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A street in Columbia, South Carolina, is flooded in 2015.

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Disasters, the COVID-19 Pandemic, and a Human Health Observing System

by Paul A. Sandifer

Disasters are a part of the human condition and have been so over the entire course of human history. As noted in the following, the frequency and impacts of disasters appear to be increasing, and some areas of the world, such as the Gulf of Mexico region in the United States, appear to suffer disaster impacts more frequently than others. This article is intended as an extension of a recent major study on development of a framework for a disaster-focused health observing system for the Gulf of Mexico region,[1,2] to a broader context of disasters including the COVID-19 pandemic and utility in other geographic areas, including outside the United States. As explored in this article, health effects of disasters are typically dealt with in an event-by-event fashion, without systematic treatment. Currently, there is insufficiently detailed health information based on data records from individuals for almost all disasters to be able to say with confidence that, based on their health conditions before and after the event, an observed change in, for example, mental health, cardiovascular health, respiratory health, or other condition resulted from the incident. Here we briefly explore disaster typology, occurrence, and known health effects, and a proposal for more comprehensive disaster-associated health surveillance and its potential applications to fill this important data gap.

Disasters

The United Nations International Strategy for Disaster Reduction (UNISDR) defines disaster as "A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts."[3] Significant social disruption beyond local capability to cope is perhaps the "essential dimension" of disasters.[4] Disasters can be grouped into four primary headings: natural (i.e., acts of nature such as extreme weather events), technological (i.e., human-caused such as the Deepwater Horizon oil spill), natech (i.e., natural disaster leads to technological failure such as the 2011 tsunami in Fukushima, Japan), and techna (i.e., technological disaster amplified by natural disaster, such as a major oil spill caused by a hurricane).[5] Climate change, large harmful algal blooms, and the COVID-19 pandemic may be classed as natech disasters, because they are natural phenomena that have been greatly intensified by human actions (or failure to act) and can cause significant social disruption beyond local capacity to cope and in affecting responses to other disasters that may occur simultaneously.[6] Both of these situations have occurred in the United States, with some areas affected by hurricanes, wildfires, floods, and tornadoes while the pandemic was raging, complicating efforts to deal effectively with either.[7] For example, how does one provide safe shelters for people forced to evacuate in the face of a hurricane while a life-threatening pandemic is underway? Economic disasters could be included along with technological disasters as human-caused. And acts of arson that result in large wildfires, mass shootings, and terrorism also can become disasters with dramatic impacts on the communities which they impact.

Globally, the number of weather- and climate-related disasters increased more than twofold between 1950 and 2012, with concomitant increases in economic impacts.[8] The United States has been tracking the impacts of major environmental disasters in terms of those that reach or exceed \$1 billion in estimated damages since 1980. In 2020, the United States experienced 22 environmental disaster events of ≥\$1 billion impact each, its highest number ever, and the incidence and intensity of such events may be increasing.[9] While mortality levels associated with weather and climate disasters globally appear to be decreasing, likely as a result of better forecasts, warnings, and preparedness and response planning, the numbers of people impacted are rising rapidly.[10] Impacts to people from climate change effects are expected to continue to rise and to become more widespread and frequent.[11]

From global to local levels, climate change can be considered a disaster. While relatively slow-moving, its consequences can range from the acute, like extreme weather events, to long-term flooding, drought, and other conditions that may threaten the continued existence of certain communities.[11] Other disaster-like incidents, particularly relevant to coastal communities, include harmful algal blooms (HABs) and diseases caused by pathogens that naturally occur in coastal waters, such as several *Vibrio* species.[12] Toxins produced by HABs are highly dangerous to humans and animals, and *Vibrio* infections associated with seafood consumption and contact with waters containing the bacteria are serious and sometimes life-threatening. The occurrence and virulence of HABs and *Vibrio* may be exacerbated by climate change.

In the United States, the Gulf of Mexico region is frequently beset by environmental disasters, with hurricanes Katrina and Rita in 2005 and Gustav and Ike in 2008, the largest marine oil spill in U.S. history, the Deepwater Horizon spill, in 2010, Hurricane Harvey in 2017, and in 2020 it was hammered by five land-falling hurricanes and one tropical storm. As of September 2021, the region has already experienced hurricanes Ida and Nicholas and at least three additional hurricanes and tropical storms.[13] Disasters such as these in the Gulf of Mexico region and elsewhere throughout the world exact a heavy toll in human health effects, as reviewed next.

Disaster Health Effects

Health effects of disasters are not routinely and systematically summarized by disaster type and effects. Human health effects of some of the major recent

Oil covering the beach in Gulf Shores, Alabama, after an oil spill in the Gulf of Mexico.

The COVID-19 pandemic has burdened all demographics, but the highest incidences of infection and mortality have been observed in minority populations.

natural and technological disasters in the United States have been reviewed by Sandifer and colleagues.[1,2,14,15,16] A brief summary of their findings is provided here, and the reader is referred to these papers and the literature cited therein for more detail. Additional material and references related to the COVID-19 pandemic are also included.

