DIFFUSION TUBE SAMPLING STRATEGIES IN TWO UK BOROUGHS

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ABSTRACT

Much of the effort towards monitoring nitrogen dioxide (NO_2) air pollution in the UK is designed around passive diffusion monitoring. This technique is relatively inexpensive and allows many more locations to be assessed than by using more expensive methods. The locations of individual tubes are rarely selected on anything other than individual merit; therefore the potential for spatial interpretation of the measurements is limited due to the resulting skewed distribution of monitoring sites. Monitoring points are often grouped together, dictated by the location of urban centres within an area, with sparse sampling towards the edges of a region due to geopolitical constraints.

This paper compares the measurement strategies from two UK boroughs; one selecting its discrete monitoring sites by individual merit, and one deploying them to conform to a regular grid. The potential for spatial interpretations of the two data sets is assessed, and a comparison of the relative strengths of the two strategies is presented. The data are analysed within a GIS, which enables comparative mapping and statistical analyses to be performed. A direct comparison of the two sampling strategies demonstrates clear differences, especially in regions where the discrete sites have large distances between them. The differences are smaller in urban areas, where the discrete sites have a greater density of points, but there is still a positive bias towards the grid technique.

INTRODUCTION

Long term studies of air pollution can yield important information about the temporal and spatial variations of a pollutant within the constraints of the specific study. The manner in which the data for a study are obtained, especially the method and position of the sampling stations, can potentially affect the perceived patterns.

In the UK air pollution is monitored using a variety of measures ranging from accurate, but expensive, real-time units, to cheaper passive diffusion techniques. Diffusion sampling is used to monitor a variety of pollutants, but is widely employed for nitrogen dioxide (NO_2). This secondary pollutant is, in the UK, largely derived from motor vehicle generated primary pollutants. As such it has become the focus of much of the UK's current pollution control efforts, as it represents a perceived health risk higher than that of the primary pollutants from which it is derived.

The observation of NO_2 by passive diffusion techniques is performed within several surveys coordinated on both national and local scales. The data collected from the NO_2 diffusion tube network are designed to be as representative as possible of the real pollution situation, as they are used as the basis of schemes aimed at regulating and reducing atmospheric pollution. Each local authority in the UK maintains four of these NO_2 diffusion tubes as part of the nationwide surveying effort, but more often, they operate many more for their own means. The tubes are positioned based on a need to measure the pollution in a way representative of the exposure of the populous to these pollutants. These criteria are set down in the national survey guidelines [1][2] and constrain the positions of the monitoring points (within fairly broad ranges) with respect to major roads [1][2]. The same guidelines govern the details of location of the diffusion tubes with respect to vertical range, and separation from structures. Consequently, within each different set up there are inherent variations in the specific positioning of the monitoring points, whilst still being within the guidelines. These may be dictated by physical or even social requirements; however, the impact of these differences when the data are presented spatially, especially over large areas, is where uncertainty may be introduced. Furthermore, the effects of turbulence generated by the movement of the air around buildings and within street canyons, and other factors such as atmospheric stability, potentially generate circulation regimes that introduce more inaccuracies, given the varied positions of monitoring sites [3]. This is especially true in populated urban areas, where the levels of NO_2 pollution are of concern.

The design of the criteria set down for the positioning of the NO_2 diffusion tubes was to allow comparisons of different sites. In theory, this would enable a roadside site in central London to be compared with one in Manchester. In practice, the actual selection of sites is carried out by the local authorities, so the final position of the tubes is biased by the requirements of that council. The individualities of the air circulations at different sites may make individual site-to-site comparisons unfeasible. Furthermore, it is clear that the locations of the individual monitoring stations, be they real time units with a sparse spatial distribution, or diffusion tubes with wider coverage, may have a profound effect on the results of any spatial analyses performed upon the output [4]. However, little is known of the extent to which the overall distribution of monitoring positions on a large scale actually influences the comparison studies.

