Odors from Sewage Sludge and Livestock: Associations with Self-Reported Health

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ABSTRACT

Objectives. Class B treated sewage sludge (TSS) contains microbes and toxicants and is applied to land in areas where livestock wastes may be present. We evaluated relationships of reports of TSS and livestock odors with acute symptoms and excessive flies.

Methods. A total of 158 adults living near liquid TSS application sites, 85 living near cake TSS application sites, and 188 living in comparison areas responded to a household survey regarding odors, health, and demographics. We identified symptom groups using factor analysis. We used generalized estimating equations to fit linear models for associations between factor scores and odors, and Poisson models for associations with specific symptoms.

Results. Most factor scores were similar between exposure groups. Covariate-adjusted z-scores for lower respiratory symptoms were 0.28 (95% confidence interval [CI] –0.10, 0.65) higher among residents who reported moderate to very strong liquid TSS odor than among residents in comparison areas, and 0.28 (95% CI 0.05, 0.50) higher among residents who reported moderate to very strong livestock odor compared with residents reporting no or faint livestock odor. The factor score for dermatologic conditions was higher among residents who reported higher liquid sludge odor (0.27, 95% CI –0.13, 0.68), primarily due to skin rash (prevalence ratio = 2.21, 95% CI 1.13, 4.32). Excessive flies were reported twice as commonly among respondents who reported moderate to very strong TSS odor than among other residents.

Conclusions. Reported odors from TSS and livestock were associated with some acute symptoms. Health departments should monitor land applications of human and animal wastes and conduct surveillance of health problems reported by neighbors.

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Waste disposal is a universal public health challenge. Industrial and agricultural production and consumption can expose people to toxicants and pathogens. Technological innovation, while advancing methods for waste treatment, has created novel anthropogenic pollutants and contributed to the capacity of humans to create greater volumes of waste in smaller areas, increasing potential health impacts.

Recycling waste is an alternative to disposal. Treated sludge from municipal wastewater, which is composed of solid residues from wastewater as well as microbes and chemicals used for treatment, contains nutrients and is used as a soil amendment. In 2004, approximately 2.6 million dry tons of treated sludge were applied to agricultural land in the United States.[1] Land-applying sludge is cheaper than landfilling or incineration, and farmers receive free fertilizer and labor. Most land-applied sludge is designated Class B, which has less stringent pathogen load-reduction requirements than Class A. Treated sludge is called "biosolids" by its producers, appliers, and regulators;[2] however, the neologism is not well recognized by people uninvolved in its production and disposition. We use the term "treated sewage sludge" (TSS).[3]

TSS is applied to agricultural land as a liquid or dewatered (semisolid) cake using tractors with sprayers, injectors, or manure spreaders. Some people living near sites where TSS is applied to land report offensive odors, excessive flies, mucous membrane irritation, headaches, and symptoms of acute respiratory, dermatological, and gastrointestinal (GI) illness.[4–8] In addition to odorant chemicals, endotoxins, allergens, and pathogens that could cause acute effects, TSS contains numerous persistent organic pollutants and heavy metals.[9–12] Genetic markers of human TSS can be detected in air samples taken downwind from cake TSS application.[13,14]

Animal wastes receive far less treatment for pathogens and vector control. Airborne pollutants from industrial swine operations have been measured in nearby communities;[15–19] residents report more mucous membrane irritation, acute respiratory symptoms,[20] stress and anxiety,[21] and interference with activities of daily living[19] during periods of acute exposure compared with unexposed periods, and their blood pressure is higher.[22] Children living or attending school near industrial swine operations have higher rates of wheezing and doctor-diagnosed asthma.[23–25] TSS and animal manure may be land applied to the same or nearby fields. Therefore, in assessing possible acute effects of TSS, it may be important to evaluate coincident exposure to airborne pollutants from livestock.

We report results of a survey conducted in rural North Carolina in which we assessed TSS odor, livestock odor, and acute symptoms in areas where TSS was recently applied and comparison areas where TSS land application is not permitted.

