly mean wind speed ($r = 0.187$, $P < 0.01$) and monthly relative humidity ($r = 0.186$, $P < 0.01$), and a negative correlation with monthly diurnal temperature range ($r = -0.161$, $P < 0.01$) and monthly atmospheric pressure ($r = -0.142$, $P < 0.05$).

A linear regression model was constructed between monthly elderly falls injury cases and the monthly mean meteorological factors (Figure 3, Table 4). Linear trends between monthly mean temperatures (Figure 3 a), and atmospheric pressure (Figure 3 b) and monthly elderly falls injury cases were observed using a scatter diagram. The multiple linear regression model (Figure 3c) was considered statistically significant ($F = 10.176$, $P < 0.01$) and explained 23.7% of the variances ($R^2 = 0.237$). Acceptable goodness of fit of the model was revealed by the results of the distribution between the standardized residual and predicted monthly elderly falls injury cases (Figure 3 d), in which all points were in the range between -2 to 2. Table 4 reveals that the monthly mean wind speed ($\beta = 76.85$, $P < 0.01$) and monthly mean atmospheric pressure ($\beta = -3.162$, $P < 0.01$) were independent factors affecting monthly elderly falls injury cases.

4. Discussion

4.1. Main findings

We found that almost 50% of injuries in the elderly were caused by falls. The monthly number of elderly falls injury cases was lowest in April and highest in December. The monthly average wind speed was positively correlated with EFIC, and the monthly average atmospheric pressure was negatively correlated with EFIC.

4.2. Comparisons with previous studies

Similar to previous studies in China, the Guangzhou Injury Monitoring System showed that 49.41% of the causes of elderly injury were falls, which occupied first place in five consecutive years (2014–2018) (Zhang et al., 2019; Lin et al., 2018). The same phenomenon also occurs in older Americans; data from the National Vital Statistics System and National Health Interview Survey showed an annual increase in falls injuries among older adults (Drew and Xu, 2020). Falls are the leading cause of death among the elderly. The China Death Surveillance Data of 2020 showed that accidental falls were the primary cause of injury deaths among elderly people (China Death Surveillance Dataset in 2020, 2021). Therefore, falls seriously threaten the health of the elderly, requiring the implementation of falls prevention programs and expanding falls prevention efforts for more general injury prevention.

We found that the monthly number of EFIC was lowest in April and highest in December, which was similar to previous studies (Lin et al., 2015; Yeung et al., 2011). One study in Hong Kong (Yeung et al., 2011) showed that the elderly falls more often in winter than in spring and summer, and another study in Taipei (Lin et al., 2015) also showed more falls in late autumn and winter than in spring and summer. One possible hypothesis may be proposed regarding the weather in these regions. First, summer in a subtropical climate is hot and humid, with occasional rainstorms and typhoons, which may not be suitable for being outside and decreasing the risk of falls. Moreover, low temperatures in winter can cause lower body temperature, decreased flexibility, and slow reactions, which can increase the risk of falls for elderly people (Liang et al., 2021). Furthermore, rain in winter can cause the ground to remain slippery for a long time. Therefore, more falls may occur in winter than in summer for the reasons above.

We also found a positive correlation between the monthly mean wind speed and EFIC. It is suggested that early warnings of extreme weather should highlight the role of high wind speeds. The elderly should stay indoors as far as possible in rainy and windy environments, or seek shelter outside when weather changes are worse (Liao et al., 2018). However, some studies have found no correlations between wind speed and EFIC (Lin et al., 2015; Modarres et al., 2012). Further studies are needed to better understand the correlation between wind speed and EFIC.

