Developing a conceptual model for the assessment of personal exposure to air pollution

S. Steinle [a, b]**, S. Reis** [a]**, C. E. Sabel** [b, c]
[a] *Centre for Ecology & Hydrology Edinburgh, Bush Estate, Penicuik, Midlothian, EH26 0QB*
[b] *Geography, College of Life & Environmental Sciences, University of Exeter, Amory Building, Rennes Drive, Exeter, EX4 4RJ*
[c] *European Centre for Environment and Human Health, Knowledge Spa,* Royal Cornwall Hospital, *Truro Cornwall, TR1 3HD*
Email: susein@ceh.ac.uk

Abstract: Human exposure to environmental pathogens and specifically air pollutants is a highly topical issue. Clean air to breathe is a basic requirement of life and the quality of air both outdoors and indoors is a crucial determinant of health (WHO, 2010). Air is however affected by pollutants such as Nitrogen Oxides (NO_x), Particulate Matter (PM), ground level Ozone (O_3) and Carbon Monoxide (CO) which can have adverse effects on public health.

Air pollutants are ubiquitous and their concentrations are typically subject to a high spatial and temporal variability. For risk and impact assessments and for the design of effective air pollution control policies as well as public health advice, it is necessary to quantify human exposure to air pollutants. This is a challenging task as human exposure is based on complex relationships and interactions between environmental and human systems. Traditionally human exposure has been assessed based on concentrations from static monitors. Now technology is available to enable us to monitor personal exposure to air pollutants.

The work described here is conducted in the frame of a joint PhD studentship between the Centre for Ecology & Hydrology and the University of Exeter. It focuses on the application of methods for personal exposure monitoring and the integration of measured data with existing pollution and contextual data in a combined approach. The aims are to understand more about potential associations between air pollution, human exposure to it and health effects in Scotland which is strongly influenced by activity patterns and a person's general activity-space.

For this purpose, an experimental design with a wearable personal monitoring device to derive personal time-activity patterns and pollutant concentrations is currently devised. Resulting personal exposure profiles will be integrated with modelled pollution concentrations and contextual data such as socioeconomic, population and health indicators.

The work presented here will focus on the development of a conceptual model integrating monitored, modelled and contextual data.

Key Words*:* Air pollution, conceptual model, contextual data, personal exposure monitoring, Scotland

1. INTRODUCTION

Human exposure to air pollutants and environmental influences in general is a highly topical issue. Substantial growth in individual traffic to satisfy increasing mobility needs and energy consumption are reflecting growing affluence and contribute to high and increasing ambient levels of air pollutants. Urban areas are

especially affected because they have high population densities and consequently high traffic flows and extensive infrastructure.

Air pollutants such as Nitrogen Oxides (NO_x), Particulate Matter (PM), ground level Ozone (O_3) and Carbon Monoxide (CO) are ubiquitous and a certain level of exposure is inevitable whether a person is indoors or outdoors. For risk and impact assessments of air pollution and the design of control policies such as the UK National Air Quality Strategy or the Local Air Quality Management (Environmental Protection UK, 2011), it is necessary to quantify human exposure to air pollution. It is the quantification of exposure to air pollution in an assessment process, however, which is particularly challenging. Moreover it is based on complex relationships and interactions between environmental and human systems.

Traditionally, one did not try to estimate personal exposure, but rather estimated population level exposure via monitoring networks and annual ambient average concentrations. However with technological advances, we are now able to monitor personal exposure with sophisticated monitors carried or worn by the person while moving in the concentration field.

For the assessment of personal exposure to air pollutants, ambient concentrations of pollutants as well as information on the person's movement patterns are required at an adequate temporal and spatial resolution. Personal exposure assessment is a fast developing research area, and present and future studies can build on the latest technologies for tracking movements such as the Global Positioning System (GPS) as well as miniaturised pollutant sensors. The development and combination of mobile technologies enables the tracking of individuals and their environmental exposures. This is a highly localised approach which is suitable to assess short term effects of air pollution. For further analysis monitored individual exposure information can be combined with existing pollution concentrations and contextual data applying advanced spatial analyses using GIS to derive conclusions about associations between concentration levels, the environment the person is moving in, and lifestyle and health.

2. RESEARCH BACKGROUND

In the following a short introduction to personal exposure to air pollution and the research background is given. This has been discussed in more detail in Steinle et al. (2011).