Mental health impacts, such as anxiety, depression, personality disorders, and posttraumatic stress symptoms, are often a dominant human effect associated with disasters. Although disaster-associated physical health effects tend to be somewhat less studied than mental effects, they encompass a wide variety of concerns, including cardiovascular issues, respiratory problems, digestive and intestinal complaints, skin, eye and throat irritation, certain infectious diseases, diabetes and asthma, and cancers. High levels of acute, chronic, and cumulative stress frequently accompany disasters and may cause or exacerbate adverse mental and physical disorders for individuals and overall community health. Mental, physical, and community health effects of disasters also can be amplified by repeated disaster exposure such as tropical cyclones followed by flooding, technological catastrophes, extensive wildfires, earthquakes, and so on. The present and continuing COVID-19 pandemic adds to the cumulative trauma, along with co-occurring environmental disasters such as multiple tropical cyclones, massive uncontrolled wildfires, flooding, tornadoes, and others. Children, adolescents, pregnant women, young mothers with children, the elderly, and people with chronic health conditions or with low social and economic resources may be particularly vulnerable to disasters in general and to multiple trauma impacts. In some circumstances, women's societal roles, vulnerability to intimate partner violence, and reproductive issues may make them more vulnerable as well. Health impacts of disasters are often broad, include both direct and indirect (e.g., via associated social and economic disruptions), and frequently have their "greatest impact among those with the least."[17]

Similarly, the COVID-19 pandemic has burdened all demographics, but the highest incidences of infection and mortality have been observed in minority populations, particularly African American, Latinx, Asian, and Native American, and among those with underlying chronic health conditions, the elderly, and in socioeconomically deprived communities.[18] White people have generally fared better than minorities, but older people, especially those with underlying chronic health conditions, have been the most susceptible to COVID-19. Not surprisingly, white adults who are older and have higher income, education, and home ownership levels "are better able than others to mitigate any adverse health effects of natural disasters."[19] It is estimated that as a result of the COVID-19 pandemic, between 2018 and 2020 the

United States suffered its greatest reduction in life expectancy since World War II, with an overall reduction of 1.87 years.[20] The effect was 2–3 times greater among Blacks and Hispanics and 8.5 times worse than among populations in comparison peer countries. The impacts of COVID-19, and ongoing health disparities among peoples of color, should provide an object lesson going forward. In the words of Dr. Anthony Fauci: "Let us promise ourselves our memory of this tragic reality—that an infectious disease disparately kills people of color—does not fade. Righting this wrong will take a decades-long commitment."[21]

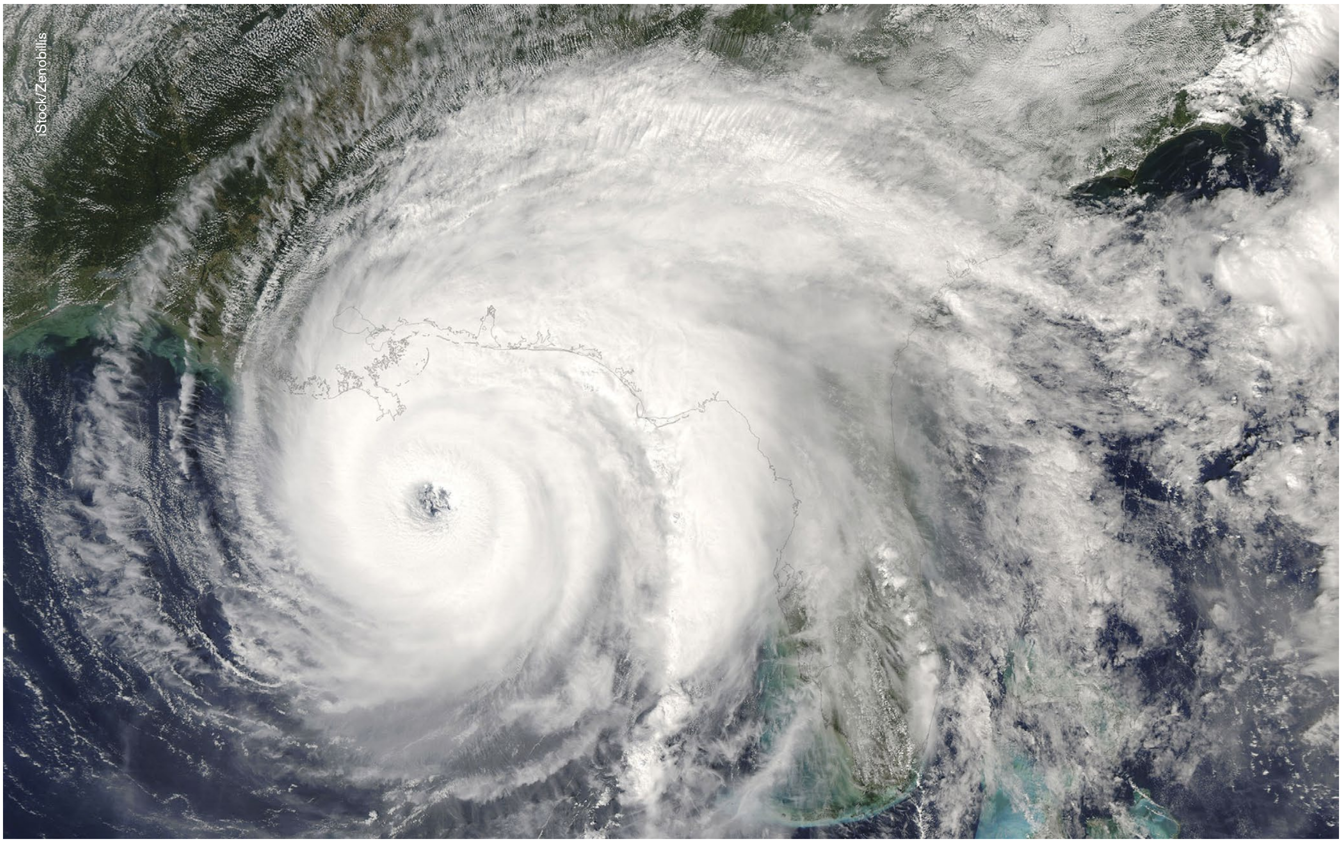
Adverse health effects of disasters and other traumas can be cumulative and enduring, as evidenced by the decades of continuing effects observed for the 1989 *Exxon Valdez* oil spill in Alaska, as well as effects of the 9-11 attack in 2001, Hurricane Katrina in 2005, and the Deepwater Horizon oil spill of 2010.[22,23] Even more sobering is the finding of continued adverse effects among Holocaust survivors more than 70 years after their childhood exposures.[24] Thus, "[disaster health effects] studies spanning multiple decades are warranted to gauge long-term and transgenerational effects."[1]

