The Environmental Health Impact of Hurricane Katrina on New Orleans

Hurricane Katrina caused unprecedented flood damage to New Orleans, Louisiana, and has been the costliest hurricane in US history. We analyzed the environmental and public health outcomes of Hurricane Katrina by using Internet searches to identify epidemiological, sociodemographic, and toxicological measurements provided by regulatory agencies.

Atmospheric scientists have now warned that global warming will increase the proportion of stronger hurricanes (categories 4–5) by 25% to 30% compared with weaker hurricanes (categories 1–2).

With the new $14.6 billion Hurricane Storm Damage Risk Reduction System providing a 100-year storm surge–defensive wall across the Southeast Louisiana coast, New Orleans will be ready for stronger storms in the future. (*Am J Public Health.* 2020;110:1480–1484. doi:10.2105/AJPH.2020.305809)

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See also Kim-Farley, p. 1448, and the *AJPH* Hurricane Katrina 15 Years After section, pp. 1460–1503.

Hurricane Katrina caused unprecedented damage to New Orleans, Louisiana, by flooding 80% of the city. Katrina was the costliest hurricane in US history and caused $17 billion in damages in Orleans Parish (county equivalent) alone.[1] Katrina also caused more deaths in Louisiana (n = 1170) than in any other Gulf Coast state.[2] In addition to its tragic human toll, Katrina left an environmental toll of oil spills, storm debris, damaged sewage and water treatment systems, abandoned housing, and widespread mold.

We identify Katrina's major health and environmental impacts on New Orleans and their enduring effects. The major categories of Katrina's environmental legacies included population relocation, abandoned neighborhoods, floodwaters and sediments, solid wastes and landfills, infrastructure damages, microbiological effects, and coastal land losses.

METHODS

We used a broad array of key words to query the Internet search engines Medline, PubMed, Google, Google Scholar, and Cochrane to identify scientific articles on biological, epidemiological, sociodemographic, and toxicological observations and measurements. The key words included "hurricanes," "climate change," "Hurricane Katrina," "Hurricane Rita," "New Orleans post-Katrina and Rita," "Louisiana post-Katrina and Rita," and "Louisiana coastal land loss." The articles we reviewed included local, state, and federal government publications; observational and surveillance investigations; mycological and toxicological investigations; and nongovernmental organization and press accounts of neighborhood-level activities and storm-related economic and built environment damages.

RESULTS

The neighborhoods hardest hit by flooding were predominantly African American and Vietnamese American neighborhoods in eastern parts of the city, which were originally established on reclaimed, low-lying, Lake Pontchartrain–bordering wetlands.[3] As Hurricane Katrina made landfall and headed inland east of the city, its counterclockwise winds forced Lake Pontchartrain's brackish waters into the city's insufficiently walled drainage canals, bursting levees and flooding 80% of the city for up to 43 days.[1,3]

Population relocation occurred soon after Katrina and continues presently as homeowners rebuild in new neighborhoods with less flood damage. Previous investigations confirmed observations that minority communities sustained more hurricane-caused damages than did affluent communities (which have greater resources to rebuild).[4]

Abandoned Neighborhoods

Orleans Parish still has more than 15 000 vacant lots and more than 5000 vacant housing units.[3] These vacancies resulted from combinations of the demolition of irreparably damaged homes and the abandonment of commercial and rental properties in the most heavily flooded areas of the city.[3] The widespread vacancies and abandoned neighborhoods stimulated increases in rodent populations, especially in

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blighted areas of eastern New Orleans, which had accumulated debris from illegal dumping and unmaintained vegetation.[5]

Floodwaters and Sediment

A variety of toxic compounds and pathogens contaminated more than 400 billion gallons of floodwaters.[6] The concentrations of these compounds initially exceeded safe human exposure limits in most cases (Table 1).[6–10]

The major toxic compounds in floodwaters that contaminated soil sediments included (1) the heavy metals arsenic (from termiticide-treated outdoor furniture, decks, and siding) and lead (from lead-based paints and plumbing); (2) the volatile organic compounds gasoline and diesel fuel (from flooded vehicles, petrochemical refineries, and fuel storage depots); (3) the polycyclic aromatic hydrocarbon, benzo(a) pyrene (from building fires spark-ignited by ruptured natural gas lines); and (4) untreated human waste from flooded sewer lift stations.[7,11–13]

As the floodwaters were pumped out of the city and into Lake Pontchartrain, they left behind a thick layer of soil sediments covering most of New Orleans.[12] Ground-based teams soon began systematic sampling of soil sediments to determine their degree of contamination and to assess potential human health risks. Table 1 compares the levels of soil sediment contaminants, including biomarkers for molds and bacteria in New Orleans before and after Hurricane Katrina.[6–10]

