Published in final edited form as:

South Med J. 2013 January ; 106(1): 74–81. doi:10.1097/SMJ.0b013e31827c54fc.

Long-term Impact of Environmental Public Health Disaster on Health System Performance: Experiences from the Graniteville, South Carolina Chlorine Spill

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Abstract

Objective—In the aftermath of an Environmental Public Health Disaster (EPHD) a healthcare system may be the least equipped to respond. Preventable visits for ambulatory care sensitive conditions (ACSCs) may be used as a population-based indicator to monitor health system access post-disaster. The objective of this study was to examine whether ACSCs rates among vulnerable sub-populations are sensitive to the impact of a disaster.

Methods—We conducted a retrospective analysis using Poisson regression with generalized estimating equations to calculate change in monthly ACSC visits at the disaster site in the post-disaster period compared to the pre-disaster period after adjusting for parallel changes in two control groups.

Results—The adjusted rate of an ACSC hospital visit pre-disaster for the direct group was 1.68 times the rate for the primary control group (95% CI: 1.47, 1.93), while the adjusted ACSC hospital rate post-disaster for the direct group was 3.10 times the rate for the primary control group (95% CI: 1.97, 5.18). For emergency department ACSC visits, the adjusted rate among those directly affected pre-disaster were 1.82 times the rate for the primary control group (95% CI: 1.61, 2.08), while the adjusted ACSC rate post-disaster was 2.81 times the rate for the primary control group (95% CI: 1.92, 5.17).

Conclusions—Results revealed increased demand on the health system altered health services delivery for vulnerable populations directly impacted by the disaster. Preventable visits for ACSCs

may advance meaningful use practice and public health surveillance by identifying and characterizing healthcare disparities during disaster recovery.

INTRODUCTION

In the aftermath of an Environmental Public Health Disaster⁶ (EPHD)—accidental or intentional release of hazardous chemicals—a health system may be the least equipped to respond to the medical needs of the affected population. Research documenting a stressed health system's ability to respond to the amplified and fluctuating demand for medical care during recovery is necessary to inform hospital preparedness and response planning.¹⁻⁵ Limited evidence suggests that increased demand for ambulatory care services exacts strain on the health system throughout recovery, exacerbating health and healthcare access disparities for vulnerable disaster populations.^{6,7} Vulnerable subgroups have chronic health needs that may be aggravated, created, and in some cases overlooked during response and recovery efforts, resulting in a separate public health emergency. An understudied, but critically important public health issue is whether declines in health system performance precipitate decreased access to care among the medically vulnerable (i.e., chronically ill, disabled, or under-resourced individuals with disadvantaged health circumstances⁸) in the months following an EPHD.^{9-15,16}

Train Derailment and Chlorine Spill

Graniteville, a medically underserved area in South Carolina, made national headlines on January 6th, 2005 when a Norfolk Southern freight train derailed at 2:39 am resulting in a ruptured tank car discharging approximately 90 tons of chlorine into an unsuspecting community. Direct chlorine inhalation resulted in 9 fatalities and 550 acute care visits. Approximately 5,400 residents within a one-mile radius of the spill were subject to a 1-2 week mandatory evacuation. Governor Mark Sanford's request for federal disaster relief was rejected; leaving this medically underserved community without additional public assistance to aide recovery efforts. Two years into recovery, Graniteville residents repeatedly reported overbooked providers and insufficient medical resources. Residents are contextual experts and community concerns, whether real or misperceived, warrant investigation anytime issues of supposed healthcare disparities are in question. We were compelled by numerous accounts of access barriers from the Graniteville community to take a closer look.

Disparities in Health System Access

Medically vulnerable populations shoulder a disproportionate burden of chronic illness and disabilities, and are the most affected, but least equipped to offset a sudden change in routine health services. Monitoring health system access for medically vulnerable populations is not currently a directive for public health surveillance efforts during disaster recovery. Mokdad et al underscore the necessity for surveillance tools that track health services delivery to medically vulnerable populations including the chronically ill.⁵ Inequities in health outcomes during recovery are likely driven by reduced health system access. Surveillance measures identifying and characterizing healthcare access-related disparities have not yet been recommended. We propose public health tracking of Ambulatory Care Sensitive Conditions (ACSC) as a proxy measure of access to quantify the long-term impact of the

2005 chlorine spill on the health care system. Surveillance of ACSC visits may signal failures in public health and the medical system to adequately meet the care needs of vulnerable disaster populations.

