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ScienceDirect
Journal of Hazardous Materials 151 (2008) 232–238
Journal of Hazardous Materials
www.elsevier.com/locate/jhazmat

The effects of seasonal variation on hazardous chemical releases

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Received 14 January 2007; received in revised form 24 May 2007; accepted 25 May 2007
Available online 31 May 2007

Abstract

Scope: Accidental and intentional chemical releases are an increasing threat to our society. These events occur year around under different seasonal circumstances. A number of papers using the Hazardous Substances Emergency Events database (HSEES) have found some evidence that season may be an important variable affecting the number of hazardous chemical releases (HCRs). To the authors' knowledge, no analyses specifically focused on seasonal variation of HCRs. Significant effects of season are useful to further HCR prevention efforts and improve preparation and training of first responders, community evacuation, and hospital preparedness.
Results: Seasonal variation is a factor in transportation HCRs, but not fixed facility HCRs. There is an overall seasonal effect for the cause of the event. There is also seasonal variation of HCRs with respect to geographical area, with more incidents in the South. The substances released also demonstrate seasonal variation with summer having more incidents involving acids, ammonia, chlorine, pesticides, paints and dyes. The number of victims treated at hospitals resulting from HCRs did not display seasonal variation.
Conclusions: This new additional information involving seasonal changes of HCRs adds to the literature on HCRs and may indirectly have implications for the prevention of incidents, training of personnel responding to HCRs, community planning, and local hazard vulnerability analyses and finally hospital preparedness.

Keywords: Hazardous chemical releases; Seasonal variation; Regional variation

1. Introduction

Thousands of hazardous chemical releases (HCRs) occur in the U.S. annually and the consequences for the community and environment can be catastrophic, especially when unexpected events occur. In 1984, a highly toxic mixture of phosgene, methyl isocyanate (MIC), chlorine, carbon monoxide, and hydrogen cyanide, as well as other hazardous gases escaped from a Union Carbide chemical plant in Bhopal, India exposing more than 200,000 people to its dangers. More recently, an explosion at a chemical factory in northeastern China released about 100 tons of toxic chemicals, including cancer-causing benzene, into the Songhua River and poisoned the water supply of ten million people. Many smaller scale events affect great numbers of people as well, such as the fatal explosion in Daytona Beach, Florida and the recent incident in Apex, NC, where a fire caused by a chemical leak was followed by several explosions forcing the evacuation of thousands, both in October, 2006. The effects of acute chemical disasters are usually overt and immediate, and the timeframe to control them is often narrow [1–3]. For that reason, the understanding of the associated risks with the transport, use, storage, and disposal of hazardous chemical substances is extremely important to establish appropriate safety measures and to consequently mitigate, prepare for or respond to unanticipated HCRs.

Human exposure to hazardous substances may be manifested as minor respiratory irritation and gastrointestinal symptoms such as nausea, vomiting, diarrhea, or abdominal pain [4,5]. The intoxication may lead to even more serious problems, including cancer, and death [6–9]. Among the identified risk factors

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doi:10.1016/j.jhazmat.2007.05.074

involved in HCRs, Welles et al. listed equipment failure, power failure, human error, improper dumping, filling or mixing, fire, motor vehicle accident, and deliberate or illegal action [5]. Equipment failure was the main factor resulting in HCR events [10,5,11]. Severe weather has potential negative effects on power systems and equipments of industrial facilities, and therefore adverse weather conditions such as storms, lightning, flooding, and tornados have played important roles in many past HCRs [2].

Such releases occur throughout the year under different seasonal circumstances. Ruckart, Orr & Kay point out that 31% of events in their analysis occurred during the summer [12], Ruckart et al. found that "the frequency of adverse weather-related events was highest in June and September" [2]. Kaye, Orr & Wattigney also found that there was a higher frequency of ammonia releases during summer [13]. However, no comprehensive analysis of seasonal variation with respect to the HCRs in the HSEES database has been performed. This analysis focuses on the seasonal variations with respect to the event type, substance released, cause of the event, geographic distribution, number of victims, and the number of victims transported to the hospital. It is hypothesized that there will be seasonal variations displayed in all of these factors.