METHODS

We conducted a door-to-door survey in selected areas of two North Carolina counties. Residents, including some in the study areas, had reported concerns about land application of TSS in public meetings or directly to the authors. We selected an area in each county where residents reported that TSS had been applied in the previous six months and obtained field locations and application amounts from mandatory reports submitted by municipalities to the North Carolina Division of Water Quality. In one study area, 5,375,400 gallons of liquid TSS containing 3%–5% solids (902 dry tons) were applied above ground via sprayers during the six months prior to data collection; in the other study area, 2,989 dry tons of dewatered cake TSS containing 28% solids was broadcast using manure spreaders during the six months prior to data collection. We used ArcMap® software[26] and county tax parcel records to enumerate residential addresses within approximately 1 kilometer (km) of at least one applied field. We enumerated a similar number of residences in two nearby comparison areas that were at least 5 km from the nearest permitted TSS application site. Permitted and comparison neighborhoods in each county were surveyed at the same time. Residents who alerted us to recent TSS application events were excluded from survey participation.

We mailed an introductory letter telling residents that interviewers would soon be visiting their neighborhood to ask people questions for a study of rural air quality and human health. Seventeen trained interviewers administered a short questionnaire in teams of two in June 2010. If they identified inhabited residences that were not on the study list, they attempted to invite members of those households to participate. If a person ≥18 years of age came to the door, interviewers asked how many people who met the eligibility criteria lived in the house and attempted to contact all eligible residents up to five times at varying times of the day and week.

Residents were eligible if they were ≥18 years of age, spoke English, and had lived in their home for ≥6 months. If no one was home at the first visit, interviewers left a door hanger summarizing the survey and alerting residents they would return. Following an approved consent process, interviewers administered the questionnaire to participating residents.

We based the questionnaire on an instrument used in a previous rural health survey conducted near concentrated animal feeding operations[27] and adapted questions based on in-depth interviews with neighbors of land-application sites,[6] a study of wastewater treatment plant workers,[28] and reports from residents near land-application sites.[5,29,30] Participants provided information about demographic and housing characteristics, health, environmental odors, and nuisances. Respondents were asked to recall how often they experienced 14 respiratory, GI, and dermatological symptoms in the previous six months (never, one day, 2–4 days, 5–7 days, or ≥8 days). They also rated the highest level of odor from livestock, sludge, agricultural chemicals, and smoke from fires that they had noticed outside in the past six months as none, faint, moderate, strong, or very strong. Because people living near livestock and TSS application sites have previously reported excessive numbers of flies as a nuisance, we asked how many days in the past six months respondents had noticed an excessive number of flies. Interviewers used a six-month calendar and retrieval cues to improve recall[31] and showed flashcards with response options. The six-month recall period was selected to capture known land-application events and maximize the number of potentially exposed areas for canvassing. At the end of the structured survey, participants were asked whether they had any concerns or observations about the outdoor environment where they live or about their health in relation to the outdoor environment; interviewers recorded their responses.

We classified TSS air pollution exposures based on location and reported odors. Residents of comparison areas were considered unexposed to TSS. People living near sites where liquid or cake TSS was applied during the six months preceding the survey were classified as having reported either no or faint TSS odor, or moderate, strong, or very strong TSS odor. Air pollution from livestock, a possible alternate explanation of symptoms reported by people living near TSS application sites, was classified for residents of all areas as none or faint vs. moderate, strong, or very strong. Reported chemical and smoke odors were also classified as none or faint vs. moderate, strong, or very strong. To assess the impact of odor groupings on reported associations, we explored model fit (via the quasi likelihood information criterion [QIC])[32] and estimated factor score differences and prevalence ratios (PRs) under different odor groupings and linear terms for odors (0 = none/faint, 1 = moderate, 2 = strong, and 3 = very strong). In all analyses, we controlled for age group, gender, race, education, smoking, and living with a smoker, using categories given in Table 1.