The following study explores the use of ACSCs as a simple, practical population-based indicator to track changes in health system access for vulnerable populations impacted by an EPHD. Our study examined whether the ACSC indicator for access increased or decreased over time, while assessing changes in the ACSC rates before and after the chlorine spill. We hypothesized that declines in access would correspond with an increase in ACSC rates among medically vulnerable populations in the disaster area and this increase would be greater than any concurrent increase in ACSCs rates for two separate control populations. This study expands disaster epidemiological research by examining the impact health sector recovery has on access to care for vulnerable populations.

METHODS

Study Population

Medicaid provides health care to nearly 25% of the state's most vulnerable residents, including low-income families, the disabled, and those in transition. Medicaid beneficiaries often experience persistent gaps in insurance coverage,¹⁷⁻²² reduced access to nonmedical services,²³ chronic health problems,²⁴ and medical service access difficulties^{19,25-29}. We chose SC Medicaid beneficiaries as a target population most representative of the "medically vulnerable".

Data Sources

Hospital and ED discharge data for SC Medicaid beneficiaries age 18 to 64 were obtained from the SC Medicaid paid UB-92 claims housed by the Office of Research and Statistics (ORS) of South Carolina State Budget and Control Board for the years 2002 to 2007. We also requested data on primary care use for this population. Medicaid beneficiary enrollment dates were collected from the SC Medicaid recipient file and linked to the SC Medicaid paid claims by a unique Medicaid recipient number in a 1 to 1 linkage. All data were stripped of personal identifiers by ORS. ORS estimated that more than 99.5% of Medicaid hospitalization and ED records were successfully linked. Individuals over the age of 65 were excluded from our analysis due to Medicare coverage and research shows little variation in hospital admissions for ACSCs among this group.^{30,31} Pregnant mothers hospitalized for child birth were excluded in denominator counts.

Approval for this study was obtained from the Institutional Review Boards at the University of South Carolina. The project was determined exempt from Human Research Subject Regulations.

Health System Capacity

To ensure comparable study of the health system across communities we matched study groups on: 1) Population Demographics; 2) Healthcare System/Capacity; and 3) HPSA/MUA designations. The town of Graniteville alongside two smaller communities in

close proximity was home to residents directly affected by the 2005 chlorine spill (i.e., direct group). Geographically close control sites were chosen in order to reflect broader local influences on health services use at the study site. Residents in the indirect group (i.e., primary control group) were in the same county as the direct group, but further south from the event (environmental data revealed that the chlorine gas traveled north). We included the primary controls because this group likely shared the same county-level healthcare resources and health system profile as the direct group. Since we could not rule out the possibility of a spillover effect due to close proximity of the disaster area, we included a secondary control group. The direct, primary, and secondary control groups were similar in terms of health system capacity (focus of our study) indicated by inpatient bed availability, presence of 1 federally qualified health care center (FQHC), more than one rural health center (RHC), and similar HPSA/MUA designations.

Study Design

We conducted a retrospective analysis of preventable hospitalization and emergency department discharge rates for ACSCs proximal to Graniteville, SC during the period from 2002 to 2007, with 2005 representing the year of the chlorine accident. We examined hospital and ED rates for ACSCs separately. To test our primary hypothesis, we compared ACSC rates for the disaster affected population before and after the chlorine spill. We also examined ACSC rates in two control groups to account for secular trends within the study area. Before and after time periods (pre-disaster: 36 months and post-disaster: 36 months) were identical for treatment and control groups alike.

