SATELLITE-DERIVED AIR POLLUTANTS AND THEIR CORRELATIONS WITH URBAN FORM IN GUANGDONG, CHINA

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ABSTRACT:

The ways cities grow and evolve spatially are crucial factors which affect urban aerosol pollution. Understanding the spatial distribution of air pollutants and their correlations with urban form is of great significance to the improvement of urban atmospheric environment and regional sustainable development of urbanization. In this study, we firstly examined the spatial variations of satellite-derived $PM_{2.5}$ and NO_2 and urban form metrics in Guangdong, and also explored their relationships. The results indicated that the highest and lowest values of $PM_{2.5}$ and NO_2 mainly occur over the Pearl River Delta (PRD) region, and over the eastern Guangdong, respectively. For the size and shape of urban patches, urban form had significant effects on air pollutants in Guangdong. $PM_{2.5}$ was positively correlated with AREA_AM, CA and SHAPE_AM, and NO_2 was positively correlated with LPI, PLAND and AREA_AM, while both of them were negatively related to PARA _AM and ENN_AM. It is inferred that polycentric urban form was associated with low $PM_{2.5}$ and NO_2 concentration, and reasonable urban planning would help mitigate the fine particle pollution.

1. INTRODUCTION

Urban development is manifested by the spatial expansion of urban land use and the evolution of ecological patterns driven by human economic development (Yan and Huang, 2013). Urban form, which reflects the spatial distribution of population, buildings, traffic roads and infrastructure, affects how the city functions, how much energy it consumes and how much air pollutants it produces (EPA, 2001; Ewing et al., 2003; Borrego et al., 2006).

Urban form can affect air quality by influencing configurations of streets, population density, distribution of emission sources and local meteorology including urban heat island effects the energy efficiency of buildings (Weng, 2003; Ewing and Rong, 2008; Zhou and Levy, 2008; Bereitschaft and Debbage, 2013). Pollutant dispersion around buildings is associated to the packing density of buildings, as well as building-height variability (Tominaga and Stathopoulos, 2013; Blocken, 2014), and the interaction of atmospheric conditions with buildings creates complex air flow structures in urban street canyons (Yazid et al., 2014; Lateb et al., 2016). Therefore, the spatial expansion and evolution of urban is a key factor affecting regional air quality (Clark et al., 2011; Han et al., 2015; Lu and Liu, 2016). Reasonable urban forms can reduce traffic congestion, save energy, and mitigate the negative impacts of aerosol emissions on regional healthy development. An in-depth understanding of urban form and its relationship with atmospheric aerosols helps to identify efficient urban land use patterns and develop healthy cities.

Located in the southernmost part of China, Guangdong experiences unprecedented rapid economic growth and population explosion in the past three decades, and its urbanization rate has increased from 66.2% in 2010 to 69.2% in 2016. Land cover changes rapidly, manifested as urban expansion, farmland loss and deforestation, resulting in more refined urban land use patterns, higher landscape fragmentation and stronger landscape heterogeneity. Due to rapid industrial development and huge energy consumption during urbanization process, air pollutant emissions have increased sharply and air quality in the province has deteriorated, greatly impairing the health of the population and the visibility over the region, have drawn widespread attention from the government and the public. The objectives of this paper are 1) to examine the spatial variation of air pollutants ($PM_{2.5}$ and NO_2) and urban form in Guangdong during 2016, and 2) to explore the correlations between air pollutants and urban form, aiming to provide a better understanding of $PM_{2.5}$, NO_2 and urban form in Guangdong as an empirical case.

2. DATA AND METHOD

The annual $PM_{2.5}$ products is downloaded from http://beta.sedac.ciesin.columbia.edu/data/set/sdei-global-annual-gwr-pm2-5-modis-misr-seawifs-aod, which consist of annual concentrations (μg/m3) of ground-level fine particulate matter ($PM_{2.5}$) with a spatial resolution of 0.1 °, combining AOD retrievals from multiple satellite instruments including the NASA Moderate Resolution Imaging Spectroradiometer (MODIS), Multi-angle Imaging SpectroRadiometer (MISR),

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and the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) (Van et al., 2016, 2018).

