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GEOGRAPHICAL INFORMATION SYSTEMS FOR INTEGRATING AIR POLLUTION MODELLING WITH OUTCOMES AND CONFOUNDERS: EFFECTS OF SOUR GAS PROCESSING PLANT EMISSIONS ON THE HEALTH AND PRODUCTIVITY OF CATTLE[1]

Scott H.M.[2], Ellahoj E.[3], Wilson D.J.[4], Martin S.W.[2], Soskolne C.L.[5], Coppock R.W.[6], Guidotti T.L.[5], Hrudey S.E.[5], Lissemore K.D.[2]

Cette communication décrit l'utilisation d'un système d'information géographique (GIS), pour intégrer l'exposition à la pollution de l'air, la santé et la productivité des bovins lors d'une étude sur l'effet d'émission de gaz acides sur la santé et la productivité en élevages bovins en Alberta (Canada). Des données longitudinales rétrospectives sur 5400 élevages allaitants et 1424 élevages laitiers ont été référencées géographiquement, puis confrontées aux données des informations sur l'éco-région et l'exposition à 231 systèmes d'émission de gaz acides. L'exposition mensuelle des fermes aux gaz acides a été estimée sur 10 ans en utilisant un modèle de dispersion Gaussienne. Les résultats du modèle sont cartographiés à l'aide du GIS, puis appliqués comme variable d'exposition. Cette étude à grande échelle n'aurait pas été possible sans l'utilisation des techniques du GIS pour intégrer et assembler la base de données finale de notre étude. Dans l'étape suivante, une méthode statistique adaptée aux expositions longitudinales et à l'état sanitaire sera utilisée pour estimer les hypothèses de recherche.

INTRODUCTION

The sour gas industry extracts and processes raw natural gas containing impurities such as hydrogen sulphide (H_2S) and longer-chain hydrocarbon compounds. These impurities are removed from the sales gas and disposed of using either: a) methods for recovery of saleable products (e.g., elemental sulphur and solution gases) or b) dispersion into the atmosphere using combustion processes (e.g., flaring and incineration) (CH2M HILL Engineering Ltd., 1993). Complete combustion of these byproducts results largely in the production of H_2O, CO_2 and SO_2 , whereas inefficient combustion practices produce a more complex mixture of pollutants (Strosher, 1996). For more than 30 years, public concerns have existed in the province of Alberta, Canada about the potential risks to the health of both animals and humans associated with exposure to these airborne pollutants (Klemm, 1972). A very limited number of studies have applied rigorous epidemiologic methods in researching the impacts of sour gas on health and production in livestock. One of the major obstacles to conducting a well-designed observational study on this subject has been a lack of useful information on the exposures to sour gas emissions experienced by animals and humans in different areas of the province. Existing air quality monitoring networks fail to capture information on the levels of exposure experienced on most rural Alberta farmsteads. Information which might be used to reconstruct historical exposure profiles is often large and unwieldy. This paper describes a novel approach to this problem utilizing a geographical information system (GIS) to integrate exposure, confounder and health information in a study of the effects of sour gas emissions on the health and productivity of dairy and beef herds in Alberta, Canada.

MATERIALS AND METHODS

The epidemiologic designs incorporated into these studies include a 10-year retrospective study of health and production in all Alberta Dairy Herd Improvement (DHI)-recorded dairy herds and a 3-year retrospective study of health and productivity in a sample of Alberta beef herds. Monthly herd-level production data were obtained for all dairy herds subscribed to Alberta DHI at any time between 1985 and 1994. DHI health outcomes data were available on an annualized basis and included culling, mortality and some morbidity information. DHI reproductive data included monthly calving interval estimates as well as information on days to first calving for individual animals. Farms were geo-referenced to a township-range legal land description (LLD) code by performing a data-linkage to files from the Alberta Dairy Control Board (ADCB); the licensing body responsible for regulating the production and sale of milk products in the province.