Some of the most pervasive and long-lasting effects of the COVID-19 pandemic, like those of the Deepwater Horizon and Hurricane Katrina, are expected to be stress-related mental disorders. For example, data from relatively early in the pandemic showed that the numbers of people with serious psychological distress in a 30-day period was approximately the same as for the entire previous year.[25] These researchers described the COVID-19 mental health impact as "unprecedented with respect to its nation-wide scale." Some researchers anticipate that a new global pandemic of mental and behavioral illness will immediately follow the COVID-19 pandemic.[26] Others coined a new term, "coronavirus syndrome," to describe the mental disorders associated with COVID and suggested that the syndrome might affect as much as 10% of the population globally, with the most severe consequences occurring after the pandemic passes.[27] Again, "Far from being felt equally, the mental health burden has fallen most on those with the least means."[28]

Serious levels of anxiety can begin well in advance of a disaster or crisis, such as in response to hurricane watch and warning notices, and then be exacerbated by the day-to-day, almost hour-to-hour litany of catastrophic losses, illnesses, and deaths reported by news media and amplified through social media and internet sources. During and following disasters and pandemics, crisis communication that is well intentioned and evidence based is


iStock/lakshmiprasad S

A doctor in a protective suit adjusts a ventilation oxygen mask for a COVID-infected patient having difficulty breathing.



A Category 5 super typhoon from outer space showing the eye of the hurricane. Some elements of this image furnished by NASA.

indispensable in fighting panic, reducing anxiety and depression, and contributing to unified social action to address the disaster impacts. However, inadequate, poorly informed and directed, or ignorantly or purposefully false communication, especially repeated and amplified via social and internet media, can increase the risk of psychological distress among the public.[29] As the Director-General of the World Health Organization observed: "We're not just fighting an epidemic, we're fighting an infodemic," meaning a massive global tsunami of misinformation.[30] In the COVID-19 pandemic, perhaps more than any previous disaster to affect the United States since Hurricane Katrina, both traditional and "new" (social and Internet) media have played outsized roles in how pandemic information and misinformation translate into positive and, most significantly, negative effects on people. This is not only true in the United States but elsewhere as well. For example, high levels of social media use were associated with greater depression among Chinese college students.[31] Other researchers in China reported that social media use, particularly viewing negative content, was associated with greater anxiety and stress, while viewing "heroic acts" and evidence-based information from experts were associated with positive outlooks and lower levels of depression.[32] It is all too clear that infodemics can be dangerous to public health.[29] Impacts of misinformation in the United States have likely contributed to hundreds of thousands of unnecessary deaths and to stigmatization of certain ethnic groups, perhaps helping to fuel the recently observed increased violence toward Asian Americans. A case in point is that the incidence of anti-Asian sentiment in tweets with "#chinesevirus" increased significantly in the week following President Trump's initial tweet using the term "Chinese Virus" for COVID-19, compared to the previous week's tweets with "#covid19."[33]

