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Research paper

# The role of urban function on road soil respiration responses

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ABSTRACT

Soil plays an important role in carbon storage. Accordingly, urban soil carbon and its storage have great impacts on urban carbon balance and future urban sustainable development. In this study, 151 traffic road soils in five urban functional areas were selected. The discrepancies of field soil respiration, soil physiochemical conditions among urban functional areas were calculated. Factor analysis and the Geographic Detector (GeoD) factor model showed that heavy metals had the most important impacts on soil respiration, followed by organic matter and urban function. Using the geographic detector method, individual factors and their interaction effects on soil respiration were tested. The GeoD interaction model demonstrated that no-linear enhanced interaction exhibited between C and ecological function, between N and residential function, S and industrial function. Moreover, no-linear enhanced interaction existed between Ti and ecological function, between Hg, Zn, Ni and residential function. The GeoD risk detector indicated that Soil temperature, N and Hg in different categories had obvious traffic road soil respiration impacts discrepancy. Overall, the results of this study will be useful for further investigation of urban soil treatment to enable healthy urban functional development.

## 1. Introduction

Globally, a total of 2500 Pg organic and inorganic carbon is held in soils, which is four times greater than in the biotic pool and about three times greater than in the atmospheric pool. Soil carbon is the last major pool of the carbon cycle, and changes in soil carbon storage can have a large effect on the global carbon budget (Knorr et al., 2005). Soil respiration (SR), including respiration by plant roots, bacteria, fungi and soil animals, is a key ecosystem process that releases carbon from the soil in the form of $CO_2$ (Kosugi et al., 2007). With rapid urbanization, soil quality and quantity in cities has changed dramatically (Koerner and Klopatek, 2010; Zhang et al., 2012; Li et al., 2017; Wang et al., 2017a,b). In contrast to the carbon emissions from urban soil, a growing number of related studies have quantified the total $CO_2$ levels in urban environments by calculating the emission inventories from estimates of fossil fuel consumption, evaluating the amount of sequestered carbon in urban vegetation, and studying short-term ambient $CO_2$ concentrations (Nowak and Crane, 2002; Sharma et al., 2017; Wang et al., 2017a,b; Trammell et al., 2017).

In 1933, the Athens charter declared that the city has four functions; providing habitat, job opportunities, rest and entertainment and commuter. Furthermore, the spatial distribution of city could be established by balancing and connecting these functions. A number of theories and approaches about designing of scientific spatial patterns had been put forward to satisfy the functionality of cities (Fenn et al., 1939). In some studies, urban functions were defined according to the basic social-economic activities, and could be organized at related functional areas such as industrial, residential, commercial, and public facilities and ecological zones.

In order to identity the key soil respiration influential factors, some control experiments or stepwise regression statistical methods had been applied (Raich and Tufekciogul, 2000; Rodeghiero and Cescatti, 2005; Lorenz and Lal, 2009; Beesley, 2014). But the response of soil respiration (SR) to interactions between natural condition and anthropogenic impacts is not well understood, but may increasingly affect future C storage under the combined urbanization impacts of heavy metal deposition, N deposition and climate change (Copeland et al., 2003; Li et al., 2013).

Different urban factions are related to different activities in the specific area, that provides an insight to explore how urbanization impact on soil respiration. Therefore, in this study, by designing field and lab experiments from five contrasting urban function areas, we challenged to investigate how changes and the interactions in physiochemical condition and urbanization regulating SR. Our main purpose was to reveal how soil physiochemical conditions and urban functions jointly influence urban traffic road SR by using statistical and geographical methods. Three main objects were: (1) to explore whether different factors have different significant impacts on SR, (2) to identify

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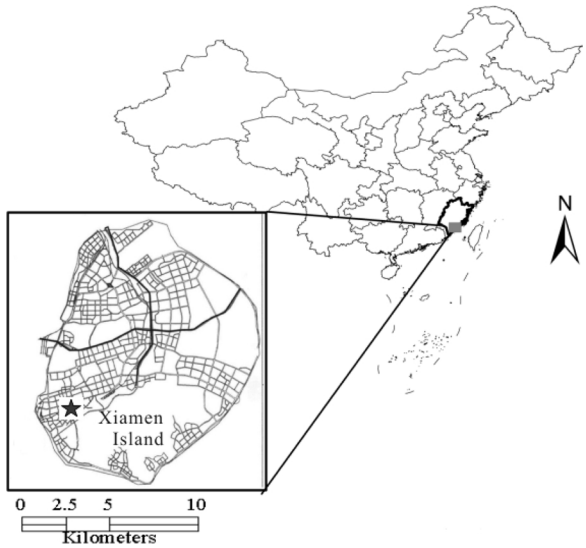


**Fig. 1.** Study area.

the combined strengths of different impact factors on SR at the group level and (3) to acquire the effect ranges. The results presented herein will facilitate future urban functional organization.