Measures

In previous studies, ACSCs have been validated as conditions for which hospitalization and emergency department rates varied among groups with different levels of access to health care.^{21,32} ACSCs have been used as an indicator of access to and adequacy of primary care^{30,33-35} and to assess health system performance.²⁷ Preventable hospitalization rates for ACSCs are higher in areas of concentrated racial and ethnic minorities³⁶⁻³⁸, with lower education levels^{39,40}, among the poor and uninsured^{38,39,41,42}, rural residents^{30,39,43}, among Medicaid/Medicare beneficiaries^{38,39,43,44}, and for medically underserved areas/populations (MUA/P)⁴⁵⁻⁵¹ or health profession shortage areas (HPSA)^{27,51-53}. ACSC-related⁵⁴⁻⁵⁶ principal diagnosis were characterized: Grand mal seizures, convulsions, severe ENT infections, bacterial pneumonia, cellulitis, skin grafts, gastroenteritis, kidney and urinary infection, dehydration, dental conditions, pelvic inflammatory disease, and hypoglycemia, tuberculosis, asthma, angina, diabetes, nutritional deficiencies, chronic obstructive pulmonary disease (COPD), congestive heart failure (CHF), and hypertension (HTN). Due to sample size limitations in the direct group we analyzed all ACSCs combined.

Denominator data for rates were obtained from ORS Medicaid eligibility files. We calculated ACSC rates by dividing the number of hospital or emergency department discharges for previously validated ACSCs (numerator) by Medicaid enrollee population counts (denominator) for each study group in a given year.

Statistical Analysis

Descriptive statistics were used to summarize patient populations pre- and post- the 2005 chlorine spill. Chi-square (χ^2) tests were conducted for categorical data and t tests for interval variables. Poisson regression with generalized estimating equations (GEE) was used to calculate the change in number of ACSC visits at the disaster site in the post-disaster period compared with the pre-disaster period after adjusting for parallel changes in the control group. The quasi-likelihood information criterion (QIC) was used to choose the best correlation structure and goodness-of-fit was determined by using the QICu.⁵⁷ Data analysis were conducted using PROC GENMOD in SAS software, Version 9.2 (SAS Institute Inc., 2002-2007)⁵⁸; an α level of .05 was used throughout.

We used the following model: $\text{Log } |E(Y)| = \beta_0 + \beta_1 (\text{study group}_i) + \beta_2 (\text{age group}_i) + \beta_3 (\text{marital}_i) + \beta_4 (\text{qualifying category}_i) + \beta_5 (\text{time period}_i) + \gamma (\text{study group}_i \times \text{time period}_i)$ where i represents population subgroups defined by distinct sets of covariates (study group, age, marital status, qualifying category, and disaster status); Y represents number of monthly ACSC hospital or ED counts; study group (i.e., direct, primary control, and secondary control); age group (18-24, 25-34, 35-44, 45-54, 55-64); marital status (divorced, married, separated, single, or widowed); qualifying category (Aide to Families with Dependent Children (AFDC), disabled, other); and time period (Pre:2002-2004 vs. Post:2005-2007). We were primarily interested in the coefficient γ , which quantified the extent to which ACSC rates for the direct group changed after the chlorine spill above and beyond the prior adverse status of some study groups and the simple effect of the 2005 accident. To estimate the combined effect of study group and disaster status through Poisson regression we calculated $\{RR = \exp(\beta_1 \times \text{study group}_i + \beta_5 \times \text{time period}_i + \gamma \times [\text{study group}_i \times \text{time period}_i])\}$. This expression assesses the impact of prior adverse status, disaster, and the interaction term of disaster $\times$ prior disadvantage.

RESULTS

Health Services Use

Table 1 displays category of service use by study group and disaster period. We detected a significant increase in post-disaster hospital ACSC visits among the direct group (pre: 42.6% vs. post: 57.4%, $p=0.03$). Results showed no difference in ACSC hospital discharges before and after the chlorine spill for the primary and secondary control groups. While both the direct (pre: 54.8% vs. post: 45.2%, $p<.01$) and primary control (pre: 52.0% vs. post: 48.0%, $p<.05$) groups revealed a significant decline in ACSC ED discharges compared to the pre-disaster period, the secondary control showed a statistically significant increase in ACSC-related ED visits post-2005 (pre: 46.7% vs. post: 53.3%, $p<.001$).

