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A novel approach for investigating the trends in nitrogen dioxide levels in UK cities

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ABSTRACT

This paper investigates the variations in levels of nitrogen dioxide, NO_2, monitored over the decade 2001–2010, in Newcastle-upon-Tyne (UK) city centre, to develop fundamental understanding of the periods of persistence of levels of NO_2 greater than 40 $\mu g\ m^{-3}$ (~21 ppb) defined as air pollution event duration. The appropriateness of the hazard theory as a mechanism to understand failure rate of the duration of poor air pollution events was explored. The results revealed two types of air quality events. The longer duration air quality events (between 24 and 68 h) were associated with the "extreme-weather" conditions and were responsible for a small number of extremely long air pollution duration events. These created bias in the results and therefore the analysis was restricted specifically to the 'normal-weather' related air pollution event durations, conforming to a geometric distribution. This novel approach shows promise as a mechanism to monitor and investigate year on year trends observed in air quality data.

1. Introduction

Air pollution has been a well-known and greatly researched topic over the past few decades but air quality remains one of the major environmental issues in modern society (Tiwary and Colls, 2010). Outdoor air pollution causes approximately 1.3 million deaths every year worldwide (WHO, 2011), and approximately 310,000 premature deaths in Europe (Department for Business Innovation and Skills, 2012). Further, approximately 40 million people within the 115 largest European cities are still exposed to air quality exceeding the European Union (EU) limit values for at least one pollutant (WHO, 2012). In 2011 UK House of Commons (HC) Environmental Audit Committee Report highlighted that, poor air quality reduces the life expectancy in UK by 7–8 months on average and that air pollution is attributable to approximately 30,000–50,000 premature deaths in UK every year with a cost implication of up to £20 billion a year to society (HC, 2011).

1.1. Policy context

The UK has been at the forefront in positively responding to the air pollution issues; this has been evident with the introduction of the 1995 Environmental Act which was later followed by the Air Quality Strategy (AQS) in 1997. Between the year 1997 and 2007, the AQS policy progressed through several revisions and each included measures (such as Local Air Quality Management Areas (AQMAs), Best Available Technology (BAT) for industries, policy measures, improvement in technology, etc.) that considered different pollutants (Environmental Protection UK, 2012). However, despite many initiatives introduced by the UK Government to improve air quality, the UK in 40 out of 43 zones monitored (Defra, 2012) continues to experience pollution exceedences on an unacceptably high number of days per annum. The Environmental Audit Committee (HC, 2011) stressed that air pollution issues still remain nearly 60 years later after the Great London Smog. This is evident from the fact that more than 60% of UK local authorities have declared one or more AQMAs for exceeding the air quality limit set by EU (Chatterton, 2011).

At present the three most problematic pollutants in Europe are ozone (O_3), nitrogen dioxide (NO_2) and particulate matter (PM). However, in the UK whilst the level of O_3 is generally within limit (100 $\mu g/m^3$, daily maximum of a running 8-h mean, Defra, 2007), the level of NO_2 and PM are the main pollutants currently posing unacceptable risk of exceedences (Chatterton, 2011). The Environmental Audit Committee (HC, 2011) highlighted that 40 out of the 43 assessment zones in the UK are failing to meet the EU targets. The UK was facing legal challenges from the EU in 2010 due to breaching the Directive 2008/50/EC for PM_{10} (particulate matter with size smaller than 10 μm) and NO_2 (Chatterton, 2011). Road

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transport is the biggest source of urban air pollution as 90% of AQMAs across the UK have been declared due to road transport related pollution (Chatterton, 2011). This is despite car industry investment in reducing tailpipe emissions from vehicles.

The UK Government's commitment to monitoring pollution and policy outcomes has led to significant investment in measuring pollution in all large towns and cities and since 1998 has established the Automatic Urban and Rural Network (AURN). These monitoring sites use precision monitors that are regularly calibrated and all data is ratified on a three monthly cycle. The data is freely available on the Department of Environment Food and Rural Affairs (Defra), website and currently provides continuous monitoring from 127 air pollution monitoring stations (http://uk-air.defra.gov.uk/networks/brief-history). These data form the basis for assessing the success of UK Government policies in delivering levels of air quality that pose, no risk to health and through rigorous analysis and research provide knowledge upon which future policies are based.

