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Extreme Natural Hazards, Disaster Epidemiology, and Public Health Implications

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Summary and Keywords

The fields of disaster medicine and public health preparedness have developed considerably with the natural hazards and humanitarian disasters over the past half-century. Developing countries, particularly Small Island Developing States and Least Developed Countries, are disproportionately affected. In April and May 2015, two massive earthquakes in Nepal killed more than 8,400 people, injured 20,000, and reduced 300,000 houses to rubble. In March 2016, Cyclone Pam destroyed homes, schools, infrastructure, and livelihoods on the Pacific island of Vanuatu, affecting half the population, including 82,000 children. Most recently, Hurricane Matthew, a Category 4 tropical storm struck parts of Haiti violently on 4 October 2016 causing the largest humanitarian emergency since the 2010 earthquake. The Directorate of Civil Protection of Haiti has so far confirmed over 500 deaths, 339 injuries, and 75 people missing. The number of evacuees is 175,509 people scattered in 224 temporary shelters. Among the approximate 2.1 million people affected, UNICEF estimates that 894,057 are children. Nearly 1,410,774 people need humanitarian assistance, including 592,581 children. All three nations will take years to recover. However, the catastrophic Great East Japan earthquake and tsunami on March 11, 2011, and Hurricane Sandy, whose storm surge hit New York City on October 29, 2012, flooding streets, tunnels, and subway lines, and cutting power in every borough of the city sent clear messages that developed countries are also vulnerable to such severe disasters. To cite “Superstorm Sandy” again, the New York Stock Exchange was closed on October 29 and 30, 2012 as a result of power outages and flooding in the Wall Street area. Such a closure for weather-related reasons had not happened since 1888!

Unsustainable development practices, ecosystem degradation, and poverty, as well as climate variability and extremes have led to an increase in both natural and man-made disaster risk at a rate that poses a threat to lives and development efforts. Fortunately, over the past decade, the public health approach to disasters has changed significantly.

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Terms such as prevention, mitigation, preparedness, recovery, and resilience are now part of the vocabulary of public health officials in national and international organizations, and more importantly, they are used to advance the cause of reducing mortality and morbidity from disasters. We now know much about the cause and nature of disasters and about populations at risk, and that knowledge allows us to anticipate some of the effects a disaster may have on the health of an affected community. This expanding body of epidemiological research has provided a basis for increasingly effective prevention and intervention strategies.

Keywords: public health, epidemiology, environment, natural hazards, advances, controversies, resiliency, research priorities, challenges, human security

The Epidemiology of Disasters

With disasters and the number of people affected by such events on the increase and certain to worsen as climate change, globalization, technological change, urbanization, and political and economic instability put more people and assets at risk, the importance of disasters as a public health problem is now widely recognized. This is reflected by the growing number of manuscripts submitted to peer-reviewed journals on topics such as disaster epidemiology and disaster medicine. Since the 1960s, a score or so of important publications on public health aspects of disasters have added substantially to the body of knowledge on the public health consequences of disasters and have either influenced or changed disaster relief practices. We review some of them here in order to highlight the historical development of the “state of the art” of public health in disaster situations.

The Early Years

In the early 1970s, major natural disasters in Peru, Nicaragua, and Bangladesh (at that time, East Pakistan) heightened awareness of disasters as a major public health problem. Epidemiologist Karl Western of the Centers for Disease Control and Prevention (CDC), in one of the earliest reviews on the role of epidemiology during natural disasters, observed that the effects of disasters on the health of populations were amenable to study by epidemiological methods and that certain common patterns of morbidity and mortality following certain disasters could be identified (Western, 1972). In November 1970, a tropical cyclone struck the coast of Bangladesh resulting in over 250,000 deaths. A paper published about a year later in *The Lancet* by Sommer and Mosley of the U.S. Centers for Disease Control, summarizing the health surveys conducted following the cyclone’s passage, vividly demonstrated the numerous complex problems faced by epidemiologists

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in disaster situations and the value of early on-the-spot assessments in getting an accurate picture of requirements in disaster areas (Sommer & Mosley, 1972). This important paper emphasized for the first time the need for valid and timely data collection and analysis as the basis of rapid and effective problem solving during natural disasters.

