Abstract:
Natural disasters such as earthquakes, hurricanes, tornadoes, floods, and volcanic eruptions may increase human exposures to toxins. Disaster management encompasses a continuous cycle involving preparedness, response, recovery, and mitigation. Toxic exposures occur in predictable segments of the disaster cycle. Although carbon monoxide poisoning is the most widely reported poisoning after natural disasters, other toxins including certain hydrocarbons, volcanic ash, and gases, as well as snake and animal bites, are also recognized hazards. Emergency response personnel and health care providers should be aware of these hazards to respond and manage these exposures effectively. This article will present an overview of toxic exposures related to natural disasters, specifically, carbon monoxide, hydrocarbons/petroleum distillates, volcanic ash, animal exposures, and snake bites. Their relation to the disaster management cycle will be presented to serve as a primer for medical personnel and health care providers assisting with disaster response or emergency planning.

Keywords:
carbon monoxide; hydrocarbon; volcanic ash; rabies; snake; envenomation; disaster; hurricane

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Toxicologic Exposures Associated With Natural Disasters: Gases, Kerosene, Ash, and Bites

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Natural disasters may be classified as geophysical (earthquakes, tsunamis, and volcanic eruptions), hydrometerological (tornadoes, hurricanes, and flooding), and geomorphologic (landslides).[1] Wildfires, forest fires, droughts and extreme temperatures (heat and cold waves) pose additional hazards. These natural hazards all have the potential to cause widespread property damage, population displacement, injury, and death. Over the past 20 years, there has been an average of 55 (range, 32-99) federally declared natural disasters annually in the United States.[2] Although coastal regions are most frequently impacted, every US state and territory has experienced a federally declared major natural disaster. Despite public concern, outbreaks of infectious diseases are extremely rare after natural disasters, with only 3 recorded outbreaks of infectious diseases in more than 600 global geophysical natural disasters between 1985 and 2004.[1] However, these incidents often result in exposure of the affected population to environmental toxins. This article will review common poisonings and toxic exposures that have been associated with natural disasters and provide recommendations for emergency personnel involved in disaster response and planning. Toxic exposures after man-made and technological disasters, such as terrorism, transportation accidents, and oil and chemical spills, are outside the scope of this article and will not be addressed.

THE DISASTER CYCLE

Several periods can be identified in a disaster or emergency management cycle. After a disaster incident, there is the response phase during which resources are mobilized to the scene to provide lifesaving interventions and direct aid. The response phase is followed by a recovery phase that may extend for months or years, depending on the extent of the environmental damage and the resources required by the community. The emphasis during this period of the disaster cycle is community recovery and the rehabilitation of the environment. Mitigation and planning for future incidents are components of the disaster cycle focused on protecting the population, reducing the impact of future disasters, and enhancing community resiliency.[3] Although usually considered a continuous cycle, these components may occur simultaneously as a region recovers from the effects of multiple events and prepares for future hazards.

Toxic exposures and poisonings occur at predictable phases within the disaster management cycle. During the planning and preparedness phase, people often stockpile fuel in anticipation of power disruption. During the response phase, sanitation and water may be compromised, food shortages may occur, or air or water quality may be adversely affected. The recovery phase can result in exposure to alternate fuel sources, toxic-cleaning products, and wild or venomous animals. This article will review toxic exposures that are known to occur during natural disasters and will relate the exposures to the disaster management cycle to inform medical disaster responders, public health planners, and emergency management professionals (Figure 1).

CARBON MONOXIDE

Carbon monoxide (CO) is an odorless, colorless, tasteless gas that is generated by the incomplete combustion of fuels. It is responsible for more than 20 000 emergency department visits and greater than 400 unintentional deaths in the United States per year.[4] Common symptoms of carbon monoxide poisoning include headache, nausea, weakness, vomiting, confusion, and chest pain. Symptoms do not correlate directly with carboxyhemoglobin concentrations; however, flu-like symptoms are most commonly reported as levels reach 10%, and seizures, coma, and death are often seen at concentrations greater than 50%. Carbon monoxide poisoning can be challenging to diagnose because its

