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Assessment of Air Quality at Neighbor Residences in the Vicinity of Swine Production Facilities

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ABSTRACT. Air sampling was completed on the front lawn of 35 homes neighboring swine farms in three different regions in the Upper Midwest of the United States. One region was dominated by large scale, swine confined animal feeding operations (CAFO's) noted as swine confinement area (SCA). The second area was dominated by smaller scale operations utilizing hoop structure facilities (HA). The third area was basically devoid of livestock, dominated by row-crop production, and served as the control area (CA). The time weighted average concentrations of hydrogen sulfide (8.42 ppb) was higher ($p = 0.047$) in SCA area than the control (3.48 ppb). However, carbon dioxide (449.6 ppm), ammonia (12.78 ppb) and PM10 (42.25 $\mu g/m^3$) were higher in the hoop structure area than the other areas. Swine population density, distance between the homes and swine facilities, and wind direction had an interactive effect on the average levels of ammonia ($p = 0.04$). The contaminant levels at the homes were relatively low compared to typical concentrations inside animal buildings. However, exceedences of federal recommended limits for hydrogen sulfide in outdoor air were observed in the swine CAFO area. Concentration of hydrogen sulfide exceeded the recommended limits of the ATSDR (30 ppb) for chronic exposure at two of the 12 homes in the CAFO area (17%). Average hydrogen sulfide concentration exceeded the EPA recommended community standards (0.7 ppb) in all three areas assessed (SCA, HA, and CA). As chronic exposure to hydrogen sulfide may be present in areas of production agriculture, a potential health risk may be present. Further studies to provide additional information regarding exposures to hydrogen sulfide in rural environments are warranted. doi:10.1300/J096v11n03_03 *[Article copies available for a fee from The Haworth Document Delivery Service: 1-800-HAWORTH. E-mail address: <docdelivery@haworthpress.com> Website: <http://www.HaworthPress.com>*

KEYWORDS. Air quality, swine confinement animal feeding operation system (swine CAFO's), hydrogen sulfide, psychological disorder, respiratory symptoms

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INTRODUCTION

Since the 1970s, swine production in the U.S. has become increasingly concentrated, shifting from small operations to fewer but much larger operations. The latter are often termed swine confined animal feeding operations (CAFO's).[1,2] There has been public concern about potential health effects of emissions such as gases, particles, bioaerosols and microbial byproducts from animal waste and feed materials. Among the several air contaminants detected inside swine facilities and considered primary causal agents for occupational health problems include hydrogen sulfide, ammonia, dusts, glucans and endotoxin.[3-10] Respiratory symptoms, skin and mucous membrane irritation and a systemic influenza-like condition (organic dust toxic syndrome) are the most frequent complaints among swine workers.[8,9] Although swine worker health risks are well documented, only a few health studies of residents living near swine CAFO facilities have been published. However, those studies reported similar physical symptoms in area residents (productive cough, chest tightness, shortness of breath, eye and nose irritation, sore throat) to CAFO workers.[11-13] Additionally the residents report stress and mood disorders.[4,13,14]

To date, researchers have not concluded any direct causal relationship between CAFO emissions and specified diseases in those who live near such facilities.[15] Furthermore, there have been no studies published on exposures of residents living in the vicinity of CAFO's. Therefore the goal of this study was to assess the concentrations of various contaminants on the premises of residences located in the vicinity of swine CAFO's relative to climatic and swine production variables. Specifically, the aims of this study were to: (1) measure the concentrations of hydrogen sulfide, ammonia, PM10, and carbon dioxide at the front lawns of area residences of people living in the vicinity of swine production facilities; (2) compare those measurements in the area of high density swine production (swine CAFO area) with those found in an area having a less intensive style of production facilities (hoop structures), and an area nearly void of livestock (control area); and (3) investigate associations between the contaminant concentrations at neighbor homes and wind direction, swine population and distance between swine facilities and homes.

METHODS

Site Description

Three areas in Iowa were chosen for air quality assessment. The three areas were differentiated by production style: (1) a swine CAFO area where animals were densely housed (about 4,000 head per building); (2) a hoop structure area where animals were housed with a medium density level (about 150 head per building); and (3) a control area with very little swine production.

