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Intraurban variability of particulate air pollution in Hong Kong - Exploring the influence of building morphology in high density urban environment by using traverse measurement

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1. Introduction

Particulate air pollution, most often measured as the concentration level of particles <2.5 or 10μm in diameter ($PM_{2.5}$ and PM_{10}), are associated in epidemiological investigations with adverse health outcomes including respiratory diseases and its relevant hospitalizations and higher mortality rates. The health impact of air pollution is even higher in the high density urban environment in Hong Kong (*Fig.1*) because the complex building morphology may reduce the ventilation, hamper the dispersion, consequently lead to a higher air pollution concentration level. Thus, there is a need to investigate the influence of building morphology on the spatial variability of particulate air pollution.

Fig. 1 The unique building morphology of high density urban environment in Hong Kong. (Photo by author)

The interaction between atmosphere and urban canopy is multi-scale (Oke 1992, 1997). At meso-scale, these interaction change the regional climatic condition thereby affect the air pollutant transport. And at local and micro-scale it leads to complex localized flow patterns and enhanced turbulence around the buildings, where the majority of both sources and receptors of pollutants are located; urban areas are complex networks of interconnected streets and buildings, and localised flows in the spaces between buildings and streets can affect overall dilution and create significant small-scale spatial variations of pollutant concentrations (Zannetti 1990, Cohen et al. 2004). Therefore, both the monitoring and modelling of those phenomenon at multi-scale integrally is currently one of the most challenging parts in the field of the environmental fluid dynamics (Zannetti 1990).

2. The Objective

Urban morphologies and geometries modify the local urban climatic condition, thereby also influence the pollutants dispersion. As mentioned, there is a need to investigate the influence of building morphology on the spatial variability of particulate air pollution. However, at present, for most of cases, there is a lack of high cost performance ratio approach for assessment and prediction intraurban air pollution spatial distribution, due to the congenital defects including high-cost, long-term (the large scale and fine monitoring network) or low resolution (the sparse monitoring network and remote sensing) of conventional intraurban air pollution assessment and prediction approaches.

In this study, instead of using conventional methods, a cost-effective geographical regression based approach was used to establish the regression model between urban morphological parameters and the particulate air pollution concentration level and further to map the intraurban spatial variation of PM_{10} and $PM_{2.5}$ in the central part of Hong Kong. The study outputs can be used to assess the urban atmospheric quality, to evaluate the relevant health impacts in existing urban context and to predict atmospheric environmental impact of the future urban development in Hong Kong.

3. Study Method

In this study, a series of traverse measurement have been conducted during summer time of 2014 for observing the spatial variability of particulate air pollution concentration in typical high density intraurban area in Hong Kong: Kowloon peninsula and the north part of Hong Kong Island. All measurement data and urban morphology parameters data (e.g. building coverage ratio and plot ratio) were analyzed using different resolution in Geographic Information System (GIS) to produce the regression analysis and geo-mapping process.

3.1 Traverse Measurement

To measure the spatial variation of particulate air pollution concentration, total 6 times of traverse measurement have been conducted along with two pre-designed measurement routes (Kowloon peninsula and Hong Kong Island respectively) during typical summer time of 2014 under selected weather condition (No rainfall, calm or light wind condition, relative humidity < 80%). The measurement was conducted using the mobile measurement platform which is a vehicle with weather condition sensors and air quality monitoring equipment on board (*Fig.2*). Routes of traverse measurements were designed to pass through a whole range of various urban morphologies based on the classification introduced by “local climate zoning system” (Stewart and Oke 2012). The high mobility of vehicle make it possible to cover a very large study area within a short time period (within 2h, the background of weather conditions and the background concentration levels keep stable) so that the spatial distribution at a large scale can be observed. The concentration level of PM_{10} and $PM_{2.5}$ were measured using the sampling interval of 1s.

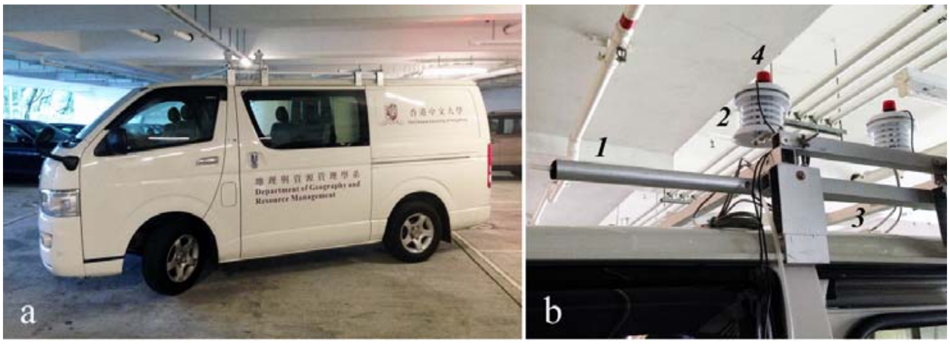

Fig. 2 The mobile measurement platform (a) and installed equipment (b: 1-PM sampling inlet, 2-Air temperature (T_a) sensor, 3-Relative humidity (RH) sensor and 4-pyranometer.)