2. Methods

This is a retrospective analysis using data from the Hazardous Substances Emergency Events Surveillance (HSEES) database. The database was established by the Agency for Toxic Substances and Disease Registry (ATSDR) in 1990, which is a federal public health agency of the U.S. Department of Health and Human Services. This database was specifically developed to facilitate collection and analysis of information related to acute releases of hazardous substances that need to be decontaminated or neutralized according to federal, state, or local law, as well as threatened releases that result in a public health action such as an evacuation [14].

Some states voluntarily contribute to the HSEES database on a continuous basis. Those who agree to do so report the time, place and circumstances of any HCRs with information on the specific material involved, the people affected and any public health response taken. Data from 1996 through 2001 were included in this analysis from 17 contributing states. Thirteen states contributed during the entire period: Alabama, Colorado, Iowa, Minnesota, Missouri, Mississippi, North Carolina, New York, Oregon, Rhode Island, Texas, Washington, and Wisconsin. An additional four states participated during portions of this time-period: Utah (2000–2001) New Jersey (2000–2001), New Hampshire (1996), and Louisiana (2001).

Wendt et al., validated the HSEES database by comparing it with two passive reporting systems: the U.S. Environmental Protection Agency's Emergency Response Notification System and the U.S. Department of Transportation's Hazardous Material Information system incident database. The HSEES data system documented about 60% of hazardous spill events found by the combined passive reporting systems and recorded more events than theses systems [15].

For this analysis, six dependent outcomes were considered that might be affected by seasonal variations. The first variable is "type of event" that is, whether the event occurred in a fixed facility or during transport of chemicals. Fixed facility events include releases at permanent structures such as industrial sites, farms, schools or other structures. Transport-related events occur during transport by water, air or ground.

The second variable is "cause of the event" which could include a number of causes such as improper chemical mixing, equipment failure, operator error, improper filling of chemicals (overfilling), and "other". "Other" consists of maintenance, system or process upset, system start-up and shutdown, factors beyond human control, power failure or electrical problems, unauthorized or improper dumping, deliberate damage, bad weather conditions, motor vehicle accident or rollover, and fire or explosion.

The third outcome variable is the category of "substances released". Substances released are grouped into 11 categories including (1) acids, (2) ammonia, (3) bases, (4) chlorine, (5) other inorganic substances, (6) paints and dyes, (7) pesticides, (8) PCBs, (9) volatile organic compounds (VOC), (10) 'other' substances not listed, and (11) 'mixture' across chemical categories. The last category consists of formulations, hetero-organics, hydrocarbons, oxy-organic, polymers and multiple substances categories mixed prior to release. "Other inorganic substances" includes all inorganic substances except acids, bases, ammonia and chlorine [16].

The 'region where the event occurred' is the fourth outcome variable. States were combined into four regions defined in this analysis as the Northeast (New Hampshire, New Jersey, New York, and Rhode Island); Midwest (Iowa, Minnesota, Missouri, and Wisconsin); South (Alabama, Louisiana, Mississippi, North Carolina and Texas) and West (Colorado, Oregon, Utah, and Washington). Although the formal definition of region uses contiguous areas, the HSEES database only includes data from 17 states during this period. The authors combined the states into these four areas based on geography and weather in order to obtain a 'best-attempt' geographic division.

The total number of victims from the event was the fifth outcome. A victim was defined as a person experiencing at least one documented adverse health effect (such as respiratory irritation or chemical burns) that likely resulted from the event and occurred within 24 h of the release. For this category, 'victims' was divided into three separate groups which included no victims, one to four victims and five or more victims. The number of victims that required transport to a hospital was a separate sixth outcome variable and was divided into three separate groups: zero, one-four and five or more. This variable included those who were observed at, treated, or admitted to a hospital setting.

The main predictor variable of interest for this analysis is the 'season' in which the chemical hazard occurred. For the HSEES data, the seasons were defined by months, and not by date of equinox or solstice: winter included the months of December through February; spring included March through May; summer was June through August; and fall includes September through November.

The Institutional Review Board of the Duke University Health System exempted this project from formal review since the database did not contain personal identifiers.