Data on the tropospheric NO_2 column concentration were collected from Royal Netherlands Meteorological Institute (KNMI) DOMINO v2.0 products, which are available at http://www.temis.nl/airpollution/no2col/no2month_tropomi.php. For this data, the spatial resolution was 0.125 × 0.125 ° latitude-longitude (equivalent to 12.5 km ×12.5 km), and the temporal resolution was 1 month. The OMI NO_2 product is a post-processing data set, based on the most complete set of OMI orbits, improved level-1b radiance data, analysed meteorological fields, and actual spacecraft data., which make it superior to the near-real time NO_2 data for scientific studies (Boersma et al., 2011).

Land cover data used in our study was 500m-resolution MODIS LUCC product (MCD12Q1) with IGBP classification scheme identifying 17 land cover classes (Friedl et al., 2010), and the accuracy is estimated to be 73.6% globally. The spatial distribution of urban elements has been mainly considered with nine landscape metrics, including Total Urban Area (CA), Percentage of Urban (PLAND), Largest Patch Index (LPI), Area-weighted mean patch area (AREA_AM), Area-weighted shape index (SHAPE_AM), Area-weighted Mean Perimeter-area ratio (PARA_MN), Area-weighted Mean Euclidean Nearest Neighbor Distance (ENN_MN), Patch Cohesion Index (COHESION) and Aggregation Index (AI). These metrics were calculated to characterize the urban form of 21 cities in Guangdong, with FRAGSTATS 4.2. After the Kolmogorov-Smirnov normal distribution test is performed on the dataset from 21 cities, the Pearson coefficient was calculated by bivariate correlation analysis to explore the correlation of air pollutants and urban metrics by Data Analysis Software SPSS 22.0.

3. RESULTS AND DISCUSSION

3.1 Spatial Variation Of $PM_{2.5}$ And NO_2 In Guangdong

The geographical distribution of ground-level annual average $PM_{2.5}$ over the Guangdong province in 2016 is shown in Figure 1. The annual $PM_{2.5}$ ranged from 14 to 38, with an average value of 25μg/m^3 in Guangdong, below the national standard for annual average $PM_{2.5}$ (35 μg/m^3). The highest values of $PM_{2.5}$ (> 25μg/m^3) mainly occur over the Pearl River Delta (PRD) region, whereas the lowest values (< 15μg/m^3) mainly occur over the eastern Guangdong. The maximum $PM_{2.5}$ occurs in Foshan, Zhongshan, Guangzhou and Dongguan, which is mainly attributed to large emissions from industrial pollution, urban traffic, and secondary aerosol generated by strong photochemical reactions. The minimum $PM_{2.5}$ mainly located in Chaozhou, Jieyang, Shantou and Shanwei, where the industry was less developed than PRD.

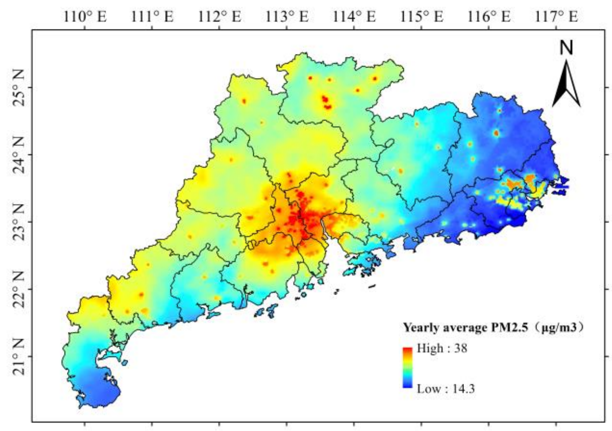

Figure 1. The spatial distribution of yearly average $PM_{2.5}$ in Guangdong, 2016

The spatial distribution of annual average NO_2 column concentration over the Guangdong province in 2016 is shown in Figure 2, which is quite different from the spatial characteristics of $PM_{2.5}$. The highest values of NO_2 mainly occur over the middle Pearl River Delta (PRD) region, including Guangzhou, Dongguan, Foshan, Zhenshen and Zhongshan. Cities along the boundary of PRD showed relatively higher NO_2 concentrations, whereas cities outside PRD had low NO_2 values.

