Hotspot Analysis For Examining The Association Between Spatial Air Pollutants And Asthma In New York State, USA Using Kernel Density Estimation (KDE)

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Abstract

- Air pollutants play a predominant role in effecting human health.
- Identifying hot spots of air pollutants in a location will facilitate in taking measures to improve human health and hence protecting the local people from health disorders.
- The present study examines the use of spatial analysis of air pollutants in New York State, U.S.A. Based on the availability of data in the study region, three air pollutants ($PM_{2.5}$, SO_2, and O_3) were considered for the hot spot analysis to identify zones with higher pollutant concentration levels for the period of 2005 to 2007.
- The corresponding asthma discharge rates were then determined for understanding the effect of exposure of high air pollutants to asthma discharge rate. In the present investigation, kernel density estimation (KDE) technique was used for hotspot analysis of air pollution from annual average air pollutants concentrations.
- Using KDE technique, air pollution hotspots and polluted sampling densities are clearly defined based on point data of air pollutants. In the study area, multiple hotspots were observed for these three air pollutants, and they are significantly correlated to the locations of asthma discharge rate.
- The spatial patterns of hazard probability reveal hotspots of PM2.5 are situated in the counties of Rockland, Westchester, Bronx, Queen, Brooklyn and Nassau.
- The hotspots of O3 coincide with that of PM2.5, and SO2 but many other hotspots areas were observed for O3.
- The major hotspots for asthma discharge rate are observed in the same counties as that of PM2.5, SO2, and O3. KDE technique enables capturing hot spots without requiring exhaustive sampling to identify risk prone areas.

- ***Keywords***: kernel density estimation (KDE); air pollution; asthma

Motivation

- The available literature on asthma studies shows a large geographic variation from local/community level all the way to country level.
- The studies on asthma and other epidemics have raised some important questions as what factors contribute to the emergence of asthma outbreak.
- Many epidemiologic studies demonstrated positive associations between air pollution and mortality
- Hotspot mapping has become a valuable technique for visualizing the geographic incidence of air pollution and asthma.
- One of the most widely used techniques for generating hotspot maps as smooth continuous surfaces is kernel density estimation (KDE).
- Hotspot mapping can be used for identifying the locations where hazardous level of air pollution exists. KDE has been widely used for hotspot analysis and detection.
- KDE is one of the methods for analyzing the first order properties of a point event distribution, in part because it is easy to understand and implement.
- Schnabel and Tietje applied the KDE method to spatially distributed heavy metal soil data and compared it with ordinary kriging.
- KDE can be used to produce a smooth density surface of point events over space by computing event intensity as density estimation.
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Objective

- The primary objective of the present work was to investigate the association between geographical incidence of air pollutants and asthma cases.
- For this study, an alternative approaches was proposed in searching the hotspots locations of air pollutants and asthma incidences.
- To use KDE for identifying the hotspots of air pollution and asthma incidence based on the monitored/survey data.
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Method

- Kernel density estimation (KDE) is used to identify the location, spatial extent and intensity of air pollution and asthma cases hotspots.
- Moreover, the spatial patterns of hazardous probability for three air pollutants ($PM_{2.5}$, SO_2, and O_3) and asthma incidence are estimated for examining the association between these two.
- The KDE method is used for visualization of hotspots of air pollutions and asthma incidence in the case study.

Study Area

- In the present work, New York State is selected as the area of study for the analysis and estimation.
  - Based on data availability, urban population, air quality influence
  - Data sets: Air quality data, Asthma Discharge Rate
- New York is a state in the Northeastern region of the United States.
- The longitude and latitude of the state are 71° 47' 25" W to 79° 45' 54" W and 40° 29' 40" N to 45° 0' 42" N respectively.
- It is the third most populous (19,378,102), and the seventh most densely populated (415.3 inhabitants per square mile) state of the 50 United States.
- New York covers 54,556 square miles and ranks as the 27th largest state by size.
- In general, New York has a humid continental climate.

Air Pollution Data

- Air quality data collected by U.S. EPA's Air Quality System (AQS)
- at the various monitoring stations located in different counties of New York State
- for the three years from 2005 to 2007 were used for the study.
- The daily data for each monitoring station were used for determination of annual average concentrations.
- The air pollution data from the United States Environmental Protection Agency (U.S. EPA) air quality system data mart
- (**Source**: http://www.epa.gov/airdata/ad_rep_mon.html/) [14].
- Three criteria air pollutant parameters (SO_2, $PM_{2.5}$, and O_3) were collected from twenty two, twenty five, and twenty five monitoring stations, respectively.
- The characteristics of the these three pollutants retrieved from the website are
- daily average (24 hrs.) concentrations of $PM_{2.5}$, daily maximum 8 hours average concentrations of O_3, and daily maximum 1 hour average concentrations of SO_2.