Our study revealed that monthly atmospheric pressure was negatively associated with EFIC. Few studies have reported an association between
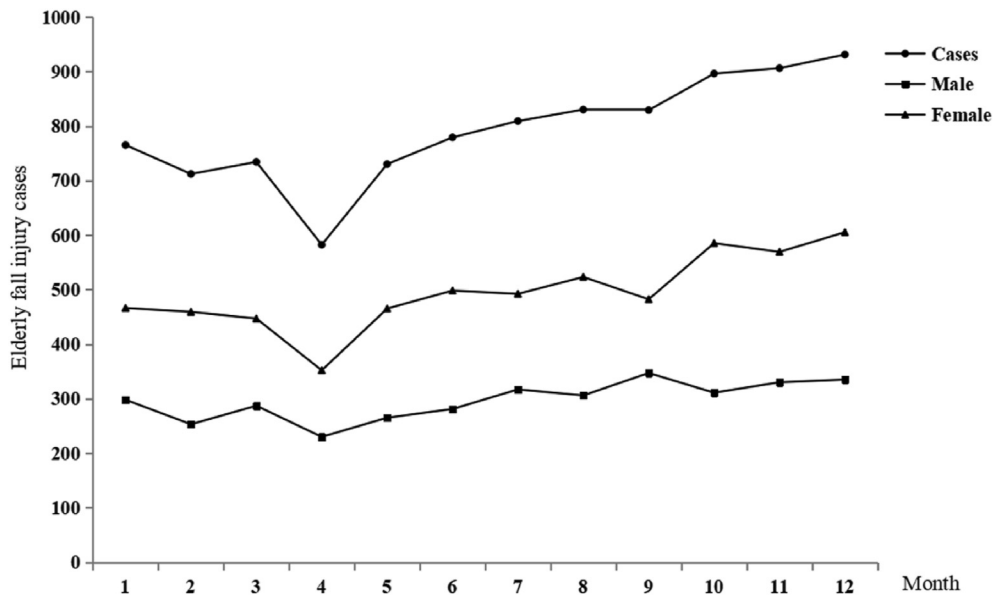
Table 1. Descriptive statistics of injury cases in Guangzhou Injury Monitoring System from 2014 to 2018 in Guangzhou, China.

Years	Elderly injury cases	Elderly falls injury cases (n, %)	Order of elderly falls cases
2014	2165	1074 (49.61)	1
2015	2750	1367 (49.71)	1
2016	4075	2029 (49.79)	1
2017	4745	2344 (49.40)	1
2018	5499	2689 (48.90)	1
Total	19234	9503 (49.41)	1

Figure 1. Monthly trends and characteristics of elderly falls injury cases in Guangzhou, China.

Table 2. Descriptive statistics of monthly elderly falls injury cases and monthly mean meteorological factors from 2014 to 2018 in Guangzhou, China.

Variables	Mean	SD	Percentile			Min	Max
			25	50	75		
Cases[a]	158.38	57.69	114.75	155.00	209.50	18.00	256.00
MT (°C)	22.20	5.58	16.51	23.26	27.85	12.82	29.66
DTR (°C)	8.20	1.78	7.05	7.98	8.99	4.71	15.11
Rainfall (mm)	6.01	5.43	1.45	4.38	8.97	0.01	25.99
WS (m/s)	2.16	.36	1.89	2.19	2.37	1.58	2.98
AP (hPa)	1,005.44	6.49	999.74	1,005.51	1,010.74	991.79	1,019.28
RH (%)	79.17	5.54	76.58	80.29	83.06	62.98	87.65
SH (h)	4.41	1.76	3.02	4.45	5.67	0.81	7.59

[a] Elderly falls injury cases. MT: mean temperature, DTR: diurnal temperature range, WS: wind speed, AP: atmospheric pressure, RH: relative humidity, SH: sunshine hours.
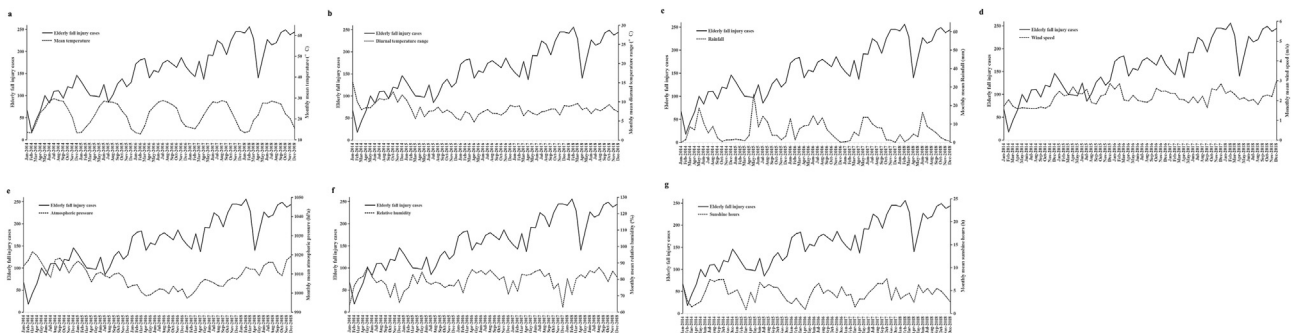