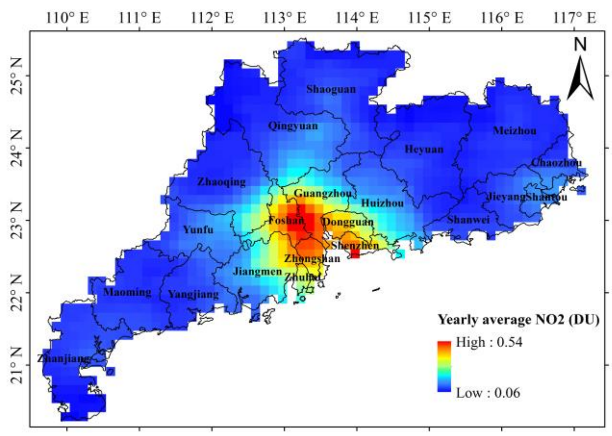

Figure 2. The spatial distribution of yearly average NO_2 in Guangdong, 2016

3.2 Urban Landscape Characteristics Of Cities In Guangdong

Nine urban landscape metrics in 21 cities were calculated by FRAGSTATS 4.2. For these metrics, CA is an important measurement to represent the expansion of urban land use, PLAND quantifies the proportional abundance of urban land in the landscape, and LPI characterizes the percentage of total landscape area comprised by the largest patch, AREA_AM is the area-weighted mean area of urban patches, SHAPE_AM measures the complexity of patch shape compared to a standard shape (square) of the same size, PARA_AM describes urban landscape configuration in terms of the complexity of patch shape, ENN_AM is interpreted as the main measurement of spatial connection between the urban patches, COHESION measures the physical connectedness of urban patches, and AI shows the like adjacencies of patches for urban land use.

The configurations of urban form for 21 cities in Guangdong varied significantly (Figure 3). All the data were standardized so that the ranges were between 0-1. Dongguan had the maximum of PLAND, LPI, COHESION and AI, and the minimum values of PARA_AM and ENN_AM. The minimum of CA and AREA_AM appeared in Foshan, and the minimum of these two metrics occurred in Yangjiang and Shanwei, respectively. Dramatic variations of the metrics in these cities suggested a diversity of urban form in Guangdong, showing a rhomboid, rhombus or constellation form.