In essence any spatial analysis, or mapping exercise, is a comparison of "like" results. If, for example, the sites within a category, e.g. all roadside sites, are deemed comparable, then their relative position to one another becomes a key factor when considered within a Geographical Information System (GIS). The selection of individual sites by individual authorities is also another factor. Geopolitical boundaries formed by the borders of the councils' areas effectively constrain the data within subsets, and the position of these boundaries relative to the larger picture will potentially play a part in defining the results. Work has progressed on the analysis of such constrained data, initially a temporal analysis, then a spatial comparison of the subsets [5][6]. Based on the conclusions of this work, the next stage is to determine whether an improved set of criteria for the placement of monitoring stations can be developed. In the following sections, two different measurement strategies, in terms of the distribution of monitoring sites, are described and analysed. The results are compared and discussed to determine which strategy produced the best representation of the real picture of the air pollution over a wide scale.

COMPARATIVE STUDY OF TWO TECHNIQUES

To accurately map air pollution across a range of spatial scales would require the sampling criteria, which effectively constrain some of the uncertainties within the sample, to be very stringent, perhaps prohibitively so in a real world application. Development of such criteria would require testing numerous different possible strategies, and assessing them against one another. To experiment with this in the field would be an extremely costly and time consuming venture, thus in this research a GIS-based system (ESRI's ArcView 8.2) was used to consider the possible options.

When sampling across a region it is necessary to consider many factors. The most important of these is the location of the pollution sources across the region. In the case of NO_2 these sources are the exhausts from motor vehicles, thus the spatial extent of the source will be largely governed by the layout of roads across an area. A representative air pollution study would need to register the pollution emitted from these sources, and also to pick up the area of influence of the source.

The other main considerations are of scale and distribution. If the requirement of the survey is to produce an accurate map of the air pollution across an area, then the size of the area, and the desired accuracy have to be considered together. It is clearly unfeasible to monitor pollution patterns to metre accuracy, so the distribution of the monitoring sites also plays an important role. The difficulty arises as to how to optimise the distribution of monitoring sites within the scale of the area. The monitoring sites need to capture sufficient detail to predict the pollution field whilst at the same time, need to be limited according to available resources.

In an effort to address this issue of scale and distribution, a comparison of two different monitoring methods employed in current studies was undertaken. The first study, examines the distribution of monitoring points in the county of Surrey in southern England. This is representative of the general pollution patterns, which result from tubes being positioned independently by various authorities. Within Surrey there are eleven different local authorities, each deploying their own diffusion tubes to suit their own monitoring needs. As each borough is a mixture of rural and urban areas, the distribution of sites within a borough, and therefore within the county as a whole, is biased towards the urban centres. The second study relates to the distribution of monitoring points in the London Borough of Tower Hamlets, which is based on a more rigorously planned grid type deployment. Tower Hamlets has 86 diffusion tubes to measure NO_2 across its area in an effort to better understand the distribution of traffic derived air pollution within its confines. The tubes are deployed roughly on a 500m grid throughout the entire borough, resulting in good even spatial coverage, with no significant deviations from the intended pattern. Figure 1 shows the locations of the 148 monitoring sites across Surrey, along with the 86 sites in Tower Hamlets, imposed over the pattern of urban areas within the region.