Typically, swine CAFO facilities as an industrialized production style are different from hoop structures in swine population density, building structures, and manure handling systems. Swine CAFO facilities house as many as 4,000 head per building, whereas hoop structures house about 150 head (Figures 1 and 2). In CAFO buildings, indoor air temperatures and humidity levels are controlled by mechanical and/or natural ventilation systems. In hoop style buildings, only natural ventilation is used, by opening and closing curtains at each end of the structure. Animal wastes are also handled in different manners. The swine CAFO facilities in the region of this study are typical of most facilities built in the late 1980s and in the 1990s in

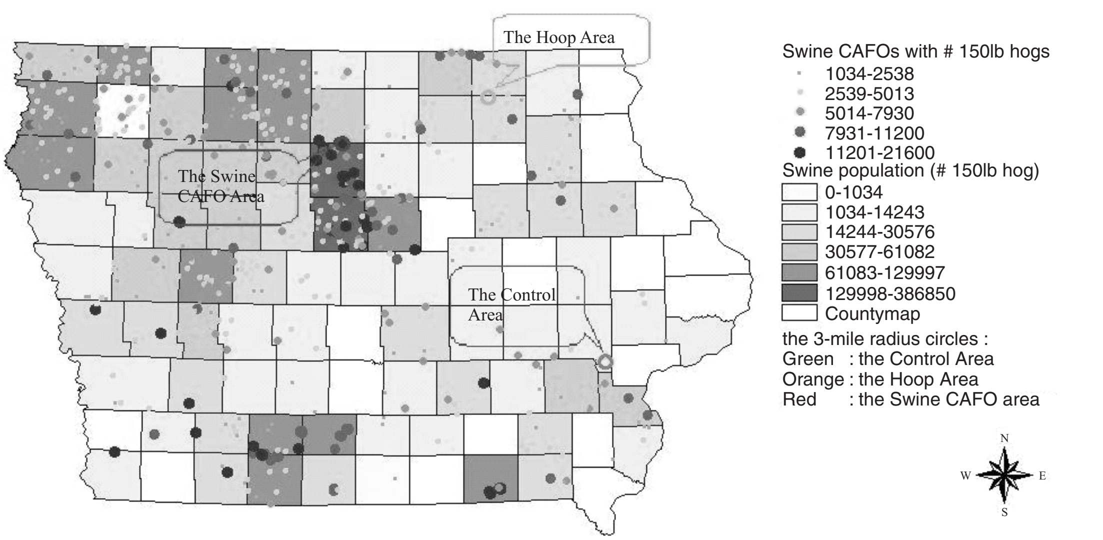
FIGURE 1. An aerial view, representative of the swine confinement animal feeding operation (CAFO) study area

the U.S. The buildings have slatted floor-pit systems where the wastes are stored for several days to months and then flushed into an outdoor earthen storage structure. Some anaerobic digestion occurs in these storage structures, resulting in the release of gases such as H_2S, NH_3, and CH_4 into the air. In hoop structures, wastes are collected in straw or other plant fiber bedding materials placed on the floor. As the manure is not stored in liquid form and exposed to air, emission of anaerobic gases is limited. However, ammonia would be an expected emittent.