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2 Department of Population Medicine, University of Guelph, Guelph, Ontario, Canada

3 Private Consultant: Geography and Cartography, Edmonton, Alberta, Canada

4 Department of Mechanical Engineering, University of Alberta, Edmonton, Alberta, Canada

5 Department of Public Health Sciences, University of Alberta, Edmonton, Alberta, Canada

6 Alberta Research Council - Alberta Environmental Centre, Vegreville, Alberta, Canada

Annualized health and production data suitable for secondary analysis were provided by Alberta Agriculture on a sample of beef farms surveyed in one of three years (1987, 1988 or 1989). Health data included calfhood and adult morbidity, reproductive performance, culling and mortality. Production data related chiefly to calf weaning weights. Farmers participating in this study provided the LLD of their farm to the investigators. Both dairy and beef farm point files represented a degree of spatial resolution equivalent to 500 metres radius. All geo-referenced LLD point files were converted to latitude / longitude (lat/lon) before applying them to a 1:1,000,000 base map of the province (generously provided by one of the authors - EE). A program has been adapted by this same author to facilitate the LLD to lat/lon conversion in Foxpro® (Microsoft Corporation, Redmond, WA, USA).

An eco-region map of the province, as provided by Agriculture Canada, was imported into the GIS as a vector file. One of four possible eco-regions (an index of soil quality, growing season, precipitation, elevation and vegetative cover) was assigned to each of the dairy and beef farm sites using a GIS overlay feature (SPANS-GIS®, Tydac Corporation, Ottawa, Canada) operating on a PC platform (OS/2®, IBM, Armonk, NY, USA). Eco-region, along with available herd management factors, were considered as potential confounders in the etiologic analyses.

An integrated approach was developed to incorporate methods from regional and local air pollution dispersion modelling as well as proximity and density to gas plant and wellsite locations. Wellsite locations (LLD) and descriptions of wellsite history, gas pool characteristics and activity status were provided by the Alberta Energy Utilities Board (AEUB). Gas processing plant locations (LLD) were provided by the same agency. Details on gas plant licensing and operating standards, as well as monthly pollutant emission volumes, were obtained from Alberta Environmental Protection. SO_2 was chosen as a marker for the complex mixtures emitted from the plants since sour gas, by definition, always contains H_2S. Weather data were obtained from Environment Canada representing seasonal 10-year averages for monthly STAbility class aRray data (STAR Data) at 14 weather stations scattered throughout the province. This data provided wind speed profiles arranged by 16 polar directions across each of 6 atmospheric stability classes.

The Industrial Source Complex Long Term (Version 3) model (ISCLT3), a Gaussian plume dispersion model, was obtained from the United States Environmental Protection Agency (USEPA). This model was operated using: a) regulatory default options (USEPA-OAQPS, 1995), b) STAR Data for the nearest weather station to the gas plant, c) gas plant monthly emissions (tonnes of SO_2), d) licensed stack parameters (stack height and width, exit velocity, exit temperature) for incinerators or, e) pseudo-parameters for flares. Model-runs were performed for each of the gas plants over all months of operation from January 1985 through December 1994. The model-runs produced post-processing point files which were centred upon Universal Transverse Mercator (UTM) coordinates for each gas plant. The associated estimates of SO_2 concentration ($\mu g/m^3$), were converted to lat/lon point files in SPANS-GIS®. These were then interpolated to vector files using a kriging function and overlaid upon the Alberta Base Map. An additive function was specified across all layers of gas plant dispersion model maps for each month of each year (generating 120 monthly maps in total). Each 12 months of a given year were then overlaid and an averaging function applied across all layers to create maps of annual averages of exposure level for each of 10 years (1985 to 1994). These maps (monthly and annual) were used to "apply" the level of exposure to the farmsite for the specified month and / or year of interest.

