APPLICATION OF ArcGIS Interpolation Techniques and Modeling of Particulate Matter to Solve Air Quality Problems

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Locations of PM$_{2.5}$ monitors in the state of Ohio 2016

Locations of Carbon Monoxide (CO) monitors in the state of Ohio 2016
BACKGROUND

• Kumar et al. (2007) demonstrated the applicability of GIS interpolation methods in estimating air quality data at unknown points.
• Manthena et al. (2009) observed that co-kriging interpolation produced better results when compared with Kriging.
• Kumar et al. (2014) evaluated GIS spatial interpolation methods and the RBF method was identified to be the best performing interpolation method.

APPLICATION TO RADON DATA

• The radon data have been collected in Ohio over the past 30 years.

• Information is available for 1479 zip-codes out of over 2000 + zip-codes.

• Estimate the radon concentrations in unmeasured zip-codes of Ohio.
## Radon Database Creation and Report Generation

### Tables

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<th>Duration</th>
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### Notes

- **Monday, August 14, 2017**
- This document outlines the process for creating a radon database and generating reports. The database is critical for tracking radon levels in various locations and assisting in the mitigation of radon-related issues. The notes include a table summarizing the data collected and an analysis of the findings. The data will be used to develop strategies for reducing radon exposure in the affected areas.
**Radon Data Analysis: County Results Summary**

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<thead>
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<th>COUNTY NAME</th>
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<td>HURON</td>
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<td>JEFFERSON</td>
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<table>
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<th>COUNTY NAME</th>
<th>GEOMETRIC MEAN</th>
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GEOMETRIC MEAN INDOOR RADON CONCENTRATIONS IN OHIO COUNTIES AND ZIP-CODES
# Spatial Interpolation Techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Approach</th>
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<tbody>
<tr>
<td>Ordinary Kriging</td>
<td>• Interpolates an unobserved location from observations of its value at nearby locations.</td>
</tr>
<tr>
<td>Ordinary Co-kriging</td>
<td>• Uses multivariable data types for the estimation.</td>
</tr>
<tr>
<td>Inverse Distance Weighting (IDW)</td>
<td>• Assumes that things that are close to one another are more alike than those farther apart.</td>
</tr>
<tr>
<td>Radial Basis Function (RBF)</td>
<td>• The surface must pass through the measured sample points.</td>
</tr>
<tr>
<td></td>
<td>• Can predict values above the maximum and below the minimum measured values.</td>
</tr>
<tr>
<td>Global Polynomial Interpolation (GPI)</td>
<td>• Fits a smooth surface that represents gradual trends in the surface over the area of interest.</td>
</tr>
<tr>
<td>Local Polynomial Interpolation (LPI)</td>
<td>• Fits many polynomials, each within specified overlapping neighborhood.</td>
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</table>
RADIAL BASIS FUNCTION (RBF)

- RBF is an exact interpolation technique in the sense that the surface must pass through the measured sample points.

- RBF is similar to IDW, except RBF can predict values above the maximum and below the minimum measured values.
Radon concentration prediction map using the RBF technique

Uranium Distribution Map

Estimated Radon Concentration (pCi/L):
- 0.71 - 1.05
- 1.05 - 2.41
- 2.41 - 2.68
- 2.68 - 2.81
- 2.81 - 3.00
- 3.00 - 3.64
- 3.64 - 4.79
- 4.79 - 7.13
- 7.13 - 12.00
- 12.00 - 21.06

Radon Concentration

INTRODUCTION

• The term “Biosolids” refers to the sludge or the waste created from the municipal treatment plants or industrial processes.

• Land applications of biosolids generate bioaerosols. Bioaerosols are airborne particles consisting of or originating from microorganisms.