3.2 Data Processing

All measured raw data can be merged into one single ArcGIS shapefile with the geo-location data recorded by GPS device (*Fig.3*). Humidity correction were conducted for data measured by the TSI DUSTTRAK™ DRX Aerosol Monitor that used in this study (Ramachandran et al. 2003, Laulainen 1993, TSI 2010). Contaminated data (e.g. data affected by exhaust emissions of very near vehicles) were manually excluded based on the video records of measurements. Further, measurement noise were eliminated by using the algorithm of Savitzky–Golay (S-G) filter.

All urban attributes data is the data represent the urban planning and design, building morphology, urban land use, population density and traffic volume. Etc. These data are collected from local government departments. For preparing the dataset for land use regression modelling, all these collected data were transformed to geographical information layer data.

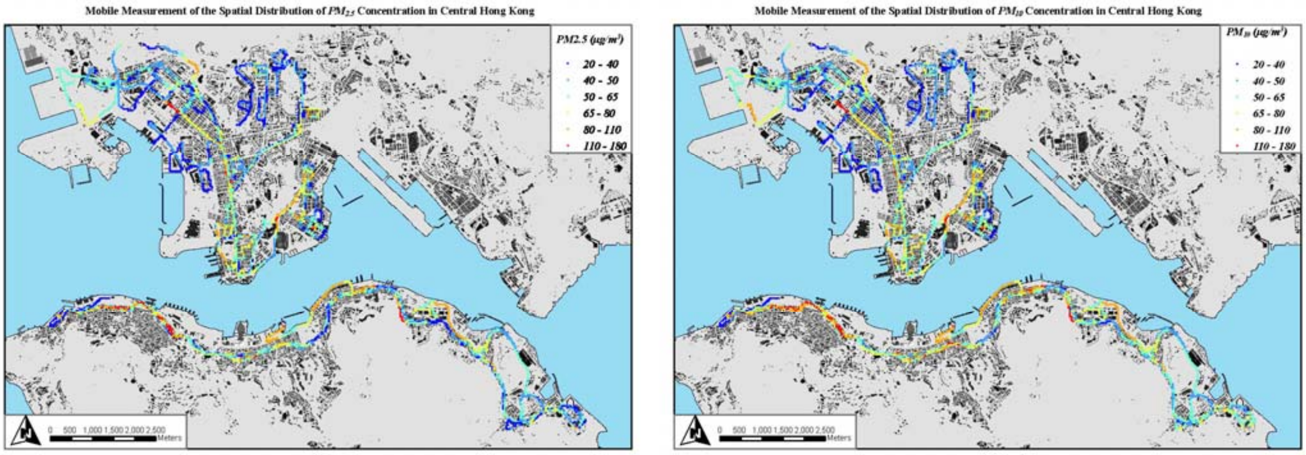

Fig. 3 Mobile measurement routes and measured data of concentration level of $PM_{2.5}$ (left) and PM_{10} (right).

3.3 Regression Modelling

Regression modelling is one of the most commonly applied statistic techniques in the urban study. It can be used to quantitatively explain relationships among different attributes of one geo-location (Andy 2005, Johnston et al. 2001). Regression techniques have been widely used for the study on the urban air pollution spatial distribution (Briggs et al. 1997, Richards et al. 2006). Figure 4 illustrates the basic workflow of the regression modelling process of this study. There are several candidate exploratory variables that represent the urban morphologies are relatively sensitive to the map resolution (e.g. SVF and FAD). Considering all data layers will be rasterized for the zonal statistics, regression modeling and final geo-spatial mapping, sensitivity tests were conducted for the purpose spatial resolutions. Collinearity among independent variables was avoided during the regression analysis. Therefore, only the most relevant impact factors were identified as the independent variables and used in the final regression model.