Environmental Observing Systems

Environmental observing systems have been in place for many years, particularly for atmospheric, weather, climate, and ocean conditions. These systems provide the raw data that make possible modern short- and long-term weather forecasts and predictions of climate trends, ocean currents, and movement and distribution of pollutants via air and water, among other things. Such observing systems are typically instituted at national to global scales and are operating in many countries around the world.[34] According to the U.S. Department of Commerce, which houses the National Weather Service as part of the National Oceanic and Atmospheric Administration, many Americans check the weather forecast almost 4 times per day, totaling some 300 billion forecasts utilized per year.[35] Similarly, the World Meteorological Organization, an agency of the United Nations, provides related information and services for its 187 member countries and 6 territories representing all major populated regions of the world.[36] Thus, on any given day, many millions of people depend on such observing systems for decisions about daily life, work and business activities, investments, and how they should react to extreme events like tropical cyclones, floods, wildfires, tsunamis, and others. Simply put, we would be in a world of hurt without these continuously operating systems that observe the physical world and enable immensely valuable predictive capacities. However, in the public health realm, similar records of important human health parameters that have predictive value are generally not continuously and systematically monitored and recorded in statistically derived population samples to support predictions, linking of cause and effect, and preparedness planning, particularly in response to environmental disasters. Cause and effect refer to the ability to identify, based on solid evidence, that specific health effects were caused by a particular disaster so that appropriate actions can be taken to treat, mitigate, prevent, and, where necessary, assign responsibility for the effects. Examples of some health parameters that may be valuable in assessing and/or predicting effects of disasters include before and after status of existing health conditions, such as occurrence and severity of cardiac events, incidence of respiratory distress, changes in self-reported and clinical indicators of mental and physical health, changes in health biomarkers derived from blood and urine samples, and others. Disasters are the kinds of events that require extensive amounts of preexisting information at the population level to enable accurate identification of acute and chronic effects on people, assessment of cause and effect, and development of methods to prevent or mitigate future adverse impacts.

Need for a Human Health Observing System

In 2010, the devastating Deepwater Horizon oil spill in the Gulf of Mexico revealed a stark and dangerous lack of background health information upon which to assess the human effects of the oil spill or other disasters.[37,38] Included in the findings of the President's National Commission on the BP Deepwater Horizon Oil Spill was the need for a "public health protocol requiring the collection of adequate baseline [health] data and long-term monitoring."[39] This lack of a significant baseline of predisaster health information persisted despite the clear warnings of the need for such information that emerged following the catastrophic effects of Hurricane Katrina in 2005.[40] The gap still exists today, and ongoing climate change, development, and other pressures are expected to increase the incidence and severity of

View of "Deepwater Horizon" offshore oil rig and Tidewater supply vessel in the Gulf of Mexico. The rig suffered a blow out while drilling at the Macondo Prospect in April 2010, then caught fire and sank, killing 11 and creating the worst oil spill ever in the Gulf.

disasters not only in the Gulf of Mexico but in many other regions as well. These risks are compounded by impacts of COVID-19 and increasing risks posed by future pandemics and intensified by pervasive health, socioeconomic, and educational disparities in the Gulf of Mexico region[41] and in many other areas in both the developing and developed world. Unfortunately, the lack of significant baseline health information has made it difficult to fully address cause-and-effect linkages, and the absence of ongoing, prospective studies has limited our ability to track putative health effects over the life-course of those impacted. A similar situation is now developing with COVID-19.