As stated previously, respondents were asked to recall how often they experienced each of 14 symptoms. Because of the commonalities among the 10 respiratory, two GI, and two dermatological symptoms, we used factor analysis to summarize the frequency distributions of related symptoms and reduce dimensionality of these data. We used varimax rotation and selected a factor analytic solution based on the percentage of overall variability explained by each factor, using the scree plot and extracting all factors with eigenvalues >1.[33] The resulting factor scores, which are standardized normal variates, were considered as the dependent variable in linear regression analyses using generalized estimating equations (GEEs) to take into account the sampling of more than one person from households. We report mean differences in factor scores of TSS vs. comparison groups, and moderate to very strong vs. no or faint livestock odor, along with their 95% confidence intervals (CIs). Additionally, we used GEEs to fit Poisson models with a log link to estimate PRs and their 95% CIs for each symptom classified as present (more than once in the past six months) vs. absent. We also fit adjusted models for reports of excessive flies on ≥5 days in the past six months vs. <5 days in the past six months. We focused on describing associations rather than hypothesis testing. In the absence of random sampling and randomization of exposure, CIs cannot be interpreted in terms of the probability that an interval estimate includes a population parameter of interest,[34] although it provides information about the precision of estimates. Three respondents, each missing values for one symptom, did not contribute to the factor scores or to the Poisson models for that symptom; one respondent missing data for five questions was excluded.

RESULTS

Of 490 houses approached in the study areas, 129 were ineligible because they appeared unoccupied, the residents had lived in their home <6 months, or the residents did not speak English. Interviewers identified eligible residents in the liquid TSS area (n=243), in the cake TSS area (n=115), and in the comparison areas (n=318); 31 eligible residents in the liquid TSS area, 14 eligible residents in the cake TSS area, and 32 eligible residents in the comparison area could not be contacted. A total of 157 of 212 eligible residents in the liquid TSS area, 85 of 101 eligible residents in the cake TSS area, and 188 of 286 eligible residents in the comparison areas consented to participate (Figure).

Respondents' demographic characteristics are shown in Table 1. Residents of the liquid TSS area were younger and had less schooling than those in the cake TSS and comparison areas. A higher proportion of those in the liquid TSS area vs. the cake TSS and comparison areas also reported smoking or living with a smoker (Table 1). In the permitted areas, 77 of 152 households (51%) had multiple respondents, while in the comparison areas, 81 of 133 households (61%) had multiple respondents (data not shown).

Fifty-six percent of respondents in the liquid application area reported no sludge odor compared with 37% of respondents in the cake application area, where 34% reported moderate/strong/very strong odor. Moderate/strong/very strong odors from agricultural chemicals were reported most frequently in the cake application area (14%), and moderate/strong/very strong odors from livestock were most common in the liquid application area (55%). Moderate to strong odor from smoke was reported by 38% of participants in the comparison areas and 37% of participants in the liquid application area (Table 2).

We chose a four-factor solution for the 14 symptoms. Based on the factor loadings in Table 3, we interpreted the factors as representing upper respiratory, lower respiratory, GI, and dermatologic symptoms. Adjusted associations of sludge and livestock odors with the factor scores are shown in Table 4. The largest mean differences were for lower respiratory symptoms among respondents who reported moderate/strong/very strong liquid TSS odor (0.28, 95% CI –0.10, 0.65) and livestock odor (0.28, 95% CI 0.05, 0.50). Because the factor scores have a standard deviation of 1, these mean differences indicate an increase of 28% in the value of the pooled standard deviation for the lower respiratory symptom scores in residents who reported moderate to very strong TSS odor relative to residents of comparison areas, and moderate to very strong compared with no or faint livestock odor. The next largest value was for dermatologic symptoms among respondents who reported higher liquid TSS odor (0.27, 95% CI –0.13, 0.68).