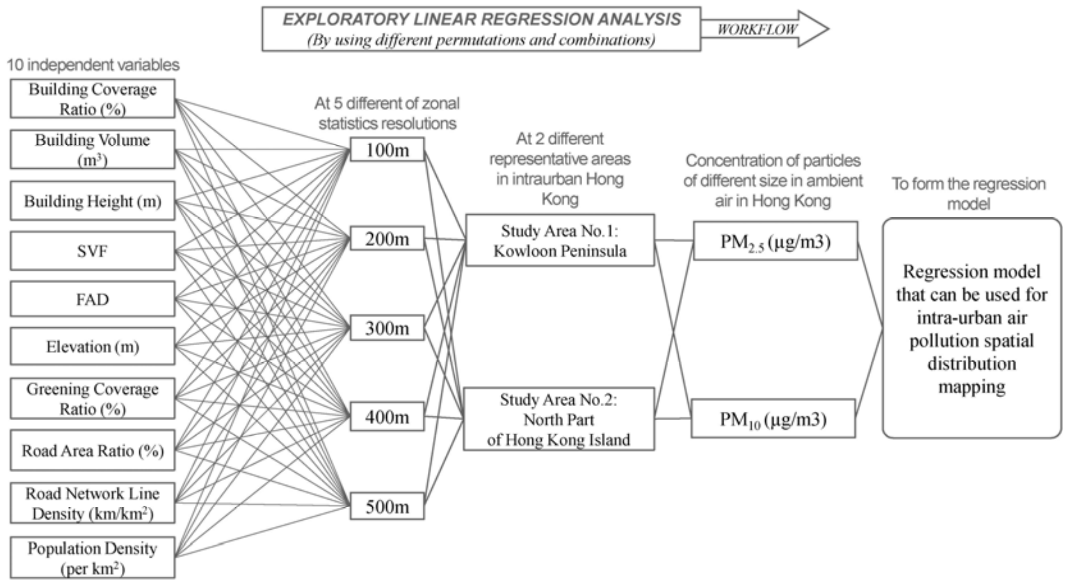

Fig. 4 The basic workflow of the regression modelling process that used in this study.

3.4 Regression Model and Spatial Mapping

Finalized regression models of the particulate air pollution concentration level are followings:

1) The regression model of the concentration level of $PM_{2.5}$:
   $(pm2.5) = 64.633(bd\_cov) + 0.168(bd\_height) + 70.536(rd\_area) + 6.101 \qquad R^2 = 0.549$
2) The regression model of the concentration level of PM_{10}:
   $(pm10) = 60.678(bd\_cov) + 0.285(bd\_height) + 64.326(rd\_area) + 10.364 \qquad R^2 = 0.557$

Where:

(pm2.5) = Concentration level of $PM_{2.5}$ ($\mu g/m^3$)
(pm10) = Concentration level of PM_{10} ($\mu g/m^3$)
(bd_height) = Building Height (m)
(bd_cov) = Building Coverage Ratio (0-1)
(rd_area) = Road Area Ratio (0-1)

Accordingly, geo-mapping of the particulate air pollution spatial variation are conducted based on the regression models *(Fig.5)*.

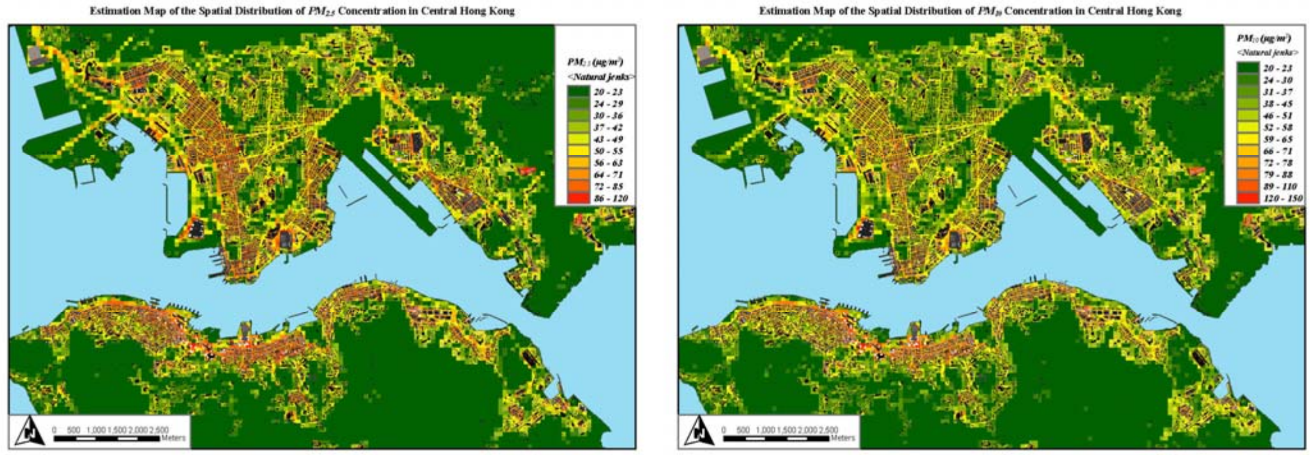

Fig. 5 Spatial variation mapping of the concentration level of $PM_{2.5}$ (left) and PM_{10} (right).

4. Conclusion

As shown by the final regression models, for both the $PM_{2.5}$ and PM_{10}, the structure of the model equation are same. The three most important impact factors of the concentration level of the intraurban particulate air pollution are building height, building coverage ratio and road area ratio. These results indicate that although the natural geographical condition of Hong Kong is more complex than some other cities and the major source of particulate air pollution of the whole city is from marine, the most decisive impact factors of intra-urban particulate air pollution concentration is still the building morphology and traffics. It is not difficult to understand and interpret these results. The building density and traffic density represents the pollution sources and emissions intensity. The building density also directly affects the dispersion of the air pollution. The emission and dispersion are the two most core phases that determine the concentration level of air pollution.

The study outputs of this study can be used both to assess the urban atmospheric quality in existing urban context and to predict atmospheric environmental impact of the future urban development. And it is also possible to integrate the regression models and produced intraurban air quality spatial variation maps into urban planning decision-making and design practice process. Further study will be conducted for more different types of air pollutants so that a comprehensive urban air quality spatial variation map system can be produced for Hong Kong.

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