A Proposed Disaster-Focused Human Health Observing System

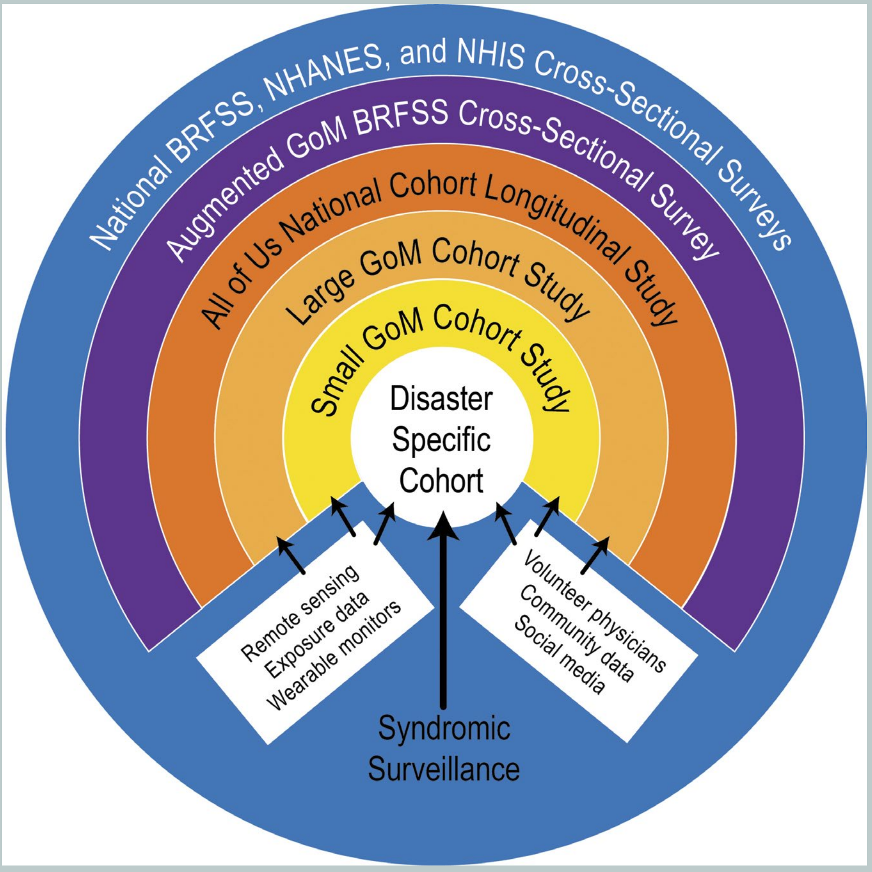
Following the Deepwater Horizon oil spill in the Gulf of Mexico in April 2010, the primary responsible party, BP, provided $500 million over a 10-year period to support independent research on impacts of the spill in the region. This led to the creation of an independent, nongovernmental entity, the Gulf of Mexico Research Initiative (GoMRI), under the leadership of Dr. Rita Colwell, who, with a research board populated with other distinguished scientists and administrators, put into place U.S. National Science Foundation-like grant making processes to support research on spill effects.[42] After extensive consultation, the GoMRI research board identified five thematic areas to be supported with its research funds: physical distribution, chemical evolution and biological degradation, environmental effects, technology developments, and public health impacts. Near the end of its 10-year life span and prior to the COVID-19 pandemic, the research board recognized the significance of the health information gap related to oil spill impacts in the Gulf of Mexico and the very high probability that similar gaps exist in other regions and with respect to virtually all kinds of environmental and health disasters. As a result, the GoMRI research board commissioned a project to design a human health observing system. The ensuing project produced a framework for a health observing system for the Gulf of Mexico region.[43,44] This framework was the result of the work of a large and expertise-diverse team of scientists and health professionals over more than two years of deliberation, expert workshops, and extensive literature review and appears to be the first of its kind. During this process, the research team considered numerous ongoing national and other health surveys, general and specific-purpose (e.g., cardiovascular disease) longitudinal studies, some disease- or effects-specific health surveillance and predictive efforts (e.g., for lyme disease, cholera, heat distress), and some national health systems. The team found no ongoing, systematic studies that link individual health characteristics over the life course with disasters. The lack of more comprehensive health monitoring has become even more apparent during the COVID-19 pandemic.[45,46,47,48]

The result of the team effort was development of a design for a disaster-focused health observing system for the Gulf of Mexico region.[49,50] While the work was initiated as a result of the Deepwater Horizon oil spill, from the beginning the system was intended to encompass other kinds of disasters as well and to be adaptable and scalable for other geographic areas and needs. The framework design takes advantage of existing and continuously running cross-sectional health surveys conducted by the U.S. Centers for Disease Control and Prevention (CDC) and a relatively new national longitudinal study, the All of Us study, being surveys conducted by the U.S. National Institutes of Health (NIH). In particular, the CDC's Behavioral Risk Factor Surveillance System was selected for emphasis because it is conducted by individual states under CDC direction, and each state has the option to expand the regular survey to include additional questions and greater coverage as it may deem necessary and can afford. This option provides the possibility of augmentation of the Behavioral Risk Factor Surveillance System with more disaster-relevant questions, including for COVID-19, such as whether a respondent was directly, indirectly, or not affected by a given disaster, and for more intensive sampling of those most at risk. Together with community-based information provided by the American Community Survey and other sources, these existing surveys will provide background and contextual health information that will complement and extend that collected in the new and most important portions of the observing system, longitudinal cohort studies. While cross-sectional data are useful for describing some facet of a population at a given point in time, they do not allow assessment of changes over time, severely limiting their utility for connecting cause and effect. In the case of a disaster, cross-sectional data cannot be used to assign observed health characteristics to the disaster. Thus, while making use of existing large-scale cross-sectional survey data for comparative purposes, the design team identified prospective longitudinal studies that would be in place collecting a wide range of health data before an event occurs, continue through the event, and then go on for a long period thereafter as essential elements for a health observing system. Similarly, Parker et al. highlighted the paucity of and critical need for longitudinal studies relative to human effects for disasters.[51] They stated: "Significant advancement in disaster research… requires well-designed surveys with large probability-based samples and *longitudinal assessment of individuals* across the life-cycle of a disaster and across multiple disasters" (emphasis added).

Altogether, the proposed health observing system consists of six distinct and related data domains, illustrated as concentric circles (Figure 1), with the three new proposed longitudinal cohort studies—the Large, Small, and Disaster-Specific Cohorts—as the heart of the system.