Figure 2. Trends and characteristics of elderly falls injury cases and meteorological factors between January, 2014 and December, 2018. Note: (a) MT: mean temperature; (b) DTR: diurnal temperature range; (c) Rainfall; (d) WS: wind speed; (e) AP: atmospheric pressure; (f) RH: relative humidity; (g) SH: sunshine hours.

atmospheric pressure and EFIC. One study observed that the risk of falling outdoors was greater at low air pressures than at high air pressures; however, at medium air pressure, the incidence of outdoor falls was the highest (Unguryanu et al., 2020). We speculate that air becomes thin during low atmospheric pressure, and elderly people may be more likely to experience fatigue and dizziness, which increases the risk of falls.

Previous studies have reported that lower air temperature was associated with more fall-related incidences and deaths (Morency et al., 2012), however some studies have found no such relationship between temperature and falls among older individuals (Driedger et al., 2016), which is consistent with our study results. Possible explanations may be related to the small sample size, short observation time (Chow et al., 2018), and different regions and climates. According to the different
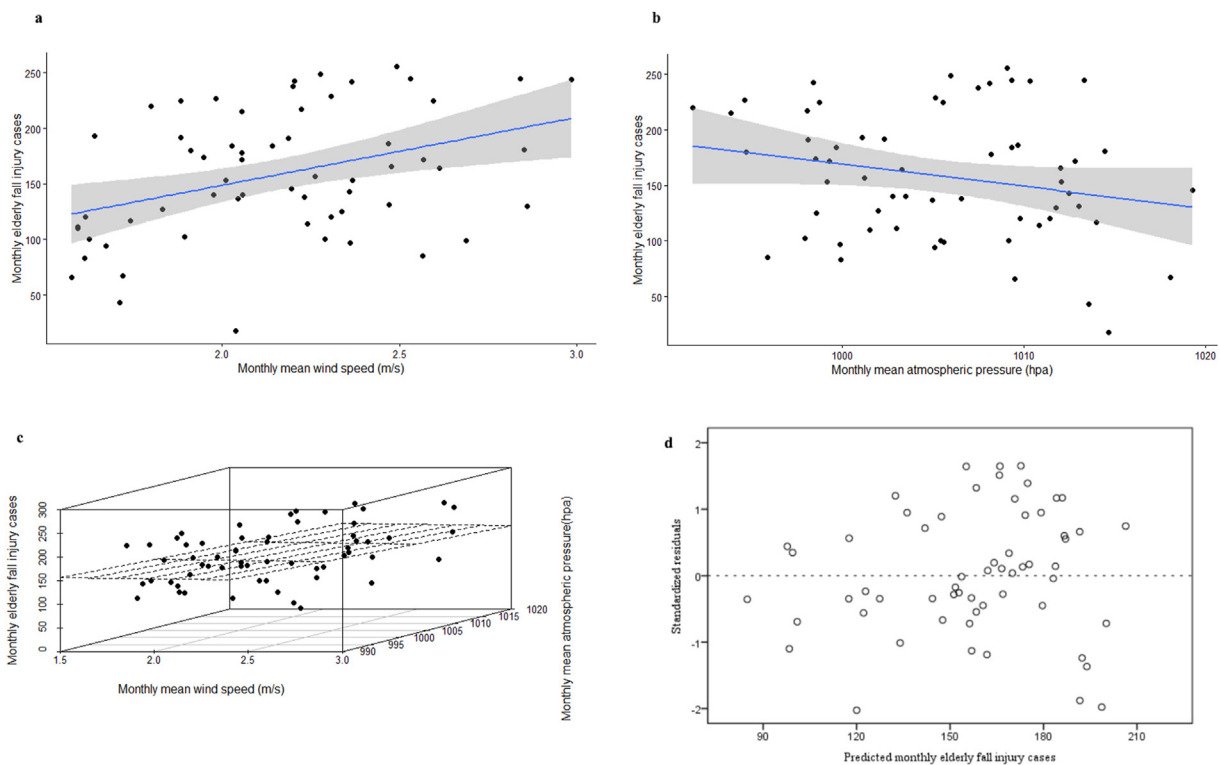
Table 3. Correlations between monthly elderly falls injury cases and weekly mean meteorological factors from 2014 to 2018 in Guangzhou, China.