In February 1976, a major earthquake struck Guatemala leaving an estimated 23,000 dead. This earthquake served as a landmark event in the history of studies of the medical and public health impact of disasters. Important epidemiologic studies conducted following the 1976 earthquake in Guatemala pinpointed significant logistical deficiencies in the international disaster relief system (Spencer et al., 1977). In particular, authors from the then recently established *Centre for Research on the Epidemiology of Disasters* (CRED) in Belgium provided new insights that proved most useful in preparing for disasters and increasing the effectiveness and acceptance of relief operations (Lechat, 1976). For example, Lechat and de Ville de Goyet identified many myths and erroneous beliefs that are widely associated with the public health impact of disasters. These include the following (Lechat, 1990):

- Myth Number 1: Foreign medical volunteers with any kind of medical background are needed. Reality: The local population almost always covers immediate lifesaving needs. Only medical personnel with skills that are unavailable in the affected country may be needed.
- Myth Number 2: Any kind of international assistance is needed, and it is needed now! Reality: A hasty response that is not based on an impartial evaluation only contributes to the chaos. It is better to wait until genuine needs have been assessed. As a matter of fact, most needs are met by the victims themselves and their local government and agencies, not by foreign interveners.
- Myth Number 3: Epidemics and plagues are inevitable after every disaster. Reality: Epidemics do not spontaneously occur after a disaster, and dead bodies will not lead to catastrophic outbreaks of exotic diseases. The key to preventing disease is to improve sanitary conditions and educate the public.

Furthermore, Lechat and de Ville de Goyet describe how in the absence of an adequate field assessment, disaster scenes were often cluttered by unnecessary/useless/outdated/ unlabeled drugs, vaccines for cholera and typhoid fever that were not needed or effectively used, medical and surgical teams without proper support, and relief programs that did not address immediate local needs. Since these relief operations were often conducted under the watchful eye of the media, medical relief efforts were pejoratively termed by the authors as “the second disaster.” These early series of papers were very influential in sensitizing governmental and non-governmental organizations (NGOs) to the

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importance of disasters as a public health problem. It was during this period of time in the mid-1970s that specialized emergency units were established by the *World Health Organization* and the *Pan American Health Organization* (PAHO), the latter by Dr. Western on assignment from CDC (Dr. Western is currently still active as the Director of International Health at the National Institute for Allergy and Infectious Diseases at the NIH).

The Guatemala earthquake was also important from the perspective of public health prevention and disaster research methodology. A major groundbreaking paper in the journal *Science* by Roger Glass and fellow CDC colleagues described the first application of analytic epidemiology to the investigation of health effects of a disaster (Glass, Urrutia, Sibony, Smith, Garcia, & Rizzon, 1977). It was the first attempt to identify risk factors for specific outcomes such as death and injury in order to develop effective strategies to prevent future disaster-related morbidity and mortality. The article described a case study of the relationship between death or injuries and the type of traditional housing structures and concluded by providing recommendations on simple construction measures to reduce deaths and injuries in earthquakes. The Glass study of the Guatemala earthquake yielded new information that altered traditional thinking about the prevention of disaster-related mortality and set the stage for all disaster epidemiology research over the following twenty years (Like Dr. Western, Roger Glass is still quite active in global health as the Director of the National Institutes of Health's *Fogarty Center for International Health*).

Not surprisingly, the next major paper on reducing health effects of a natural disaster was also written by Glass in 1979, when he turned his attention from earthquakes to the problem of preventing deaths and injuries from tornadoes (Glass et al., 1980). Despite widespread dissemination of tornado citizen-safety recommendations and guidelines in the United States, the effectiveness of these recommendations in reducing the toll of deaths and injuries had never been tested. Glass and colleagues examined the circumstances of death and severe injury among victims of a tornado disaster in Wichita Falls, Texas, and the protective measures taken by a representative sample of community residents who suffered no major injury, a practice that was found useful in identifying new prevention strategies. People in mobile homes or in motor vehicles were found to be at greatest risk. Information presented in the Glass earthquake and tornado articles have provided the scientific basis for increasingly effective prevention and targeted intervention strategies to decrease mortality in several different disaster situations. For example, results of the tornado study just described and those of others who have followed Glass's lead have changed local land-use regulations regarding the level of danger represented by mobile homes and safety guidelines for topics like fleeing in cars.