The Large Cohort is designed to be a statistically representative sample of the population in the Gulf of Mexico region (or any defined region), with additional

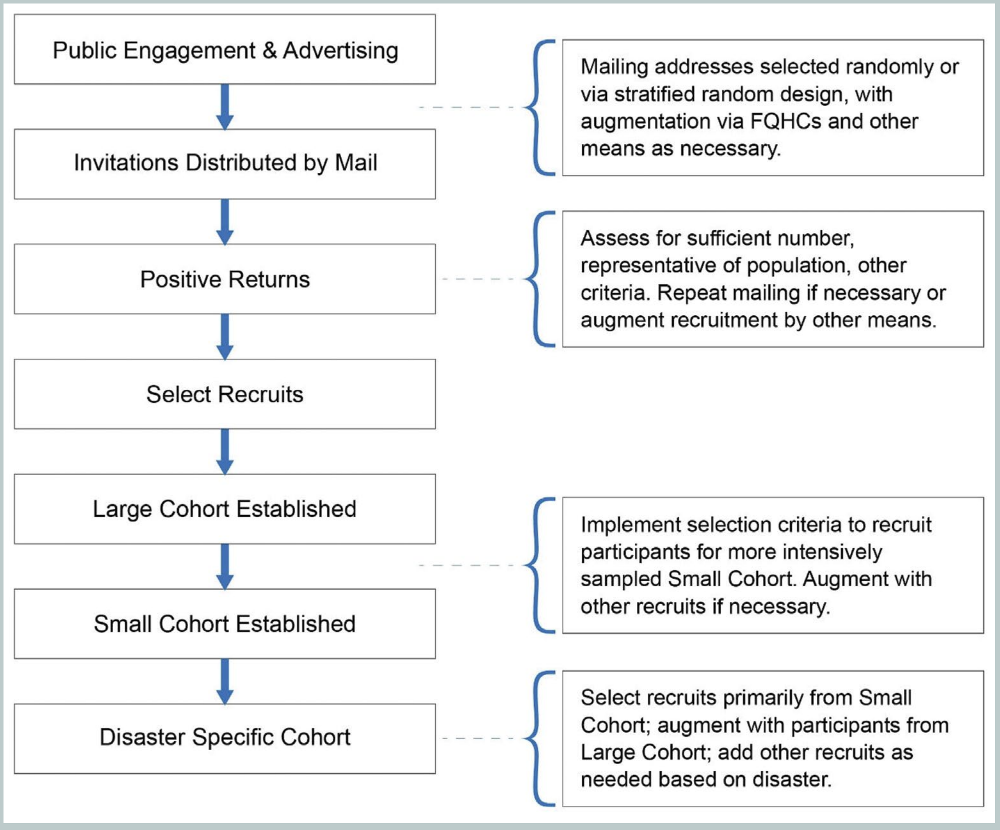
Figure 1. Conceptual framework for a Gulf of Mexico Health Observing System.



Source: Sandifer et al.[1,2]

sampling as necessary to ensure inclusion of appropriate numbers of those expected to be most vulnerable to impacts, such as members of minority communities, pregnant women, children, people with serious chronic disease, and the elderly. Initial contacts with potential participants will follow identification by stratified random sampling methods, and volunteers willing to provide health information will be recruited to the system's cohort studies (Figure 2). Members of the Large Cohort will be expected to provide a considerable amount of personally provided information about their health, demographic characteristics, and other factors and to undergo a limited amount of clinical evaluation for both mental and physical health parameters at periodic intervals e.g., every 1 to 3 years) (Table 1). Participants willing to undergo more extensive clinical evaluations, provide biological specimens for biomarker analyses, and/or allow access to their electronic health records will be enlisted in the Small Cohort, which is intended as a more intensively sampled subset of the Large Cohort. Disaster- or Crisis-Specific Cohorts will be populated as much as possible from the Large and Small Cohorts, based on the geographic extent of a specific crisis area, such as the impact footprint of a hurricane or major forest fire. For crises of larger proportion, such as the COVID-19 pandemic, subsets of regional cohorts across the country could be selected to follow the onset and outcomes of the disasters/crises and any mitigative actions taken to reduce their impact.[52] The cohort studies are intended to continue indefinitely, allowing periodic assessments of health effects over the life course for statistically meaningful population samples augmented by additional sampling within socioeconomically deprived groups and those with chronic health issues. In addition, other health-related data could be assembled from remote sensing and exposure databases, social media, portable health monitors worn by volunteers (Figure 1), and potentially even from sentinel organisms in the environment. For example, social media and computer-based tools can provide early warning of illness outbreaks and enable individual and community monitoring of pollution and other situations.[53,54] Another potentially rich source of surveillance data to augment those from the longitudinal cohorts is syndromic surveillance.[55,56] Syndromic surveillance (SyS) is a CDC-coordinated public health early warning system to collect electronic chief complaint

Figure 2. Simplified schematic of participant recruitment process for longitudinal cohorts in the proposed Gulf of Mexico Health Observing System. FQHCs refer to federally qualified health centers.



Source: Sandifer et al.[2]

records from hospital and other emergency departments to track outbreaks of diseases like influenza and some hazards. While SyS provides rapid, although not real-time, information, as currently conducted it has serious limitations, in particular lack of collection of mental health complaints. However, with additional effort, SyS could provide important input for disaster-focused health observing systems.