Statistical analysis was performed using "A Language and Environment for Statistical Computing", R Development Core Team, R Foundation for Statistical Computing, Vienna, Austria (http://www.r-project.org). Univariate analyses were performed by calculating the frequency and percentage of each categorical variable. Bivariate and multivariate analyses were used for further comparisons of data followed by the adjusted odds ratio analyses for significant differences across season. Type of event, cause of the event, substance category, region of event, and total number of victims and severity of victims (hospitalized) are presented for each season with winter as the baseline for comparison. Winter was used as the baseline variable because fewer incidents occurred during this season; it was therefore set as the base category for comparison with other seasons. Adjustments to the data were made for the following confounding factors: total number of chemicals spilled, evacuation order status (yes or no), status of release (actual or threatened), area of release which includes: residential status (distance in miles from residential area), time of release (day or night), and number of people living within a 1/4 mile of the release. All models of analyses were stratified by the season in which the event occurred.

3. Results

Tables 1 and 2 present data and significance levels for univariate, bivariate and multivariate analyses with the adjusted odds ratios and significance values presented in Table 2. Significant odds ratios are at the $p < 0.05$ level.

Results of the univariate and bivariate analyses are displayed in Table 1. There was an overall effect of seasonal variation for the type of event ($p < 0.001$), the cause of the event ($p < 0.001$), chemical substance category ($p < 0.001$), region where the event occurred ($p < 0.001$), and total number of victims ($p < 0.048$).

The majority of the events that occurred during this period were in fixed facilities (76.2%) as opposed to during transport (23.8%). Equipment failure (40.9%) was the most frequent cause of the event followed by operator error (20.6%). The majority of HCR events involved a mixture of chemicals (27.2%), followed by other inorganic substances (18.9%) and 'VOC' (16.9%). Over half of the events occurred in the South (50.6%) whereas the Midwest (20.1%), West (15.3%) and Northeast (13.9%), combined, had the other half. A minority (1.3%) of events had victims that required a visit to the hospital for treatment and admittance.

There were more events in the summer (28.8%) than other seasons, closely followed by spring (27.6%), fall (22.6%) and winter (21.1%). The majority of HCRs occurred in an industrial (54.3%) type of area, whereas 22.4% were located in commercial areas. Table 2, adjusted for the previously defined confounding variables demonstrates significantly more transportation HCRs

Table 1
Frequency and percents by season

Variable	Category	Season					p value
		Total % (N)	Winter % (N)	Spring % (N)	Summer % (N)	Fall % (N)	
Type of event	Transportation	23.78 (9456)	20.08 (1685)	26.21 (2871)	24.93 (2854)	22.81 (2046)	<0.001
	Fixed facility	76.22 (30310)	79.92 (6706)	73.79 (8083)	75.07 (8596)	77.19 (6925)	
Cause of the event	Improper mixing	0.82 (326)	0.67 (56)	0.93 (102)	0.86 (98)	0.78 (70)	<0.001
	Equipment failure	40.88 (16257)	43.15 (3621)	39.08 (4281)	40.60 (4649)	41.31 (3706)	
	Operator Error	20.56 (8176)	20.01 (1679)	21.55 (2361)	20.37 (2333)	20.09 (1803)	
	Improper filling, overfill	1.60 (638)	1.74 (146)	1.52 (167)	1.65 (189)	1.51 (136)	
	Other	17.97 (7148)	18.38 (1542)	16.51 (1808)	17.69 (2025)	19.76 (1773)	
	Missing	18.16 (7221)					
Substance released	Acid	8.44 (3355)	7.94 (666)	7.73 (847)	9.39 (1075)	8.55 (767)	<0.001
	Ammonia	6.16 (2451)	5.47 (459)	6.07 (666)	6.77 (776)	6.13 (550)	
	Bases	4.19 (1667)	4.49 (377)	4.11 (450)	4.05 (464)	4.19 (376)	
	Chlorine	2.59 (1032)	2.23 (187)	2.31 (253)	3.27 (374)	2.43 (218)	
	Other inorganic substances	18.90 (7514)	21.30 (1787)	17.09 (1872)	17.45 (1998)	20.70 (1857)	
	Paints and dyes	2.60 (1033)	2.09 (175)	2.63 (288)	3.05 (349)	2.46 (221)	
	Pesticides	6.91 (2750)	4.41 (370)	10.62 (1163)	7.07 (810)	4.54 (407)	
	PCBÏs	1.36 (540)	1.24 (104)	1.42 (156)	1.70 (195)	0.95 (85)	
	VOC	16.85 (6702)	17.93 (1505)	15.91 (1743)	16.85 (1930)	16.99 (1524)	
	Other	4.81 (1915)	4.65 (390)	4.74 (519)	4.70 (538)	5.22 (468)	
	Mixtures	27.18 (10807)	28.26 (2371)	27.36 (2997)	25.68 (2941)	27.84 (2498)	
Region where event occurred	West	15.34 (6101)	15.19 (1275)	15.36 (1682)	14.96 (1713)	15.95 (1431)	<0.001
	South	50.58 (20112)	53.86 (4520)	48.14 (5273)	49.27 (5641)	52.15 (4678)	
	Midwest	20.14 (8009)	16.90 (1418)	23.77 (2604)	21.00 (2404)	17.65 (1583)	
	Northeast	13.94 (5544)	14.04 (1178)	12.74 (1395)	14.78 (1692)	14.26 (1279)	
Number of victims per event	0	92.12 (36633)	92.53 (7764)	92.26 (10106)	91.74 (10504)	92.06 (8259)	=0.048
	1–4	6.72 (2674)	6.23 (523)	6.75 (739)	7.16 (820)	6.60 (592)	
	>=5	1.15 (459)	1.24 (104)	0.99 (109)	1.10 (126)	1.34 (120)	

