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Using Atmospheric Visibility to Assess the Effects of Air Pollution on Hospital Admissions for Respiratory Diseases

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ABSTRACT

Air pollution is a significant hazard to human health. Atmospheric visibility is an aggregative indicator of air pollution and meteorological conditions. Yet, only a few studies have reported the relationship between atmospheric visibility and health risks. This study attempted to utilize atmospheric visibility to assess the effects of air pollution on hospital admissions for respiratory diseases (ICD-9: 460-519). Daily measurements of air pollutants, atmospheric visibility, and Taiwan's National Health Insurance Research Database were obtained for the year 2010 in Taichung. We compared the differences in different locations (coastal and urban areas). A Poisson regression analysis was used to evaluate the relationship between the atmospheric visibility and the respiratory consultation rate, with adjustment for potential confounding factors, including meteorological factors, spatial variances, and types of air pollution. The primary results indicated that air pollution and atmospheric visibility degradation were both more serious in the urban area than in the coastal area. The atmospheric visibilities were divided into Q_1 (25th percentile), Q_2 (50th percentile), and Q_3 (75th percentile); these divisions show the inversely proportional trend between atmospheric visibility range and health risks. It was also observed the similar inversely proportional trend between particulate matter and health risks. Under the hazard periods of atmospheric visibility ≤ 10 km, the relative significant health risks of 1.088 and 1.042 were observed in the coastal area and urban area, respectively. The relative health risks of particulate matters were 1.053 in the coastal area and 1.101 in the urban area during the periods of $PM_{2.5} \geq 35$ µg m^{-3}. This study establishes a new perspective from which to assess the effects of air pollution on hospital admissions for respiratory diseases by utilizing atmospheric visibility. Additionally, it provides a convenient way for the public to understand the relationship between air pollution and its effects on human health.

Keywords: $PM_{2.5}$; Relative risk; Air quality; Health effect; Respiratory diseases; Particulate matter; Atmospheric visibility.

INTRODUCTION

In recent years, the effect of air pollution on the environment and human health has increasingly gained public attention. Epidemiological studies worldwide have been focused on the adverse effects (respiratory diseases, cardiovascular diseases, impaired lung functions, cancer, and heart diseases) of suspended particles and gas pollutants on human health (Yu *et al.*, 2012; Pan *et al.*, 2015). Studies have shown that for each increase in $PM_{2.5}$ mass concentration by 10 µg m^{-3}, all-cause mortality increased by 1.4, 1.5, 2.7, and 0.8% in Barcelona, Stockholm, Madrid, and the Netherlands, respectively (Mate *et al.*, 2010; Guaita *et al.*, 2011; Ostro *et al.*, 2011; Tobías *et al.*, 2011; Meister *et al.*, 2012), mainly because of the harm from the air pollutants to the cardiovascular and respiratory systems (Chan *et al.*, 2006; Jimenez *et al.*, 2009; Guo *et al.*, 2010; Jimenez *et al.*, 2010; Tsai *et al.*, 2010; Yu *et al.*, 2012).

The characteristics and concentrations of air pollutants are not only derived from pollution sources but also affected by terrain and meteorological factors (Lin *et al.*, 2005; Chen *et al.*, 2007; Chou *et al.*, 2008; Kuo *et al.*, 2008; Zhou *et al.*, 2012). Therefore, the spatial representativeness of the hourly concentration of air pollutants collected by monitoring stations has been questioned. For regions that lack air pollutant monitoring, available data for the assessment of the effects of air pollutants on human health as well as forecasts and prevention have been severely lacking. Previous studies have shown that atmospheric visibility can be used as a comprehensive indicator of air pollution and

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meteorological conditions and as a direct factor identified by the public in judging the air quality from personal experience. The relationship between atmospheric visibility and human health has rarely been addressed, although in regions lacking measurements of air pollutants, atmospheric visibility has been proposed as a new indicator of assessing air quality and human health risks (Schwartz, 1991; Abbey *et al.*, 1995; Vajanapoom *et al.*, 2002; Huang *et al.*, 2009; Thach *et al.*, 2010; Ge *et al.*, 2011).