Primary care visits declined in all three study areas post-2005. For the direct group, fewer beneficiaries sought care from a clinic (pre: 71.9% vs. post: 28.1%, $p<.0001$) and RHC (pre: 60.9% vs. post: 39.2%, $p<.001$) in the post disaster-period. After 2005, disaster affected Medicaid beneficiaries increasingly sought primary care from the local FQHC (pre: 35.5% vs. post: 64.5%, $p<.0001$). Conversely, primary care visits to a RHC surged in the post-

disaster period for both control groups, while the direct group showed statistically significant declines in RHC visits.

Trends in Ambulatory Care Sensitive Conditions Rates

Crude ACSC hospital rates among the direct group were declining in the years pre-event (Figure 1). After the 2005 chlorine spill trends in ACSC hospital rates reversed and established a new trend among the directly affected. Trends in the primary control group remained stable across years, while annual trends among the secondary control group increased from 2003 to 2005. Unadjusted ACSC emergency department rates for the direct group were higher before the chlorine spill and steadily declined in the years following the disaster (Figure 1). Annual emergency department ACSC rates for the primary control group exhibited a slow decline, while ED-related ACSC rates for secondary controls steadily increased in the post-2005 period. Elevated pre-2005 hospital ACSC rates in the direct group signify access to primary care issues; suggesting health care disparities were present pre- event potentially exacerbated post-disaster health system access.

Post-Disaster Changes in Health System Access

Because annual trend data could potentially mask real disparities in access, we examined pre- and post-mean ACSC visits per subject using an independent group t-test (Satterthwaite's method for unequal variances) in Table 2. Although the total number of emergency department visits were lower post-EPHD for the direct group (N= 401 vs. 487); mean visit per subject was higher (mean= pre: 1.46 vs. post: 2.33, $p<.0001$) and the range in repeat visits doubled (9 to 18) during the post-EPHD period. During the post-disaster period, the direct group exhibited 1.3 more ACSC hospital visits per subject and the range in repeat visits increased from 5 in the pre-event period to 20 post-chlorine spill. Results showed individual-level access to primary care declined for beneficiaries in the direct group post-EPHD.

Contrary to our hypothesis, there was not a statistically significant higher rate of hospital and emergency department visits for ACSCs among Medicaid enrollees directly affected by the 2005 chlorine spill compared to the secondary control group (study group x disaster status interaction term). We performed a similar sub-analysis comparing only the direct and primary control groups. The significant interaction effect (i.e., estimated differences in slopes=.4220) for study group by time period suggested that the increase in monthly ACSC visits post-EPHD is greater in the direct group than in the control group (study area x disaster status interaction term, $p<.05$) (Table 3). The adjusted rate of an ACSC hospital visit pre-EPHD for the direct group was 1.68 times the rate for the primary control group (95% CI: 1.47, 1.93), while the adjusted ACSC hospital rate post-EPHD for the direct group was 3.10 times the rate for the primary control group (95% CI: 1.97, 5.18). For ACSC emergency department visits, the adjusted rate among those directly affected pre-disaster were 1.82 times the rate for the primary control group (95% CI: 1.61, 2.08). The adjusted ACSC emergency department rate post-disaster was 2.81 times the rate for the primary control group (95% CI: 1.92, 5.17).

DISCUSSION

Reduced health system performance during disaster recovery creates a new vulnerable population that is likely to experience long-term disruptions in access to care. Our results indicate increased demand on the health system altered health services delivery for Medicaid beneficiaries directly impacted by the chlorine spill. The 2005 chlorine spill resulted in decreased access to care for Medicaid beneficiaries. To our knowledge, this is the first study to examine an overstressed health system's ability to respond in the months and years following an EPHD. Our findings corroborate mounting evidence that excess demand on the health system promotes discontinuity of care and disrupts access to care for vulnerable subgroups during recovery.⁵⁹⁻⁶¹

Limitations

Upon closer examination the secondary control group was deemed an unsuitable comparison community. County-level preventable hospitalization rates⁶² for the secondary control group (31.1 per 10,000) were much higher than those in the direct or indirect groups (11.4 per 10,000), indicating substantial baseline disparities in access between the direct and secondary control groups. Elevated ACSC emergency department and hospital rates in the secondary control group likely underestimated pre- versus post- changes in rates for the direct group, masking the true effect of the 2005 chlorine spill.