Variables	Cases[a]	MT	DTR	Rainfall	WS	AP	RH	SH
Cases[a]	1.000							
MT	-0.044	1.000						
DTR	-0.161**	0.055	1.000					
Rainfall	0.111	0.116**	-0.461**	1.000				
WS	0.187**	-0.313**	-0.257**	-0.166**	1.000			
AP	-0.142*	-0.351**	0.194**	-0.465**	0.183**	1.000		
RH	0.186**	0.287**	-0.564**	0.664**	-0.348**	-0.492**	1.000	
SH	-0.032	0.382**	0.725**	-0.420**	-0.019	-0.138**	-0.562**	1.000

[a] Elderly falls injury cases. MT: mean temperature, DTR: diurnal temperature range, WS: wind speed, AP: atmospheric pressure, RH: relative humidity, SH: sunshine hours.

* $p < 0.05$.

** $p < 0.01$.

Figure 3. Goodness of fit of linear regression models of monthly elderly falls injury cases. Note: (a) Scatter diagram between monthly mean temperature and monthly elderly falls injury cases. (b) Scatter diagram of monthly atmospheric pressure and elderly falls injury cases. (c) Linear regression model between monthly elderly falls injury cases and monthly mean meteorological factors. (d) Goodness of fit of linear regression model between monthly elderly falls injury cases and monthly mean meteorological factors.

Table 4. Associations between monthly elderly falls injury cases and monthly mean meteorological factors from linear regression analysis from 2014 to 2018 in Guangzhou, China.

Variables	β	95%CI		β^{a}	t	p	VIF	F	P	Adjusted R Square
		Lower	Upper							
Model								10.176	<0.01	0.237
Constant	3172.304	1078.068	5266.539	-	3.033	<0.01	-			
WS (m/s)	76.850	38.901	114.798	0.479	4.055	<0.01	1.081			
AP (hPa)	-3.162	-5.266	-1.059	-0.356	-3.010	<0.01	1.081			

[a] Standardized regression coefficient. WS: wind speed; AP: atmospheric pressure.

meteorological conditions of the local climate, formulating targeted suggestions and measures of falls may obtain better benefits for administrative departments (Liao et al., 2018).

4.3. Strengths and limitations

Our study had the following strengths. First, the study obtained all the collected data, including monthly EFIC data from Guangzhou Injury Monitoring System and meteorological data from Guangzhou Meteorological Bureau, providing legitimacy, credibility and reducing the possibility of mistakes. Second, to the best of our knowledge, there are few studies in Guangzhou that focused mainly on EFIC and meteorological factors. Through this experiment, we provided evidence for the formulation of injury prevention measures.

However, there are some limitations to our study. First, the weather data and associations in our study represent only subtropical regions. Second, there were only five sentinel hospitals in Guangzhou and the sample size was small. Finally, as a preliminary exploratory correlation study, some confounding factors failed to be effectively controlled, resulting in a weak causal link between the study variables and outcomes. Further studies need to include more confounding factors.

4. Conclusions

Falls are the primary cause of injury among the elderly in Guangzhou, China. Decreasing outdoor activities during high wind and low atmospheric pressure weather may help reduce the number of EFIC. Studies on different meteorological conditions and their associations with falls may contribute to formulating targeted preventive measures for falls among elderly people.

Declarations

Author contribution statement

Wei-Quan Lin; Hui Liu; Lin Lin: Conceived and designed the experiments.

Wei-Quan Lin; Lin Lin; Le-Xin Yuan; Le-Le Pan; Ting-Yuan Huang; Min-Ying Sun; Fa-Ju Qin: Performed the experiments.

Wei-Quan Lin; Guo-Zhen Lin; Lin Lin; Le-Xin Yuan; Ting-Yuan Huang: Analyzed and interpreted the data.

Wei-Quan Lin; Ting-Yuan Huang; Min-Ying Sun; Fa-Ju Qin; Chang Wang; Yao-Hui Li; Qin Zhou; Di Wu; Bo-Heng Liang: Contributed reagents, materials, analysis tools or data.

Wei-Quan Lin; Lin Lin; Le-Xin Yuan; Le-Le Pan; Hui Liu: Wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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