The purposes of this study are (1) to identify the major air pollutants causing atmospheric visibility degradation using multivariate regression analyses; (2) to investigate the effect of the major air pollutants on respiratory diseases; (3) to understand the association between atmospheric visibility degradation and respiratory diseases; and (4) to assess the new ideal of using atmospheric visibility to replace air pollutants and thereby investigate the effects of air pollution on human health.

MATERIALS AND METHODS

Background

This study was conducted in Taichung City, located in central Taiwan, with an area of approximately 2,215 square kilometers. In 2010, the population of Taichung City was over 2.65 million. The majority of the area is in the subtropical climate zone, with an annual average temperature (TEMP) of approximately 22°C; the wet and dry seasons are distinct, with precipitation concentrated in the summer. Taichung climate is milder than the climate of other major Taiwanese cities. Because of rapid economic development, exhaust from automobiles and emissions from various industries and coal-burning power plants have been increasing each year, which has significantly deteriorated the air quality of Taichung and drastically reduced atmospheric visibility. Taichung city can be divided into the urban area and coastal area according to topographical characteristics. Urban area is a basin surrounded by the Central Mountain Range (CMR) and Tatu Hill. Coastal area is located between the Taiwan Strait and Tatu Hill. In this study, coastal and urban areas were selected to investigate the differences in human health hazards from air pollution resulting from factors such as terrain segmentation and anthropogenic emissions. The constructed methodology can be applicable to more counties in Taiwan Island.

Environmental and Meteorological Data

In this study, hourly data of the concentrations of air pollutants (PM_{10}, $PM_{2.5}$, SO_2, and NO_2) and meteorological factors (wind speed (WS), wind direction (WD), temperature (TEMP), and relative humidity (RH)) were collected during the period from Jan. 1, 2010, to Dec. 31, 2010, in the coastal area (Shalu station) and the urban area (average values of data from the Chungming, Xitun, and Dali stations) from the air quality monitoring network of the Environmental Protection Agency (EPA) of Taiwan (Fig. 1). The atmospheric visibility data were obtained from the manual recorded data at the coastal area (Wuqi station) and the urban area (Taichung station) collected by the Central Weather Bureau (CWB) in Taiwan. The data that were affected by sandstorms and typhoons (a sandstorm from Mar. 21–24 in the spring; the peripheral circulation influence of typhoons from Aug. 30–Sept. 2, Sept. 9–10, Sept. 17–20, and Oct. 21–23, in the summer and autumn) were excluded in the analysis.

Hospital Admissions

This study used one million random-drawn medical records in the Longitudinal Health Insurance Database in the year