A combination of pre- and posthurricane initiatives made elevated soil lead levels less of an exposure problem than anticipated. Before Katrina, federal grants supported soil lead removal and replacement initiatives on inner-city playgrounds.[7–9] A series of simultaneous municipal grants sponsored neighborhood pediatric blood lead–monitoring programs.[7–9] The regulation of leaded paints and their disposal, the elimination of lead additives from gasoline, and the replacement of lead plumbing with plastic began in the 1980s.[9] Neighborhood blood lead levels in children soon decreased following the combined impact of these prehurricane initiatives and continued to fall after Katrina as storm debris and construction wastes were rapidly removed to nearby landfills (Table 1).[6–12]

Storm Debris, Solid Wastes, and Landfills

The rapid disposal of storm debris and solid wastes posed major logistical problems for New Orleans. First, the volume of storm wastes and debris was immense. Solid wastes needing disposal included 350 000 abandoned vehicles, 120 million cubic yards of storm debris, and about 750 000 white goods (i.e., standard kitchen appliances, such as refrigerators, freezers, washers, and dryers). Second, the transportation of wastes outside the disaster impact zone was not permitted for several reasons, including the potentially hazardous nature of the wastes, (e.g., arsenical leachates from pesticide-treated wood and siding) and the potential for spreading endemic, subterranean Formosan termites. The local established landfills were also not designed to accept noncommercial and hazardous wastes. Lastly, air quality concerns eliminated onsite open-air incineration as an option.[11]

Massive waste and debris removal requirements left little time for the careful separation of hazardous commercial and household wastes from construction and demolition debris before transport to reopened landfills. The only solution was local waste disposal at existing and closed landfills. Although never secured for hazardous wastes, the Agriculture Street landfill reopened temporarily in 1965 to accept a variety of wastes from Hurricane Betsy.[11] In 1994, arsenic, lead, and petrochemicals were detected in soil in new neighborhoods built on top of the abandoned landfill, later designated a Superfund site.[11] Based on this past experience, even the construction and demolition debris sent to non-secured landfills during flooding disasters retained the potential to leach toxic substances from termiticide-treated wood and siding and petrochemicals from flooded vehicles, service stations, and oil storage depots,

TABLE 1—Levels of Soil Sediment Contaminants Before and After Hurricane Katrina: New Orleans, LA; September 29, 2005

Compound Concentration	1999–2001[a]	September 2005[b]	February 2006[c]	February 2006[d]	2013–2017[a]	Safe Levels[e]	Clean-Up Levels[f]
Arsenic mg/kg soil	NR	4.73 (1.19–34.20)	10.60–11.80	45.50–78.00	< 0.39	< 0.39	< 12.00
Lead mg/kg soil	99.00	290.90 (20.90–1090.00)	93.50–108.30	613.00–1160.04	54.00	< 100	400
Diesel mg/kg soil	NR	NR	524.1–956.8	7590–17 400	NR	65	650
B(a)P µg/kg soil	NR	NR	975.5–1359.6	2870–17 700	NR	100	330
EU/m² soil[g]	NR	NR	indoors: 23.3; outdoors: 10.5	NR	NR	1.0	1.0
β-D-glucan[h] µg/m³ soil[g]	NR	NR	4.4	NR	NR	0.3	1.0

Note. B(a)P = benzo(a)pyrene; EU = bacterial endotoxin units; NR = not reported.
[a]From Mielke et al.[9]
[b]From Presley et al.[8]
[c]From Roper et al.[6]
[d]From Solomon and Rotkin-Ellman.[7]
[e]According to the Environmental Protection Agency.
[f]According to the Louisiana Department of Environmental Quality.
[g]From the Centers for Disease Control and Prevention.[10]
[h]β-D-glucan is a mold biomarker.

especially during heavy rains and hurricanes.[11,13]

The Chef Menteur Landfill in eastern New Orleans was designed for municipal use and not equipped for hazardous wastes. In early February 2006, New Orleans mayor C. Ray Nagin signed an executive order permitting the dumping of Hurricane Katrina storm debris in the Chef Menteur Landfill. Granted emergency powers by the city council in the wake of the hurricane, Mayor Nagin was able to override city-zoning ordinances and grant a six-month permit that turned the Chef Menteur site from a light industrial zone into a temporarily reopened landfill. The landfill was located less than two miles from a predominantly Vietnamese community in eastern New Orleans.[14]

Drainage canals ringed the landfill, which remained saturated with floodwaters. One of the primary drainage canals along the landfill, the Maxent Canal, ran through the most concentrated Vietnamese American community in the United States in Village de l'Est near Lake Borgne, an arm of the Gulf of Mexico.[14] The community is adjacent to the Bayou Sauvage Wildlife Refuge—the nation's largest urban wildlife preserve. The Maxent Canal continues to be an irrigation source for crops of sprouts and vegetables, which in turn provide a revenue and food source for the Vietnamese community.[14] According to the 2010 census, Village de l'Est, the community next to the canal, had a population of 8008. The population was mostly African American (43%) and Asian American (45%).[14]