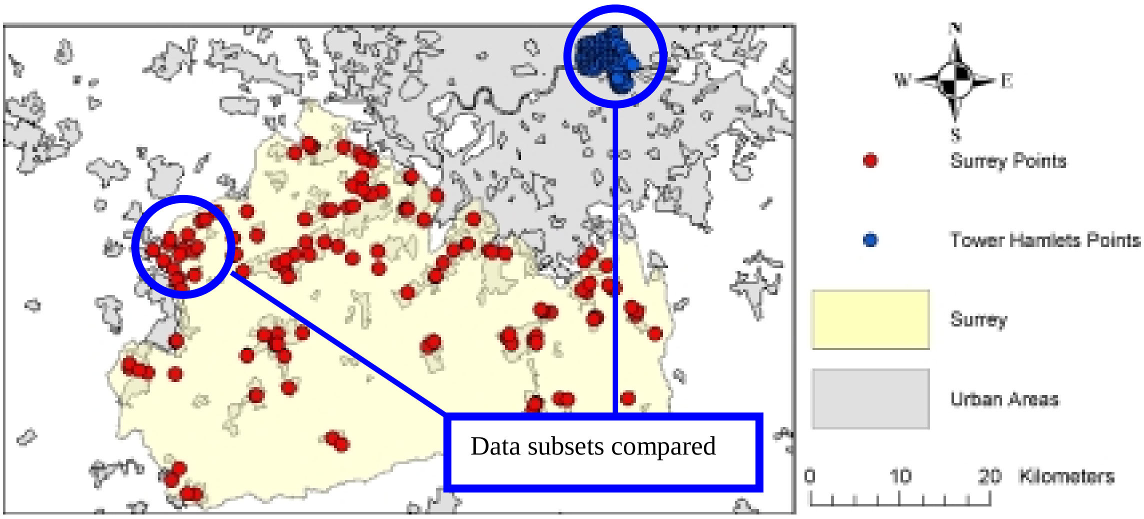

Figure 1: Relative location of compared points

To enable a comparison, the same pollution field had to be investigated using both sampling strategies, and the differences between the results noted. In order to achieve this, a hypothetical pollution field was generated within the GIS, from an independent data set and applied to an area of Surrey. The area of Surrey selected was representative of an urban area with a relatively high density of sampling points and of a similar size to the Tower Hamlets region. The imposed pollution field chosen, although hypothetical, was also representative of an urban region. The Tower Hamlets sampling pattern was then transposed and overlaid over the same area in Surrey as shown in Figure 2. This was done to enable some similarity of scale to the sampling, as there are areas of Surrey where the whole Tower Hamlets scheme would fit over a single monitoring point in the rural areas. Using this comparison also ensured that the two compared patterns were based on urbanised areas, thus highlighting directly the disparities in the two schemes.

A section of code was used to extract the values of the underlying pollution pattern at the position of each sampling point in the two schemes. The data extracted from the hypothetical pollution field or base layer were re-interpolated to produce new pollution patterns which were then compared with the original. The interpolation scheme used was the same as the one used to create the original base pattern, and was based on an Inverse Distance Weighted (IDW) method.

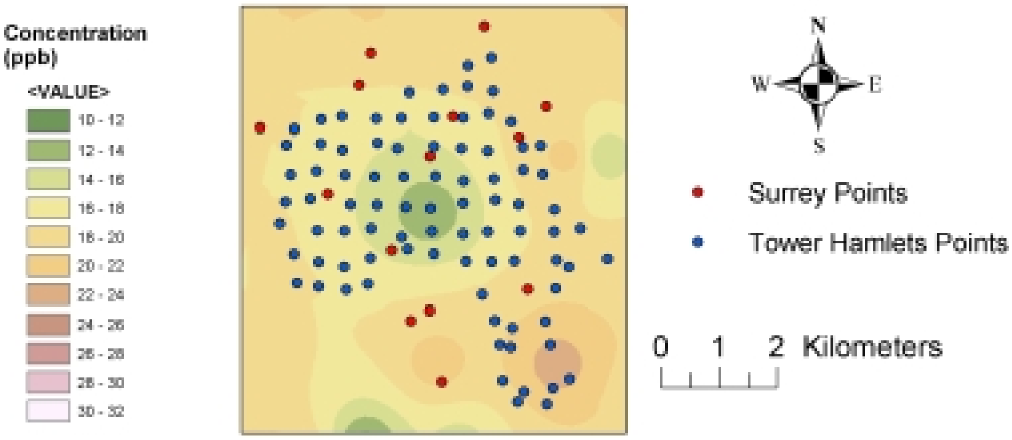

Figure 2: Sampling points overlaid on source pattern

Figure 3 shows the results from the Surrey sampling scheme, which was by far the sparser of the two. It is immediately apparent that the representation of the original pollution field based on this sampling scheme is limited in its application. Minimal detail of the original pollution field is reproduced which results in a very general picture. The values across the whole of the area sampled are heavily influenced by a few especially high or low values. The “real” high and low areas of pollution are almost entirely missed by this scheme. Whilst this is a slightly artificial application of the sampling strategy, it does point out some weaknesses. One of the main advantages of using diffusion tube sampling is that the relatively low cost means that more tubes can be deployed to provide greater spatial coverage. If the method of deployment then prohibits any useful spatial patterns from being discerned, then effectively, this advantage is not being realised.