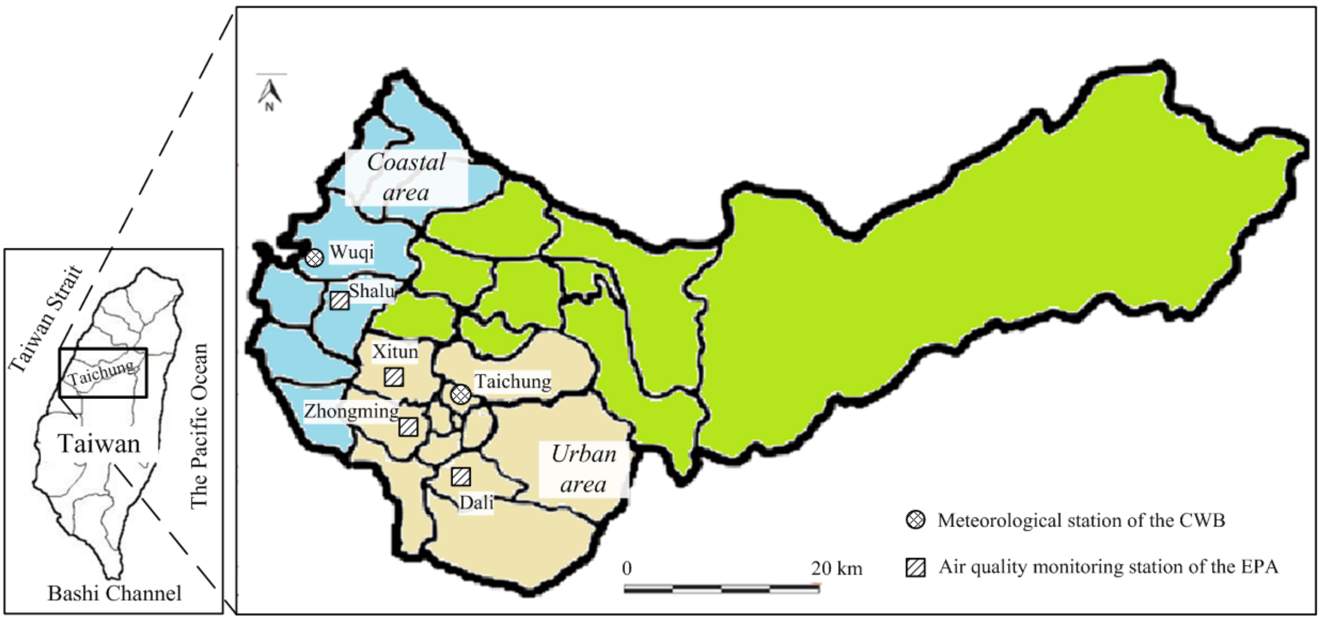

Fig. 1. The air quality monitoring network of the Environmental Protection Agency (EPA) of Taiwan is from the coastal area (Shalu) and the urban areas (Chungming, Xitun, and Dali) in Taichung. The atmospheric visibility data were obtained from the manual recorded data at the coastal area (Wuqi) and the urban area (Taichung).

2010 (LHID2010) from the National Health Insurance Research Database, from which the daily medical records of patients from the Taichung area from Jan. 1–Dec. 31, 2010, were retrieved. Cigarette smoking is the most important risk factor for chronic obstructive pulmonary disease (COPD) development (Sichletidis *et al.*, 2014) and seasonal influenza is an acute viral infection caused by an influenza virus (Zhang *et al.*, 2010). In order to investigate the general health effects of air pollution, admissions for COPD and influenza were excluded from total respiratory admissions. The data was categorized according to International Classification of Diseases, 9th revision (ICD-9). The selected principal diagnosis for respiratory diseases (ICD9 codes 460–519) excluding influenza (ICD9 code 487) (Hansen *et al.*, 2012) and COPD (ICD9 codes 490–492, 494–496) was drawn from the original data set.

Statistical Methods

First, the mean ± standard deviation and quartile values exhibited the distribution comparisons of diseases, air pollutants and weather factors between the urban and coastal regions. Second, the correlations between atmospheric visibility and air pollutants were analyzed using the Spearman correlation method under different conditions and meteorological factors. Environmental studies have found that the relative humidity, NO_2 concentrations, and particulate matter in the atmosphere can influence the visibility (Appel *et al.*, 1985; IMPROVE, 2006, 2010; Kuo *et al.*, 2013). To establish the correlation between air pollutants ($PM_{2.5}$, SO_2, and NO_2) and atmospheric visibility, a multivariate regression analysis was conducted in which the insignificant variables were excluded and the influence of humidity on the model was neglected. Lai and Sequeira (2001) applied the RH-adjustment to increase the explained variation of visibility from 28% to almost 70% in Hung Kung. Chen *et al.* (2014) also indicated that the RH-adjustment increased the variation of $PM_{2.5}$ to visibility in Taichung. The equation (Lee and Sequeira, 2002), in which the R^2 change was used as the basis of the judgment to analyze major particulate pollutants responsible for the atmospheric visibility degradation and to investigate the effect of these major air pollutants on human health, is shown as follows ($adjRHPM_{2.5}$ represents the $PM_{2.5}$ mass concentration after the RH adjustment):