Tracking health service encounters in the disaster area proved challenging as a large portion of SC residents sought medical care across state lines in Georgia. One advantage in using Medicaid claims data (primarily used for billing purposes) is patient encounters are captured irrespective of provider location, including services received in other states. Medicaid beneficiaries are a relatively homogenous population with a higher percentage of individuals that are disabled, low-income, and chronically ill. We would therefore expect higher rates of ACSCs for this population, limiting generalizability to other populations. Alternatively, patterns of ACSC rates across subpopulations are likely to provide evidence for health system overload strengthening our results and should be explored in other sub-populations, including the privately insured, uninsured, and Medicare beneficiaries. Although we were unable to measure changes in physician practice and referral patterns, patient satisfaction, and disease severity trends, the inclusion of control groups adequately accounted for secular changes in ACSC visits over time.

Though we cannot infer causation due to inherent design limitations; after ruling out major threats to validity we can assert with confidence that ACSC rates among directly affected Medicaid beneficiaries were impacted by the 2005 chlorine spill. Other explanations for the association might include changes in Medicaid eligibility and enrollment patterns. Data showed enrollment rates remained stable in all groups throughout the study period.

Conclusions

Access to healthcare services must be closely monitored throughout recovery to avert differential health outcomes in vulnerable populations. Hospital surge plans are in place to care for large numbers of trauma patients during the acute response; consequently there are

currently no plans in place that direct care for large volumes of incident or exacerbated chronically ill patients during recovery efforts. Surveillance of ACSCs may better position public health and medical professionals to characterize and respond to disaster-related exacerbation of chronic health conditions and subsequent changes in system access with improved sensitivity. Our results contribute to a national discussion sponsored by the Centers for Disease Control and Prevention examining meaningful ways to integrate health information technology in public health surveillance activities.⁶³ We recommend ACSC surveillance as a meaningful use strategy to investigate long-term trends in health service utilization; enabling real-time measure of specific ACSC rates including asthma, congestive heart failure, diabetes, and hypertension throughout the disaster response cycle. By leveraging existing public health data, ACSC surveillance pre-event, following the acute response, and throughout recovery efforts can be used as a scalable health metric to enhance public health situational awareness at the local, state, regional, or national level. Public health surveillance of ambulatory care data should be used to inform evidence-based hospital recovery plans that expand primary care services. Anticipating increased primary care needs will better equip health systems to effectively manage patient load and improve access to care for all members of the population in disaster recovery.

Acknowledgments

We acknowledge the Graniteville Community Coalition who helped bring into focus the real issues facing the medically vulnerable during disaster recovery.

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Figure 1.

Unadjusted Hospital and Emergency Department Rates for Ambulatory Care Sensitive Conditions[±] by study area: South Carolina Medicaid Beneficiaries, 2002 to 2007.

Data Source: South Carolina Office of Research and Statistics. [±]All discharge diagnosis combined for: Grand mal seizures, convulsions, severe ear, nose, and throat infections, bacterial pneumonia, cellulitis, skin grafts, gastroenteritis, kidney and urinary infection, dehydration, dental conditions, pelvic inflammatory disease, and hypoglycemia, Tuberculosis, asthma, angina, diabetes, nutritional deficiencies, chronic obstructive pulmonary disease, congestive heart failure, and hypertension.

Service Use by South Carolina Medicaid beneficiaries Age 18 to 64 with an Ambulatory Care Sensitive Condition[±] discharge, Pre-and Post-Event by Study Area.

Table 1

Visits	Direct (N=1,090)				Control (N=2,590)			
	Pre-(2002-2004)		Post-(2005-2007)		Pre-(2002-2004)		Post-(2005-2007)	
	No.	%	No.	%	No.	%	No.	%
Service								
Hospital	86	42.6	116	57.4	223	53.9	191	46.1
ED	487	54.8	401	45.2	1160	53.3	1016	46.7
Primary Care								
Clinic	597	71.9	233	28.1	1004	73.5	363	26.7
FQHC	323	35.5	587	64.5	949	57.5	702	42.5
MD Office	3153	51.0	3026	49.0	6439	51.4	6098	48.6
RHC	1752	60.9	1127	39.2	318	43.0	422	57.0

Data source: South Carolina Office of Research and Statistics.