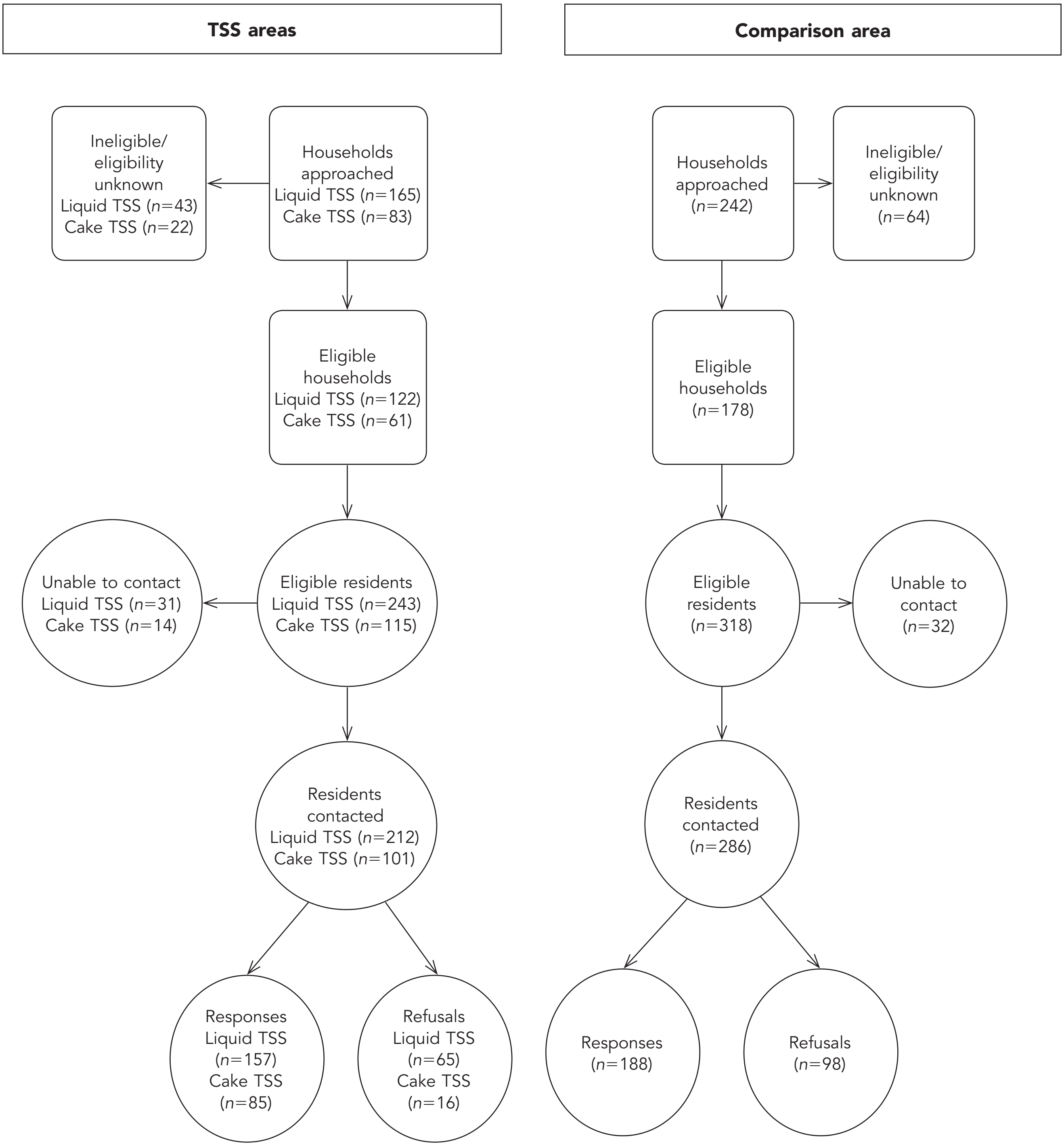
Table 5 presents PRs for individual symptoms. Most PRs ranged from 0.8 to 1.5. The PRs for skin rash were 1.66 (95% CI 0.91, 3.03) among respondents who reported no or faint liquid TSS odor and 2.21 (95% CI 1.13, 4.32) among those who reported moderate, strong, or very strong liquid TSS odor, suggesting a dose-response relationship. Similarly, the PRs for wheezing in the liquid TSS area were 1.35 (95% CI 0.73, 2.50) for none or faint odor and 1.76 (95% CI 0.99, 3.16) for moderate/strong/very strong odor. The highest PR among cake TSS respondents was 1.54 (95% CI 0.72,

Table 1. Sociodemographic characteristics and smoking status of North Carolina residents (*n*=430) who participated in a study of odors from TSS and livestock and self-reported health, 2010

