

NPB FINAL RESEARCH GRANT REPORT FORMAT

As a requirement of each research grant, a final report detailing the project results must be provided to the National Pork Board. Please write the industry summary with the producer in mind. The remaining content of the report can be written for a scientific audience. ALL final reports must be submitted in the following format or the report will be returned for correction. PLEASE DO NOT INCLUDE ANY TYPE OF COVER PAGE.

Project Title and NPB project identification number

Improved spatial analysis to understand swine CAFOs and the surrounding environment and public health concerns
#20-067 (project #PR-005276)

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Industry Summary: Public health agencies often create exposure indexes to measure the impact of agriculture. However, it's important to consider how agriculture, the environment, and public health are interconnected when developing these indexes for research that can benefit everyone. Having better indices helps us answer the epidemiologically intriguing question of whether these communities would have similar negative health issues if there were no pig farms and find evidence-based solutions that are sustainable. With the goal to create better indices that measure potential exposure to large hog farms, while accounting for social, geographical, and environmental factors that makes up the complexity of the current situation, we created three geographical indexes at the census tract level: 1) number of households within 1-mile from a large hog farm, 2) Geostatistical interpolation that account for both the number of animals and the number of manure lagoons, and 3) hog density per square kilometer. Then, we compared these 3 indices with Center for Disease Prevention and Control (CDC)'s Environmental Justice Index (EJI) and Social Vulnerability Index (SVI), as well as several soil, water, environment variables. Finally, we also compared these indexes with three-selected health conditions: all-cause mortality, infant mortality, and diabetes (diabetes was used as a control: a health condition unlikely to be associated with exposure to hog farming).

Key Findings:

- In the preliminary analysis, moderate correlation was observed between all 3 CAFO exposure indices and the CDC's EJI. The SVI was correlated with the 1-mile buffer index suggesting socially vulnerable neighborhoods are on average within 1-mile buffer from these large pig farms.
- All 3 CAFO exposure indices were moderately correlated with crop-agricultural land area and landfill areas. Minor correlation was observed between public water sources and the three indices.
- Among the three health outcomes compared, including diabetes, all were associated with all the three indices, even after accounting for the social vulnerability. However, when accounted for both social vulnerability and crop-agricultural lands the strength of associations seem to diminish slightly.
- Overall, regardless of how the exposure to hog CAFOs was measured, their association with CDC's environmental justice, social vulnerability indices, or selected health conditions was observed. However, CAFOs are in census tracts that have large crop-agricultural lands and landfill areas making it difficult to distinguish the potential exposures that could contribute to complex ways influencing soil, water, or air quality in these areas beyond the mere presence of hog CAFOs.

Keywords: CAFO, spatial index, Exposure to hog CAFOs, public health, North Carolina

Scientific Abstract:

Introduction: Often in the view of environmental and public health, despite inconclusive body of literature, there is an implicit bias towards animal agriculture where it is villainized yet often neglected. Understanding the status quo of agriculture, environment, and public health aspects collectively is needed for betterment of translational research that can support sustainable, evidence-based, actionable solutions, and finding middle grounds. Spatial analysis would facilitate understanding the heterogeneity of exposure landscape and would support areas to focus on collecting finer scale data related to CAFO land use, propose targeted changes and determine allowable water, air, soil quality thresholds per CAFO location in vulnerable geographical areas.

Objectives: To quantify the status quo how the human or environmental exposure to hog CAFOs may be measured, accounting for site-specific social, geographical, and environmental factors.

Materials & Methods: Three spatial indexes were created at the census tract level, in North Carolina, to measure the exposure to hog CAFOs: 1) number of households within 1-mile from a large hog farm, 2) hog density per square kilometer, and 3) Geostatistical interpolation using co-Kriging that account for both the number of animals and the number of manure lagoons (Supplementary figure 1). The latter determined the risk as a continuous risk that can affect isotropically in the surrounding areas of the farm and the lagoons. These three indices were then compared against the CDC's Environmental Justice Index (EJI) and Social Vulnerability Index (SVI), the agricultural land area, number of public water sources, soil runoff characteristics, landfill, and air quality at the census tract; by calculating the correlation coefficient. Additionally a simple regression analysis was conducted to quantify the association between three indices and three selected health conditions (all-cause mortality, infant mortality, and diabetes; which was used as a control i.e. a health condition unlikely to be associated with exposure to hog farming), while adjusting for potential confounders recognized through the correlation analysis. In the absence of yearly data on core variables, this ecological study was done purely spatially.