* Chi-square test for equal proportions.

[±] All discharge diagnosis combined for: Grand mal seizures, convulsions, severe ear, nose, and throat infections, bacterial pneumonia, cellulitis, skin grafts, gastroenteritis, kidney and urinary infection, dehydration, dental conditions, pelvic inflammatory disease, and hypoglycemia. Tuberculosis, asthma, angina, diabetes, nutritional deficiencies, chronic obstructive pulmonary disease, congestive heart failure, and hypertension. ASC= Ambulatory Care Sensitive Condition. ED=Emergency Department. MD= Medical Doctor. RHC= Rural Health Center. FQHC= Federally Qualified Health Center.

Table 2

Mean Emergency Department and hospital visits per subject for Ambulatory Care Sensitive Conditions[±] by study area: South Carolina Medicaid, 2002-2007.

Visits	Pre- (2002-2004)				Post- (2005-2007)			
	N	Mean ±SD	Variance	Range	N	Mean ±SD	Variance	Range
<i>ED*</i>								
Direct	487	1.46 ± 1.29	1.65	1-9	401	2.33 ± 3.00	8.99	1-18
Control	1169	1.87 ± 2.05	4.22	1-14	1016	2.29 ± 2.34	5.48	1-20
<i>Hospital*</i>								
Direct	86	0.33 ± 0.71	0.52	1-5	116	1.67 ± 3.72	13.85	1-20
Control	223	0.77 ± 2.95	8.72	1-30	190	0.60 ± 1.65	2.71	1-17

Data source: South Carolina Office of Research and Statistics. ED=Emergency Department

* Independent group t-test for Pre-/Post-mean ED and hospital visits for each group (Satterthwaite's method for unequal variances).

§ difference between post-disaster mean and the pre-disaster mean in each study group.

± A11 discharge diagnosis combined for: Grand mat seizures, convulsions, severe ear, nose, and throat infections, bacterial pneumonia, cellulitis, skin grafts, gastroenteritis, kidney and urinary infection, dehydration, dental conditions, pelvic inflammatory disease, and hypoglycemia, Tuberculosis, asthma, angina, diabetes, nutritional deficiencies, chronic obstructive pulmonary disease, congestive heart failure, and hypertension.

Table 3

Adjusted Pre- and Post-Rate Ratios (RRs)[‡] for Ambulatory Care Sensitive Condition related Hospital and Emergency Department Admissions for Direct vs. Control: South Carolina Medicaid, 2002-2007.

	Unadjusted Rate		Adjusted Rate [‡]		Adjusted RR [‡] (95% CI)	Study Group × Time Period Interaction P value
	Pre-ACSC Visits (Rate per 100)	Post-ACSC Visits (Rate per 100)	Pre-ACSC Rate (95% CI)	Post-ACSC Rate (95% CI)		
<i>Hospital</i>						
Direct	93 (2.28)	134 (3.21)	1.68 (1.47, 1.93)	3.10 (1.97, 5.18)	4.24 (1.80, 9.98)	0.03
Control	223 (1.81)	191 (1.63)	1.00	1.00		
<i>ED</i>						
Direct	545 (13.35)	453 (11.09)	1.82 (1.61, 2.08)	2.81 (1.92, 5.17)	2.80 (1.55, 5.08)	0.01
Control	1,160 (9.39)	1,016 (8.68)	1.00	1.00		

Data source: South Carolina Office of Research and Statistics.

[‡] Rate = $\exp(\beta_1 \times \text{study group}_i + \beta_8 \times \text{time period}_i + \gamma \times [\text{study group}_i \times \text{time period}_i])$.

* Rate ratios (RR) and Confidence Intervals were calculated using GEE-adjusted Poisson regression to adjust for within-study group correlation between pre and post measurements.