FIGURE 2. Inside of a hoop structure facility for swine production

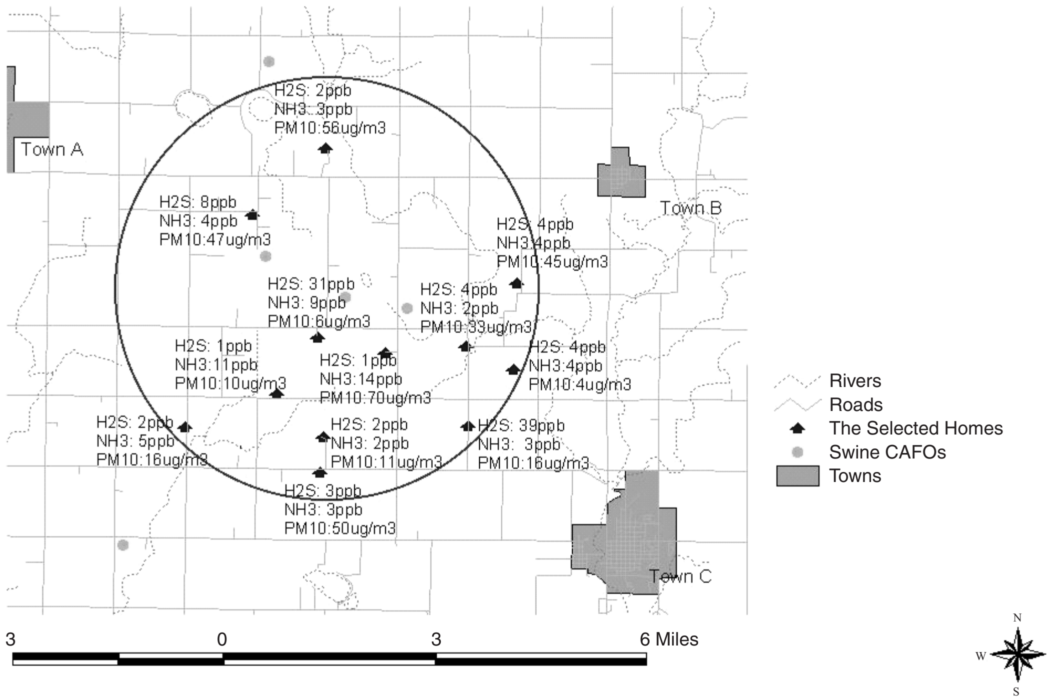
The swine population densities in the three chosen counties were as follows: 150 head/km^2 in the swine CAFO area; 49 head/km^2 in the hoop area; and 7 head/km^2 in the control area. Specific areas studied within the three counties were defined by a circle with a three-mile (4.8 km) radius. These areas were chosen as they contained both a high number of residents and swine production facilities. The swine CAFO area had six swine CAFO facilities, with numbers in each ranging from 4,500 to 16,500 animals (Figure 3). The second study area was 80 miles from the CAFO area, dominated by smaller farms utilizing hoop structure buildings. The control area was basically devoid of livestock and dominated by row-crop production (Figure 3). The CAFO area had 73 homes, the hoop structure area had 57 homes, and the control area contained 85 homes. Among the homes, 12 in each area were randomly chosen and agreed to participate in the study (Figure 4); however, one home in the hoop area declined to participate in air sampling. The CAFO area was visited from August to October, the hoop area from September to October, and the control area from June to July. One visit for air sampling was made to each participating home.

FIGURE 3. Swine CAFO's and swine population in Iowa: Locations of the case and control areas: the dots represent facilities that have a permit[a] from the Department of Natural Resources (DNR[b])



a. A permit is required for operations with anaerobic or earthen manure lagoons when their capacities are greater than 200,000 lbs
b. Source from 1997 Iowa DNR database

FIGURE 4. The map of the high swine population density area: The swine CAFO area with the concentrations of contaminants at the selected homes



Sampling and Analysis Methods

The air quality was assessed from a site in the front lawn of neighborhood homes. The air was assessed for carbon dioxide, hydrogen sulfide, particulate matter with a mass median aerodynamic diameter less than 10 μm (PM10), and ammonia. Additionally, wind direction, speed, and temperature were monitored at the same time. Sampling was conducted for a 4 to 5 hour period on one day at each residence, typically between the hours of 8 a.m. to 5 p.m. Carbon dioxide was monitored with a Non-Dispersive Infrared sensor (Q-trak, model # 5881, TSI Incorporated, Shoreview, MN) and recorded every 5 minutes over the sampling period. Hydrogen sulfide was monitored using a Jerome gold film monitor (Arizona Instrument, Phoenix, AZ) with data-logger, at five minute intervals. Ammonia was monitored using an impinger containing sulfuric acid solution (H_2SO_4, 0.01 N) at a flow rate of 1 LPM. Chemical analysis was completed with NIOSH Method 6015 for samples in the CAFO and the control area and with alkali-phenate indophenol (APIP) method for those in the hoop area.[16] PM10 samples were collected using PM10 impactors (Air Diagnostic and Engineering Inc., Naples, ME) at flowrate of 20 LPM and measured gravimetrically.