Results: In the preliminary analysis, moderate correlation (0.11 – 0.31) was observed between all 3 indices and the CDC's EJI and SVI suggesting the exposure to CAFOs is likely related to areas affected by social vulnerability or were determined to have environmental justice issues (Supplementary figure 2). The SVI was correlated with 1-mile buffer index at correlation coefficient 0.31, indicating socially vulnerable neighborhoods are on average within 1-mile buffer from CAFOs. Known public water sources, number of landfills, and crop-agricultural land areas were all moderately correlated with the indices. All three-health conditions indicated strong associations to social vulnerability compared to the three CAFO exposure indices; suggesting it's applicability as a confounding factor when determining the association between CAFO exposure and the disease outcomes in the regression analysis. However, even after accounting for the social vulnerability, the association between CAFO exposure was statistically significant including for diabetes. However, when accounted for both social vulnerability and crop-agricultural lands the strength of associations seem to diminish (Supplementary Table 1).

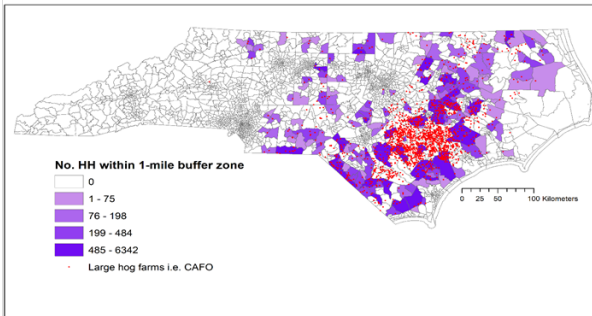
Discussion: The indices provide finer scale exposure measure for hog farming areas compared to previous estimates that were at zip code level, which are often subjected to change. Limitations of the analysis include variance of correlations, assumption that residents lived in the census tract all throughout their life and the exposures were due to the residential environment, and inability to tease apart the nature of exposure through an ecological study. Overall, regardless of how the exposure to hog CAFOs was measured, all suggested moderate association with CDC's environmental justice, social vulnerability indices, and selected health conditions; indicating that these neighborhoods have collective environmental, socioeconomic, and health issues. However, associations does not imply causation and CAFOs are located in census tracts that have large crop-agricultural lands and landfill areas making it challenging to prove or disprove association to exposures that could contribute to potentially affect soil, water, or air in these census tracts; which is much more complex than the mere presence of hog CAFOs.

Please add page numbers at bottom center of each page. Do not include any other headers or footers. All tables, figures and graphics must be included in **this report** and must be submitted electronically to grants@pork.org. Publication of the Final Report will follow Section 5.a as outlined in the Research Contract.

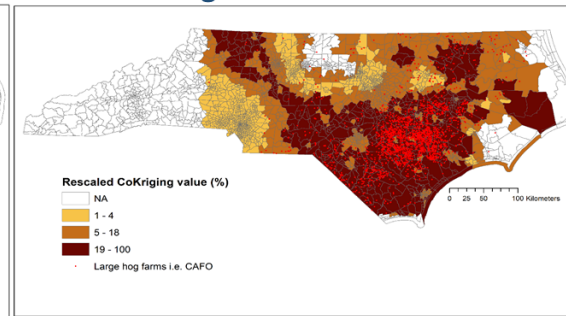
Any publications, presentations or abstracts of the project results, need to recognize proper funding credit by using this statement: "Funding, wholly or in part, was provided by the National Pork Checkoff" (Or in the case of state Pork Producers Association funding "on behalf of the [state] Pork Producers Association"). Thank you for your attention to these instructions. Please contact the National Pork Board via E-mail: grants@pork.org if you have any questions.

Supplementary material

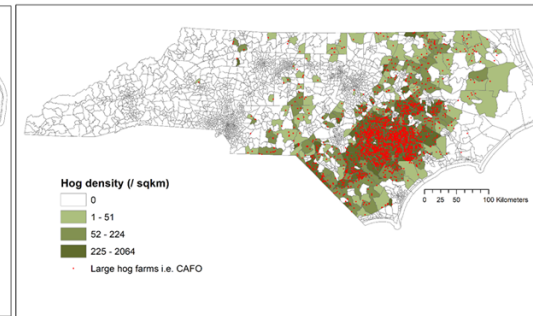
Index 1: Number of households within 1-mile buffer zones