Table 2
Adjusted odds ratios and significance by season using winter as baseline

Variable	Category	Season					
		Spring		Summer		Fall	
		Odds ratio (confidence interval)	p value	Odds ratio (confidence interval)	p value	Odds ratio (confidence interval)	p value
Transportation*	Transportation	1.26 (1.13–1.40)	<0.001	1.20 (1.08–1.34)	<0.001	1.08 (0.97–1.21)	=0.167
Number of victims per event	1	0.95 (0.81–1.10)	=0.493	1.01 (0.86–1.17)	=0.916	1.03 (0.88–1.21)	=0.713
Cause of the event	Improper mixing	1.31 (0.87–1.99)	=0.193	1.24 (0.82–1.88)	=0.308	0.89 (0.56–1.42)	=0.683
	Equipment failure	0.96 (0.87–1.07)	=0.462	0.98 (0.89–1.08)	=0.654	0.92 (0.83–1.02)	=0.127
	Operator Error	1.06 (0.95–1.18)	=0.275	0.98 (0.88–1.08)	=0.659	0.97 (0.87–1.09)	=0.639
	Improper filling, overfill	1.00 (0.72–1.39)	=0.999	0.93 (0.67–1.29)	=0.649	0.83 (0.58–1.18)	=0.303
	Other	0.95 (0.84–1.08)	=0.412	1.06 (0.94–1.20)	=0.349	1.21 (1.06–1.37)	=0.004
Substance released	Acid	1.02 (0.88–1.20)	=0.770	1.26 (1.09–1.47)	=0.002	1.20 (1.02–1.41)	=0.026
	Ammonia	1.15 (0.97–1.39)	=0.109	1.28 (1.07–1.52)	=0.005	1.20 (0.99–1.44)	=0.060
	Bases	0.87 (0.71–1.06)	=0.164	0.83 (0.67–1.01)	=0.062	0.86 (0.70–1.07)	=0.173
	Chlorine	1.23 (0.93–1.64)	=0.146	1.76 (1.36–2.30)	<0.001	1.20 (0.89–1.62)	=0.229
	Other inorganic substances	0.82 (0.73–0.92)	<0.001	0.74 (0.66–0.83)	<0.001	0.89 (0.79–1.01)	=0.069
	Paints and dyes	1.29 (0.99–1.71)	=0.065	1.45 (1.12–1.90)	=0.006	1.27 (0.96–1.70)	=0.101
	Pesticides	2.13 (1.77–2.57)	<0.001	1.42 (1.17–1.72)	<0.001	1.10 (0.89–1.37)	=0.369
	PCBǐs	0.83 (0.59–1.17)	=0.281	1.14 (0.83–1.58)	=0.426	0.73 (0.49–1.06)	=0.100
	VOC	0.82 (0.72–0.94)	=0.003	0.96 (0.85–1.08)	=0.484	0.91 (0.80–1.04)	=0.153
	Other	1.08 (0.88–1.32)	=0.465	0.99 (0.81–1.21)	=0.905	1.14 (0.93–1.41)	=0.208
	Mixtures	0.93 (0.83–1.03)	=0.156	0.85 (0.77–0.94)	=0.002	0.96 (0.86–1.07)	=0.456
Region where event occurred	West	1.00 (0.89–1.12)	=0.989	0.86 (0.77–0.97)	=0.013	1.05 (0.93–1.18)	=0.450
	South	0.92 (0.83–1.01)	=0.082	0.92 (0.78–0.95)	=0.072	0.86 (0.83–1.00)	=0.004
	Midwest	1.38 (1.22–1.55)	<0.001	1.21 (1.08–1.36)	=0.001	1.02 (0.90–1.16)	=0.733
	Northeast	0.80 (0.72–0.90)	<0.001	1.08 (0.97–1.20)	=0.185	1.14 (1.01–1.28)	=0.033