2.1. Personal exposure to air pollutants

The assessment of exposure to air pollutants in space and time is not trivial since air pollutants are ever-present and there is a large variety of substances interacting, reacting and thereby creating many heterogeneous pollutant mixes. It is impossible to identify any individual air pollutant as a causal agent of an adverse health effect (Goldberg, 2007). Environmental, meteorological and microclimatic influences which are changing dynamically add to the complexity as well as humans moving in space and time showing individual behavioural patterns (McKone et al., 2008). As a consequence, people can be exposed in any environment to a large variety of pollutants and pollutant mixes (Branis, 2010, Goldberg, 2007).

2.2. Cause-effect relationship – from state to exposure

For risk assessment and Health Impact Assessment (HIA), conceptual models reflecting the relations between environmental and human systems are commonly used. The idea behind such cause-effect relationship models is to conduct impact pathway analyses by structuring and simplifying working with the complex interactions between environmental and socio-economic factors (EEA, 2007).

A conceptual model for a strategic approach to assess environmental effects on health (Morris et al., 2006) is the modified DPSEEA model (Drivers, Pressures, State, Exposure, Effects and Actions) shown in Figure 1. In comparison to the standard model, the modified DPSEEA model uses "Context" additionally. Context is introduced as a "bubble" around "Exposure" and "Effect" in a way that the transition from environmental state (i.e. ambient concentrations) to exposure and effects includes contextual issues. For this study context includes individual information from questionnaires (neighbourhood, lifestyle…), urban-rural classification (URC), land cover map 2007 (LCM) and Scottish Index of Multiple Deprivation (SIMD). By representing external influences, context is crucial for personal exposure assessment as it includes, among other things, personal living conditions which determine to a large part someone's characteristic individual exposure.
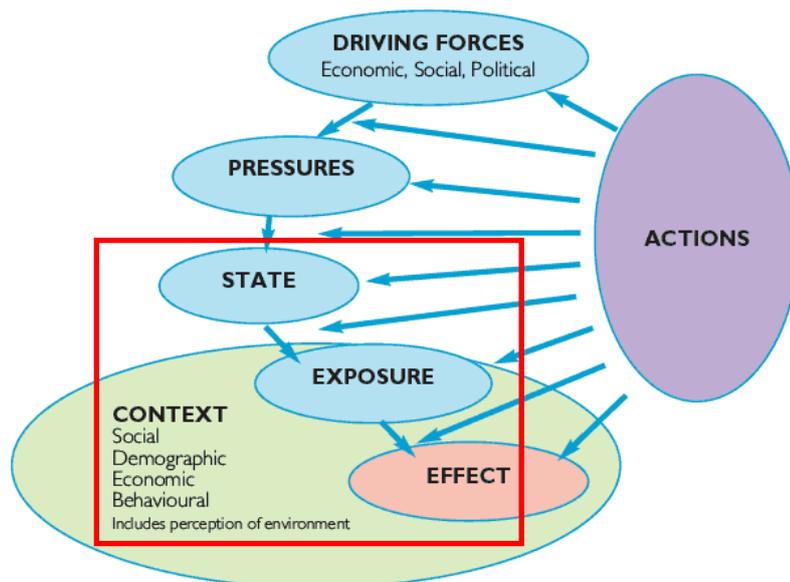

Figure 1 The modified DPSEEA model (The Scottish Government, 2008).

The focus of the work described here is on "State", which in this case is the ambient concentration of air pollutants, and "Exposure" which represents the individual human exposure to a specific air pollutant, as well as the relationship between them. "Effects" are touched upon in our analysis by incorporating health and socioeconomic indicators.

3. AIMS AND OBJECTIVES

The focus of our work is on the application of methods for personal exposure monitoring as well as the integration of measured data with existing pollution and contextual data in a combined approach.

Our objectives are to:
- Monitor air pollution with a personal monitoring device across all micro-environments (MEs) the individual visits during the monitoring period to test the hypothesis that exposure to air pollution is significantly different between individuals depending on environment and lifestyle.
- Develop a conceptual model combining monitored pollution and time-activity data with existing pollution and contextual data. This enables the use of a wider pool of data for an integrated personal exposure assessment approach.

- Apply the model to improve the understanding of everyday exposure to air pollutants and the potential associations between air pollution, human exposure to it and health effects in Scotland.