Critical Infrastructure Damages

New Orleans continues to face major environmental health threats from hurricane damage to its critical infrastructure services, including its storm and wastewater management and its drinking water treatment systems.[15] Fifteen years after Hurricane Katrina, New Orleans continues to rebuild 400 miles of streets and underground water, sewer, and drainage systems in an unprecedented civil engineering project costing $4.3 billion.[15] Although more than $15 billion was invested in flood-protection levees, pumps, generators, and drainage systems since Hurricane Katrina, widespread street flooding still occurs regularly in low-lying areas throughout New Orleans after heavy downpours.[15]

Microbiological Effects

Human fecal coliforms from flooded sewer lift stations contributed most of the bacterial endotoxins to Katrina's floodwaters. However, the levels of endotoxin units dropped within weeks as soil sediments dried out and fecal coliforms desiccated and died.[12,16] In addition, the levels of most volatile organic compounds, including diesel and gasoline, decreased rapidly from evaporation as flooded soil sediments dried up.[11,16]

West Nile virus disease is the most common arthropod-borne infectious disease reported in Louisiana every August and September during the peak of hurricane season.[17] Over the 20-year reporting period, 1999 to 2018, the mean number of West Nile virus disease cases per year was 91 (range 0–335 cases per year), for an annual incidence rate of 1.21 cases per 100 000 persons per year.[17] However, in 2005, Louisiana reported 171 cases of West Nile virus disease to the US Centers for Disease Control and Prevention for a 53% increase above the mean.[17] The combination of increased favorable, flooded breeding sites for *Culex* species mosquitoes and the loss of formal mosquito-control capabilities after the sequential hurricanes of 2005 supported the increase in the mean annual number of West Nile virus disease cases.

Vibrio bacteria prefer salt and brackish water ecosystems, and human infections occur infrequently year round in Gulf coastal communities, with about 50 cases of *Vibrio vulnificus* reported every year across the Gulf Coast.[18–20] Twenty-four hurricane-associated *Vibrio* infections and six deaths were reported in Louisiana following hurricanes Katrina and Rita.[20] Most of these infections were wound infections caused by *V. vulnificus* following laceration and puncture wounds sustained while wading in contaminated floodwaters or sediment.[18,19] There were a few nonfatal cases of gastroenteritis following floodwater exposures caused by *Vibrio parahemolyticus*.[18] Only four cases of *Vibrio cholerae*, were reported, two of which occurred in a couple who consumed undercooked shrimp.[18]

Despite the observed increase in the city's rodent population, there were no increased reports of rodent-borne infectious diseases traditionally associated with prolonged flooding events, such as leptospirosis.[5,19] In addition, there were no increased reports of legionellosis cases, which are more often associated with freshwater aerosol exposures rather than salt and brackish floodwater exposures.[19]

Mold is ubiquitous in humid, tropical Deep South areas, such as New Orleans. Prolonged periods of flooding allow mold to propagate in indoor environments.[10] Continued flooding in most of New Orleans from the sequential hurricanes of 2005 promoted extensive indoor mold growth.[10] Investigators observed mold growth in 46% of flooded homes and measured β-D-glucan air levels indoors and outdoors.[10] The β-D-glucans are polysaccharide sugars, which occur naturally in fungal cell walls. They serve as very reliable biomarkers of mold spore contamination.[10]

Mean β-D-glucan air levels indoors of 1.6 micrograms per cubic meter exceeded the recommended indoor remediation levels of 1.0 micrograms per cubic meter.[10] They also exceeded outdoor levels of 0.9 micrograms per cubic meter.[10] Mold exposures at these levels caused acute health effects in susceptible persons, including coughing; airway hyperreactivity; influenza-like symptoms; eye, nose, and throat irritation; and skin rashes.[10]

Later investigations analyzed dust for molds and mycotoxins from water-damaged homes in New Orleans after Hurricane Katrina.[21] Fungal cultures and polymerase chain reaction assays confirmed the predominant mold species as *Aspergillus* and *Penicillium*.[10,21] Although exposures to mycotoxin-producing molds are associated with acute adverse health outcomes, no long-term adverse effects were observed after Katrina.[10,21]

Coastal Land Losses

Hurricane Katrina had a dramatic impact on the accelerated erosion of Louisiana's coastline and its protective barrier islands.[22] Land losses between 2004 and 2008, the period encompassing hurricanes Katrina and Rita (849.5 km^2), exceeded land losses over the previous 26 years (1978–2004; 743.3 km^2).[22] In less than one year, Louisiana experienced a loss of more than