$$adjRHPM_{2.5} = PM_{2.5} \times (RH / (1 - RH)) \quad (1)$$

Final, Poisson regression was analyzed the health effects of the $PM_{2.5}$ mass concentration or atmospheric visibility in the urban and coastal areas on the clinical visiting rate of patients with respiratory diseases. Regarding $PM_{2.5}$, the standard value of the daily average concentration of the EPA (35 $\mu g\ m^{-3}$) and the first quintile (Q1) of the daily concentration were used as the reference groups. Although there is no clear international standard of atmospheric visibility, Cheng and Tsai (2000) indicated that the average visual range in the Taichung urban area was approximately 8–10 km and the annual average visibility in the coastal suburban area is approximately 12 km. According to the previous study, visibility of 10 km and Q1 of the daily measurement were set as the reference group in this study. An adjustment was performed for interfering factors such as RH, WS, temperature, etc. SAS (version 9.3; SAS Institute, Inc., Cary, NC) was used to conduct the statistical analyses, and $p < 0.001$ was set as the level of statistical significance.

RESULTS

Data Description

Table 1 shows the distributions of diseases and air pollutants in the coastal and urban areas in 2010. The average number of clinical visits in the urban area was approximately three to four times greater than that in the coastal area, and the distributions of the average number of clinical visits of patients with respiratory disease, influenza, and COPD were statistically significant between the two areas ($p < 0.001$). With respect to atmospheric visibility, the two areas also had statistical significance ($p < 0.001$). With respect to gaseous pollutants (SO_2 and NO_2), the NO_2 concentrations in the two areas were significantly different ($p < 0.001$). For the meteorological factors, the distributions of RH and WS in the two areas exhibited statistical significance ($p < 0.001$). Regarding particulate matter (PM_{10} and $PM_{2.5}$), the differences in the concentrations in the two areas were not statistically significant; however, the daily average $PM_{2.5}$ mass concentration in the urban area (36.1 $\mu g\ m^{-3}$) exceeded the standard value of the Taiwan EPA regulations (35 $\mu g\ m^{-3}$).

Correlation between Environmental and Meteorological Data

Table 2 shows the correlations between PM_{10}, $PM_{2.5-10}$, $PM_{2.5}$, NO_2, RH, WS, TEMP, and atmospheric visibility for the coastal and urban areas. In the two areas, atmospheric visibility was negatively correlated with PM_{10}, $PM_{2.5-10}$, $PM_{2.5}$, NO_2, and RH ($p < 0.001$) but was positively correlated with WS ($p < 0.001$). Compared with the urban area, atmospheric visibility displayed a positive correlation with TEMP in the coastal area ($p < 0.001$). PM_{10} was positively correlated with SO_2 and NO_2 but negatively correlated with WS and RH.

Contribution of Air Pollutants to Atmospheric Visibility

The effects of $PM_{2.5}$, $PM_{2.5-10}$, NO_2, and SO_2 on atmospheric visibility were investigated using a multivariate regression analysis; the results are shown in Table 3. In both the coastal and urban areas, regardless of the weather conditions, the $PM_{2.5}$ mass concentration after adjusting the relative humidity ($adjRHPM_{2.5}$) had the greatest effect on atmospheric visibility with each contribution (R^2 change) over 0.46. The $PM_{2.5}$ mass concentration always shows a negative correlation with visibility ($p < 0.001$). Therefore, in this study, $PM_{2.5}$ was the dominant air pollutant leading to atmospheric visibility degradation.

Correlation between Air Pollutants and the Clinical Visit Incidence of Patients with Respiratory Diseases

Table 4 illustrates that based on different weather conditions in the coastal and urban areas, the daily average standard provided by the EPA for the $PM_{2.5}$ mass concentration (35 μg m^{-3}) and Q1 were used as the reference groups. The relationship between air pollutants and the clinical visiting rate of patients with respiratory diseases was then investigated.