Characteristic	*Liquid TSS application* N *(percent)*	*Cake TSS application* N *(percent)*	*Comparison areas* N *(percent)*
Age group (in years)			
18–34	38 (24.2)	13 (15.3)	31 (16.5)
35–44	40 (25.5)	13 (15.3)	51 (27.1)
45–54	32 (20.4)	21 (24.7)	45 (23.9)
55–64	27 (17.2)	23 (27.1)	32 (17.0)
≥65	20 (12.7)	15 (17.7)	29 (15.4)
Gender			
Female	87 (55.4)	45 (52.9)	101 (53.7)
Male	70 (44.6)	40 (47.1)	87 (46.3)
Race			
White	129 (82.2)	77 (90.6)	145 (77.1)
Nonwhite	28 (17.8)	8 (9.4)	43 (22.9)
Education			
≤High school	75 (47.8)	25 (29.4)	47 (25.0)
Some college	59 (37.6)	23 (27.1)	74 (39.4)
≥College	23 (14.7)	37 (43.5)	67 (35.6)
Current smoker			
No	100 (63.7)	71 (83.5)	150 (79.8)
Yes	57 (36.3)	14 (16.5)	38 (20.2)
Lives with a smoker			
No	123 (78.3)	76 (89.4)	167 (88.8)
Yes	34 (21.7)	9 (10.6)	21 (11.2)
Total	157 (100.0)	85 (100.0)	188 (100.0)

TSS = treated sewage sludge

Figure. Household enumeration and participant eligibility, response, and refusal status of North Carolina households in a study of odors from TSS and livestock and self-reported health, 2010



TSS = treated sewage sludge

Table 2. Environmental odors reported by North Carolina residents (*n*=430) who participated in a study of odors from TSS and livestock and self-reported health, 2010

Type of odor	*Liquid TSS application (n=157)* N *(percent)*	*Cake TSS application (n=85)* N *(percent)*	*Comparison areas (n=188)* N *(percent)*
Sludge			
None	88 (56.1)	31 (36.5)	188 (100.0)
Faint	19 (12.1)	13 (15.3)	
Moderate	20 (12.7)	12 (14.1)	
Strong	13 (8.3)	13 (15.3)	
Very strong	17 (10.9)	16 (18.8)	
Agricultural chemicals			
None, faint	145 (92.4)	73 (85.9)	175 (93.1)
Moderate, strong, very strong	12 (7.6)	12 (14.1)	13 (6.9)
Livestock manure			
None, faint	71 (45.2)	51 (60.0)	128 (68.1)
Moderate, strong, very strong	86 (54.8)	34 (40.0)	60 (31.9)
Smoke			
None, faint	99 (63.1)	61 (71.8)	117 (62.2)
Moderate, strong, very strong	58 (36.9)	24 (28.2)	71 (37.8)

TSS = treated sewage sludge

3.29) for wheezing among those reporting moderate/strong/very strong TSS odor. Among respondents who reported moderate, strong, or very strong livestock odor, PRs for difficulty breathing and wheezing were 1.52 (95% CI 1.02, 2.27) and 1.54 (95% CI 0.95, 2.51), respectively. Under several different odor groupings or use of linear terms for odors, model fit (QIC) did not improve consistently across symptoms/factors under alternate schemes, and strengths of associations between odors and symptoms/factors were unchanged.

Living in areas where TSS was applied and reporting moderate to very strong livestock odor were associated with reports of excessive flies on ≥5 days in the past six months. Adjusted PRs were 2.27 (95% CI 1.55, 3.33) and 1.95 (95% CI 1.25, 3.05) for no or faint and moderate to very strong liquid TSS, respectively; 1.27

Table 3. Pattern matrix for factor analysis (varimax rotation, four-factor solution) of self-reported symptoms in past six months for North Carolina residents (*n*=430) who participated in a study of odors from TSS and livestock and self-reported health, 2010

Symptom	*Factor 1 Upper respiratory*	*Factor 2 Lower respiratory*	*Factor 3 Gastrointestinal*	*Factor 4 Dermatologic*
Sneeze	0.712[a]	0.103	0.166	0.071
Runny nose	0.743[a]	0.133	−0.010	−0.083
Nasal congestion	0.785[a]	0.172	0.086	−0.049
Eye irritation	0.641[a]	−0.004	0.079	0.162
Nasal irritation	0.644[a]	0.256	−0.020	0.190
Sore throat	0.502[a]	0.373	0.021	−0.204
Headache	0.467[a]	0.048	0.429	−0.088
Difficulty breathing	0.100	0.797[a]	0.205	0.179
Cough	0.258	0.686[a]	−0.044	−0.140
Wheeze	0.122	0.787[a]	0.248	0.119
Abdominal pain	0.060	0.140	0.710[a]	0.258
Nausea	0.062	0.149	0.771[a]	−0.203
Skin rash	0.211	0.135	0.002	0.659[a]
Skin ulcers	−0.097	−0.042	−0.005	0.668[a]
Number of items	7	3	2	2
Eigenvalue	4.05	1.53	1.16	1.05
Percent variance explained	29	11	8	8