Data Analysis

Data were statistically analyzed to compare the air quality in the vicinity of swine CAFO's to those in the hoop area and in the control area with analysis of covariance (ANCOVA) using Statistical Analysis System (SAS 8.0). We examined the null hypothesis that there was no difference in mean concentrations of the measured air contaminants in the three areas (Ho: $X_{\text{AVE Control area}} = X_{\text{AVE Hoop area}} = X_{\text{AVE Swine CAFO area}}$). Individual comparisons were calculated using least significance difference (LSD) method.

Multiple regression analysis was used to analyze relationships between hydrogen sulfide, ammonia, and PM10, to the independent variables of wind speed, direction, temperature, humidity, distance from home to the variable CAFO's in the region, and swine population at the CAFO's. As shown in Figures 4 and 6, the concentrations of H_2S and NH_3 at a residence are related to the population of swine and distance between the CAFO and home, and the wind direction. An equation (Equation 1) was developed from the regression that describes the interactive relationships of swine population (P), distance of the CAFO from residence (D), wind direction (W), PDW on H_2S and ammonia concentrations at neighbor residences.

$$PDW = \sum_{N=1}^{6} \frac{(Weight_{total-swine} \times Wind_{direction})}{D} \quad (1)$$

N: swine buildings in the swine CAFO area
$Weight_{total\text{-}swine}$: swine population as total weight (lb)
Wind direction: upwind = 0, downwind = 1
D: distances between the swine CAFO and homes (Km)

There were six swine buildings in the 3 mile-radius area where air quality was assessed at neighbor residences (Figure 4). Hence, six swine population, distance, and wind direction factors (PDWs) were calculated for each home as followed:

1. When the CAFO was downwind (at the same time air emissions were measured) of a home, the population of the swine confinement facility was multiplied by one. If the CAFO was upwind of a home, swine population was multiplied by zero. (Based on a previous study,[5] we assumed upwind CAFO's would not contribute to air contamination at the residence.) The concentration of contaminants at a given home was calculated by summing the PDW's of the six CAFO's in the three mile radius.
2. The product of the animal weight and the wind direction was divided by the distance between each animal building and the selected home because concentrations of dispersed contaminants are inversely related to the distance.
3. Finally, the calculated total PDWs represent levels of the contaminants, considering varied distances between the selected homes and the six swine buildings. It also takes into account the effect of wind.

Temperature, relative humidity, and wind speed were controlled in the regression analysis. The concentration of hydrogen sulfide and ammonia were log-transformed, due to non-normal distribution of the data.

RESULTS

Two of the 12 home sites (17%) in the CAFO area had measured H_2S concentrations between 30-39 ppb which exceeds recommended levels made by the Environmental Protection Agency (EPA) of 0.7ppb for lifetime exposure, and also exceeded recommendations of the Agency for Toxic Substance and Disease Registry (ATSDR) of 30 ppb for chronic exposures.[6] No individual measures exceeded the ammonia level recommended by either agency (maximum reading = 67.95 ppb). The EPA recommends a maximum exposure of 144 ppb for lifetime exposure to ammonia and 500 ppb for acute exposures. The ATSDR recommends a maximum of 300 ppb for chronic exposures.[6] The average levels of contaminants in all three areas did not exceed the ambient air quality standards[17,18] (Table 1).

Figure 5 displays the average concentrations of the four contaminants assessed in the three different areas. In ANCOVA tests, CO_2 levels were different in the three areas ($p < 0.05$) while there were no differences in the levels of H_2S, ammonia, and PM10 at the 5% significance level. However, the Tukey and Scheffé tests for individual comparisons among the three areas showed that: (1) H_2S levels were significantly higher in the CAFO area compared to the control area ($p = 0.047$); (2) in the hoop area, CO_2, PM10, and ammonia levels were higher than in the control area (p-values were 0.02, 0.049, 0.038, respectively); (3) and CO_2 and PM10 levels were higher in the hoop area than swine CAFO area (p-values were 0.034 and 0.049, respectively) (Table 2).