In the coastal area, the incidence of clinical visits of patients with respiratory diseases when the $PM_{2.5}$ mass concentrations were above the standard value was 1.053 (95% CI, 1.036–1.071) times greater than that when the $PM_{2.5}$ concentrations were below the standard value. Furthermore,

Table 1. The distributions of diseases and air pollution indicators in the coastal and urban areas in 2010.

Area	Variables	Unit	N	Mean	SD	Q_1	Q_2	Q_3
Coastal	Respiratory***	day^{-1}	348	212.6	75.5	178.0	217.0	260.0
	Influenza***	day^{-1}	348	3.9	2.5	2.0	4.0	6.0
	COPD***	day^{-1}	348	5.6	3.3	3.0	6.0	8.0
	Visibility***	km	348	13.4	4.3	10.3	12.7	16.0
	PM_{10}	μg m^{-3}	348	53.1	41.6	28.0	44.8	67.4
	$PM_{2.5–10}$	μg m^{-3}	348	17.8	14.7	8.1	14.6	23.9
	$PM_{2.5}$	μg m^{-3}	348	33.3	17.9	19.6	30.1	44.1
	SO_2	μg m^{-3}	348	9.5	3.7	6.8	8.9	11.2
	NO_2***	μg m^{-3}	348	30.2	12.2	21.5	27.4	35.2
	RH***	%	348	0.8	0.1	0.7	0.8	0.8
	WS***	m s^{-1}	348	3.5	1.7	2.3	3.1	4.3
	TEMP	°C	348	23.3	5.2	19.5	24.0	28.2
Urban	Respiratory	day^{-1}	348	837.8	297.5	726.0	870.0	999.0
	Influenza	day^{-1}	348	16.8	6.7	12.0	16.0	21.0
	COPD	day^{-1}	348	19.4	9.9	12.0	21.0	26.0
	Visibility	km	348	9.5	1.9	8.3	9.8	10.8
	PM_{10}	μg m^{-3}	348	58.6	37.3	36.3	51.1	74.7
	$PM_{2.5–10}$	μg m^{-3}	348	20.8	11.4	13.0	17.7	26.4
	$PM_{2.5}$	μg m^{-3}	348	36.1	17.6	22.3	32.9	47.4
	SO_2	μg m^{-3}	348	8.8	2.9	6.7	8.4	10.3
	NO_2	μg m^{-3}	348	39.8	14.4	28.5	38.7	48.0
	RH	%	348	0.7	0.1	0.7	0.7	0.8
	WS	m s^{-1}	348	2.7	1.3	1.8	2.2	3.1
	TEMP	°C	348	24.0	5.1	20.0	25.2	28.4

COPD: Chronic obstructive pulmonary disease, RH: Relative humidity, WS: Wind speed, TEMP: Temperature.
*** $p < 0.001$, It was recognized for comparing the difference between coastal and urban area.

Table 2. The correlations between PM_{10}, $PM_{2.5–10}$, $PM_{2.5}$, NO_2, RH, WS, TEMP and atmospheric visibility of the coastal and urban areas.