150 square miles of estuarine marsh and an increase of more than 200 square miles of open water, mostly attributed to Katrina.[22]

Future Predictions

The problems faced in Louisiana after Hurricane Katina should serve as a warning to other cities and nations. Experts predict that annual costs for repairing categories 4 and 5 hurricane damage in flooded coastal cities will one day reach $1 trillion per year.[23] Global warming has now resulted in a proportional increase in stronger hurricanes compared with weaker ones.[24]

Scientists at the National Center for Atmospheric Research applied the Anthropogenic Climate Change Index to an assessment of the effects of global warming on hurricane activity over time.[24] Although the index did not detect increases in hurricane frequency, it did detect proportional differences between weaker (categories 1 and 2) and stronger (categories 4 and 5) hurricanes.[24] The proportion of category 4 and 5 hurricanes has now increased 25% to 30% per degree centigrade of global warming as balanced by a similar proportional decrease in category 1 and 2 hurricanes.[24]

Will New Orleans Be Ready?

With funding from the federal government, the Louisiana Coastal Protection and Restoration Authority created after Katrina collaborated with the US Army Corps of Engineers to design and construct one of the largest flood-protection systems in the world, the massive Hurricane Storm Damage Risk Reduction System (HSDRRS). Authorized by Congress after Katrina, HSDRRS is a $14.6 billion project spanning five coastal Louisiana parishes that consists of storm surge barriers, canals, sector gates, floodwalls, floodgates, and levees (Figure 1).[25] The system provides a 100-year storm surge–defensive wall around New Orleans designed to protect the city from a 1 in 100 or 1% probability of a similar event (Figure 1).

Open canals continue to serve as major storm drainage conduits for most of New Orleans and receive street-drained storm water from a series of antiquated pumping stations to deliver to Lake Pontchartrain. As part of the HSDRRS, the Corps completed the Permanent Canal Closures and Pumps Project in 2019 to replace the interim canal closure structures and temporary pumps on the city's three main storm water drainage canals—the 17th Street, Orleans Avenue, and London Avenue canals.[25]

The permanent canal closures and pumps are now located at the mouths of each outfall canal on Lake Pontchartrain and provide permanent storm surge gates that are closed before approaching hurricanes. In addition, the permanent canal closures and pumps have massive pumps run by dedicated generators that can remove storm water received from inner-city pump stations by pumping storm water directly into Lake Pontchartrain when the barrier gates are closed. These facilities can withstand 200 miles per hour winds in three-second gusts and 155 miles per hour sustained winds.[25] The structures also include control buildings, safe staff housing, and onsite diesel fuel storage for generators, enabling continuous operation at full capacity for up to five days.[25] Although some elements of the HSDRRS performed well during Hurricane Isaac (category 1, maximum sustained winds 81 mph) in August 2012, none of these hurricane protection systems have been tested since Katrina by stronger hurricanes of categories 3, 4, and 5.

DISCUSSION

Hurricane Katrina left a long-term environmental legacy of soil contamination and damaged critical infrastructure throughout New Orleans that continues to require monitoring and remediation. Katrina was a threat not only to the unique culture of New Orleans but also to the nation's economy, trade balance, seafood supply, and energy supply. Only federal and state policy changes that restore and preserve buffering barrier islands and coastal wetlands, improve onshore hurricane protection systems, and upgrade antiquated municipal drainage infrastructures will protect New Orleans and other hurricane-prone coastal regions of the

Note. This 1.8-mile long, $1.3 billion barrier, built by the US Army Corps of Engineers and operated by the Louisiana Flood Protection Authority, is a vital part of the Hurricane Storm Damage Risk Reduction System, which protects the community of Village de L-Est and eastern New Orleans from hurricane-spawned storm surges. Lake Borgne is an arm of the Gulf of Mexico connected to Lake Pontchartrain by 2 passes, the Rigolets and the Chef Menteur.

Source. Louisiana Flood Protection Authority. Available at https://www.floodauthority.org/the-system/lake-borgne-surge-barrier. Public domain.

FIGURE 1—The Lake Borgne Storm Surge Barrier: New Orleans, LA

United States from costly, catastrophic storm damage. *AJPH*

CONTRIBUTORS

J. H. Diaz wrote the section on floodwaters and sediments and the section on biological effects, edited the commentary, and served as corresponding author. J. H. Diaz and D. J. Harrington cowrote the sections on coastal land. J. H. Diaz, C. Hu, and A. L. Katner cowrote the sections on solid wastes and landfills. K. F. Brisolara and A. L. Katner cowrote the sections on population relocation and abandoned neighborhoods. All authors contributed to research and contributed references.

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CONFLICTS OF INTEREST

All authors report no conflicts of interest.

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