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Before the eruption of Mt. St Helens in eastern Washington State, in May of 1980, little information was available in the literature on the health effects of volcanic eruptions. The Mt. St Helens blast generated more studies and investigations regarding health effects of natural disasters than any other single natural disaster before or since. In 1986, an entire issue of *American Journal of Public Health* summarized key findings of many of these investigations (Buist & Bernstein, 1986). The historical importance of this particular issue of *American Journal of Public Health* lay in its comprehensive overview of virtually all existing knowledge (and most of what is still known today) about the health effects of explosive volcanism and appropriate control measures.

During the past 30 years, the uses of epidemiology in disaster situations has been reviewed in a number of reports, with periodic updates on the "state of the art" appearing every decade or so. As a result, a considerable body of knowledge and experience has been regularly documented (Gregg, 1989; Lechat, 1990; Logue, Melick, & Hansen, 1981; Levy & Sidel, 1997). These updates and reviews have provided readers with substantial technical descriptions of each type of natural disaster, pertinent summaries of previous disasters and copious data on findings from past epidemiologic investigations and their public health consequences. In particular, the paper by Logue and colleagues provides an excellent summary of the great variety of research designs, methods, study groups and data-collection instruments that have been used over the years to study post-disaster health effects (Logue, Melick, & Hansen, 1981). A common theme that runs through every single report is that, although all natural disasters are unique, there are some similarities in their health effects that, if recognized, can ensure that health and emergency medical relief and limited resources are well managed.

With regard to disaster relief efforts, since the 1970s, as already noted, it has been recognized that international disaster assistance has been plagued by inappropriate donations, non-essential pharmaceuticals, and a diversity of medications. After several years of study (based on epidemiological data, population profiles, disease patterns and certain assumptions borne out by emergency experience), field-testing and modifications, standard lists of essential drugs, medical supplies, and equipment for use in an emergency were first published in 1984 by the *World Health Organization* (WHO) with the assistance of the office of the *UN High Commissioner for Refugees (UNHCR)* and the London School of Hygiene and Tropical Medicine. It was called an "Emergency Health Kit" and was updated in 1990 with additional contributions by others, such as *UNICEF*, Médecins Sans Frontières (MSF), the *International Federation of the Red Cross and Red Crescent Societies*, and *International Committee of the Red Cross* (now called "*The New Emergency Health Kit"*) (Desenclos, 1988). The *WHO Emergency Health Kit* has now been adopted by most relief organizations and national authorities as a reliable, standardized, inexpensive, appropriate, and quickly available source of the essential drugs and health

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equipment urgently needed in a disaster situation. In addition to the development of the *WHO Emergency Health Kit* in the early 1980s (e.g., medications for 10,000 people for three months), another major innovation during the past 10–15 years has been the introduction by MSF of pre-packaged specialty kits (e.g., emergency surgery, cholera, immunization, sanitation, etc.).

Unfortunately, despite these admirable attempts at defining essential drug lists and providing some degree of standardization, on-the-ground problems persisted with unsorted shipments, unintelligible labeling, perishable goods, outdated products, late arrival, and customs restrictions. For example, after the 1988 Armenian earthquake, the international relief community sent no less than 5,000 tons of drugs and consumable medical supplies to the country. According to a simple, yet elegant analysis by Autier and colleagues from MSF, because of difficulties with identification and sorting, only 30% of the drugs were immediately usable by the health workers in Armenia; 11% were useless, and 8% had already expired (Autier et al., 1990). Ultimately, 20% of all the drugs provided by international aid had to be destroyed. Furthermore, it took 50 people six months merely to inventory the drugs sent to Armenia in the first few weeks after the earthquake. More positively, articles such as this one and earlier ones by Lechat and de Ville de Goyet, were followed by a major initiative of PAHO to develop a computer system called *SUMA* (Supply Management), which is designed to sort, classify, and make an inventory of relief supplies at the port(s) of entry in a disaster-affected country in order to assure appropriate distribution (De Ville de Goyet, Acosta, Sabbat, & Pluut, 1996).