Coastal area	Visibility	PM_{10}	$PM_{2.5–10}$	$PM_{2.5}$	SO_2	NO_2	RH	WS	TEMP
Visibility	1.00								
PM_{10}	–0.49***	1.00							
$PM_{2.5–10}$	–0.30***	0.93***	1.00						
$PM_{2.5}$	–0.66***	0.80***	0.52***	1.00					
SO_2	–0.11	0.31***	0.13	0.51***	1.00				
NO_2	–0.46***	0.47***	0.22***	0.72***	0.64***	1.00			
RH	–0.28***	–0.20***	–0.16	–0.20***	–0.29***	–0.10	1.00		
WS	0.50***	–0.37***	–0.19	–0.55***	–0.22***	–0.57***	0.08	1.00	
TEMP	0.40***	–0.23***	–0.15	–0.29***	0.05	–0.29***	0.14	0.27***	1.00
Urban area	**Visibility**	**PM_{10}**	**$PM_{2.5–10}$**	**$PM_{2.5}$**	**SO_2**	**NO_2**	**RH**	**WS**	**TEMP**
Visibility	1.00								
PM_{10}	–0.39***	1.00							
$PM_{2.5–10}$	–0.24***	0.92***	1.00						
$PM_{2.5}$	–0.51***	0.86***	0.61***	1.00					
SO_2	–0.32***	0.51***	0.30***	0.68***	1.00				
NO_2	–0.44***	0.51***	0.30***	0.69***	0.66	1.00			
RH	–0.43***	–0.27***	–0.25***	–0.25***	–0.27***	–0.11	1.00		
WS	0.34***	–0.26***	–0.14	–0.36***	–0.31***	–0.61***	–0.16	1.00	
TEMP	0.18	–0.16	–0.11	–0.21***	–0.09	–0.55***	0.11	0.36***	1.00

*** $p < 0.001$.

Table 3. The effects of $PM_{2.5}$, $PM_{2.5–10}$, NO_2 and SO_2 on atmospheric visibility were investigated using a multivariate regression analysis.

		All Year (N = 348)		
		B	R^2 Change	Accumulated R^2
Coastal area	Intercept	17.70		
	adjRHPM$_{2.5}$***	–0.02	0.46	0.46
	NO_2***	–0.11	0.03	0.49
	SO_2	0.24	0.02	0.51
	adjRHPM$_{2.5–10}$	–0.01	0.01	0.52
Urban area	Intercept	11.86		
	adjRHPM$_{2.5}$***	–0.02	0.54	0.54
	SO_2	0.05	0.00	0.54
	NO_2	–0.01	0.00	0.54

Unit: $\mu g\ m^{-3}$; adjRHPM$_{2.5}$ = $PM_{2.5} \times (1/(1 - RH))$.
*** $p < 0.001$.

Table 4. Correlation between $PM_{2.5}$ and the incidence of clinical visits of patients with respiratory diseases in the coastal and urban areas.

	All year (N = 348)		
	$PM_{2.5}$ ($\mu g\ m^{-3}$)	RR	95%CI
Coastal area	≥ 35	1.053	1.036–1.071
	< 35	1	
	≥ 44.1	1.119	1.090–1.150
	30.1–44.1	1.070	1.043–1.098
	19.6–30.1	1.032	1.007–1.057
	< 19.6	1	
Urban area	≥ 35	1.101	1.092–1.111
	< 35	1	
	≥ 47.4	1.146	1.133–1.160
	32.9–47.4	1.103	1.091–1.115
	22.3–32.9	1.049	1.038–1.061
	< 22.3	1	

based on the $PM_{2.5}$ concentrations in 2010, four groups (Q1–Q4) were generated, and the group with the lowest $PM_{2.5}$ concentration (the $PM_{2.5}$ mass concentration < Q1) was set as the reference group to assess the clinical visit incidence of patients with respiratory diseases compared with the other three groups. From the low concentration group to the high concentration group, the clinical visit incidences of patients with respiratory diseases in the three groups were 1.032 (95% CI, 1.007–1.057), 1.070 (95% CI, 1.043–1.098), and 1.119 (95% CI, 1.090–1.150) times greater than that of the reference group, respectively. All of the results were statistically significant. The relative risk of the clinical visit incidence of patients with respiratory diseases showed a gradually increasing trend with an increasing $PM_{2.5}$ concentration.