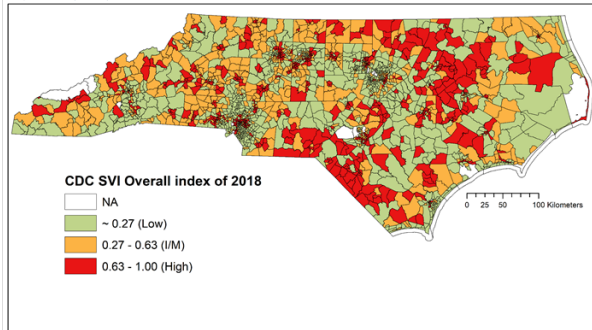
Index 2: Co-kriging using number of pigs and manure lagoons



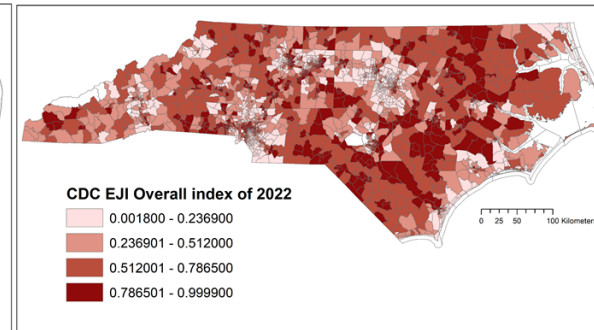
Index 3: hog density per square kilometer