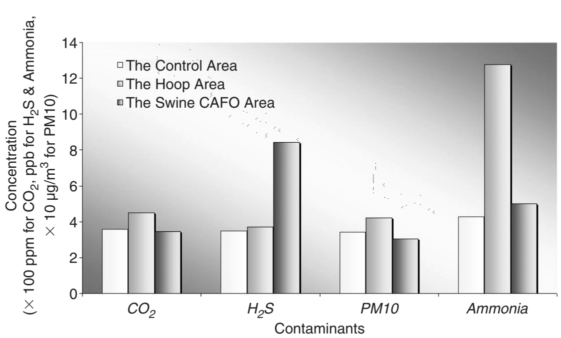
The concentrations of ammonia and H_2S measured on the premises of rural residents were affected by the number of swine and distance between farm and residence and the wind direction (PDW factor). Ammonia was more

TABLE 1. Contaminate levels in the selected three areas; average, maximum, and minimum concentrations and coefficient of variations in the areas.

	CO_2 (ppm)		H_2S (ppb)		PM10 (µg/m^3)		Ammonia (ppb)	
	Mean CV(%)	Max Min	Mean CV(%)	Max Min	Mean CV(%)	Max Min	Mean CV(%)	Max Min
Control area (N = 12)	357.9 24.75	462.0 130.0	3.48 65.84	9.0 1.0	34.26 76.39	87.86 11.11	4.27 75.85	12.34 0.59
Hoop area (N = 11)	449.6 35.77	808.0 314.0	3.70 41.68	6.0 2.0	42.25 77.28	106.38 12.71	12.78 154.25	67.95 0.00
CAFO area (N = 12)	345.8 22.16	441.0 154.0	8.42 150.58	39.0 2.0	30.28 75.63	70.04 3.89	5.01 77.01	13.50 1.60
Average (N = 35)	382.6 27.56	.	5.24 7.73	.	37.91 76.43	.	6.72 102.37	.
Standard	.		0.72 ppb[a], 30 ppb[c], 50 ppb[d]		150 µg/m^3[e]		144 ppb[a], 300 ppb[b], 150 ppb[d]	

[a] EPA community standards[19]
[b] ATSDR community standard for intermediate exposure (15 to 364 days)[6]
[c] ATSDR community standard for chronic exposure (365 days and longer)[6]
[d] Iowa Concentrated Animal Feeding Operation Air Quality Study[15]
[e] National Ambiant Air Qualité Standards (NAAQS)[19]

FIGURE 5. Average levels of the contaminants in the three chosen areas



strongly associated with PDW ($p < 0.05$) than hydrogen sulfide ($p = 0.06$). Results showed that the increase in ammonia and hydrogen sulfide concentrations were approximately twice the relative increase in PDW (β-values of ammonia and H_2S concentrations = 0.5648 and 0.4754, respectively). Also, the R-square values for correlations between ammonia, hydrogen sulfide and PDW were quite robust ($r^2 = 0.5$) (Table 3, Figure 6). Particulate matter under 10 microns (PM10) was also collected, but there was no association found relative to PDW factors.

DISCUSSION

The results showed that the swine CAFO area had higher concentrations of H_2S than the control area. However, the other contaminants were higher in the hoop area than in other areas. Gas generation, building management techniques, and environmental factors may explain the outcomes. Hydrogen sulfide is produced primarily through anaerobic digestion in CAFO-style production facilities where liquid manure is stored for several months prior to land disposal. In contrast, wastes in hoop buildings are stored in solid form under aerobic conditions until bedding materials are replaced. This method is not a suitable microbial environment for H_2S production, but it does allow ammonia production and offgassing as there is little water to "trap" the ammonia. Management practices and environmental conditions may affect the amounts of emissions as well. If hoop buildings are not well-kept, and bedding is not changed regularly, more ammonia and particles could be generated in the hoop buildings than in well-maintained swine CAFO structures. Furthermore, contaminant dispersion is influenced by topographic factors, such as weather and diurnal changes. For example, gas concentrations

TABLE 2. Statistical analysis results for individual comparisons of contaminants' concentrations in the three areas.