In the urban area, the clinical visit incidence of patients with respiratory diseases when the $PM_{2.5}$ concentrations were higher than the standard was 1.101 (95% CI, 1.092–1.111) times greater than that when the $PM_{2.5}$ concentrations were below the standard. Similarly, when grouping based on the $PM_{2.5}$ concentration, from the low concentration group to the high concentration group, the clinical visit incidences of patients with respiratory diseases in the three groups were 1.049 (95% CI, 1.038–1.061), 1.103 (95% CI, 1.091–1.115), and 1.146 (95% CI, 1.133–1.160) times greater than that of the reference group, respectively. All of the results were statistically significant. Moreover, the clinical visit incidence of the patients with respiratory diseases showed a gradually increasing trend with increasing $PM_{2.5}$ concentration.

These results show that regardless of the area, the incidence of clinical visits by patients with respiratory diseases increased with an increasing $PM_{2.5}$ concentration.

Correlation between Atmospheric Visibility and the Clinical Visit Incidence of Patients with Respiratory Diseases

Table 3 shows that the high $PM_{2.5}$ mass concentrations caused the atmospheric visibility degradation; furthermore, the correlation between atmospheric visibility and the clinical visit incidence of patients with respiratory diseases was further investigated. In the analysis, two different methods were used to categorize atmospheric visibility: one method used 10 km as the threshold, and the other was based on the quartile method (Q1–Q3). Table 5 illustrates the correlation between atmospheric visibility and the clinical visit incidence of patients with respiratory diseases in the coastal and urban areas. In the coastal area, the incidence of clinical visits by patients with respiratory diseases when the atmospheric visibility was less than 10 km was 1.088 (95% CI, 1.069–1.108) times greater than that when atmospheric visibility was above 10 km. All of the results were statistically significant. However, the atmospheric visibility was divided into quartiles based on the 2010 atmospheric visibility data. The corresponding results show that in the coastal area, from the high atmospheric visibility group to the low atmospheric visibility group, the clinical visit incidences of patients with respiratory diseases in the three groups were 1.016 (95% CI, 0.994–1.039), 1.072 (95% CI, 1.049–1.096), and 1.147 (95% CI, 1.121–1.175) times greater than that of the reference group, respectively. The results showed that the clinical visit incidence of the patients with respiratory diseases increased with decreasing atmospheric visibility.

In the urban area, the clinical visit incidence of patients with respiratory diseases when the atmospheric visibility

Table 5. The correlation between atmospheric visibility and the incidence of clinical visits of patients with respiratory diseases in the coastal and urban areas.

	All year (N = 348)		
	Visibility (km)	RR	95%CI
Coastal area	< 10	1.088	1.069–1.108
	≥ 10	1	
	< 10.3	1.147	1.121–1.175
	10.3–12.7	1.072	1.049–1.096
	12.7–16.0	1.016	0.994–1.039
	≥ 16.0	1	
Urban area	< 10	1.042	1.033–1.050
	≥ 10	1	
	< 8.3	1.125	1.113–1.138
	8.3–9.8	1.092	1.081–1.104
	9.8–10.8	1.057	1.046–1.068
	≥ 10.8	1	

was less than 10 km was 1.042 (95% CI, 1.033–1.050) times greater than that when the atmospheric visibility was above 10 km. Next, groups (Q1–Q3) were generated based on the 2010 atmospheric visibility data, in which the group with the highest atmospheric visibility (Q3 ≤ the highest atmospheric visibility) was set as the reference group; the incidences of clinical visits by patients with respiratory diseases were compared with this group. From the high atmospheric visibility group to the low atmospheric visibility group, the clinical visit incidences of patients with respiratory diseases in the three groups were 1.057 (95% CI, 1.046–1.068), 1.092 (95% CI, 1.081–1.104), and 1.125 (95% CI, 1.113–1.138) times greater than that of the reference group, respectively. The incidence of clinical visits by patients with respiratory diseases increased with decreasing atmospheric visibility.

DISCUSSION

In terms of regional differences, the significant variables in the coastal and urban areas included the total number of clinical visits in the sample, atmospheric visibility, NO_2, RH, and WS. The variation in the total number of clinical visits in the sample was caused by regional population differences, whereas the variation of WS was derived from the differences caused by terrain and buildings in the two areas. The significant variables in the coastal and urban areas included atmospheric visibility, PM, SO_2, NO_2 and WS.