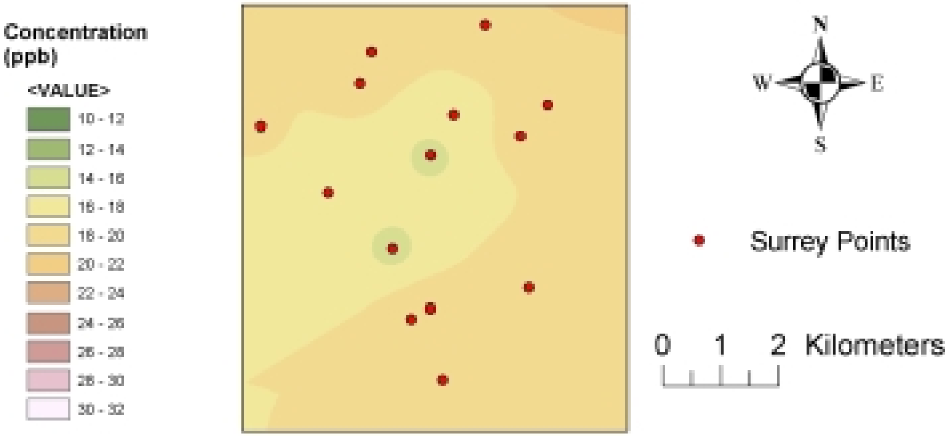

Figure 3: Output resulting from Surrey pattern

Figure 4 shows the same results for the Tower Hamlets grid style sampling scheme. This scheme enables features in the original data to be far more effectively distinguished. Whilst the abundance of points compared with the Surrey scheme would have suggested this, the strength of the grid in resolving not just the location of detail, but also its extent, was particularly good. The detail towards the centre of the images, where the Tower Hamlets grid is at its most consistent shows an almost identical pattern to the original imposed pollution field. The strength of the gridded sampling pattern is also evident towards the edges of its domain, compared with the sparser sampling pattern, which shows considerable variations in results across the whole domain. This greater ability of the grid scheme to determine patterns across an area allows far greater confidence to be attributed to any conclusions drawn from the data from the grid samples. This is especially useful in urban areas where variations in pollutant levels occur more often over shorter spatial scales.

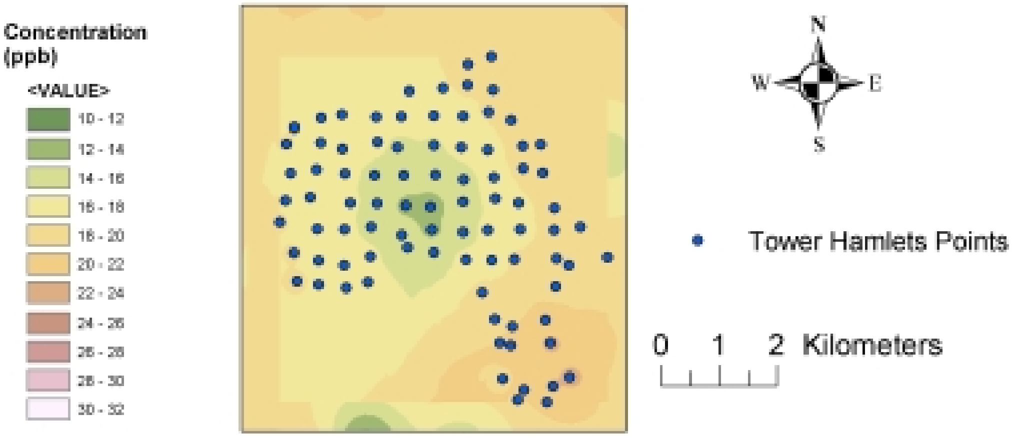

Figure 4: Output resulting from Tower Hamlets Pattern

CONCLUSIONS

The significant advantages demonstrated by the Tower Hamlets based grid technique, over the more typical random style pattern are clear. This strength to resolve patterns and locations of pollution "hot spots" could be invaluable. As many of the diffusion tubes deployed nationwide have now completed their original task to provide data for local air quality reviews, the extension of this regular gridded style monitoring to a larger area could provide some interesting insight into large-scale air pollution problems. Whilst it may not be practicable to deploy diffusion tubes at the high density utilised in Tower Hamlets in all areas, it is clear that in major urban areas, this kind of deployment could yield more accurate pollution fields. This would ultimately provide more representative predictions of the exposure of the populous to these pollutants.

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