CDC's Social Vulnerability Index (SVI) of 2018

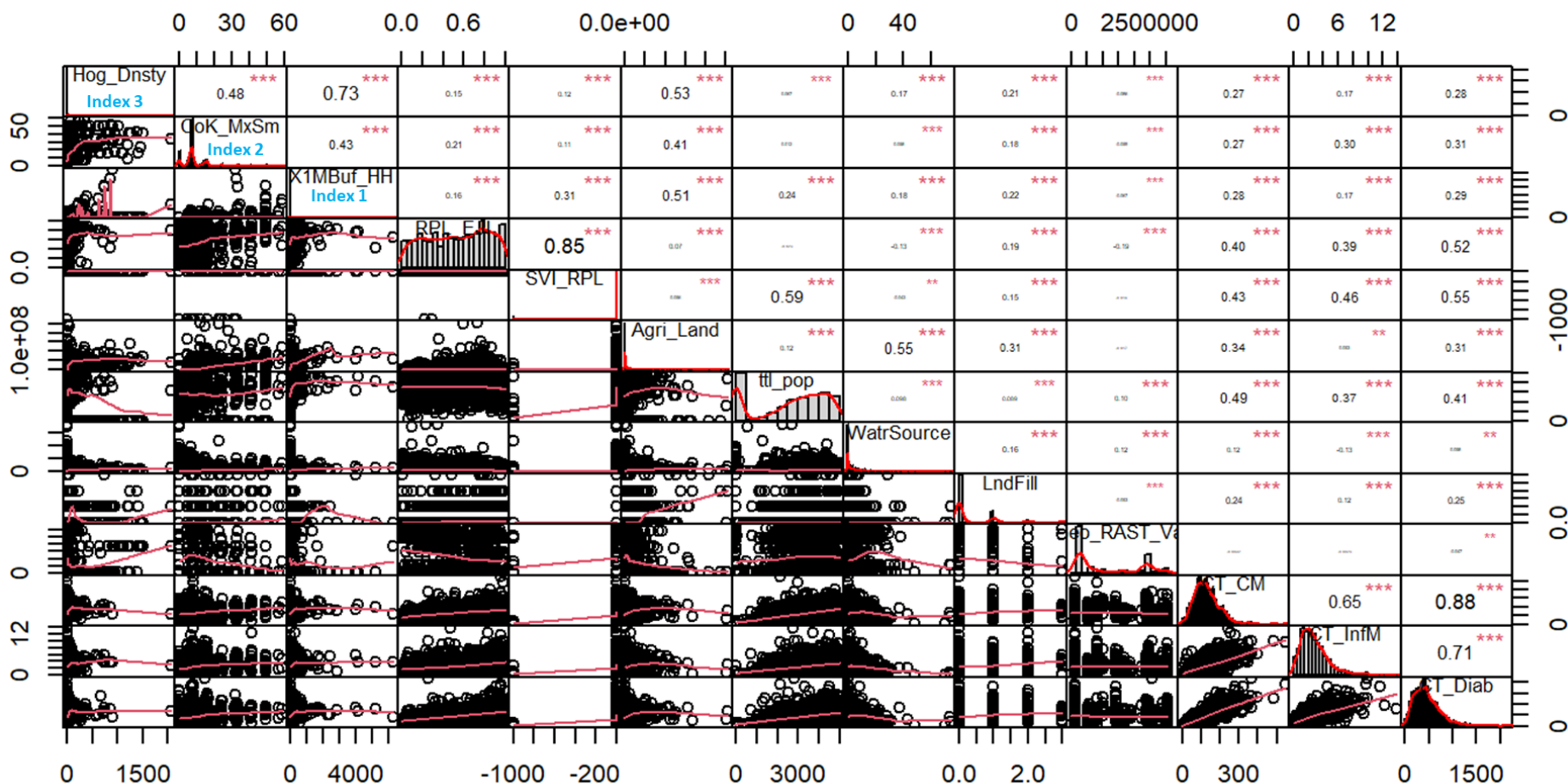


CDC's Environmental Justice Index (EJI) of 2022



Supplement Figure 1. Top row: Three spatial indices created at census tract level to determine the potential exposure to large hog farms (i.e. CAFOs: Concentrated Animal Feeding Operations) in the state of North Carolina. Index 1) number of households within 1-mile from a large hog farm, 2) hog density per square kilometer, and 3) Geostatistical interpolation that account for both the number of animals and the number of manure lagoons. Hog farms, as acquired from the North Carolina Department of Environmental Quality (DEQ) are depicted as point locations. Bottom row: Center for Disease Prevention and Control (CDC)'s Social vulnerability index (SVI) and the Environmental Justice Index (EJI).

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Supplement Figure 3. Correlation between the three spatial indices (rows 1,2,3 of the matrix), CDC’s Environmental Justice Index (EJI) and Social Vulnerability Index (SVI) (rows 4 and 5); other variables including the agricultural and area, total human population, number of public water sources, number of landfill sites, soil runoff value (rows 6: 10); and selected health conditions (rows 11:13). **Reading guide examples: hog density index and agricultural land area are correlated at 0.53 coefficient, 1-mile buffer index and CDC SVI are correlated at 0.31 coefficient.**

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Table 1. Regression results depicting the association between CDC’s Environmental Justice Index (EJI); Social Vulnerability Index (SVI), cropland area; the three indices and the three selected health conditions. Regression estimate (confidence interval) and statistical significance at p-value 0.05** are listed.

Regression Model	CDC SVI	CDC EJI	Crop-agriculture land area	Index 1	Index 2	Index 3
				Number of households within 1-mile from a large hog farm	Geostatistical interpolation that account for both the number of animals and the number of manure lagoons.	Hog density per square kilometer
All cause mortality	0.12 (0.10 - 0.14); **	87.83 (80.54 - 95.12); **	5.6e-07 (4.7e -07 - 6.5e-07);**	0.02 (0.016 - 0.027); **	1.43 (1.22 - 1.65);**	0.07 (0.05 - 0.09);**
All cause mortality adjusted for Social Vulnerability (SVI)				0.02 (0.015 - 0.026); **	1.42 (1.21 - 1.63);**	0.06 (0.04 - 0.08); **
All cause mortality adjusted for AVI and Agricultural land area				0.009 (0.004 - 0.015); **	1.05 (0.81 - 1.29);**	0.02 (0.018 - 0.04);**
Infant mortality	0.002 (0.001 - 0.003); **	2.18 (1.98 - 2.38); **	4.0e-09 (1.5e -09 - 6.5e-09);**	0.0004 (0.0002 - 0.0005); **	0.03 (0.02 - 0.04); **	0.001 (0.001 - 0.002);**
Infant mortality adjusted for Social Vulnerability (SVI)				0.0003 (0.0002 - 0.0005); **	0.03 (0.02 - 0.04); **	0.001 (0.001 - 0.002);**
Infant mortality adjusted for AVI and Agricultural land area				0.0003 (0.0002 - 0.0005);**	0.03 (0.03 - 0.04);**	0.001 (0.0009 - 0.002);**
Diabetes cases	0.44 (0.36 - 0.53); **	458.36 (427.89 - 488.82); **	2.1e-06 (1.7e -06 - 2.5e-06);**	0.09(0.06 - 0.11); **	6.17 (5.24 - 7.11);**	0.37 (0.27 0.46);**
Diabetes cases adjusted for Social Vulnerability (SVI)				0.08(0.06 - 0.11);**	6.14 (5.22 - 7.05); **	0.36 (0.27 - 0.45); **
Diabetes cases adjusted for AVI and Agricultural land area				0.04(0.02 - 0.07);**	5.01 (3.94 - 6.07);**	0.21 (0.19 - 0.35);**

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