during spring (OR = 1.26 $p < 0.001$), and summer (OR = 1.20, $p < 0.001$) compared to winter.

The number of HCRs in spring was significantly higher in the Midwest (OR = 1.38, $p < 0.001$) and lower in the Northeast (OR = 0.80, $p < 0.001$). In the summer, more incidents occurred in the Midwest (OR = 1.21, $p < 0.001$) and less were reported in the West (OR = 0.86, $p < 0.01$). In the fall, there were less HCRs reported in the South (OR = 0.86, $p < 0.004$) and more in the Northeast (OR = 1.14, $p < 0.033$).

With respect to substance released, there were several significant effects related to seasonal variation. Table 2 indicates there were comparatively higher levels of incidents in the fall involving acids (OR = 1.2, $p < 0.026$). In spring, there was an increase in HCRs involving pesticides (OR = 2.13, $p < 0.001$), and a significant decrease in other inorganic substances (OR = 0.82, $p < 0.001$) and VOC (OR = 0.082, $p < 0.003$). In the summer, there were more incidents involving acids (OR = 1.26, $p < 0.002$), ammonia (OR = 1.28, $p < 0.005$), pesticides (OR = 1.42 $p < 0.001$), paints and dyes (OR = 1.45, $p < 0.006$), and chlorine (OR = 1.76, $p < 0.001$), with fewer incidents involving other inorganic substances (decrease, OR = 0.82, $p < 0.001$) and mixture across chemical categories (OR = 0.85, $p < 0.002$).

Only the "Other" category for cause of the event showed a significant increase during the fall season on HCR events (OR = 1.21, $p < 0.004$). There was no support for seasonal variation in either the number of victims or the number of victims requiring transport to the hospital when the data were adjusted for confounding factors.

In general, there was an effect of seasonal variation on types of events, cause of the event, chemicals involved in the event, and region of the country when the data is adjusted for confounding factors.

4. Discussion

In this analysis, the authors found that more HCRs occurred in fixed facilities than during transport, a finding consistent with many other studies [2,14,5,7]. Table 3 illustrates comparative results from several studies on this measure. Ruckart et al., also support these data using a similar sample demonstrating higher fixed facility incidents (87%) and even less transportation events (6%) in a Texas sample [17] as compared to transportation HCRs found in this analysis (24%). Welles et al. reported 79% fixed facility HCR incidents in New York State between 1993 and 2002 [5] and Hu (2004), found 84% and 16% incidence of HCRs in fixed-facility versus transportation events, respectively, in Louisiana in 2001 [7].