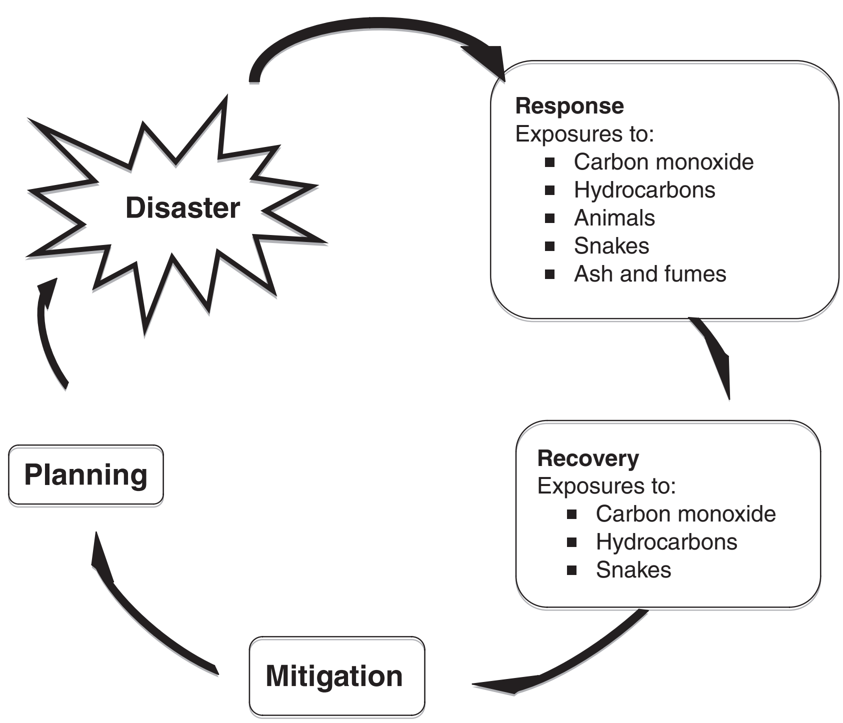

Figure 1. Toxicologic exposures and the disaster cycle.

symptoms are vague and mimic many other common illnesses. During the response and recovery periods after natural disasters, CO exposure and toxicity may become a significant public health concern.

To diagnose and treat CO toxicity, it is important to have a high index of suspicion. In particular, persons presenting with flu-like illness without fever should raise a red flag. For a first responder, the first step in treatment is removing the patient from the source of CO. The next step is to place the patient on 100% oxygen by nonrebreather mask and to continue oxygen administration until the patient is asymptomatic. Confirmation of the diagnosis can be obtained by measurement of the percentage of carboxyhemoglobin with a co-oximeter; but treatment should not be delayed to obtain labs. Consultation with a medical toxicologist, poison control center (1-800-222-1222), and/or facility with hyperbaric oxygen (HBO) should be undertaken for patients with cardiovascular or neurological compromise or with a carboxyhemoglobin level greater than 40%. Pregnant women with lower carboxyhemoglobin levels may also be candidates for HBO treatment because of known deleterious effects on the fetus. Although HBO has been advocated to prevent or minimize delayed neurological sequelae, review of published clinical trials does not demonstrate conclusive evidence about its efficacy in preventing neurological sequelae.[5]

Toxic CO exposures during hurricanes are well documented in the literature. The Florida Department of Health and the Centers for Disease Control and Prevention (CDC) analyzed CO poisoning cases occurring during the 2004 Florida hurricane season.[6] They evaluated a convenience sample of 10 hospitals and found 167 nonfatal exposures and 6 deaths attributable to CO toxicity. Of note, 31% of the cases were in children less than 16 years of age. Increased CO exposure cases were also found after Hurricane Katrina. A retrospective analysis of data from the Mississippi poison control center's database demonstrated a significant call increase in CO cases in comparison to the same period for the previous 3 years.[7]

Carbon monoxide toxicity has been reported in other types of natural disasters. A retrospective analysis of the 2009 Kentucky ice storm demonstrated increased CO exposure in comparison to the same period in the preceding year.[8] Carbon monoxide poisoning was also found to be the leading cause of storm-related deaths in this natural disaster. In 2002, a case series done at Duke University Medical Center documented 200 cases of CO poisoning in the first 10 days after a major ice storm.[9]