Asthma data

- County- wise asthma hospital discharge data for the period 2005 through 2007 were obtained from Department of Health, New York State's Asthma Surveillance Summary Report, 2009
- (Source:https://www.health.ny.gov/statistics/ny_asthma/pdf/2009_asthma_surveillance_ summary_report.pdf) [15]. The International Classification of Disease, Ninth Revision, Clinical Modification (ICD-9-CM) diagnosis code 493 was used to identify asthma hospitalization discharge diagnosis [16].
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Asthma hospital discharge rate (ADR)

- ADR indicates the number of asthma-related hospital discharges per 10,000 populations for a specified period of time.
- ADR for 2005, 2006, and 2007 were calculated by dividing the number of asthma hospital discharges by the estimated population for that time period in a particular zone and then multiplying by 10,000.
- The estimated rates represent crude rate on the basis of estimated population of the county.
- The county wise population estimates for the year 2005, 2006 and 2007 were obtained from the United States' Census Bureau
- (Source: http://www.census.gov/popest/data/ intercensal/county/tables/CO-EST00INT-01/CO-EST00INT-01–36.csv45) [17,18].

Kernel Density Estimation (KDE)

- KDE estimation was used
  - for calculating the weighted density of an event over a gridded surface within a kernel or spatial filter,
  - and to visualize the spatial distribution of cumulative incidence.
- Kernel density estimation was performed with the Spatial Analyst Extension for ArcGIS 10.
- The general form of a kernel density estimator (KDE) in a 2-D space [11] is given by
- $$\lambda(x) = \sum_{i=1}^{n} \frac{1}{nh} K\left(\frac{x - X_i}{h}\right) \qquad \text{(eq.1)}$$
- where λ(x) is the density at location x, h is the bandwidth of the KDE, n is the number of sampling points, x-Xi is the distance to each point x to location Xi, K is the weight of a point i at distance is x-Xi to location x. K is usually modelled as a kernel function of the ratio between x-Xi and h.

KDE contd

- In this study, a quadratic kernel function [10] is used for estimation. This is given by
- $$K\left(\frac{x-X_i}{h}\right) = \begin{cases} {}^{3}/_{4}\,(1-x^2) & if\ |x| \leq 1 \\ 0\,, & x > 1 \end{cases} \qquad \text{(eq.2)}$$
-
- This function was employed to estimate air pollutants and asthma densities using cumulative incidence as the weight. The resulting outputs are map surfaces representing the cumulative risk for air pollution episodes and asthma incidences across the New York State.

Results

- In United State of America, the pollution control standards (maximum allowable concentrations) for the investigated pollutants are as:
  - $PM_{2.5}$-12 µg/m^3 (annual average) and 35 µg/m^3 (24 hours average),
  - SO_2- 75 ppb (maximum 1 hr. average), and
  - O_3- 75 ppb (maximum 8 hrs. average).
- Moreover, the high variability of the pollutant concentrations at various air pollutants requires a detailed evaluation and interpretation.
- The application of KDE method is an efficient tool in achieving better understanding of the hazardous level of the air pollution and asthma incidence.

Table 1 summarizes the descriptive statistics of pollutants and asthma

Table 1: Descriptive statistics of data				
	Minimum	Maximum	Mean	Standard Deviation
2005				
Asthma Rate	37.77	94.05	53.04	8.39
Ozone	29.56	44.48	40.21	1.17
$PM_{2.5}$	7.15	16.15	11.39	1.15
SO_2	2.58	18.65	8.46	2.88
2006				
Asthma Rate	37.34	98.30	52.46	9.77
Ozone	30.49	41.92	37.42	1.21
$PM_{2.5}$	5.68	13.30	8.73	1.05
SO_2	2.14	18.69	6.91	2.31
2007				
Asthma Rate	36.56	94.87	50.96	10.43
Ozone	31.75	42.69	39.08	1.76
$PM_{2.5}$	5.73	15.91	9.49	1.08
SO_2	2.81	13.79	7.18	2.38

