Transportation Research Part D xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Detrended cross-correlation analysis of urban traffic congestion and NO_2 concentrations in Chengdu

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ARTICLE INFO

Article history:
Received 22 December 2015
Revised 30 December 2016
Accepted 30 December 2016
Available online xxxx

Keywords:
Detrended cross-correlation analysis
Traffic congestion
Hourly average congestion length
Vehicle emissions
Global positioning system

ABSTRACT

In urban congested road sections, usually there exhibits elevated exhaust emissions due to longer idling and more frequent acceleration of vehicles. Using detrended cross-correlation analysis (DCCA), the relationship between air pollution and traffic congestion in the urban area of Chengdu was investigated. In order for a better quantification of the congested condition in a relatively large spatial region, a new measure, i.e., the congestion length (CL), is developed, extracted, and estimated using the Google Real-Time Traffic Maps and GIS technology. Relationships between the hourly average congestion length (HACL) and NO_2 concentrations in the urban area of Chengdu from 12 May to 17 May, 2013 were analyzed. A high long-term cross-correlation between HACL and NO_2 was observed, implying the ambient NO_2 concentration fluctuations are positively cross-correlated with urban traffic congestion in the form of a power function. However, the ambient NO_2 concentration did not respond immediately to the change of road traffic due to a relatively slow and lagged photochemical reaction process. A time lagged cross-correlation was further analyzed and showed that the time lag could be as large as 10 h. These findings can be used for improving air quality forecasting accuracy by taking into account the time lags in correlation between emissions and air quality.

1. Introduction

Nitrogen Dioxide (NO_2) is one of the primary pollutants and can adversely impact both human health and the environment. Approximately 50% of the total NO_2 emissions are from road way traffic, primarily from vehicle tailpipes (Basarić et al., 2014; Frey et al., 2010; Shon et al., 2011). In recent years, traffic flow tends to exceed available road capacity in China. Thus, queuing time in congested roadways has increased, leading to more idling and acceleration. As a result, vehicle emissions have increased (Ahn et al., 2002; Colberga et al., 2005). Hence, information regarding urban traffic congestion is essential for effective air quality management.

Many efforts have been made to understand the relationship between traffic activities and air quality (Sjödin et al., 1996; Premananda Singh and Gokhale, 2015). For example, Kendrick et al. (2015) found that the ambient NO and NO_2 concentration along an intersection of two busy streets was closely associated with the traffic volume. Researchers have shown that a

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http://dx.doi.org/10.1016/j.trd.2016.12.012

better understanding of the relationship between NO_2 concentrations and road traffic congestion can lead to more robust air pollution forecasting models. For example, some research has aimed to estimate the traffic-contributed NO_2 concentration using meteorology and road traffic data. A variety of approaches such as Multi-layer Perceptron, Support Vector Machine, Multiple Linear Regression, and Neural Networks have been used for this purpose (Shi and Harrison, 1997; Gardner and Dorling, 1999; Perez and Trier, 2001; Kukkonen et al., 2003; Makra, 2005; Juhos et al., 2008).

Continuous traffic volume data is crucial to understand the relationship between traffic congestion and NO_2 concentrations. Several observable factors can be used to define a congestion condition for given roadway segments such as increased traffic density, vehicle speeds, and queuing time (Schäfer et al., 2002; Smit et al., 2008; Jeske, 2013). It's preferable that the information is measured consistently in the traffic flow. However, one of the key limitations of the current traffic information for congested roadway segments is that the traffic data are measured statically, which implies that the traffic data could only reflect the traffic situation of predetermined locations where measurements were made. Of course, the coverage of the traffic situation can be extended by increasing the number of measuring stations. However this is costly. These limitations make it difficult to quantify the relationship between NO_2 concentrations and traffic congestion in a large region such as an entire city.

Previous studies on cross-correlations between NO_2 concentrations and traffic data usually assume that the investigated time series are stationary (Rand, 2005). However, recent studies have shown that both NO_2 concentrations (Shi et al., 2008; Lee and Lin, 2008) and traffic data time series (Shang et al., 2008; Li and Shang, 2007) are nonstationary and nonlinear, which indicate there exist nonlinearly increasing or decreasing trends in these time series.