Welles further identified that over 50% of these fixed facilities were residences yielding more injuries with fewer incidences compared to industrialized facilities [5]. Preston, (submitted) found that transportation accidents were responsible for relatively more victims (8.47%) than fixed facilities HCRs (7.56%) [18], indicating a need for greater mitigation efforts on roadways

Table 3
Comparisons using HSEES data for types of incidents

Analysis	Fixed-facility (%)	Transport (%)	States	Year
Welles [5]	79	21	New York	1993–2002
Hu [7]	84	16	Louisiana	2001
Ruckart et al. [2]	87	6	Texas	2000–2001
Ruckart et al. [17], Zimmerman et al.	76	24	17	1996–2001

and transport vehicles and increased education to first responders in preparing for and responding to transportation HCRs.

The authors also found a relationship between seasonal variation and transportation incidents with significantly more releases occurring in summer and spring. Hu & Raymond found that more transportation-related events occur during rail transport, but that ground transportation of hazardous chemicals were more likely to cause injuries [7]. Further research is needed to gain a better understanding of road conditions, roadway design, and traffic patterns that may be associated with these findings.

In this analysis, equipment failure (24%) and operator error (21%) were the two most frequent causes leading to an HCR event. Welles et al., found equipment failure was also the leading cause (39%) of HCRs, followed by human error (33%) [5], but with greater incidence than reported here. Orr & Ruckart also found equipment failure (44%) as the most frequent cause of events, with improper filling, loading or packing (23%) as the second most frequent factor, followed by, human error (17%) using data from 15 states during 2002 [10]. The only variable associated with seasonal variation in this analysis for 'cause of the event' was the category "other" which occurred more often during the fall than in winter. Since many factors were pooled to form this category, including poor weather conditions, it would be informative to assess the individual factors within this category for relevant effects in future studies.

More HCRs occur during the summer than winter. These data are supported by Ruckart et al., who reported more chemical releases in the months of June and September in Texas from 2000–2001 [2]. This analysis shows more events in summer (June–August). Conversely, findings reported here do not support previous work by Ruckart et al. [2] during the fall and winter months in Texas alone. These results also conflict with those found by Orr & Ruckart [10], who found that more events occurred between October and December in the states of Texas, Louisiana and New Jersey. These analyses indicate fewer incidents in winter and fall months with data over a longer time-period and more states. Both Ruckart et al. [2] and Orr & Ruckart [10] looked temporally using months, while this analysis used seasons, complicating the ability to compare studies. Comparisons are also complicated due to differences in the number of states and time-periods used in each analysis.

There were more acid, ammonia, chlorine, paints and dyes, and pesticide incidents in summer than winter. The importance of this finding is strengthened because HCRs of acids, ammonia, chlorine and other inorganic substances include the highest percentage of victims [19,17]. Since all of these agents have varying degrees of health effects, it is important to reduce the number of these events. When these events do occur, a strategy to decrease morbidity and mortality includes evacuation. There is little research to help decide when these protocols should be implemented. The results of this analysis support the use of such protocols more with specific types of chemical releases in specific seasons and areas of the country. Preston et al (submitted) found that the use of protocols were necessary to reduce the number of victims when acid, ammonia or chlorine are involved in the HCRs [18]. Welles also found that certain chemicals were associated with adverse health effects in New York State. These data also show that the adverse health effects occur to both the workforce (employees and responders), but also non-workforce populations (the public and students) [5]. This analysis indicates the need for continued prevention, training and public awareness efforts with an emphasis during the summer when there are a significantly greater number of HCRs, which involve acids, ammonia, chlorine, pesticides, paints and dyes. These findings should assist HAZMAT responders and emergency managers, with preparedness activities and response protocols, plans and training, to consider evacuation as a life-saving approach when these types of releases occur.

More HCRs were found in the Southern states in this data set. Although, the HSEES data has five States in the Southern region, whereas the other regions have four, these five States have over 50% of the HCRs. Seasonal variation for HCRs in the South demonstrated a significantly lower number of HCRs in the fall. In addition, there were significantly more HCRs located in the Midwest during spring and summer, whereas in the Northeast, there were significantly more incidents in the fall and less in the spring. It has been reported that weather contributes to some chemical spills and in particular rain events (Ruckart et al.). However, the data in that analysis (Ruckart et al.) attributed many events to one particular tropical storm [2] so may not be generalizable. The states that were considered the Southern region in this analysis were also coastal states that tend to have a large number of adverse weather conditions during the summer months due to the hurricane season. Future analyses that would be useful should include all Southern states in a state-level analysis specifically assessing the association between adverse weather conditions and HCRs. Whereas weather-related evacuations occur, the added danger of HCRs during inclement weather also has important public safety implications.