Areas[a]		CO_2	H_2S	PM10	Ammonia
CA & HA	Comparison	HA > CA	HA > CA	HA > CA	HA > CA
	P-value	0.020	0.674	0.049	0.038
CA & SCA	Comparison	SCA > CA	SCA > CA	SCA > CA	SCA > CA
	P-value	0.755	0.047	0.941	0.523
HA & SCA	Comparison	HA > SCA	SCA > HA	HA > SCA	HA > SCA
	P-value	0.034	0.106	0.049	0.132

[a] CA–control area: HA–hoop area: SCA–swine CAFO area

TABLE 3. The interaction effect of swine population, distance between swine confinements and the homes, and wind direction (PDW[b]): The results of regression analysis (n = 12).

Variables	Slope		R^2
	β	Pr.	
CO_2 (ppm)	0.3908	0.2091	0.1527
H_2S[a] (ppb)	0.4754	0.0628	0.5023
PM10 ($\mu g/m^3$)	−0.0375	0.9047	0.2010
Ammonia[a] (ppb)	0.5648*	0.0404	0.4996

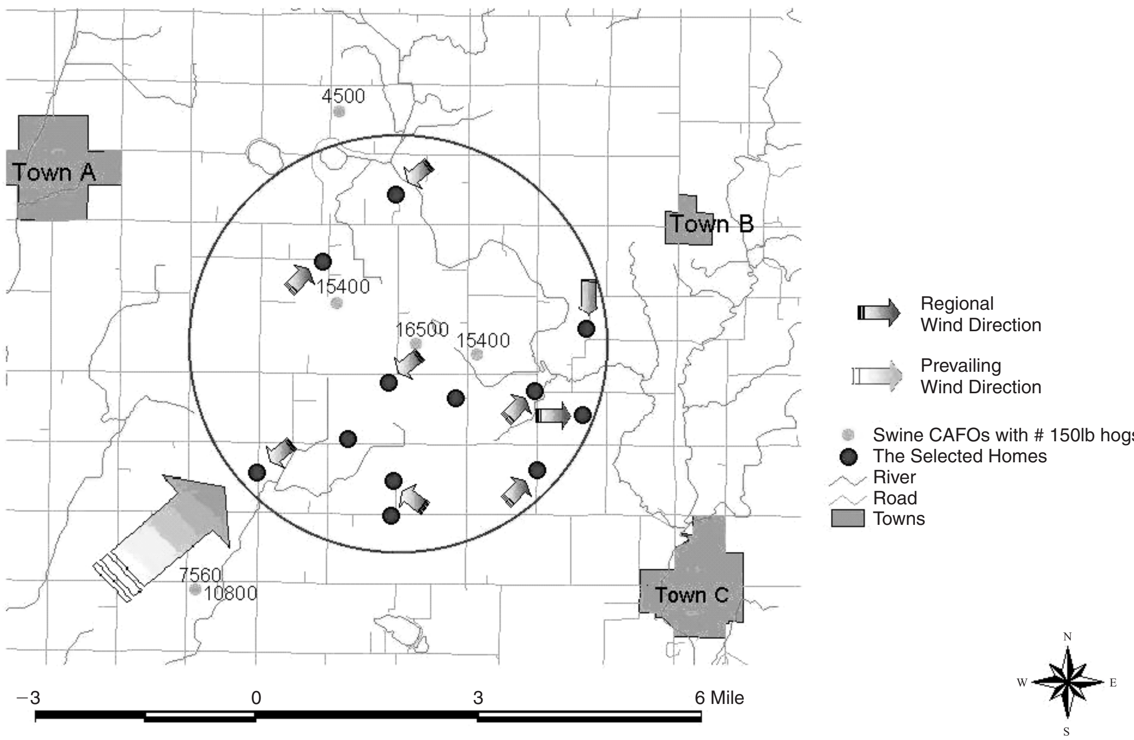
[a] These data were transformed to logarithms[3]
[b] Unit : lb/km*10[6]
* Significant at 5% significance level

in the evening may be much higher than in the daytime as the air temperature cools. This temperature change can decrease updraft, with a subsequent decrease in contaminant dispersion rates (inversion). Gas properties may complicate the dispersion. Ammonia and carbon dioxide are lighter than air and disperse upward, while H_2S is heavier than air and remains on the ground. These conditions may have contributed to higher levels of carbon dioxide, ammonia and PM10 in the hoop area than in the swine CAFO area.