To eliminate the effect of nonstationarity, the detrended fluctuation analysis (DFA) (Peng et al., 1994) has been proposed to analyze the long-term auto-correlations in time series, particularly for single time series. In order to study the cross-correlation between two nonstationary time series, Podobnik and Stanley (2008) proposed the method of detrended cross-correlation analysis (DCCA). This approach has been used to quantify the long-term cross–correlations between two nonstationary time series (Vassoler and Zebende, 2012; Shi, 2014a).

Vehicle emissions can be affected by a variety of factors, such as vehicle speed, travel time, traffic conditions, roadway conditions, driver behavior, and others. Thus, vehicle emissions can vary from trip to trip and from route to route. Due to the complexity of photochemical reactions in the atmosphere, especially the NO_x/VOC-O_3 cycle (Kumar et al., 2008; Shao et al., 2009), the NO_2 concentrations in the atmosphere do not respond immediately to changes in traffic. A lag in time is expected between the NO_2 concentrations and urban traffic congestion.

In this study, a new indicator describing urban traffic congestion combined with Google Real-Time Traffic Maps and GIS technology is proposed. The main objective of this study is to investigate the cross-correlations between NO_2 concentrations and traffic congestion in the urban area of Chengdu with the DCCA method. A better understanding of the relation between traffic congestion and air pollution is demonstrated.

2. The study data and material

In general, traffic congestion data are mainly acquired by two approaches. One is to use stationary traffic volume measurements within a relatively small region or point (Shang et al., 2008; Anbaroglu et al., 2014). However, this approach makes it difficult to reconstruct the real time traffic conditions for the whole urban area because traffic data were measured only at several predetermined locations. Another approach is to use GPS floating car technology (Kerner et al., 2005; Zhang et al., 2011), installed in the vehicle to collect vehicle locations and thus to determine the traffic speed of the road network. However, this approach is expensive and time-consuming since a large number of cars have to be deployed to follow the traffic. In recent years, the development of mobile devices for communication has enabled the deployment of GPS on a cellphone, which makes it possible to collect traffic information via mobile phone users when they are driving their vehicles. As a result, a new way to provide traffic information has been added to Google Maps, a product by Google Inc. using internet/cellphone/GPS technology. The traffic information provided by Google Maps is real-time and with relatively high space and time resolution in most downtown areas (Seymour et al., 2007; Jeske, 2013). Furthermore, these traffic maps are colored differently to represent different traffic conditions, e.g., red for congestion and green for free-flowing (Di et al., 2016). Therefore, the length of the roadway colored in red is referred to as the congestion length herein. Since the Google traffic maps are free to access, the proposed method for traffic analysis is handy with low cost. However, these products have not been widely used for traffic and environmental studies.

Vehicle emissions are highly affected by traffic conditions (e.g., traffic volumes, traffic speed of road network, and others). Heavy congestion indicates a relatively high frequency of stop-and-go events and leads to relatively high emissions due to a large traffic volume at low speeds. The Real Time Traffic Information (RTTI) of Google Maps are presented by coloring the roadways, i.e., red, yellow and green for different traffic conditions. The red color in Google Maps refer to heavy traffic with both low speeds and high volumes, the green color refers to free flow traffic condition with high speeds and likely low volume, and the yellow color refers to somewhere in the middle between heavy traffic and free flow. Since the heavy traffic condition is usually associated with high vehicle emissions, only the red traffic data is taken into account.

In this study, the hourly average congested length (HACL) is extracted from the Google real-time traffic maps to represent the urban traffic congestion using GIS technologies. The estimation of HACL will be discussed in the following section. The study area is located in Chengdu city, Sichuan Province, China with an area of approximately 541 km^2 as shown in Fig. 1.

Please cite this article in press as: Shi, K., et al. Detrended cross-correlation analysis of urban traffic congestion and NO_2 concentrations in Chengdu. Transport. Res. Part D (2017), http://dx.doi.org/10.1016/j.trd.2016.12.012