## 2. Materials and methods

### 2.1. Study area

Xiamen in southeastern China was selected for this case study. The city is characterized by mild weather, with the annual average temperatures of 22.7 °C, annual precipitation of 19.1 cm and intense solar radiation all year with average sunshine duration of 1877.5 h in 2015. Xiamen had a high urbanization rate of 79.65% in 2015. The city is characterized by rapid population growth with a wide range of both direct and indirect $CO_2$ sources, such as mobile emissions and land use changes (Fig. 1).

Soil from traffic roads in Xiamen was selected for urban soil representation. Traffic road in Xiamen is developed and characterized by strict traffic discipline. For example, types and running times of the vehicles are strictly arranged in different urban functional areas. Therefore, roads showed discrepancies across urban functional areas.

### 2.2. Experimental design and field measurements

To identify the effects of urban function on urban SR, 151 traffic soil samples in five typical functional areas of Xiamen were selected (Fig. 2). According to the urban planning discipline combined with 'The Code for Classification of Urban Land Use and Planning Standards of Development' (GB/T 21010-2007) (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2011), urban functional areas including industrial, commercial, residential, ecological and public facility areas were defined in this study and extracted by remote sensing and geographical information system tool (ArcGIS software 10.0).

Soil respiration rate, soil temperature and soil humidity were collected by using a Licor-6400 with a soil chamber. Prior to measurement, grass under the chamber was removed to minimize the effects of vegetation respiration. Following removal of roots, soil samples were oven dried (105 °C), sieved (2 mm) and ground, after which Total C and N were determined by dry combustion (Perkin-Elmer 2400 Series II CHNS/O Analyzer, Perkin-Elmer, Boston, MA, USA). Additionally, inorganic C content was determined by the acetic acid method, and heavy metals were measured by ICP-MASS.

### 2.3. Factor analysis

For factor analysis, multiple variables are grouped to reduce dimensionality according to the size of the correlation, such that correlation between variables within the same group is higher and the variable correlation between different groups is lower. New factors are formed in each group, and the factors are not related to each other. All variables can be expressed as a linear combination of common factors. Eq. (1) shows the factor analysis model:

$$\begin{aligned} X_1 &= a_{11}F_1 + a_{12}F_2 + \ldots + a_{1m}F_m + \varepsilon_1 \\ X_2 &= a_{21}F_1 + a_{22}F_2 + \ldots + a_{2m}F_m + \varepsilon_2 \\ &\vdots \\ X_p &= a_{11}F_1 + a_{p2}F_2 + \ldots + a_{pm}F_m + \varepsilon_p \end{aligned} \tag{1}$$

where the matrix A = $(a_{ij})$ is the factor load matrix and $a_{ij}$ is the factor loading, which is a correlation coefficient of the common factor $F_i$ and variable $X_j$. $\varepsilon$ represents influencing factors other than the common factors (Lattin et al., 2003). We conducted factor analyses to test how urban traffic road SR varies as a function of soil physiochemical conditions and urban functions.

### 2.4. Geographic detector model description

The geographical detector model (GeoD) is a spatial analysis model based on the theory of spatial heterogeneity and applied widely in many ecological researches. The model quantitatively detects and identifies various interactions between a geographical attribute and its explanatory factors (Wang et al., 2010). GeoD is composed of risk, factor, ecological, and interactive detectors. The Geographic Detector model is freely available from www.sssampling.org/geogdetector. Assuming that urban functions and certain physiochemical conditions jointly influence SR, the risk detector is used to search for the range in which factors significantly affect SR, while the factor detector is used to explore the impact of different factors on the research target. Additionally, the ecological detector is used to explore whether different factors have different significant impacts and the interactive detector is used to identify the combined strengths of different impact factors on SR. SR was set as the dependent variable in statistical analysis. Multiple physiochemical and urban function factors set as independent variables were input into the GeoD model for simulations.

### 2.5. Standardization

Different data type exists on physicochemical condition and urbanization functions. For demonstrate impacts on SR from parameters, we standardized the data according to Eq. (2).

$$y_i = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}} \tag{2}$$

where $y_i$ is the standardized data, $x_i$ is the original data. $x_{\min}$ and $x_{\max}$ represent the minimum and the maximum value of the original data respectively.

## 3. Results and discussion

### 3.1. Soil characteristics

The surveyed soil $CO_2$ emissions ranged from 0.216 μmol m$^{-2}$ s$^{-1}$ to 4.051 μmol m$^{-2}$ s$^{-1}$, with an average of 1.604 μmol m$^{-2}$ s$^{-1}$. The SR was lowest in the public facility area, and increased from 0.531 μmol m$^{-2}$ s$^{-1}$ to the highest value of 2.117 μmol m$^{-2}$ s$^{-1}$ in the residential area. Overall, the SR rate in this study was slightly lower than those exhibited in the similar climatic condition area such as Changle, Fujian Province (with 2.26 ± 0.29 μmol m$^{-2}$ s$^{-1}$) and Taicang, Jiangsu Province (2.33 ± 0.13 μmol m$^{-2}$ s$^{-1}$) (Jiang et al., 2014). But it was far lower than the other studies reported in Phoenix,