The results indicated that there was no seasonal variation in total number of victims, or for the initial cause of the event and therefore there is no support for evacuation based on season for these two factors. However, Preston et al. (submitted) found an increased number of victims with acid, ammonia and chlorine releases and these chemicals have a higher incidence of releases in summer [18]. These data support this by displaying a non-significant trend toward an increase number of victims in summer (Table 1).

It is difficult to study disasters in a controlled environment and though the ability to study disasters through prospective, randomized trials would be preferable, this is not currently practical and would involve significant logistical and technical concerns. Therefore, this analysis represents an attempt to obtain information from less than ideal circumstances. The HSEES database is used to collect detailed information about each HCR event and is an important resource. However, since the purpose of the database is not specifically for research purposes, it is difficult to use these data for predictive purposes for an individual incident.

There were limitations to the data in these analyses. First, not all states were included in the data for all years. Some states were just represented in one or two years, while others have data for all five years. Most states are not included at all in the data system. Another shortcoming is the definition of season used for this analysis. Instead of defining season using the dates of the equinox and solstice, they were defined by a 3-month period. This definition could add bias to the overall seasonal variation found in this analysis as compared to one performed using the equinox and solstice.

The lack of standardized data collection from site-to-site was also a limitation of this data. Real-time data collection from HCR incidents is exceedingly difficult. The data collection environment is less than ideal and data collection is a “best effort” attempt. As a result, the type of data collected with each incident may be slightly different. Therefore, a recommended next step would be the promotion of a nationwide standardized database that includes all states. A complete data set, with uniform reporting from all 50 states will be a significant advancement in the ability to guide mitigation, preparedness and response activities to HCRs.

Finally, it would be helpful to have data on specific weather conditions and detailed seasonal information, neither of which was included in this dataset and limits the use of these findings. More recently, weather-related data was added to the HSEES data. This should allow for improved information with this focus in the future.

5. Conclusions

There are a number of conclusions that can be drawn from these data. This analysis is the first to show that even with fair data, on a small sample of HCRs in the United States, that HCRs demonstrate seasonal variation. The analysis also points out that improved standardized data collection efforts should be implemented on a national basis, which includes necessary variables to enhance the training and mission of communities, hospitals and first responders to meet these needs.

Second, season can affect the type of event, the substance released, and regions of the country, but season does not significantly influence the number of victims, hospitalization of victims or the initial cause of the HCR.

Third, since there are more transportation incidents during spring and summer compared to other seasons, and ground transportation accidents have relatively more victims [18], emphasis needs to focus on the education and training for responders to these types of HCRs during these seasons in the future. Future research should focus on road conditions in an effort to understand why these incidents have greater numbers of victims.

Fourth, the many substances released vary with the season. Many of these substances (acid, ammonia, chlorine) cause adverse health effects and have the highest percentage of victims. Therefore, more emphasis on education, training and evacuation to reduce and prevent morbidity and mortality from these chemical releases, during the appropriate seasons is necessary.

Fifth, in the United States, there are regional effects with respect to seasonal variations. Although the reasons for these findings are yet unknown, these analyses are a first step. Future analyses should focus on what types of substances are involved in HCRs in specific regions. This will further aid prevention and relief efforts. Then efforts need to be made to adjust preparation and training to the chemicals involved at different times of the year, in different locations.

Future research involving the HSEES database should include reports of regional changes with weather and road conditions over the course of the year. Some generalized categories of weather conditions have been added to the HSEES system in mid-2000 improving the database, with the possibility of explaining some of the variation. To obtain more comprehensive information about HCRs throughout the U.S. and help standardize the data, future research should include all 50 States in the HSEES. Thus, improving prediction models of hazardous chemical events, allowing for more effective support systems for first responders, saving lives, and decreasing human injuries and death.