In the regression analysis, H_2S and ammonia concentrations were log transformed since the data were not normally distributed; however, the concentrations were used without taking log-transformation in ANCOVA tests to compare the concentrations among the three areas. Typically assumed parametric analysis such as regression analysis, ANOVA, and ANCOVA requires normal distribution and homogeneity of variances in datasets. However, the ANOVA including ANCOVA tests have been demonstrated to be fairly robust to violations of these assumptions.[20-22] Although several H_2S measurements were relatively high compared to other measures, we did not consider these measures as outliers, but accurate measures, because a high standard of quality assurance was followed in our analytical technique.

Based on the precautionary principle,[23] we conclude that residents living in areas with concentrated CAFO buildings may have potential health risks. Studies in other settings have suggested health risks from chronic low level exposures to hydrogen sulfide.[24-27] Previous reports revealed residents in the CAFO region had excess self-reported symptoms of respiratory conditions.[12] Individual measures of H_2S and ammonia in several homes near the swine CAFO and the hoop areas were higher than the recommended levels for community environments by the EPA and the ASTDR. Although the average level of each contaminant was relatively low, the combined effect of the contaminants could increase health risks. For example, the respiratory tract is a target organ for several environmental contaminants; H_2S, ammonia, and endotoxins are respiratory irritants, and small size particles (PM10) can deposit deep into the airways creating an additive or synergistic health effect.[28] These substances are irritants and inflammatory substances, and may be responsible for respiratory symptoms reported in previous studies. Particles combined with ammonia have been shown to have a synergistic adverse effect on the respiratory tract.[27] Psychological problems such as depression as well as respiratory symptoms have been common complaints among participating families living near the swine CAFO buildings in previous studies.[4,12] These finding were similar to out-

FIGURE 6. The locations of the homes in the swine CAFO area and wind directions; the small arrows indicate wind directions measured during the sampling periods and the one large arrow indicated the predominant wind direction during the entire year as measured by the nearest meteorological station of the National Weather Service (www.nws.noaa.gov)



comes in other published studies, in which people living near industrial facilities that emitted H_2S gases experienced various psychological symptoms such as confusion, anger, unusual fatigue, and depression.[24,26] Although the data presented here do not constitute proof of a direct physical cause of disease, several hypotheses may explain observed symptoms. These include: (1) unpleasant odors can affect mood; stress and depression, in particular, may suppress the immune system; (2) social-economic pressures that people experienced as a result of living in these areas may exacerbate stress-related disorders; and (3) the contaminants may produce the negative effects directly or indirectly. Hypotheses one and two above can be classified as extra toxic mechanisms, as reviewed by Donham.[9] The last hypothesis is supported by results from several clinical studies. Significant neurobehavioral and psychological disorders, including central nervous system symptoms, were reported among people exposed to low levels of H_2S.[24,27] Damage to the central nervous system was found among victims exposed to H_2S acutely (high levels for a short time)[29] or chronically (low levels over a long period), resulting in neurobehavioral impairments.[24,27] A previously reported health survey of the residents of homes in this study where these measures were taken revealed a significantly higher rate of respiratory symptoms (e.g., bronchitis and asthma), but no excess symptoms of anxiety or depression.[12] The levels of contaminants detected in this study were generally lower than ATSDR and EPA recommendations (with the exception of H_2S). However, H_2S did exceed EPA standards[19] and ATSDR[6] standards for chronic exposure (based on a one day measure). A cause-effect relationship for such low level concentrations to cause health problems remains uncertain. It is reasonable as a "precautionary principle" to use best management practices to protect neighbors from potential health effects of air emissions from swine production facilities.[22]

The swine population, distance and wind direction factor (PDW) influenced the concentrations of ammonia. This outcome is a reflection of an increase in contaminants when hogs are densely housed and when homes are located downwind from swine CAFO's. People living near and downwind of swine CAFO buildings have greater exposures and presumed greater health risks than others; hence, those communities need to be more conscientious about their health.

Study limitations were small population size and single time-weighted measurement (4-5 hours) per home. These limitations lessen the ability to generate generalizable information on the relationship of varied environmental conditions such as temperature, and season of the year. Further studies are necessary to better understand the causal relationship between concentration of airborne contaminants released from CAFO operations and the health problems of those living near swine CAFO's.

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