• Human activities like application, spreading, disking etc. are responsible for aerosolization of the bioaerosols.
FIELD PROGRAM

BIO-AEROSOLS DISPERSION MODELING AND RISK EVALUATION

Application of biosolids on the farm field

Direct readings

Impingers and impactors collecting biological samples

BDRM spreadsheet
**Conceptual Flow Chart To Study PM**

- **Field Characteristics**
  - Length
  - Width

- **Met Data**
  - Temperature
  - Wind Velocity
  - Atmospheric Stability

- **Emission Rate**
  - ER = f (Emission factor, area, time)

- **Dispersal Characteristics**
  - Height

- **Operational Characteristics**
  - Spreading
  - Disking
  - Time Lag

- **Dispersion Coefficients**
  - \( \sigma = f \) (wind velocity, downwind distance, atmospheric stability)

- **Dispersion and Transport**
  - Concentration = f (emission rate, dispersion coefficients, downwind distance, wind velocity)

- **Risk Calculation**
  - Risk = f (concentration, dose response, exposure time, path)

- **Exposure time**

- **Dose response data**

Monday, August 14, 2017
Dispersion Over a Farm Field

Wind Direction

Wind Velocity Profile

L: Length

W: Width
**DISPERSION MODULE: SHEAR LAYER MODEL**

- Analytical solution to the convection-diffusion equations in shear layer ($z>0$)

\[
C(x,z) = \sum_{i=1}^{i} Q \cdot \frac{z^{a^{i-1}}}{A} \cdot \left[ \frac{A + x^{1-s} \cdot B \cdot \exp\left(\frac{B}{x}\right) + D}{S - 1} \right]_{x-(\frac{X}{2})}^{x+(\frac{X}{2})}
\]

- Analytical solution to the convection-diffusion equations in shear layer ($z=0$)

\[
C(x) = \sum_{i=1}^{i} \left[ \frac{Q}{y(s) \cdot (m + n - 2)^2 \cdot K1} \cdot \ln[(x)] \right]_{x-(\frac{X}{2})}^{x+(\frac{X}{2})}
\]

PARTICULATE MATTER INSTRUMENTATION

Grimm: Mass Concentrations for the sizes 0.23µm to 20µm

FEI Quanta 3D FEG Dual Beam Electron Microscope
Sampling Procedure

- In order to collect the first set of particulate matter data, nine sampling points are selected.
  - Two points outside the field, one on each side (D1 and D9)
  - Two just on the edge of the field (D2 and D8)
  - One at the center of the field (D5)
  - And the remaining four points in the direction of wind (D3, D4, D6 and D7)
  - At sampling locations D1, D2, D5, D8 and D9 data is collected at various vertical distances such as 0.5 m, 1.5 m, 2.5 m and 3.5 m.
- Davis weather station is used to keep track of the weather data.

FIELD STUDY: SUMMER 2008
SHEAR LAYER MODEL EVALUATION

EVALUATION OF AREA SOURCE MODELS USING VAN DEN BERG (1993) FIELD DATA

**DEVELOPMENT OF PARTICULATE MATTER DEPOSITION (PMD) MODEL FOR AN AREA SOURCE**

- Ermak (1977) equation for a point source:

\[
C_{(x,y,z)} = \frac{Q}{2\pi \sigma_y \sigma_z u} \exp\left\{ -\frac{y^2}{2\sigma_y^2} \right\} \times \exp\left\{ -\frac{V_g (z-h)}{2K} - \frac{V_g^2 \sigma_z^2}{8K^2} \right\} \times \left[ \exp\left\{ -\frac{(z-h)^2}{2\sigma_z^2} \right\} + \exp\left\{ -\frac{(z+h)^2}{2\sigma_z^2} \right\} \right] - \sqrt{2\pi} \frac{V_1 \sigma_z}{K} \times \exp\left\{ \frac{V_1 (z+h)}{K} + \frac{V_1^2 \sigma_z^2}{2K^2} \right\} \times \text{erfc}\left[ \frac{V_1 \sigma_z + z + h}{\sqrt{2K} \sqrt{2\sigma_z}} \right].
\]

\[
\int \text{point source} = \text{line source} \quad \int \text{line source} = \text{Area source}
\]