4. PERSONAL EXPOSURE MONITORING AND ASSESSMENT

The study area for this research project is Scotland, a country with highly heterogeneous physical and social environments. The Central Belt between Edinburgh and Glasgow is densely populated with a high level of infrastructure, whereas large parts of the country are rural, have significantly less population and hence infrastructure and industry. This distribution is also reflected in concentrations of air pollutants such as NO_2 (Figure 2).
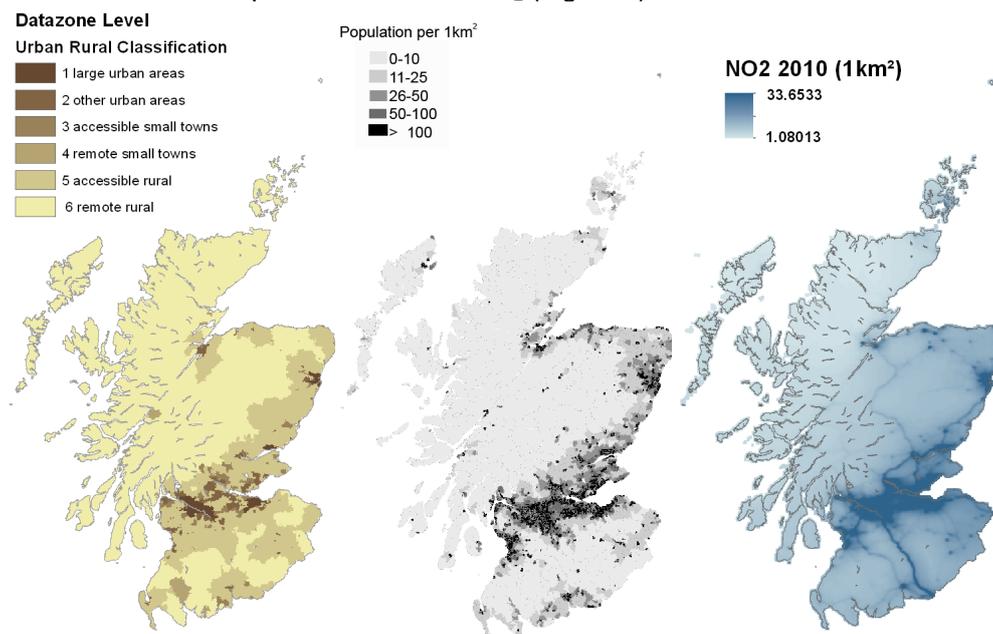

Figure 2 Scottish Government urban rural classification 2009/10 (left, www.sns.gov.uk), population density (1 km^2) based on 2009 midyear estimates (centre, www.sns.gov.uk) on data zone (DZ) level and the NO_2 estimated annual background concentration (μg/m^3) for 2010 (1 km^2, http://www.scottishairquality.co.uk/maps.php).

Exposure estimates based on surrogate measurements such as point measurements or models of environmental pollution imply an approximation of actual exposure. The main drawback when applying these methods to derive exposure estimates is that they do not take direct account of people moving in space, i.e. within the changing pollution field, and time (Briggs, 2000). In contrast, a personal monitoring device measures the actual concentration a person is exposed to in real-time MEs.

By deriving concentration – exposure profiles with a personal monitor, differences in air pollution concentration and thus exposure to it can be assessed and integrated with further contextual and modelled datasets.

A personal monitoring device is required to fulfil these objectives. It needs to include sensors to measure ambient pollutant concentrations, for instance NO_2 and CO. Also integrated should be a GPS receiver for logging location and time, and sensors for environmental parameters such as relative humidity and temperature. The latter two are indicators which support the GPS receiver in differentiating between indoor and outdoor MEs as the GPS is often unable to receive a sufficient signal in indoor environments. It is important to keep track of people in indoor

environments as this is the ME where people in industrialised countries spend about 85% of their time (Lazaridis et al., 2010).

The design of a mobile monitor aims to provide information on the pollutant concentration, the duration and frequency of exposure as well as the pattern of exposure. Although this information can be logged with a device, time-activity-diaries (TAD) are necessary to assign contextual richness to a geographic coordinate and for validation. An exposure study without information gained by the use of TAD and questionnaires is inherently deficient (Briggs, 2000). Participants would have to fill in a short TAD once a day where they are asked to recall the day's activities to support the data derived from the monitoring device. A questionnaire designed for this study would need to provide information on socioeconomic context such as housing type, number of people living in the household, profession but also on general information such as age, gender and family status and the person's activity-space.

