DEVELOPMENT OF THE GIS-BASED REGRESSION TECHNIQUE FOR PREDICTING TRAFFIC-RELATED POLLUTANTS (CORNWALL, UK)

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INTRODUCTION

Health

Traffic emissions are a major contributor to tropospheric air pollution and the main source of nitrogen dioxide (NO_2) in the UK (NETCEN n.d.). Due to its relative ease of monitoring nitrogen dioxide, itself a health-damaging pollutant, is often used as a proxy marker for other traffic-related air pollutants (e.g. carbon monoxide, PM_{10} (particulate matter with an aerodynamic diameter of less than 10 µm) and $PM_{2.5}$, black smoke, benzene, polycyclic aromatic hydrocarbons (PAHs) and metals, including arsenic). Human exposure to traffic-related pollution can contribute to an increased risk of death, especially relating to cardiopulmonary causes, and can increase the risk of respiratory symptoms (Krzyzanowski *et al.* 2005). The elderly and children are particularly susceptible to the health insults associated with air pollution and there may also be severe long-term health implications of the effects of pollutants on developing lung tissue (WHO 2005).

Legislation

Based primarily on health effects, the UK National Air Quality Strategy (NAQS) implemented limit values on concentrations of traffic-related pollutants (benzene, 1,3-butadiene, carbon monoxide, lead, PM_{10}, sulphur dioxide and nitrogen dioxide). The limit values applying to nitrogen dioxide are 200 µg m^{-3} (hourly mean) and 40 µg m^{-3} (annual mean) to be met by December 2005. These standards are continued to 2010 by the EU First Air Quality Daughter Directive (99/30/EC) (DETR 2000). The NAQS 2005 annual objectives apply to "*…non-occupational near-ground level outdoor locations where a person might reasonably be expected to be exposed over the relevant averaging period*"; hence the annual mean nitrogen dioxide objective (40 µg m^{-3}) applies at the façade of residential properties, schools, hospitals, libraries, etc., while the NAQS hourly mean objective for nitrogen dioxide (200 µg m^{-3}) also applies at kerbside sites (e.g. pavements of busy shopping streets). It is the responsibility of local authorities in the UK to ensure that the population is not exposed to concentrations in excess of NAQS objectives by monitoring, modelling and mapping traffic-related pollutants (e.g. nitrogen dioxide) in susceptible areas. At present however, there is no universally agreed methodology for application to air quality datasets (AQEG 2003).

Context of study

This study attempts to improve the understanding and the mapping of nitrogen dioxide dispersion in Cornish towns using GIS techniques, to inform the decision making of local Environmental Health, transport and planning departments. The technique used in this study builds on concepts introduced in other works (specifically Briggs *et al.* 1997) and seeks to contribute to the broader knowledge base of GIS mapping of traffic-related pollutants.

METHOD

SAVIAH regression model

Using the SAVIAH model developed by Briggs *et al.* (1997; 2000), this study demonstrates the use of multiple linear regression analysis and GIS overlay to predict the spatial dispersion of nitrogen dioxide as a proxy for all traffic-related atmospheric pollutants. The use of GIS is central to the regression technique reported here, providing the means for data capture, processing, analysis and presentation.

Spatially extensive diffusion tube surveys were carried out by the Air Quality Unit (AQU) at Cornwall College on behalf of the Cornwall Air Quality Forum (CAQF) across 63 sites in Bodmin, North Cornwall, UK (SX074667) in 2003 (Parsons and Salter 2003a; Barnes *et al.* 2005). These provided annual average nitrogen dioxide concentration data points at a range of locations from kerbside to background and were used to calibrate the SAVIAH regression model to local variables. Each of the three variables: traffic volume (*Traff*), land use (*Land*) and altitude (*Alt*), were weighted as per the SAVIAH equation (Equation 1) and the mean annual NO_2 concentration (*C*) calculated for each site.

$$\boldsymbol{C} = 38.52 + 0.003705\ \boldsymbol{Traff} + 0.232\ \boldsymbol{Land} - 5.673 \log_{10}(\boldsymbol{Alt}) \qquad (1)$$

Where $\boldsymbol{C}$ = mean annual NO_2 concentration

$$\boldsymbol{Traff} = 15\ Tvol_{0\text{-}40} + Tvol_{40\text{-}300} \qquad (2)$$

$$\boldsymbol{Land} = 8\ HDH_{0\text{-}300} + Ind_{0\text{-}300} \qquad (3)$$

$\boldsymbol{Alt}$ = Altitude (m AOD)

[From Briggs *et al.* (2000)]

Metadata regarding the variables is depicted in Table 1. The *Traff* and *Land* components were calculated in a GIS (ESRI™ ArcGIS® v.9.1) (Equations 2 and 3), by intersecting the data layers within 40 m and 300 m buffers around each monitoring site. Visual Basic code "GRIDSPOT" (http://arcscripts.esri.com/details.asp?dbid=12773) was used to determine the *Alt* component.