Deng *et al.* (2008) observed that $PM_{2.5}$ was the main contributing pollutant to atmospheric visibility degradation in the Pearl River Delta (PRD) region. Chen *et al.* (2014) used long path visibility transmissometer 3 (LPV3) to measure the atmospheric visibility in Taichung during winter; they found that $PM_{2.5}$ was the major pollutant affecting atmospheric visibility. In their study, the contribution of PM_{10} to atmospheric visibility was 0.50, of which the regression contributions of $PM_{2.5–10}$ and $PM_{2.5}$ to atmospheric visibility were 0.14 and 0.66, respectively, indicating that $PM_{2.5}$ was the major air pollutant causing the atmospheric visibility degradation; this result is consistent with those of previous studies.

In this study, the differences in the effect of different areas on the incidence of clinical visits by patients with respiratory diseases were investigated. Analyses of the regional conditions indicate that the clinical visit incidence of patients with respiratory diseases increased when the $PM_{2.5}$ concentration was greater than 35 µg m^{-3}. After dividing the $PM_{2.5}$ concentration into four equal quartiles using the Q1, Q2, and Q3 divisions, compared with the reference group (the group with the lowest $PM_{2.5}$ concentration), the clinical visit incidence of patients with respiratory diseases in the other three groups increased. Previous studies (Barnett *et al.*, 2006; Guo *et al.*, 2010; Ma *et al.*, 2011; Hansen *et al.*, 2012) indicated that an increased $PM_{2.5}$ concentration causes an increased risk of respiratory diseases, which is consistent with the results of this study.

Regarding the feasibility of using atmospheric visibility to replace air pollutants to assess respiratory diseases, the present study results show that with a decrease in atmospheric visibility, the clinical visit incidence of patients with respiratory diseases increased. Because of the lack of clear specification on the value in previous studies, the interquartile range (IQR) in the region was used as the indicator of the visibility reduction to investigate the relative risk of diseases, including respiratory and cardiovascular diseases (Huang *et al.*, 2009; Thach *et al.*, 2010; Ge *et al.*, 2011; Lee *et al.*, 2014). The reported results revealed that with a reduction in atmospheric visibility, the relative risks of the diseases increased.

Regardless of the increase in the $PM_{2.5}$ concentration or the decrease in atmospheric visibility, the incidence of clinical visits by patients with respiratory diseases increased, indicating that it was also possible to assess the risk of a specific disease from the viewpoint of atmospheric visibility. Atmospheric visibility includes more factors than only $PM_{2.5}$; thus, it is more suitable for the public's use to judge real-time air pollution.

CONCLUSION

With respect to the relationship between atmospheric visibility and air pollutants, the correlation and multivariate regression analyses showed that particulate matter was the main factor leading to reduced atmospheric visibility, of which the effect of $PM_{2.5}$ was the most prominent. Regarding air pollutants as human health hazards, regardless of the categorization using the 35 µg m^{-3} or Q1, Q2, and Q3 dividing methods, all of the results revealed that an increased $PM_{2.5}$ concentration led to an increased incidence of clinical visits by patients with respiratory diseases, particularly in the severely polluted area (urban area). Regarding visibility degradation as a human health hazard, the clinical visit incidence of patients with respiratory diseases increased with decreasing visibility, independently of the categorization methods (categorizing by a critical range of 10 km or by Q1, Q2, and Q3 dividing methods), particularly in the severely polluted area (urban area). In this study, direct evidence for replacing the air pollutants with atmospheric visibility was provided, in which a reasonable regression equation between the two was first established, and their respective risk for respiratory diseases was individually assessed, showing the same results. Compared with the $PM_{2.5}$ mass concentration, atmospheric visibility takes into account more factors and, thus, is more suitable for determining real-time air pollution and for early warnings of human health risks.

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