5. DEVELOPING CONCEPTUAL MODEL INTEGRATING MONITORED AND EXISTING DATA

To further analyse the nature of personal exposure to air pollutants in Scotland we have developed a conceptual model for integrating the monitored data with existing pollution and contextual data in a combined approach. Based on this model, we aim to understand more about potential associations between air pollution, human exposure to it and health effects in Scotland, which is strongly influenced by activity patterns and a person's general activity-space.

The conceptual model combines monitored individual exposure information with pollution concentrations and contextual data to derive conclusions about associations between concentration levels, a person's activity-space, lifestyle and health status (Figure 4). This integration of data allows linking the state of the physical environment with contextual, demographic and epidemiological data with the aim of improving health impact and risk assessment.
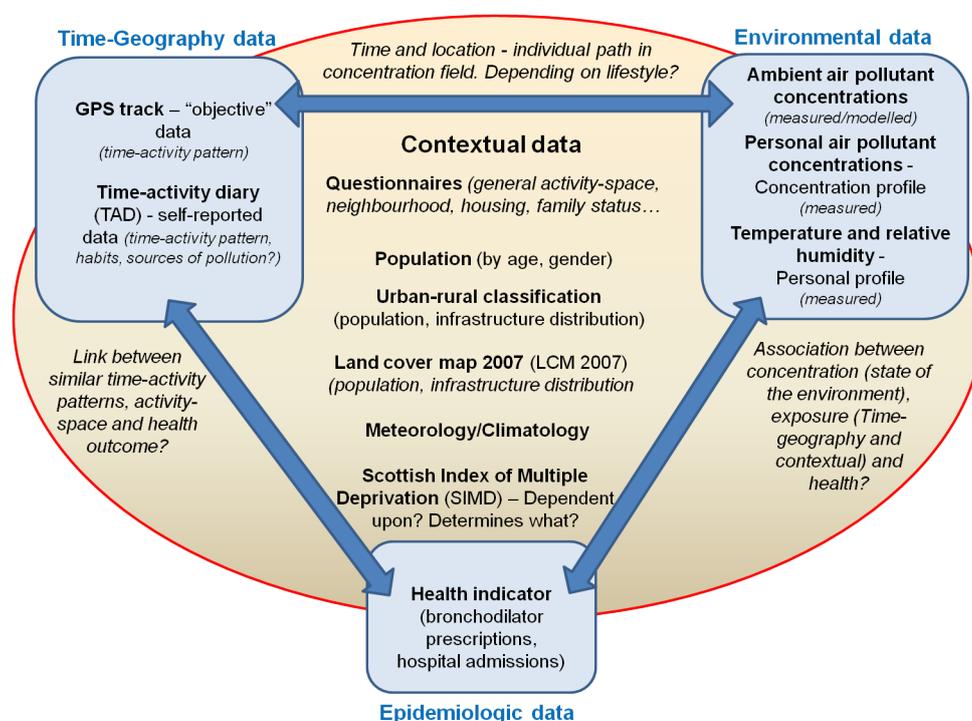

Figure 3 A conceptual model combining personal monitoring data with existing datasets for the assessment of associations between individual exposure of air pollution, environment, lifestyle and health.

The challenge is the integration of datasets which all have different spatio-temporal formats and were derived in very different ways. The data collected (Figure 3) covers individual time-geography, environmental (physical), epidemiological and contextual data.

Bringing together self-reported (TADs, questionnaires) and automatically logged datasets can be problematic, as geographic coordinates from the GPS sensor have to be matched with descriptions of real locations and activities (Mavoa et al., 2011).

To derive information on personal exposure, time-geography data has to be integrated with measured environmental data, in this case the concentration of the pollutants. Pollutant concentration measured with a personal monitoring device is relevant for short-term exposure and presents a localised approach. Personal exposure profiles will be embedded with less detailed monitored and/or modelled pollution data to gain information about the distribution of pollutants in the long-term and how the individual is moving in this changing pollution field.

Environmental and time-geography data combined are used to gain information on potential exposure to pollutants of concern. In the next step, this information is integrated with epidemiological and contextual data to see if there are any correlations/associations between the distribution of the population, different age groups, genders, socio-economic status, movement patterns, the person's general activity-space and the resulting potential exposure and health status.