A feature of SPANS-GIS® was utilized to perform a simpler modelling procedure based on an exponential decay of emission levels with distance from plant (ignoring wind speed and direction). This feature, called "Potential Mapping", tests the utility of the enormous resources expended in conducting the intensive modelling using ISCLT3 versus a much simpler approach. The results of a regional langragian dispersion model (RELAD) were provided to the investigators by Lawrence Cheng, an atmospheric chemist (Alberta Environmental Centre, 1993). These point files estimated the 10-year average concentrations of SO_2 resulting from long-range transport of pollutants to a resolution of one township (approximately 10km x 10km).

A proximity / density function was applied to determine the potential for exposure to wellsite pollutants on or near each farm.

RESULTS

In Alberta, approximately half of the ADCB-licensed dairy herds subscribe to Alberta DHI. There were 1424 dairy farms for which DHI information was collected at any time during the study period (1985-1994). Electronic linkage of DHI farm records to current LLD records maintained by ADCB was possible for only half of the herds. Exhaustive searches of paper archives resulted in the complete record-linkage of all but 34 herds in total.

There were a total of 6400 beef herds surveyed in one of three years (1987-1989). Approximately 5400 of these farms provided sufficient information on LLD to allow for mapping and use in subsequent analysis.

There were over 180,000 oil or gas well sites on file with the AEUB. Legal land descriptions were available for all of these sites. Problems were encountered with determining the exact content of each well as some of this information was considered proprietary by the oil or gas company.

The AEUB and AEP have files on 231 sour gas plants which had been operational for any period of time up to 1994. Of these, 57 plants were classified as "recovery" plants (they recover sulphur for future sales) and the remainder were classified as acid-flaring plants (all by-products were flared). From 1985 to 1994 the number of active gas plants rose from 129 to 172. Thus, while there is the potential for modelling the dispersion from (231 plants x 12 months x 10 years =) 27720 model runs, in reality not all plants were operational at all times and the actual number of model runs was considerably less. A total of 120 monthly and 10 yearly sour gas processing plant exposure maps were created for the province of Alberta. Exposure status was assigned as a variable to the Foxpro® database containing all relevent information on health and production outcomes, confounders and exposure. This dataset provided the basis for subsequent analyses suitable to longitudinal epidemiologic investigation.

DISCUSSION

A GIS represents the complete array of hardware and software capable of integrating maps and graphics with data referable to a defined geographical location (PAHO, 1996). Recent advances in desktop computing capabilities have resulted in a technology transfer of GIS analytic capabilities from the domain of a select-few mainframe users to a multitude of potential applications in more modest settings. Thorough reviews of the potential applications of GIS technology in studies of environment and health (Briggs and Elliott, 1995) and environmental health data linkage (Nurminen and Briggs, 1996) have been published.

In the present study, the determination of exposure assessment proved the most onerous task. Because of the large surface area of the province, the relatively uninhabited landscapes, and the costs associated with conducting active air pollution monitoring, little information is available to allow for real-time exposure assessments in the province as a whole. In addition, simple surrogate measures such as distance to the gas plants may ignore the meteorological effects on air pollution dispersion and the fact that pollutant output from these sources is often very seasonal. Historical environmental pollution-source information is maintained for regulatory purposes by government agencies. The volume of information is quite large and becomes unwieldy when attempts are made to estimate downwind exposures based on point-source parameters. A study of this nature would be virtually impossible to conduct without a GIS. Estimates of exposure at each specific farmsite might be attempted without the GIS while ignoring exposures at surrounding locations. One of the benefits of modelling exposure for the entire province is in the potential application of the completed database to further environmental health studies. In addition, by attempting to model all locations in the province, an effort can be made to compare the results of the modelling exercise against findings from existing air monitoring sites not located at the study farms. However, it must be remembered that SO_2, as a surrogate marker of exposure to sour gas emissions, is not restricted to emissions from sour gas plants. Studies are needed in this area to determine the validity and utility of these exposure assessment methods.

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