A collation of the available information from the UK Government reports (Defra, 2004, 2007, 2010, 2012; HC, 2010) suggests that the number of AQMAs has increased steadily between 2003 and 2010 and approximately 90% of those declared AQMA throughout the years are due to road transport (HC, 2010). In 2010 the number of UK monitored sites subject to breaches of NO_2 hourly levels has increased rapidly since 2009, however, the total number of Local Authorities (LAs) who declared AQMA sites has only slightly increased. This suggests that many LAs have begun the practice to join together previously identified AQMA sites of NO_2 and declared larger local AQMAs. This practice has become necessary in the UK because AQMA declarations are traffic related. Solving traffic-related problems locally (for example relocation of traffic queues to open space, cascading of queues to spread the pollution along routes (Tate and Bell, 2000)) often can cause rerouting of traffic and a consequential displacement of the air quality problem. Therefore, in order to develop traffic management measures to resolve the air quality issue a much wider management area needs to be declared. According to Defra (2012), 63% of UK Local Authorities out of a total of 403 Local Authorities have declared one or more AQMAs in 2011, which is a significant increase compared to the corresponding figure of 29% in 2003, (Defra, 2004), while the number of AQMAs declared for NO_2 has risen by nearly 350% from 160 to 549 AQMAs, during the same period.

1.2. Methods for air quality data analysis

Different approaches to the analysis of the AURN and similar air quality data have been adopted in other studies, of which an overview is given in this section. A simple but effective method for detecting small changes in time series is the cumulative sum technique, CUSUM (Barratt et al., 2007). Beevers and Carslaw (2005) applied the CUSUM method to study trends in ambient concentrations and have shown that the trends in NO_2 have not shown a decline in recent years as was expected to have occurred with the continuing decline in urban NO_x emissions (associated with the introduction of Euro standards vehicle; LEEZEN, 2012). Beevers and Carslaw (2005) analysed the trends in annual mean NO_x and NO_2 between 1998 and 2005 at a selection of roadside and kerbside monitoring sites and found that whilst most of the sites show a decline in NO_x, NO_2 concentrations show little change or an increase. Also, the ambient NO_2/NO_x ratio increased at some sites by more than would be expected due to the decrease in NO_x on its own. In particular nitrogen oxide concentrations at London Marylebone Road increased up to the year 2000 and have since declined whilst NO_2 concentrations changed inline with NO_x until 2003 when they showed a large increase. Building on this earlier work an approach was developed to detect abrupt changes to the concentration of NO_2 and other species in ambient time series data (Carslaw et al., 2006). Such changes can arise for various reasons, for example, the rapid introduction of a new technology or traffic management measure. The technique was developed further to allow the uncertainty in the timing of the change point (the uncertainty level) to be quantified and the uncertainty interval with which it is associated. The uncertainty quantification was derived using randomisation and bootstrap re-sampling techniques. These methods are appropriate where the uncertainty distribution is non-normal as is the case for most air pollutant concentration distributions.

This paper presents the results of the application of the Hazard Base Modelling approach, with theory and earlier research described in the next Section 1.3, to establish whether the changes in the duration of air pollution events can be revealed. Precision data for the period 2001–2010, available from an AURN monitoring site in Newcastle-upon-Tyne, UK, was used for this study. Firstly, by way of context, the current state of the air quality in the UK is presented followed by a short description of the characteristics of the monitoring site from which the pollution data used in this study was captured. Next, the changes in pollution concentrations over the period 2001–2010 are presented and the method by which the pollution event durations were defined is described. Subsequently, the steps in the hazard modelling process are defined in the context of air quality before the results of the analysis are presented.

1.3. Hazard theory and its application to air pollution data analysis

Whilst trend analysis addresses the changes in magnitude of pollutant levels it does not explicitly deal with the prevalence or persistence of pollution over time. A statistical method that can embrace this type of approach is the Hazard Theory proposed by

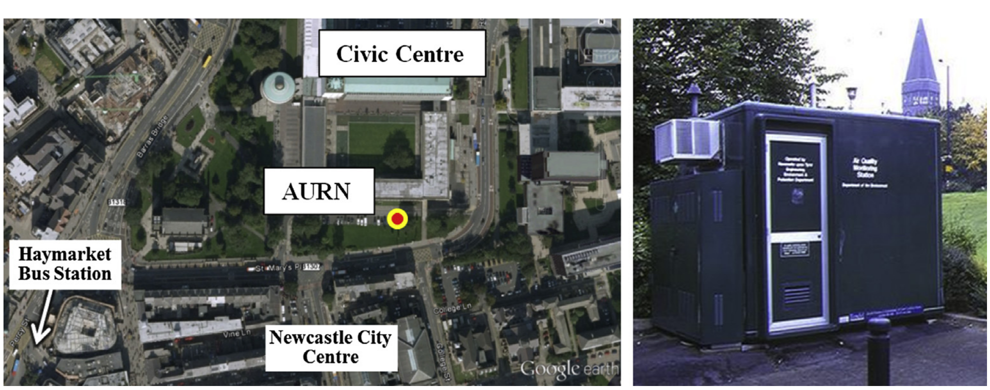

Fig. 1. Map of Newcastle area (left) and photo of AURN station (right).