The increase in CO exposure seen after natural disasters is largely due to the improper use of carbon-based fuels such as gasoline, kerosene, or propane as alternative sources of energy during power outages. The use of gas-powered generators without adequate ventilation is the most common cause of CO toxicity. A CDC analysis of CO exposure during the 2004 Florida hurricane season found that 96% of the nonfatal exposures and 5 of the 6 fatal exposures were associated with portable generator use. A review of the CO exposures during Hurricanes Katrina and Rita implicated personal power generator use in 93% of the 27 total incidents.[10] An analysis of CO exposures after Hurricane Ike in 2008 showed that 82% to 87% of toxic exposures were associated with improper generator use.[4]

Although gas-powered generators are the primary cause of CO toxicity, there are other notable sources of CO exposure that occur in the response and recovery periods after a natural disaster. An analysis of CO poisoning after a major ice storm in Maine found that approximately 30% of cases were due to other causes including kerosene space heaters, propane space heaters, charcoal grills, portable gas stoves, a fireplace, and a gas-powered cement cutter.[11] A descriptive study of CO exposure after a severe flood in North Dakota found 18 exposure incidents involving 33 people due to the use of gasoline-powered pressure washer use in basements.[12]

The CDC has published tips to help prevent CO toxicity in the aftermath of natural disasters. Generators, power washers, and other gas-powered equipment should not be used inside a basement, a garage, or other enclosed areas, even if doors and windows are open. Gasoline powered equipment should not be used near a window, a door, or an intake vent and should be a minimum of 10 ft from all household openings. Charcoal grills, lanterns, and portable camping stoves should not be used inside a home, tent, or camper. Every home should have a battery-powered CO detector, and the batteries should be checked at least twice a year.

HYDROCARBON TOXICITY

Hydrocarbons are commonly used as fuels, lubricants, solvents, and degreasers. The hydrocarbons include organic compounds derived from petroleum distillation such as gasoline, kerosene, and lighter fluid. Toxic exposure to hydrocarbon fuels is a concern during natural disasters. The degree of toxicity is directly related to the particular substance, amount, and route of exposure. Pulmonary aspiration is the primary health concern. Aspiration risk is greatest for substances with a low viscosity and low surface tension such as the aliphatic hydrocarbons and simple petroleum distillates, gasoline, and kerosene. A few milliliters of these compounds can result in chemical pneumonitis. With a few exceptions, ingestions and dermal absorption tend to be low risk for significant toxicity. Eye contact can result in local irritation.

The diagnosis of hydrocarbon toxicity is based on history and physical examination. Acute symptoms of pulmonary aspiration include coughing and choking that can quickly progress to severe respiratory distress. Ingestions typically result in nausea and vomiting. The treatment for hydrocarbon toxicity is supportive care, beginning with decontamination. Patients should be removed from the source. If there is dermal or ocular exposure, copious irrigation should be performed, and contaminated clothing should be removed. Most cases involve minor exposures, and patients who are asymptomatic after a 4- to 6-hour observation period may be discharged. More severe cases with hypoxia, respiratory distress, and/or an infiltrate on chest radiograph should be hospitalized.

During natural disasters, there appears to be an increase in hydrocarbon exposures, such as gasoline and kerosene, during the evacuation and landfall periods of hurricanes. A review of Texas poison center calls during Hurricane Ike showed a statistical increase in calls related to gasoline exposure in the evacuation, landfall, and postevacuation periods in comparison to the preevacuation period.[13] Similar results were found in a study looking at toxic exposures in Mississippi after Hurricane Katrina.[7] During the first 2 weeks after landfall, there was a notable increase in lamp oil exposures. This study also showed a notable increase in gasoline exposure up to 4 weeks after landfall. This increase in gasoline exposure is likely secondary to the siphoning of gas for use in automobiles and gas-powered equipment during power outages.[13] Neither of the above studies addressed the extent and severity of the exposures.

Prevention strategies ought to be employed to limit exposure to these alternative fuel sources during natural disasters. It is important that gasoline be stored in approved gasoline containers and kept in well-ventilated areas. Storage containers should be kept out of the reach of children. When siphoning gas, it is important to use only a siphon pump. The collecting container should be lower than the gas tank to allow gravity to help the process.

VOLCANIC TOXICITY

A volcanic eruption is the expulsion of solid material and gas from a hole in the earth's surface. There are at least 455 million people worldwide that reside within exposure range of a historically active volcano.[14] Toxicity as a result of a volcanic eruption is therefore a valid health concern.