References

[1] P.A. Bertazzi, C. Zocchetti, A.C. Pesatori, S. Guercilena, M. Sanarico, L. Racie, Mortality in an area contaminated by TCDD following an industrial incident, Med. Lav. 80 (4) (1989) 316–329.

[2] P.Z. Ruckart, J. Borders, J. Villanacci, R. Harris, M. Samples-Ruiz, The role of adverse weather conditions in acute releases of hazardous substances, Texas, 2000–2001, J. Hazard. Mater. 115 (2004) 27–31.

[3] S.N. Kales, D.C. Christiani, Acute chemical emergencies, N. Engl. J. Med. 350 (8) (2004) 800–808.

[4] H.D. Kim, S.K. Lee, B.Y. Chun, D.H. Lee, S.C. Hong, B.K. Jang, Illness associated with contamination of drinking water supplies with phenol, J. Korean Med. Sci. 9 (3) (1994) 218–223.

[5] W.L. Welles, R.E. Wilburn, J.K. Ehrlich, C.M. Floridia, New York hazardous substances emergency events surveillance: learning from hazardous substances releases to improve safety, J. Hazard. Mater. 115 (2004) 39–49.

[6] J.F. Deng, C.C. Yang, W.J. Tsai, J. Ger, M.L. Wu, Acute ethylene chlorohydrin poisonings: experience of a poison control center, Clin. Toxicol. 39 (6) (2001) 587–593.

[7] C.Y. Hu, D.J. Raymond, Lessons learned from hazardous chemical incidents—Louisiana Hazardous Substances Emergency Events Surveillance (HSEES) system, J. Hazard. Mater. 115 (2004) 33–38.

[8] A. Suruda, D. Wallace, Fatal work-related injuries in the U.S. chemical industry 1984–89, Int. Arch. Environ. Health 68 (1996) 425–429.

[9] I. Takase, K. Kono, A. Tamura, H. Nishio, T. Dote, K. Suzuki, Case report: Fatality due to acute fluoride poisoning in the workplace, Legal Med. 6 (2004) 197–200.

[10] M.F. Orr, P.Z. Ruckart, Surveillance of hazardous substance releases due to systems interruptions, 2002, J. Hazard. Mater. (2006).

[11] M.G. Weisskopf, J.M. Drew, L.P. Hanrahan, H.A. Anderson, Hazardous ammonia releases in Wisconsin: trends and risk factors for evacuation and injury, Wis. Med. J. (2000 Nov).

[12] P.Z. Ruckart, M.R. Orr, W.E. Kay, Hazardous-Chemical Releases in the Home, J. Environ. Health 67 (5) (2004) 14–19.

[13] W.E. Kaye, M.F. Orr, W.A. Wattigney, Surveillance of hazardous substance emergency events: identifying areas for public health prevention, Int. J. Hyg. Environ. Health 208 (2005) 37–44.

[14] J.L. Burgess, D.F. Kovalchick, L. Harter, K.B. Kyes, J.F. Lymp, C.A. Brodkin, Hazardous material events evaluation of transport to health care facility and evacuation decisions, Am. J. Emerg. Med. 19 (2) (2001) 99–105.

[15] R.D. Wendt, H.I. Hall, P.A. Price-Green, V.R. Dhara, W.E. Kaye, A comparison of three surveillance systems, J. Environ. Health 58 (9) (1996) 5–13.

[16] Hazardous Substances Emergency Events Surveillance (HSEES) Training Manual, Division of Health Studies, Agency for Toxic Substances and Disease Registry, (May 2002) 44.

[17] P.Z. Ruckart, W.A. Wattigney, W.E. Kaye, Risk factors for acute chemical releases with public health consequences: Hazardous Substances Emergency Events Surveillance in the U.S. 1996–2001, Environ Health (2004) 3–10.

[18] R.J. Preston, D. Marcozzi, R. Lima, R. Pietrobon, L. Braga, D. Jacobs, The effect of evacuation on the number of victims following hazardous chemical release, 2007, submitted for publication.

[19] Agency for Toxic Substances and Disease Registry (ATS0DR), Toxic Fact Sheet for Ammonia, (September 2004), http://www.atsdr.cdc.gov/substances/ammonia/index.html.