Members of minority and disadvantaged communities and people who suffer poorer health often have been inadequately represented in health studies. As envisioned for the Gulf of Mexico, the health observing system would undertake robust community engagement and awareness efforts before beginning to recruit volunteers, with the intent that the observing system operate on community-based participatory research principles and specifically reach out to underserved and economically deprived communities, including those described as environmental justice communities. According to the U.S. Environmental Protection Agency (EPA), environmental justice refers to the "fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation and enforcement of environmental laws, regulations and policies."[57] Environmental justice communities are typically low in wealth, minority dominated, and frequent or historic recipients of disproportionate shares of negative environmental consequences of governmental and business policies and actions. Concerns related to treatment of disadvantaged and environmental justice communities are by no means limited to the United States but are widespread internationally.[58]

The engagement effort planned for the health observing system in the Gulf of Mexico region proposes to include public news media, health care providers, and numerous willing community-based and community-involved entities that are respected and trusted. One successful community-based participatory research approach is the "Learn! Leverage! Lead!" method, where a community is engaged to assess and strengthen its knowledge base related to health-associated effects of disasters (Learn), enhance its

Interior of a house damaged by Hurricane Katrina in New Orleans in 2005.

capacity to reduce health and social impacts through sharing of information (Leverage), and develop and implement best management practices and tools to reduce vulnerabilities and protect the most susceptible members (Lead).[59] This approach is currently being applied in a project entitled "EJ Strong: Strengthening Communities for Disaster Risk Reduction, Response & Recovery in South Carolina" (Figure 3). The EJ Strong project is funded by the EPA via the South Carolina Department of Health and Environmental Control and involves experts and graduate students from South Carolina Department of Health and Environmental Control, the University of South Carolina, the College of Charleston, and Clemson University in delivering capacity-building training in disaster risk reduction to and in partnership with environmental justice communities in the state.

Although initially developed for a large region, the basic health observing system framework is scalable and could be implemented from the level of a local community, to that of a large municipality, state, region, or nation. Disaster- or Crisis-Specific Cohort(s) could also be focused on a specific socioeconomic, ethnic, or other group as desired. For example, Group-Specific cohorts could be established to focus on groups of individuals who have certain chronic conditions (e.g., diabetes, heart disease, obesity) or have experienced specific disasters or infections, including COVID-19. Using the community-based participatory research approach already outlined, environmental justice communities could be approached to populate one or more health cohorts that could be incorporated into a regional or national health observing system.

Next Steps: Testing and Implementing the Observing System

Two policy actions have been recommended as first steps toward meeting the critical need to implement a robust, continuously operating health observing system in the United States. These are (1) rapid implementation of a pilot project with federal agency leadership, and (2) simultaneous establishment of a high-level expert committee to advise Congress and the President on establishment of a nationwide health observing system, possibly composed of linked regionally based systems.[60] Both should involve not only federal health agencies, but also key players from state health departments, academic and clinical institutions, philanthropic organizations, and the private sector. All of these should participate in funding and building out a truly operational system.

Flooding in the French Quarter, New Orleans, after Hurricane Katrina in 2005.

One option for a pilot project would be to center it in the mid Gulf of Mexico region, perhaps at the city of New Orleans and surrounding parishes. These areas were heavily impacted by Hurricane Katrina and the Deepwater Horizon oil spill, with devastating effects, and have been hit again in 2021. As a result, health care organizations, public agencies, nongovernmental organizations (NGOs), and other institutions in the greater New Orleans area have a wealth of hard-won experience dealing with disaster-associated mental, physical, and community health effects, and there are many underserved and vulnerable people in the region. Depending on interest, similar pilot projects could be undertaken in other regions or in other countries. As previously noted, the basic design should be adaptable and scalable.

The entire scope of the observing system, incorporating the national survey elements that serve as an information "backbone" and the Large, Small, and Crisis/Group-Specific Cohorts, could be established in an area on a trial basis. An augmented Behavioral Risk Factor Surveillance System survey could be undertaken in the area with the additional questions primarily focused on COVID-19 issues, including incidence and severity of infections and severity, longevity of effects, COVID-related anxiety, depression, and posttraumatic stress symptoms, and other manifestations of the disease. Community or Group-Specific Cohorts could be created for some of the groups of most concern, such as individuals with chronic health issues, those who have had COVID-19, and/or those who have shared racial/ethnic and socioeconomic characteristics that make them more susceptible. Additional group-specific cohorts could be created if/when another environmental disaster such as a hurricane or flood hits the area. For example, a group-specific cohort could be established for a collection of EJ communities to assess long-term effects of disasters including COVID-19 in communities that were already suffering significant environmental, economic, and health stress before a disaster event.

Stress has been identified previously as among the most pernicious effects of disasters and crises, resulting in short- and long-term impacts and being associated with increased adverse health effects and mortality in many studies.[61] A major strength of the observing system design that could be explored in a pilot project is its emphasis on clinical assessments of stress and its association with adverse health outcomes. As designed, the health observing system includes collection of biological samples from which biomarkers can be derived

Table 1. Examples of types of data proposed for collection in the Gulf of Mexico Community Health Observing System cohort studies. All but personally provided information (PPI) will be obtained in clinical settings.