[a]Factor loadings with values >0.45 contributed to the interpretation of the factors.

TSS = treated sewage sludge

Table 4. Mean factor score differences and 95% CIs from GEE linear models for odors from liquid TSS, cake TSS, and livestock for North Carolina residents (*n*=430) who participated in a study of odors from TSS and livestock and self-reported health, 2010

	Liquid TSS odor[a]		*Cake TSS odor*[a]		*Livestock odor*[b]
Symptom factor	*None or faint Difference*[c] *(95% CI)*	*Moderate/strong/ very strong Difference*[c] *(95% CI)*	*None or faint Difference*[c] *(95% CI)*	*Moderate/strong/ very strong Difference*[c] *(95% CI)*	*Moderate/strong/ very strong Difference*[c] *(95% CI)*
Upper respiratory	0.05 (−0.20, 0.30)	−0.06 (−0.35, 0.24)	−0.09 (−0.37, 0.19)	0.01 (−0.33, 0.35)	−0.06 (−0.28. 0.15)
Lower respiratory	−0.01 (−0.28, 0.26)	0.28 (−0.10, 0.65)	0.21 (−0.17, 0.59)	−0.10 (−0.37, 0.16)	0.28 (0.05, 0.50)
Gastrointestinal	0.04 (−0.20, 0.27)	0.15 (−0.22, 0.52)	0.08 (−0.26, 0.42)	0.18 (−0.15, 0.51)	0.04 (−0.18, 0.25)
Dermatologic	−0.02 (−0.23, 0.20)	0.27 (−0.13, 0.68)	−0.11 (−0.41, 0.19)	0.16 (−0.17, 0.50)	−0.10 (−0.30, 0.11)

[a]Residents of the comparison areas were the referent group for none or faint and moderate/strong/very strong TSS odor.

[b]Residents who reported no or faint livestock odor were the referent group for moderate/strong/very strong livestock odor.

[c]Factor score differences were adjusted for age, race, gender, education, smoking, passive smoking, agricultural chemical odors, and odors from burning. A positive score indicates higher symptom reporting among the exposed.

CI = confidence interval

GEE = generalized estimating equation

TSS = treated sewage sludge

Table 5. Prevalence ratios and 95% CIs from GEE models for odors from livestock, liquid TSS, and cake TSS for North Carolina residents (*n*=430) who participated in a study of odors from TSS and livestock and self-reported health, 2010

