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Spatial distribution and sources identification of elements in $PM_{2.5}$ among the coastal city group in the Western Taiwan Strait region, China

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HIGHLIGHTS

- Elements in $PM_{2.5}$ among the city group in the Western Taiwan Strait were studied.
- PCA and CA results indicated that multi-sources contributed to the elements.
- Elements were abundant in several fast growing locations.
- Elements were much highly enriched at the northern sites than the southern sites.
- Air masses from the Northern China might elevate the element concentration.

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ABSTRACT

The main purpose of this study was to investigate the spatial variations of 20 elements (Al, Si, Ti, Ca, Fe, Mg, Cr, Mn, Ni, P, S, K, Cu, Cl, V, Se, Br, As, Zn, and Pb) in $PM_{2.5}$ (particle matters ≤ 2.5 μm in aerodynamic diameter) in the coastal city group in the Western Taiwan Strait (WTS) region, China during spring 2011. The average $PM_{2.5}$ mass concentration at 13 sites was 77.0 μg/m^3 and the elemental fraction accounted for about 10–20%. Multivariate analyses (principal component analysis and cluster analysis) and a correlation matrix were used to identify the sources of elements in $PM_{2.5}$. The results revealed that the elements originated mainly from traffic emissions, coal combustion, pyrometallurgical processes, and crustal sources. Spatially, the concentrations of elements were generally higher in several rapidly growing locations, and the enrichment factors (EFs) for most elements were much higher at the northern sites than those at the southern sites, suggesting that the air quality in the northern part of the study area was strongly affected by anthropogenic activity. Backward wind trajectory analysis during the sampling period indicated that the concentrations of elements in $PM_{2.5}$ in the WTS region were greatly impacted by dust particles transported from Northern China in spring.

1. Introduction

Atmospheric aerosol particles have been widely investigated in the past few decades because of their direct or indirect adverse effects on human health. Exposure to fine particles ($PM_{2.5}$: particle matters ≤ 2.5 μm in aerodynamic diameter) is a major health concern, because they can be inhaled deeply into the lungs, causing some severe symptoms (Pope, 2000). Trace element content is one of the major factors that can influence the toxicity of airborne particulate matter (Harrison and Yin, 2000). Exposure to some elements, even at extremely low concentrations, can cause various conditions in humans. For example, Pb can cause blood poisoning and anemia, and Zn can lead to arteriosclerosis, heart disease and hypertension, while exposure to Cd and Fe can lead to itai–itai disease and pneumoconiosis, respectively (Fang et al., 2010).

Natural emissions and anthropogenic activity are two primary processes that can lead to an increase in elemental concentrations in the atmosphere. Previous studies have indicated that, in general, Ca, Mg, Al, Si, Fe, and Mn were rich in soils and resuspended dust (Marcazzan et al., 2001; Lee and Hills, 2003; Kim et al., 2006); the presence of Na, Ca, Mg, and K were attributed to sea salt (Kim et al., 2006). All of the elements mentioned above were mainly derived from natural sources, whereas Cr, Pb, Cu, Zn, Cd, Sb, Br, Fe, Ba, Mn, K, Ni, and V, etc., were emitted from various human activities, such as vehicle exhausts, industrial processes, coal combustion, and oil burning (Wu et al., 2007; Fang et al., 2010; and reference therein).

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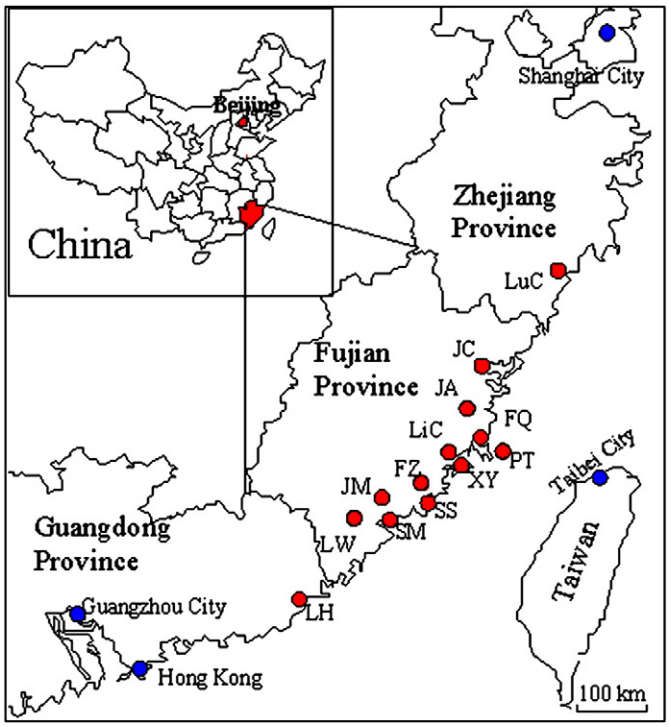

Fig 1. Thirteen $PM_{2.5}$ sampling sites among the coastal city group in the WTS region (sampling sites are marked by red dots and the comparison sites are marked by blue dots).