Contextual data includes a mix of routinely collected/derived physical environment, socio-economic and demographic indicators as well as self-reported background information from questionnaires designed for this study. The urban-rural classification as well as the 2007 land-cover map is integrated with demographic data to derive the actual distribution of the population and infrastructure in the country. The Scottish Index of Multiple Deprivation (SIMD) is integrated to see if there are links/associations between population social status and health.

Information from questionnaires informs on the individual's general activity-space. Differences such as living in a rural area and relying on a car, as opposed to living in an urban area and using public transport and spending more time in the transport ME due to congestion can be determined. This information can be related to epidemiological data to investigate if these differences eventually influence/determine the health status of a person.

The integration of all data is complex and challenging due to the variety of spatio-temporal formats as well as the raw data formats. We have manipulated and transformed original data into a suitable format for integration with other data using the Feature Manipulation Engine (FME) software. For the integration and visualisation of data we use the Geographic Information System (GIS) ArcGIS 10. By integrating individual time-activity, air pollution, health and contextual data we intend to identify and provide advice on which method(s) for assessing human exposure to air pollutants prove(s) to be the most accurate, effective and practicable one(s) to inform policy development.

6. DISCUSSION AND CONCLUSION

The use of personal exposure monitoring devices does quantify exposure to ambient pollutants such as NO_2 and CO and is expected to improve monitoring strategies and HIA. A better understanding of spatio-temporal changes in concentration levels and their relationships to specific environments and sources can support decision making with regard to emission control policies and public health protection.

This approach aims to facilitate the analysis of the complex interactions between pollutant concentrations, exposure and health impacts in a larger context. The synchronised logging of all three components - time, location and concentration – determines an individual's actual exposure to a specific pollutant while moving in space and time. By integrating personal exposure information with additional pollution and contextual data in a conceptual model, we aim to identify associations

between the physical and socioeconomic environment and health impact. This approach will enhance HIA research. It can be extended to other pollutants depending on the availability of suitable mobile sensors that can be integrated into a device.

ACKNOWLEDGMENTS

References

Branis, M., *Personal Exposure Measurements*, In: Lazaridis, M. and Colbeck, I., Human Exposure to Pollutants via Dermal Absorption and Inhalation, 97-141, 2010.

Briggs, D.J., *Exposure assessment*, In: Elliott, P., Wakefield, J.C., Best, N.G. and Briggs, D.J., Spatial Epidemiology. Methods and Applications, 336-359, London, 2000.

EEA, *The DPSIR framework used by the EEA*, http://root-devel.ew.eea.europa.eu/ia2dec/knowledge_base/Frameworks/doc101182, 12/04/2011.

Environmental Protection UK, *Air Pollution Laws*, http://www.environmental-protection.org.uk/air-quality-and-climate/air-quality/laws/, 10/05/2011.

Goldberg, M.S., On the interpretation of epidemiological studies of ambient air pollution, *J Expos Sci Environ Epidemiol,* 17 (2), 66-70, 2007.

Lazaridis, M. and Colbeck, I., *Environmental Levels*, In: Lazaridis, M. and Colbeck, I., Human Exposure to Pollutants via Dermal Absorption and Inhalation, 1-39, 2010.

Mavoa, S., Oliver, M., Witten, K. and Badland, H., Linking GPS and travel diary data using sequence alignment in a study of children's independent mobility, *International Journal of Health Geographics,* 10 (1), 64, 2011.

McKone, T.E., Ryan, P.B. and Ozkaynak, H., Exposure information in environmental health research: Current opportunities and future directions for particulate matter, ozone, and toxic air pollutants, *J Expos Sci Environ Epidemiol,* 19 (1), 30-44, 2008.

Morris, G.P., Beck, S.A., Hanlon, P. and Robertson, R., Getting strategic about the environment and health, *Public Health,* 120 (10), 889-903, 2006.

Steinle, S., Reis, S. and Sabel, C.E., *Assessment of personal exposure to air pollutants in Scotland – an integrated approach using personal monitoring data* In: Chan, F., Marinova, D.a. and Anderssen, R.S., MODSIM2011, 19th International Congress on Modelling and Simulation., Modelling and Simulation Society of Australia and New Zealand, 2011.

The Scottish Government, *Good Places, Better Health: A new approach to the environment and health in Scotland: Implementation Plan,* 1-21, Edinburgh, 2008.

WHO, *WHO guidelines for indoor air quality: selected pollutants,* World Health Organization, 2010.