	Liquid TSS odor[a]		*Cake TSS odor*[a]		*Livestock odor*[b]
	None or faint PR[c] *(95% CI)*	*Moderate/strong/ very strong PR*[c] *(95% CI)*	*None or faint PR*[c] *(95% CI)*	*Moderate/strong/ very strong PR*[c] *(95% CI)*	*Moderate/strong/ very strong PR*[c] *(95% CI)*
Upper respiratory					
Sneeze	1.09 (0.87, 1.37)	1.01 (0.73. 1.38)	1.20 (0.89, 1.60)	1.05 (0.75. 1.47)	0.97 (0.79, 1.18)
Runny nose	1.03 (0.86, 1.25)	0.79 (0.58, 1.07)	0.99 (0.78, 1.25)	0.82 (0.61, 1.09)	1.16 (0.98, 1.38)
Nasal congestion	1.08 (0.89. 1.32)	1.09 (0.86, 1.38)	0.94 (0.71, 1.24)	1.05 (0.79, 1.39)	0.93 (0.78, 1.10)
Eye irritation	0.83 (0.61, 1.14)	0.95 (0.63, 1.43)	0.95 (0.64, 1.42)	1.12 (0.72, 1.76)	0.99 (0.75, 1.29)
Nasal irritation	0.77 (0.48, 1.26)	1.38 (0.84, 2.26)	0.75 (0.36, 1.56)	1.17 (0.66, 2.10)	0.76 (0.51, 1.13)
Sore throat	1.13 (0.86, 1.48)	1.21 (0.86, 1.72)	1.41 (0.97, 2.04)	0.74 (0.45, 1.21)	1.08 (0.85, 1.36)
Headache	0.98 (0.81, 1.18)	1.01 (0.77, 1.33)	0.97 (0.72, 1.32)	1.05 (0.77, 1.44)	1.03 (0.87, 1.23)
Lower respiratory					
Difficulty breathing	1.18 (0.71, 1.97)	1.09 (0.58, 2.05)	1.41 (0.69, 2.88)	1.37 (0.75, 2.52)	1.52 (1.02, 2.27)
Cough	0.98 (0.72, 1.34)	1.05 (0.73, 1.53)	1.19 (0.78, 1.81)	0.90 (0.54, 1.50)	1.31 (1.01, 1.71)
Wheeze	1.35 (0.73, 2.50)	1.76 (0.99, 3.16)	1.42 (0.57, 3.51)	1.54 (0.72, 3.29)	1.54 (0.95, 2.51)
Gastrointestinal					
Abdominal pain	0.90 (0.60, 1.33)	1.00 (0.66, 1.51)	0.46 (0.24, 0.88)	0.88 (0.50, 1.53)	1.08 (0.78, 1.50)
Nausea	0.85 (0.51, 1.42)	1.39 (0.79, 2.45)	1.49 (0.79, 2.82)	1.77 (0.96, 3.26)	1.04 (0.69, 1.55)
Dermatologic[d]					
Skin rash[e]	1.66 (0.91, 3.03)	2.21 (1.13, 4.32)	1.17 (0.50, 2.76)	1.00 (0.41, 2.46)	0.75 (0.44. 1.28)

[a]Residents of the comparison areas were the referent group for none or faint and moderate/strong/very strong TSS odor.

[b]Residents who reported no or faint livestock odor were the referent group for moderate/strong/very strong livestock odor.

[c]PR adjusted for age, race, gender, education, smoking, passive smoking, agricultural chemical odors, and odors from burning.

[d]Skin ulcer was also in this factor group, but the model for this symptom did not converge due to the small number of cases.

[e]Present if ever reported in the past six months

CI = confidence interval

GEE = general estimating equation

TSS = treated sewage sludge

PR = prevalence ratio

(95% CI 0.65, 2.48) and 1.99 (95% CI 1.21, 3.25) for no or faint and moderate to very strong cake TSS; and 1.66 (95% CI 1.22, 2.25) for moderate to very strong livestock odor (data not shown).

Ninety-four participants in comparison areas (50%), 94 participants in the liquid TSS area (60%), and 61 participants in the cake TSS area (75%) answered open-ended questions about general health and environmental concerns. Considering liquid and cake TSS areas combined, 30 respondents said they were concerned about sludge; 16 respondents raised environmental concerns including well- and surface-water contamination, air quality, wildlife, and livestock; and several respondents reported seeing TSS run into local waterways. Thirteen respondents reported concerns about the chronic effects of drinking TSS-contaminated well water and breathing polluted air. Ten respondents commented on offensive TSS odors. Three respondents said they do not go outside when the odor is present. Four respondents mentioned other nuisances they associate with sludge application, including flies, truck traffic, sludge spillage on roads, and sludge spray on car windshields when residents drive behind trucks hauling sludge. Two respondents mentioned a desire to be notified before TSS is applied in their neighborhood (data not shown).

Twelve participants in the comparison areas, 17 participants in the liquid TSS area, and none in the cake TSS area responded to open-ended questions with concerns about livestock. Nineteen participants mentioned unpleasant odors and eight respondents were concerned about surface- and well-water contamination. Four respondents said chicken manure contaminated their well water. Four respondents reported flies as a nuisance that they associated with livestock odors. Two respondents said exposure to chicken manure impacted their health, either because of an allergic reaction to air pollution or because of contaminated drinking water (data not shown).