Table 1. Data types and sources

Variable	Data type	Source
NO_2 concentrations	Annual hourly average NO_2 concentration ($\mu g\ m^{-3}$)	Diffusion tube field survey
Traffic volume	Annual average daily traffic (AADT) shapefiles	Cornwall County Council (CCC)
Topography and land cover	OS MasterMap topographic layer	CCC
	Digital aerial photography	CCC
Altitude	DSM raster tiles	CCC

Having calculated the SAVIAH equation for all 63 monitoring sites a sub-set of representative sites (n = 16) were chosen using stratified random sampling. The monitored (observed) NO_2 concentrations were compared with the (predicted) concentrations calculated from the SAVIAH equation using linear regression analysis. Substituting the SAVIAH predicted concentrations into the resulting regression equation as "*x*", the locally calibrated equation was then applied to the remaining (47) sites. Observed and predicted results were again compared using regression analysis to assess the equation's validity.

Modified regression model

The SAVIAH equation was modified to try to improve the data "fit". Regression calculations on the individual variables against monitored NO_2 concentrations showed that for the Bodmin data only the *Traff* component bore any significant correlation. The *Land* and *Alt* variables were therefore replaced by "*Distance to buildings*" (Euclidean distance of each monitoring site to the nearest building) to represent the negative influence of buildings on pollutant dispersal. Multiple linear regression analysis was calculated against monitored data from all 63 sites of the 2003 monitoring survey and the spatial correlation of the residuals was examined statistically in ArcGIS®. The modified regression equation derived from this analysis is shown in Equation 4.

$$\boldsymbol{C} = 17.6 + 0.000776\ \boldsymbol{Traff} - 6.25\ \log_{10}(\textbf{\textit{Distance to buildings}}) \qquad (4)$$

Subsequent diffusion tube monitoring on a finer spatial resolution than the 2003 survey (n = 40) has been in progress since 2004. Twelve-month average NO_2 data (to 30 June 2006) for these sites were used to validate the modified regression equation and predicted and observed NO_2 concentrations were compared in a regression analysis.

RESULTS

Using values from a nitrogen dioxide diffusion tube survey in Bodmin (2003) the SAVIAH model was shown not to correlate well with the monitored data at this location (R^2=0.0%; p=0.904). However a modified version of Briggs' model using variables relating to traffic volume and proximity to buildings in a GIS-based regression technique (Barnes 2006) provided an improved fit (R^2 = 83.0%, p = 0.000). Further comparison of the modified model against an independent dataset from a recent (2006) diffusion tube "cluster" survey in the town also showed reasonable correlation (R^2 = 55.5%, p = 0.000) (Fig. 1).

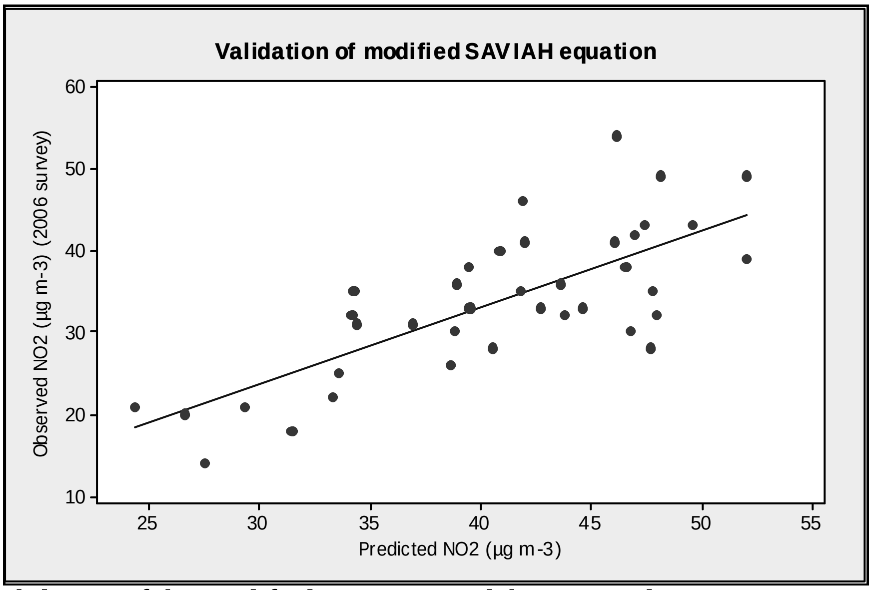

Fig. 1; Validation of the modified SAVIAH model using Bodmin 2006 monitoring data (R^2=55.5%; p=0.000)

A 10 m resolution nitrogen dioxide prediction map produced using the modified model depicts the spatial variation of traffic pollutants in the town and their dispersion from source. The purpose of the prediction map is to provide local environmental health, traffic and spatial planning departments with the necessary information for them to act to reduce public exposure to traffic pollution.

DISCUSSION

The high degree of correlation between *Distance to buildings* and monitored NO_2 suggests that the proximity of houses to roads not only increases the risk of exposure to the inhabitants but actually elevates concentrations by restricting the dispersion of traffic-related pollutants. This intensifying effect of canyon streets on pollution levels has been observed in Bodmin and in other towns in Cornwall (Parsons and Salter 2003b). The obligations for Environmental Health and Planning Officers are to ensure that members of the public are not exposed and to restrict the development of roadside properties where this would exacerbate the problem. The ability of this model to identify elevated concentrations associated with close proximity to buildings is therefore of great value.

CONCLUSION

This investigation set out to test whether the SAVIAH equation devised by Briggs *et al.* (1997, 2000) may be applied in Cornish towns, and found that, while local calibration of the existing model did not fit the monitored data at this site, a modified model based on the original technique could be developed to give a reasonable fit.

Further work will be undertaken to refine this technique especially with respect to the representation of traffic pollutants in canyon streets in other small rural towns in Cornwall.

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