The primary toxic concerns in volcanic eruptions are exposure to ash and volcanic gases. Ash is mildly fibrinogenic and therefore has the potential to cause pulmonary fibrosis. Silica, a primary component of ash, may cause silicosis if present in high enough concentrations. However, there are currently no documented cases of acute silicosis attributable to a volcanic exposure.

The most abundant gases released during a volcanic eruption are carbon dioxide and sulfur dioxide.[15] The primary health effect of excess carbon dioxide exposure is asphyxiation through displacement of oxygen. Sulfur dioxide is a highly water-soluble gas and forms sulfurous acid when in contact with water. As a result, sulfur dioxide causes rapid onset of mucous membrane and upper respiratory tract irritation: conjunctivitis, rhinitis, skin erythema, sore throat, cough, wheezing, and hoarseness. High-level exposure can cause tracheobronchitis, laryngeal edema, noncardiogenic pulmonary edema, and chemical pneumonitis. Longo et al[16] evaluated the effects of elevated sulfur dioxide exposure as a result of increased activity at Kilauea volcano in Hawaii and found an increase in complaints of headache, cough, pharyngitis, and acute airway problems. Acid aerosols such as hydrochloride, hydrofluoric, and hydrogen sulfide have also been implicated as potential health hazards, causing pneumonitis and eye irritation.[14]

Efforts should be made to reduce the risk of toxic volcanic ash exposure that typically occurs during the incident and early response phase. First-line responders should ensure that they are wearing appropriate personal protective equipment. Public health campaigns should emphasize the importance of avoiding basements or low-lying enclosures where toxic gases may accumulate. Persons with underlying respiratory illness may benefit from staying indoors if it is safe to do so.

ANIMAL EXPOSURES AND RABIES

Animals may be left behind by their owners when natural disasters result in evacuation or population displacement. Pet abandonment can occur if shelters are unable to provide suitable emergency housing for both people and their pets. Pets transported from their routine environments during evacuation may become fearful or disoriented, resulting in bites. Animal exposures occur primarily during the response phase of the disaster cycle, typically during the first 72 hours. During this period, pets may be transported to unfamiliar surroundings or left unattended by their owners. Encounters with strangers or displacement from home may lead to biting behaviors as animals attempt to defend their owners or territory. A significant increase in dog bites treated in emergency departments (RR, 4.1; 95% confidence interval, 2.0-8.10) was noted compared with the prior reference year in 20 hospitals in 18 flood-affected North Carolina counties after Hurricane Floyd.[17]

Rabies is a zoometric infection that causes fatal viral encephalitis if untreated. Rabies may become a concern because of difficulty identifying at-risk animals after a bite amid the chaos surrounding evacuation. Warner[18] noted an increased incidence of domestic animal bites seen by disaster medical personnel working in a federal disaster medical field hospital in Texas after Hurricane Ike. Domestic animal bites were the third most common trauma complaint in this case series, accounting for 22% of trauma visits to the field hospital, with dogs accounting for 55% of the animal bites, cats 20%, and snakes 5% in this observational report. Most of the victims (80%) were bitten by their own pet. Fifteen total cases were seen. The author noted that animal bites typically account for only 1% of trauma visits to the local medical facility. One patient required transfer for operative debridement and antibiotics after a dog bite to the hand. No patient required rabies postexposure prophylaxis. Warner noted that rabies vaccine and immune globulin are not included in the pharmacy cache for deploying federal disaster medical assistance teams. Evacuated pets should be monitored for aggressive behavior during the early response phase after a disaster and should be isolated if their behavior appears erratic or aggressive. National Veterinary Response Teams are a federal resource under the auspices of the Health and Human Services National Disaster Medical System that could provide expert consultation about animal rabies and the need for postexposure prophylaxis at the scene of a natural disaster. Poison control centers can also assist in providing this type of information.