DISCUSSION

Airborne particles and gases from TSS and livestock include odorant chemicals, irritants, and allergens, pollutants that could cause exposed people to experience malodor, physical symptoms, and reduced quality of life.[35] Previous studies of land-applied TSS have not examined TSS and livestock exposures simultaneously. Using residence in areas where TSS is applied to land and reported odors from TSS and livestock as measures of exposure, we evaluated reported physical symptoms and the presence of excessive flies as a measure of quality of life.

Approximately 27% of TSS neighbors reported moderate to very strong TSS odor. Differences in reports of TSS odor near liquid and cake TSS application may be due to residential proximity, weather conditions, TSS characteristics, application practices, odor sensitivity, and other personal characteristics. Compared with residents of areas where land application of TSS was not permitted, residents who reported moderate to very strong liquid TSS odor had higher factor scores for lower respiratory symptoms, primarily due to excessive wheezing. Respondents who reported moderate to very strong livestock odor also had a higher factor score for lower respiratory symptoms compared with those who reported no or faint odor. The factor score for dermatologic symptoms was also elevated among residents of the liquid TSS area who reported stronger TSS odor, primarily due to an elevated PR for skin rash. Other symptom factor scores and prevalence of specific symptoms were similar among groups.

Many residents near livestock operations and sites where TSS is applied to land have reported reduced quality of life, in part due to pests. In our survey, people residing near TSS land-application sites reported observing excessive flies approximately twice as often as residents of comparison areas. Reports of excessive flies were 66% higher among residents who reported moderate to very strong livestock odor.

We designed the study to address several potential biases. We enumerated all inhabited households in defined areas and attempted to interview all residents; 74% of invited residents agreed to participate. We compared residents of areas where TSS is land applied with residents of nearby rural areas where land application of TSS was not permitted. We used memory aids to promote symptom recall during the past six months. We adjusted TSS PRs for differences in age; gender; race; education; smoking; other household smokers; and odors from livestock, agricultural chemicals, and smoke. Participants who responded to open-ended questions reported concerns about TSS that were similar to those described in in-depth interviews with 34 residents conducted in three states.[6]

Limitations

This study was subject to several limitations. First, we studied potentially exposed areas in only two counties during a six-month time window. Six months is an extended time period for recalling minor symptoms and may have resulted in under- or overreporting of symptoms.[36] We cannot determine temporal relationships between episodes of exposure and symptoms within the recall period. Second, the sample size was relatively small. Participation among invited residents was lower in the comparison areas than in the TSS areas. Third, residents of the liquid TSS area were younger, completed fewer years of school, and smoked more than residents in comparison areas. These differences could affect reporting of symptoms, and covariate adjustment may not adequately control for differences between populations in other determinants of symptoms. Fourth, we did not measure particles or gases present at respondents' homes and did not account for variation in odor sensitivity, odor frequency vs. intensity, time outside at home, and other behaviors that could affect exposure. Finally, some respondents may not have known what TSS is. As such, errors in reporting odors and outcomes could be correlated.

CONCLUSION

Reported lower respiratory and dermatologic conditions were higher among respondents who reported stronger liquid TSS odors. Excessive flies were reported more frequently by residents of both TSS areas. These estimates control for reported livestock odor, which was also related to reported lower respiratory symptoms. Land application of Class B TSS is regulated because it can contain pathogens and toxicants that are harmful to health and the environment. Case reports suggest that land application of TSS can produce acute health impacts; however, quantifying them is challenging because the presence of an effect depends on (*1*) concentrations of hazardous pollutants in the source material, (*2*) the quantity applied, (*3*) the distance to neighbors, (*4*) weather conditions and barriers that affect the direction and distance of transport, and (*5*) sensitivity of exposed people.

Studies of a small number of application events have limited power to detect impacts if only a subset of such events produces acute health problems for susceptible individuals. Cross-sectional surveys can only produce snapshots of events in a few locations during a short time period. Systematic surveillance of reports of illness from land application of TSS should include large areas and numerous application events for longer time periods. Such surveillance is of interest to health and environmental officials;[7] however, the symptom reports[7] and TSS records[3] needed for surveillance are not routinely collected. As TSS production and land application grows, systematic exposure and disease surveillance are needed to better identify the TSS sources and land-application situations that prompt reports of illness.

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