PPI from Questionnaires	PPI from Questionnaires	
Demographic information, including ethnicity, sex/gender identity, marital/partner status, children Socioeconomic information, including ability to deal with minor financial emergencies General health status Personal health history, including chronic and major diseases Family health history, including chronic and major diseases Life history and behavioral factors, including alcohol, tobacco, and illicit drug use, nutrition, exercise, sleep Health care access and services utilization	Prescribed medications Previous disaster/trauma experiences including in childhood Residence and adequacy of housing Known or suspected exposure to toxic or infectious substances or organisms Social, religious, tribal, community attachments and memberships Marginalization and discrimination (political, racism, ethnic, ageism, economic) Feeling of security or insecurity in home and neighborhood Level of trust in government/ societal structures	
Mental Health Measures	**Physical Health Measures**	**Biospecimens**
Anxiety Depression PTSD/PTSS Resilience Alcohol abuse Religiosity General self-efficacy Social capital Sense of control	Blood pressure Heart rate Height and weight Waist–hip ratio Body mass index Lung function Cardiovascular fitness Balance Ambulatory fitness	Blood Plasma Serum Saliva Urine Hair DNA, mtDNA, telomere Nails (finger and toe)

Note. Abbreviated slightly from Sandifer et al.[1,2]

and used for the express purpose of calculating allostatic load, a measure of physiological stress effects indicated by dysregulation of human neuroendocrine, immune/inflammatory, cardiovascular, respiratory, and metabolic systems plus certain anthropomorphic characteristics.[62] Having clinical measurements of allostatic load at intervals across the life course for individuals before, during, and following stressful events would increase understanding of the mechanisms by which stress causes adverse health outcomes and help identify mitigative and treatment options, hopefully before worst effects are expressed. Measurements of allostatic load may be especially important for disadvantaged communities due to potentially higher allostatic load and impaired immune responses.[63]

Finally, in addition to finding out how well the proposed observing system design works in the real world and what adaptations may need to be incorporated for wider use, pilot projects also could provide information on effects of interruptions in medical care, interventions, and medication due to the COVID-19 pandemic or other crises. Postponements of needed medical procedures and regular clinical examinations have led to increased illness and deaths following other disasters and are highly likely in the case of COVID-19.[64] The need for systematic sampling and testing at population levels has been demonstrated very clearly during the COVID-19 pandemic.[65] Unfortunately, lack of systematic sampling has been a continuing problem in the U.S. response to COVID-19 and remains so more than 1.5 years into the pandemic.[66] One or more pilot projects such as recommended here could demonstrate the value of ongoing sampling of statistically representative samples of various populations, leading to a much deeper understanding of actual incidence of diseases or conditions of interest. They would also enable "learning by doing" that would help inform the construction of a nationwide, linked network of regional health observatories. In addition, components of a health observing system could be incorporated into

Figure 3. Logo for the EJ Strong Disaster Risk Reduction project focused on environmental justice communities in South Carolina.

resilience-building activities with environmental justice and other communities.

In summary, strengths of the proposed observing system include (1) extensive use of existing national health surveys and studies; (2) establishment of new ongoing, longitudinal cohorts to ensure continuing collection of both baseline (before) and effects (after disaster) data to enable linking of effect with cause; (3) a focus on representative population samples that would provide epidemiologically and individually relevant health information over the human life course and as affected by disasters and other crises; (4) commitment to inclusion of those who are frequently missed, marginalized, and vulnerable; and (5) incorporation of a wide range of clinically derived and self-reported health metrics that would enable detailed health assessments and tracking of health effects.

Conclusions

Hurricane Katrina and the Deepwater Horizon oil spill in the Gulf of Mexico highlighted the lack of adequate pre-existing health information with which to compare after-disaster health conditions in affected populations. More recently, and perhaps more than any previous disaster in the last 100 years, the COVID-19 pandemic has drawn attention to the urgent need for comprehensive health monitoring.[67] Globally as well as in the United States, we can realistically expect ongoing effects of the COVID-19 pandemic that will be debilitating and long-lasting, in particular, mental health impacts.[68] These effects, the high probability of future pandemics, and the certainty of recurrent natural and technological disasters necessitate creation of improved health observing systems in the United States and elsewhere. While establishment of the GoMRI was a one-time occurrence related to a particular major disaster, and with a responsible party able to provide all the funding, the example it provides for funding independent, objective research may be useful for creation of similar locally structured entities to support health observing systems for the long term. Of course, a key element that would have to be identified is one or more significant sources of long-term funding. With or without a GoMRI-like entity, the health observing system framework provided here could serve as a starting template for use in other countries. The U.S. cross-sectional national surveys could be replaced with "backbone" elements derived from locally available health surveys and other information sources. Most important would be establishment of longitudinal cohort studies at least in areas most vulnerable to or with a history of recurring disasters. As in the United States, successful implementation of health observing systems is likely to require involvement of governmental entities from national to local scales, as well as academic, private-sector, and philanthropic and other nongovernmental organizations.

As Jeremy Farrar, a leading infectious disease researcher in the United Kingdom, stated: "Everything starts with smarter surveillance. If you don't look, you don't see. If you don't see, you will always respond too late."[69]

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