- The minimum annual average concentrations of $PM_{2.5}$ for 2005, 2006, and 2007 were
  - 6.7 μg/m^3, 5.5 μg/m^3, and 5.6 μg/m^3, respectively.
- The maximum average concentrations of $PM_{2.5}$ for 2005, 2006 and 2007 were
  - 17 μg/m^3, 14.4 μg/m^3, and 16.1 μg/m^3, respectively.
- The maximum values of annual average of maximum 8 hours daily average concentration of O_3 in 2005, 2006, and 2007 were
  - 46.38 ppb, 45.03 ppb, and 47.93 ppb respectively.
- The minimum values of annual average of maximum 8 hours daily average concentrations of O_3 in 2005, 2006, and 2007 were found to be
  - 6.84 ppb, 26.41 ppb, and 16.78 ppb respectively.

Hotspot Patterns

- The hotspot patterns of $PM_{2.5,}$ SO_2, O_3, and ADR on the kernel density map are shown in Figure 1, Figure 2, Figure 3, and Figure 4, respectively.
- KDE transforms a dot pattern into a continuous surface, providing a more useful representation of pollution and asthma cases distributions, allowing for easier detection of possible pollution hotspots and its association with asthma cases.
- Results show that the asthma cases hotspots associated with the three air pollutants in the study area.
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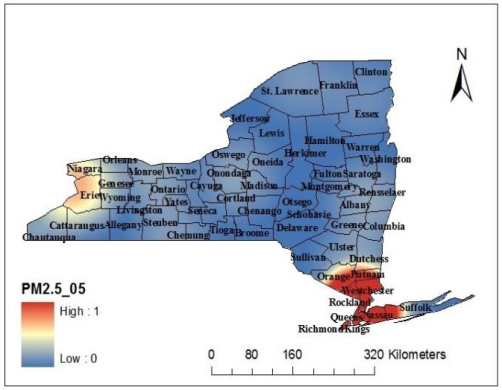
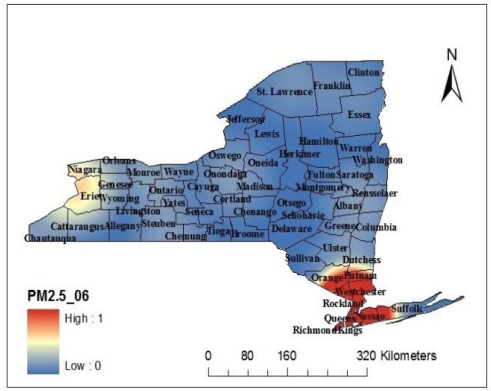




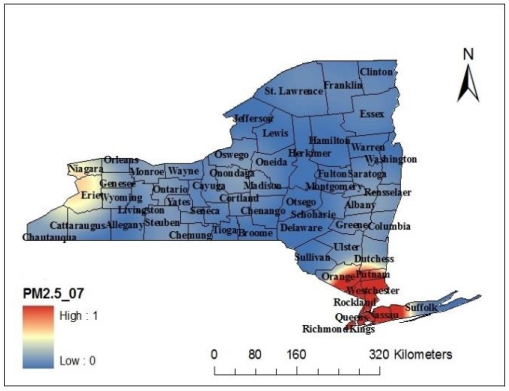
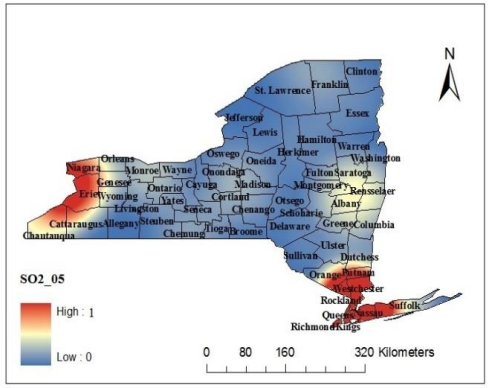
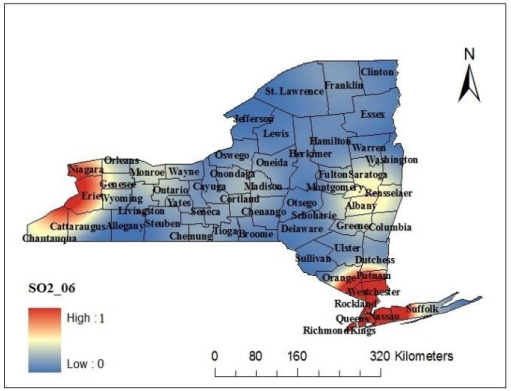