![Diagram of a point source and an area source](image-url)
PMD model equation of concentration incorporating deposition for an area source is given by:

\[
C_{(x,y,z)} = \frac{Q}{2\sqrt{2\pi}u} \times \sum_{i=1}^{n} \left[ \frac{1}{\sigma_{z,i}} \exp\left\{ -\frac{V_g(z) - V_g^2 \sigma_{z,i}^2}{2K} \right\} \times 2 \times \exp\left\{ -\frac{(z)^2}{2\sigma_{z,i}^2} \right\} \right] - \sqrt{2\pi} \frac{V_i \sigma_{z,i}}{K} \\
\times \exp\left[ \frac{V_i(z)}{K} + \frac{V_i^2 \sigma_{z,i}^2}{2K^2} \right] \times \text{erfc}\left[ \frac{V_i \sigma_{z,i}}{\sqrt{2K}} + \frac{z}{\sqrt{2\sigma_{z,i}}} \right] \times 2 \times \text{erf}\left[ \frac{Y / 2}{\sqrt{2\sigma_{y,i}}} \right] \delta X
\]

Where,

\[V_1 = V_d - V_g/2; \quad V_d = \text{deposition velocity and } V_g = \text{gravitational settling velocity}\]

\[\sigma_y = \text{horizontal dispersion parameter} = 0.84678xtan(a - blnx)\]

\[\sigma_z = \text{vertical dispersion coefficient} = cx^d\]

\[
C_{m(x,y,z)} = C_{(x,y,z)} \times \left[ Q - \int_0^x V_d C_{(x',z)} \, dx' \right]
\]

EVALUATION OF PMD MODEL

Particle size : 2μm

Particle size : 0.23μm

# Statistical Evaluation of PMD Model and Ermak Model

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<th>Model</th>
<th>NMSE</th>
<th>r</th>
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<th>FB</th>
<th>VG</th>
<th>MG</th>
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EXTENDING PMD MODEL TO IAQ IN FRAMER’S HOME

Predictive Screening Model

Meteorological Data
Ohio EPA (2016)

Air Flow, Ventilation Information
Home Owner
q_0, q_1, q_2, F_0, F_1

Dimensions of House
Lucas County Auditor’s Website (2016)
V, A

Deposition and Resuspension Rates
Thatcher and Leyton (1993)
D_i, Λ

Ambient Concentrations (C_0) using Area Source Model
Nimmatoori and Kumar (2013)
Q, σ_x, σ_y, X, Y, δX, n, x

Indoor Concentrations (C_i) using Single Compartment Mass Balance Model
Wadden et al. (1983)
C_0

Particle Deposition (D_i) on Floor using Analytical Particle Deposition Model
Indoor Concentrations from Single Compartment Mass Balance Model

- The pollutant flow into and out of the indoor volume, including recycling and interior sources and sinks, can be expressed utilizing single compartment mass balance model.

Mass balance equation

\[ V \frac{d C_i}{dt} = k q_0 C_0 (1 - F_0) + k q_1 C_1 (1 - F_1) + k q_2 C_0 - k (q_0 + q_1 + q_2) C_i + S - R \] \quad (8)

Solution for equation

\[ C_i = \frac{k (q_0 (1 - F_0) + q_2) C_0 + S - R}{k (q_0 + q_1 F_1 + q_2)} \left[ 1 - e^{-\left(\frac{k}{V}\right)(q_0 + q_1 F_1 + q_2) t} \right] + C_s e^{-\left(\frac{k}{V}\right)(q_0 + q_1 F_1 + q_2) t} \] \quad (9)
DEPOSITION MODEL

The deposition of particles inside houses is assessed by attaining analytical solution for the floor mass balance equation.