Significant amounts of potentially toxic metals are thought to be discharged by human activities, the emissions from which are estimated to be three times greater than natural emissions (WHO, 2000; Fang et al., 2012).

In China, many studies on the elemental characterization of aerosols have been conducted in several large cities, such as Beijing (Zhang et al., 2009), Tianjin (Gu et al., 2011), and Xi'an (Cao et al., 2011), and in the two rapidly developing regions of the Pearl River Delta (PRD) and the Yangtze River Delta (YRD) (Wong et al., 2003; Huang et al., 2009). The Western Taiwan Straits (WTS) region, where ambitious plans for regional economic development were launched by the government of Fujian Province, China, in 2004, lies in southeast China, with the PRD region to the south and the YRD region to the north. The WTS region covers the whole of Fujian Province and several adjacent cities of Zhejiang, Jiangxi, and Guangdong Provinces, with a total area of 270,000 km^2. Benefiting from the favorable geographical location and rich resources, the coastal city group in the WTS region is undergoing active development. However, apart from Fuzhou and Xiamen cities (Xu et al., 2012; Zhao et al., 2011), studies focusing on cities to the west of the Taiwan Strait were scarce. Therefore, in the present study, for the first time, a wide ranging survey of elements in $PM_{2.5}$ was initiated in the coastal city group in the WTS region.

In this work, we integrated a number of statistical techniques, such as cluster analysis (CA), principal component analysis (PCA), enrichment factor (EF) analysis, and backward trajectories analysis, to study the concentrations and sources of elements in $PM_{2.5}$ among the coastal city group in the WTS region. The aims of this study were (1) to present the concentration levels of elements in atmospheric $PM_{2.5}$ in the coastal city group; (2) to identify the natural and anthropogenic sources of elements and assess the degree of influence of human activity; and (3) to investigate the spatial variation of elemental concentrations and the spatial enrichment of elements among the coastal city group in the WTS region.

2. Material and methods

2.1. Sites description

Thirteen sites among eight cities in the WTS region were chosen for this study, including one city in Zhejiang Province, six cities in Fujian Province, and one city in Guangdong Province. The study area lies between latitudes 23°33′ N and 28°20′ N, and longitudes 115°50′ E and 120°40′ E. The six coastal cities of Fujian Province, i.e. Ningde, Fuzhou, Putian, Quanzhou, Xiamen and Zhangzhou, have a total population of 29 million and produce about 84% of the GDP of the whole province. The area has a typical subtropical monsoon climate with the prevailing wind direction being northerly and northeasterly in

Table 1
Detailed description of the 13 sampling locations among the coastal city group in the WTS region.

Location (city, province)	Sites[a]	Sampling height (m)	N[b]	Population density (/km^2)	Vehicle population (thousand)	Description
Wenzhou, Zhejiang	LuC	20	10	774	1149	Situated in the central area of cities; represents a residential and commercial environment of urban area
Ningde, Fujian	JC	21	10	252	270	Situated in the central area of cities; represents a residential and commercial environment of urban area
Fuzhou, Fujian	JA	30	10	585	1055	Situated in the central area of cities; about 30 m away from the main traffic road
	FQ	20	10			On the roof of the monitoring station of Fuqing City
	PT	10	10			A managed station of reservoir, the pollution was least
Putian, Fujian	LiC	20	10	745	650	On the roof of the monitoring station of Putian City
	XY	30	10			On the roof of a building in the government of Xiuyu district; represents a residential and commercial environment of urban area
Quanzhou, Fujian	FZ	30	10	737	2109	On the roof of monitoring station of Quanzhou Environmental Protection Bureau; represents a residential environment
	SS	25	10			On the roof of a building in a high school
Xiamen, Fujian	JM	5	10	2250	643	Located at the institute of urban environment, CAS; about 30 m away from the main traffic roads; a lot of municipal construction work is going
	SM	20	10			On the roof of a building in a primary school; about 100 m away from the main traffic road
Zhangzhou, Fujian	LW	15	9	395	847	Represents an industrial, commercial and traffic mixed environment
Shantou, Guangdong	LH	18	10	2454	668	Represents a cultural and educational area

[a] Site full names: LuC, Lucheng; JC, Jiaocheng; JA, Jin'an; FQ, Fuqing; PT, Pintan; LiC, Licheng; XY, Xiuyu; FZ, Fengze; SS, Shishi; JM, Jimei; SM, Siming; LW, Longwen; and LH, Longhu.
[b] Number of samples collected.