SNAKE BITES

Snake exposures may increase after natural disasters, especially floods, as reptiles follow food sources in seeking higher ground.[19] Snakes laying in flood waters may go unnoticed by disaster responders or people returning home.[19] Common venomous snake bite symptoms include local pain and swelling, paresthesias, nausea, and vomiting. Although most snake bites are caused by nonvenomous snakes, local tissue necrosis, coagulopathy, systemic toxicity, and death may occur after crotalinae snake envenomations (eg, rattlesnakes, water moccasins, and copperheads). Coral snake envenomations (*Micrurus* species) may cause life-threatening neurotoxicity, specifically paralysis, if not treated. Specific antivenom is available for crotaline envenomations—CroFab® (Crotalidae Polyvalent Immune Fab Ovine). Production of coral snake antivenom has been discontinued in the United States, although it can still be obtained from selected health care facilities. Despite numerous popular media reports of increased wild snake exposures after hurricanes and floods, an increase in snake envenomations after natural disasters has not been well documented. Review of snake exposure calls to a regional poison center in Alabama after 3 federal-declared flood disasters showed no increase compared with the prior reference years.[20] Snake exposures have also been reported to increase during droughts and dry season as snakes migrate to residential gardens and watered fields. Envenomations have been reported to increase in India during the dry or harvest season as farmers encounter snakes while harvesting crops.[21]

Not all snake exposures after a disaster may be from indigenous species. Estimates are that 3% of US households have an exotic pet reptile, with snakes being the most common.[22] Exotic pet snakes kept in urban areas may escape or be transported by their owners during an evacuation.[23] After Hurricane Irene, a 10-ft albino Burmese python escaped from an urban apartment.[24] Although medical personnel may have difficulty identifying indigenous snakes, exotic snake exposures present an even greater identification challenge. Expert consultation for snake identification is available through poison control centers at (800) 222-1222. There are currently no domestic producers for elapidae antivenom.[22] Exotic snake antivenom is not readily available in the United States, and its use mandates expert consultation with a medical toxicologist and/or poison control center.

Published recommendations for people returning after recession of flood waters after Hurricane Katrina included exercising caution inside closets, in bookcases, under furniture, and in enclosed spaces where snakes may hide.[25] Controlling indoor rodents will result in snakes leaving to locate food outside the house. The pharmacy cache carried by federal disaster medical response teams does contain crotaline antivenom.[18] Disaster response

TABLE 1. Toxic exposures after natural disasters.

Exposure	Toxicity	Management	Mitigation/Prevention
Carbon monoxide	Mild—headache, nausea, dizziness Moderate—vomiting, dyspnea, tachycardia, drowsiness, chest pain, confusion Severe—dysrhythmias, seizures, hypotension, coma, death	Removal from source 100% oxygen via nonrebreather mask until asymptomatic Hyperbaric chamber for severe neurological and/or cardiovascular toxicity or pregnant women	Avoid using gasoline-powered equipment indoors Maintain 10-ft distance between gasoline-powered generators and doors, windows, or vents Use of CO detectors
Hydrocarbons/petroleum distillates (kerosene, gasoline)	Mild aspiration—coughing, gagging, tachypnea Moderate to severe aspiration—chemical pneumonitis, hypoxia, respiratory failure Dermal/ocular—local irritation	Removal from source Removal of contaminated clothing Supportive care (eg, oxygen) for respiratory issues Copious irrigation for dermal or ocular involvement	Proper storage of gasoline and kerosene in approved containers and away from children Use of a siphon pump
Ash	Pulmonary irritant silicosis?	Removal from source Supportive care	Seek shelter indoors
Volcanic gases	Pulmonary irritant, asphyxiant	Removal from source Supportive care	Avoid low lying areas where gases may accumulate, for example, basements
Rabies	Central nervous system virus causing encephalitis that typically progresses to death	Human rabies immune globulin, human rabies vaccine	Animal shelters for pets
Venomous snakes—crotaline (rattlesnakes, water moccasins, copperheads)	Local tissue necrosis, coagulopathy, nausea, vomiting, syncope	Crotaline antivenom Supportive care	Protective clothing?

personnel should be aware of the need for correct identification of the snake after a bite and of local sources of antivenom if indicated (Table 1).

SUMMARY

Medical personnel responding to natural disasters should expect to encounter persons affected by various toxic exposures. These exposures may occur at any stage of the disaster management cycle, but most frequently occur during the response and recovery phases. The most commonly reported exposure is carbon monoxide. Carbon monoxide poisoning typically occurs as people use electrical generators and power tools in poorly ventilated spaces. Although data are limited, hydrocarbon and volcanic ash exposures may also occur after natural disasters. Animal exposures may increase after natural disasters, leading to consideration of the need for rabies postexposure prophylaxis. Snake bites may increase after floods. In many cases, toxic exposures are preventable. Mitigation efforts directed toward educating the public about the safe use of generators, storage of alternative fuels, and transport of animals may decrease toxic exposures after natural disasters.

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