Figure 1: Hotspots maps of $PM_{2.5}$ concentrations





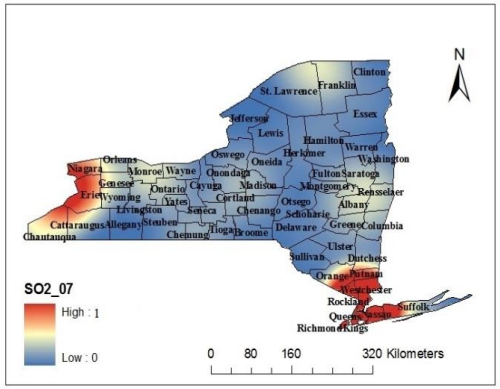
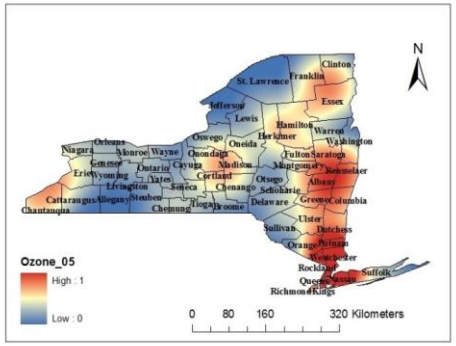
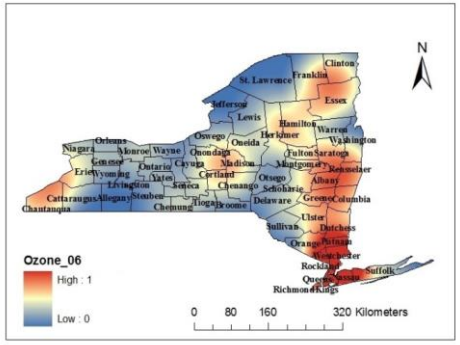


Figure 2: Hotspots maps of SO_2 concentrations





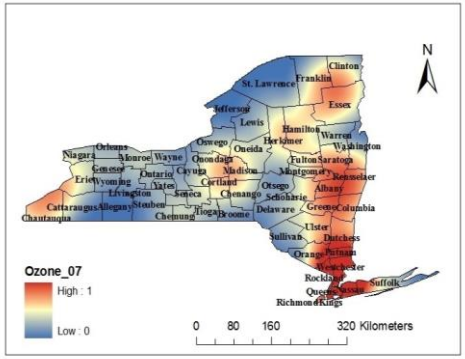
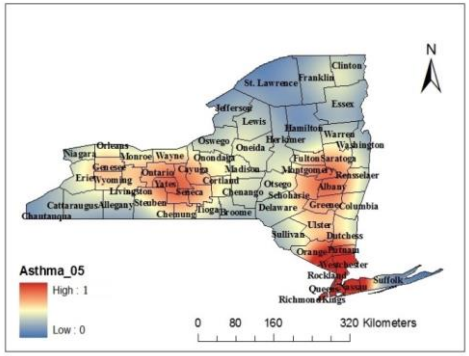
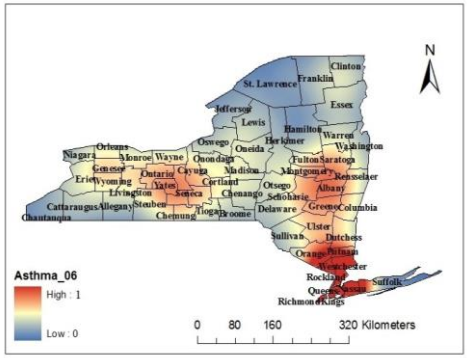


Figure 3: Hotspots maps of O_3 concentrations





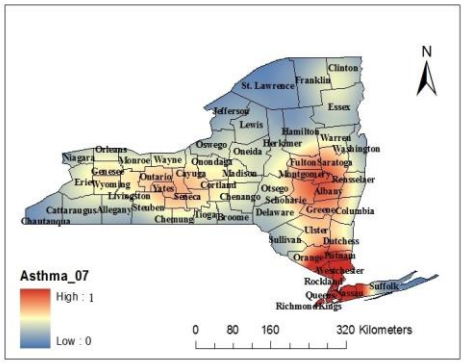


Figure 4: Hotspots maps of asthma discharge rate

Observations

- The maximum values of annual average of maximum 1 hour daily average concentration of SO2 in 2005, 2006, and 2007 were found to be 22.99 ppb, 19.86 ppb, and 23.16 ppb respectively.
- The minimum values of annual average of maximum 1 hr. daily average concentrations of SO2 in 2005, 2006, and 2007 was found to be 1.9 ppb, 1.79 ppb, and 1.93 ppb respectively.