\[
\frac{d D_f}{dt} = D C_i - \Lambda D_f \tag{10}
\]

\[
D_f = \frac{D}{(1 + \Delta t)} \left[ \frac{k(q_0(1 - F_0) + q_2)C_0 + S - R}{k(q_0 + q_1F_1 + q_2)} \left( t + \frac{Ve^{-\left(\frac{k}{V}\right)(q_0 + q_1F_1 + q_2)t}}{k(q_0 + q_1F_1 + q_2)} \right) - \frac{V C_e e^{-\left(\frac{k}{V}\right)(q_0 + q_1F_1 + q_2)t}}{k(q_0 + q_1F_1 + q_2)} \right] + \frac{K_i}{(1 + \Delta t)} \tag{11}
\]
INDOOR AIR QUALITY FIELD STUDY

Study House 1 (Filters 3 and 4)

Study House 2 (Filters 5 and 6)

Study House 3 (Filters 7 and 8)

Control House 1 (Filter 1)

Control House 2 (Filter 2)
CONCLUSIONS

- Interpolation of monitoring data
- PM model development
Questions?

Thank you
PARTICULATE MATTER SHAPE CHARACTERISTICS

- Triangle, 0.604
- Square, 0.785
- Pentagon, 0.860
- Hexagon, 0.902
- Spherical, 1
- Agglomerates, >1
PARTICLE SIZE DISTRIBUTION INSIDE FARMER’S HOME
**METHODOLOGY SCREENING MODEL**

- The concentrations near the house can be predicted using the PMD model.
- The levels inside the house can be estimated using the single compartment mass balance model.
Fig. 2. Characteristic profiles describe PM$_{10}$ concentration decay with height at the aerosol source. The solid line represents best-fit first-order approximation. The first pass ($i = 1$) is 0–6 m from the PM$_{10}$ samplers, $i = 2$ is 6–12 m from the samplers, $i = 3$ is 12–18 m, and $i = 4$ is 18–24 m.

$$E = \frac{1}{W} \sum_i \int_{z_0}^{H_i} U_H \left( \frac{h}{H_0} \right)^p \left( a_i \ln(h) + b_i \right) t_i \cos \theta_i \, dh,$$
MODELING: EMISSION RATE CALCULATION

- The important equation used to calculate the emission rate *during the application* is

\[
E = \frac{1}{w} \cdot x \cdot \int_{h}^{z} C(h) \cdot U(h) \cdot t \, dh
\]

- Where
  - E: Aerosol emission factor (PM$_{10}$) (mg/m$^2$)
  - t: exposure time (s)
  - C (h): background concentration (mg/m$^3$)
  - U (h): Horizontal wind speed (m/s)
  - Z$_0$: soil roughness length (m)
  - H: Height of the plume (m)
Predictive Screening Model

The model consists of three components:

- Ambient concentrations were estimated outside farm house based on the spread of biosolids using the area source model (Nimma toori and Kumar (2013b));

- Indoor concentrations were estimated based on the ambient concentrations using single compartment mass balance model (Wadden et al. (1983));

- Deposition of particulate matter on the floor was predicted based on the indoor concentrations for various stability classes by predicting the ambient concentrations for low, medium and high emission rates using a new analytical particle deposition model.
METHODOLOGY: EXPERIMENTAL SETUP

- Inside the instruments were placed on a table which was at a height of 0.75 m from the floor level to account for the breathing level of occupants
- Outside the instruments were placed in a cage and erected at a height of 1.5 m using a tripod, taking into account average receptor height
**Numerical Dispersion Model Predictions**

- The contours were plotted from the edge of the field in the direction of the wind to help in visual evaluation of the area of the impact.
- In all stability conditions, the application process affected the largest area downwind of the field.
- The concentration was observed highest during the stable conditions, followed by unstable conditions.
PARTICULATE MATTER CONCENTRATIONS MODELED BY RKε FOR LOW AND HIGH WIND SPEEDS

(A) Ground-level concentrations for $u = 1$ m/s (top view)

(B) Concentrations in air at $u = 1$ m/s (side view)

(C) Ground-level concentrations for $u = 6$ m/s (top view)

(D) Concentrations in air at $u = 6$ m/s (side view)