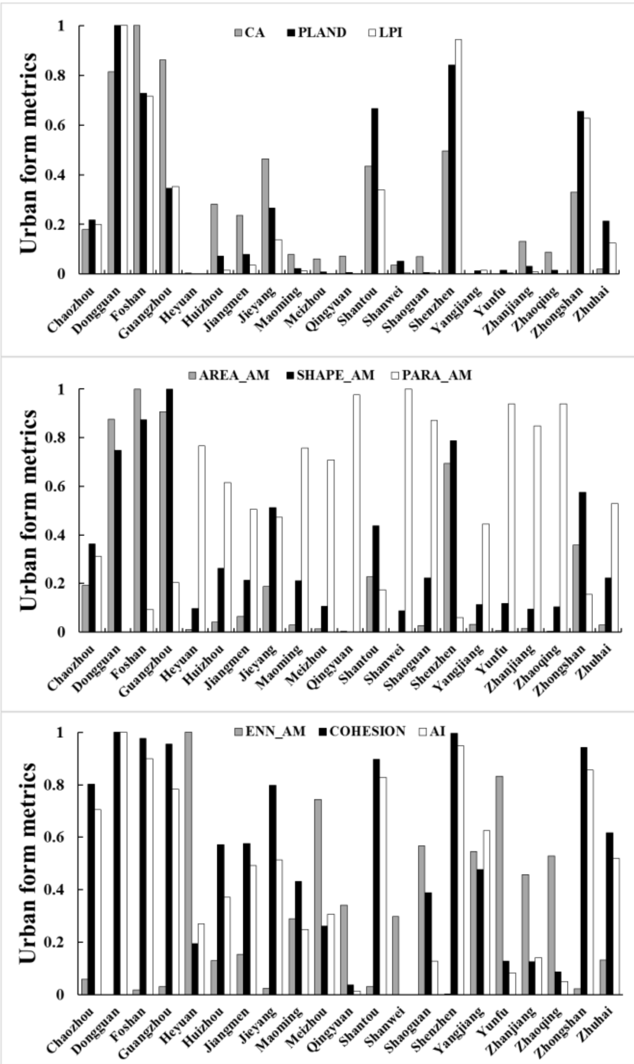

Figure 3. Nine urban form metrics of 21 cities in Guangdong, 2016

3.3 Relationship Between Air Pollutants And Urban Landscape In Guangdong

Table 1 shows the relationships of $PM_{2.5}$, NO_2 and urban form metrics, respectively. AREA_AM, CA and SHAPE_AM had the most significant impacts on the distribution of $PM_{2.5}$, while LPI, PLAND and AREA_AM played the most significant impacts in the distribution of NO_2, with the correlation coefficient being 0.862, 0.821 and 0.785. Due to the fast economic development in Guangdong, the urbanization process accelerated rapidly in Guangdong and the total urban areas were tremendously enlarged. The larger the city appeared, the more energy was consumed. Meanwhile, the wide distribution of various urban patches led to a large amount of air pollutant emissions. In theory, according to the relationships between $PM_{2.5}$, NO_2 and urban landscape pattern, the problem of $PM_{2.5}$ and NO_2 could be dealt with by changing the percentage of specific patches, but it would be difficult to decrease construction land area in quickly developing cities. So urban landscape configuration is of great significance to regional air pollution.

Moreover, $PM_{2.5}$ and NO_2 were negatively related to PARA_AM and ENN_AM. The Pearson coefficients of NO_2 and PARA_AM, ENN_AM were -0.765 and -0.62 at the significance level of P=0.01, implying the closely negative relationship between NO_2 and urban patch configuration. Therefore, important facilities should be constructed in the sub-centres of the city to decrease travelling distances between different urban patches. It could be inferred that the polycentric urban form reduces commuting distance and leads to less vehicle pollution, posing a positive impact on urban air quality (Loo and Chow, 2011).

	$PM_{2.5}$	NO_2
CA	0.488*	0.696**
PLAND	0.345	0.821**
LPI	0.421	0.862**
AREA_AM	0.542*	0.785**
SHAPE_AM	0.449*	0.774*
PARA_AM	-0.276	-0.765**
ENN_AM	-0.187	-0.62**
COHESION	0.279	0.734**
AI	0.263	0.757**

** Significance at the 0.01 level.
* Significance at the 0.05 level.

Table 1. The Pearson coefficient (r) between urban form metrics and air pollutants

4. CONCLUSION

Rapid Urbanization and economic development have resulted in dramatic increase in energy consumption, and consequently a large amount of pollutant emissions. This study tries to investigate the implication for reasonable urban form to alleviate environmental problems. In this paper, we explored satellite-derived $PM_{2.5}$ and NO_2 variations and their relationships with to urban form in Guangdong province based on satellite data of $PM_{2.5}$ concentration and land use map. Urban form was characterized using nine spatial metrics, including size, shape, regularity and fragmentation of urban patches. Results showed that the spatial patterns of $PM_{2.5}$ and NO_2 vary among the cities and the maximum values mainly occurs in the developed Pearl River Delta. The relationships between air pollutants and urban form metrics inferred that the spatial distributions of $PM_{2.5}$ and NO_2 were closely related to the size, shape and fragmentation of urban patches, suggested that optimizing urban form could improve regional air quality.

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