Discussion

- The results demonstrate that the hotspots of hazard probability for $PM_{2.5}$ and SO_2 are similar.
  - The spatial patterns of hazard probability also reveal hotspots of $PM_{2.5}$ are situated in the counties of Rockland, Westchester, Bronx, Queen, Brooklyn and Nassau.
- All these counties are situated in the coastal part of south-east side of the state.
- Two other counties (Erie and Nagara) also show hotspots.
- The same trend is observed in each of the three years (2005 to 2007).
- Similar spatial trends are observed for SO_2 in each of the three year.
- The hotspots of O_3 are revealing those spatial trends are similar in each year (2005 to 2007).
- The hotspots of O_3 coincide with that of $PM_{2.5}$, and SO_2 but many other hotspots areas were observed for O_3.
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Discussion Contd.

- The hotspots for ADR are represented in Fig. 4, clearly indicates that the major hotspots for ADR are observed in the same counties as that of $PM_{2.5}$, SO_2, and O_3.
- But, the distribution patterns are more similar to O_3 episode. Furthermore, the hotspots are observed in the same counties in three years (2005 to 2007).
- Hotspot analyses clearly indicate that there are multiple hotspots of hazard probability and these are identified in same location in each year.

Conclusions

- An important component of human health protection due to poor air quality is identification hotspots in respect to poor air quality in the area.
  - Three air pollutants ($PM_{2.5}$, SO_2, and O_3) and asthma discharge rate (ADR) were considered for the hot spot analyses to examine the association of air pollution and asthma in New York State, U.S.A.
  - Higher concentrations zone were identified and the ADR in those areas were determined for understanding the effect of exposure of high air pollutants to asthma discharge rate (ADR).
- Kernel density estimation (KDE) technique was used for hotspot analyses.
- Results show that there are multiple hotspots for these three air pollutants and they are significantly correlated to the locations of ADR in the study area.
  - Air pollution hotspots are clearly defined using the KDE approach based on point data of air pollutants.
  - Furthermore, the risk prone areas are explored by this technique (KDE) and the hotspot areas are captured without requiring exhaustive sampling.

More work

- Modeling validation
- Daily correlation
- Other regions

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Questions and Answers

THANK YOU

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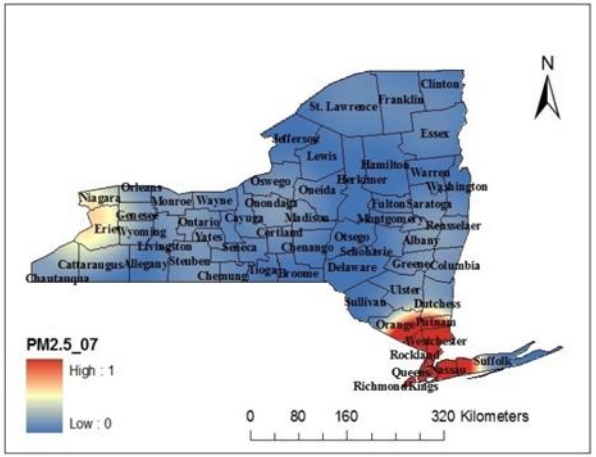
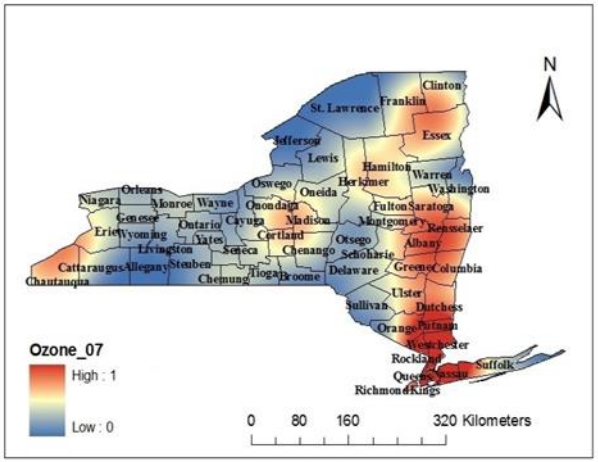
PM concentration: HotSpot Maps, New York, 2007



Ozone concentration: HotSpot Maps, New York, 2007



Astham Discharge concentration: HotSpot Maps, New York, 2007