Another important reason why the usefulness of international disaster assistance has been diminished by inappropriate donations and non-essential pharmaceuticals and other supplies (in addition to unrealistic requests by disaster-affected communities) has been the lack of assessment of real needs by potential donors and other relief organizations. Several articles over the years have been published that describe efforts to develop rapid and valid epidemiologic assessment techniques. Guha-Sapir and Lechat, for example, have developed useful needs-assessment indicators for use following natural disasters (“quick and dirty” surveys) (Guha-Sapir, 1991). The former’s article (Guha-Sapir, 1991) described an organized approach to data collection in disaster situations that provided much useful guidance to disaster managers when they need to make crucial decisions based on sound information.

Accelerating Interest

Lechat and Guha-Sapir also point out the great difficulty in applying well-known or standardized epidemiologic techniques in the context of great destruction, public fear, communal disruption, and the breakdown of the usual infrastructure for collecting and

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assembling data (Guha-Sapir, 1991; Lechat, 1976; Lechat, 1990). As a result, in their discussion of assessment methods, they highlight the importance of simplicity, speed of use, and operational feasibility. Articles such as this clearly served as the inspiration to WHO in the 1990s, to sponsor the development of a series of written protocols on rapid needs assessment in several different disaster situations (e.g., natural disasters, sudden population displacements, famine, communicable disease outbreaks, and chemical accidents).

During the late 1980s and early 1990s, interest in the epidemiology of natural disasters clearly accelerated. Several university research centers now concentrate on the health and medical effects of disasters, including collaborating centers under the sponsorship of WHO. Some of these institutions have developed curricula that include basic epidemiology and information systems for disasters. In addition, new professional societies and scientific forums for the presentation of original work in this field have appeared.

One such scientific forum was held July 10–12, 1989, at the Johns Hopkins University in Baltimore Maryland. This symposium, entitled *The International Workshop on Earthquake Injury Epidemiology for Mitigation and Response*, brought together a group of interested professionals, all directly or peripherally interested in the research, planning, mitigation, and response aspects associated with earthquake-induced injuries and deaths. It aimed to build on the foundations laid by Glass in the mid-1970s: identify critical knowledge gaps and develop a research agenda for the study of earthquake health effects. Practical preventive interventions that could be based on research findings were discussed during the workshop, and some agreement on data collection needs and methodologies was reached. But the truly unique contribution of this workshop was its emphasis on the absolute requirement of a multi-disciplinary scientific approach to the successful study of earthquake-related injury. For example, understanding the mechanisms of building failure in earthquakes requires structural engineering competence, while medical expertise is necessary to understand the process of human injury in earthquake-induced building failure. Working alone, neither structural engineers nor epidemiologists can provide a complete description of the health effects of such disasters. Over the years, the lessons drawn from this symposium on earthquakes have proven very useful to the prevention of deaths and injuries in other natural (and technological) disasters. The widely disseminated proceedings of the *Johns Hopkins University Workshop* have been used by other scientists, planners in urban and rural development and, perhaps most importantly, by government agencies charged with maximizing the safety of citizens in earthquake-prone parts of the world (Jones, Noji, Krimgold, & Smith, 1989).

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The Refugee-Natural Hazard Nexus

During the 1990s, and well into the 21st century, there has been a steady increase in technical publications in the form of journal articles, books, and manuals documenting public health outcomes and proposing more effective responses to disaster-affected populations (International Federation of Red Cross Red Crescent Societies, 2011; UNHCR, 2006; UNICEF, 2005; MSF, 1997). Although several articles appeared in medical journals during and after the civil war in Nigeria and Biafra in the late 1960s, and the devastating civil war pitting East against West Pakistan that ultimately led to the establishment of a new country, Bangladesh (Mayer, 1969; Seaman, 1972), there was a marked increase in the number of published papers relating to the health problems of refugees during the late 1970s and early 1980s. This coincided with the exodus of millions of refugees from Indo-China and Afghanistan into neighboring countries, such as Thailand and Pakistan. Although the precipitating events are different, this research foreshadowed similar problems for refugees from natural hazards. Articles began to appear describing public health assessment and surveillance methods and accurately documenting the major health problems of refugees in Southeast Asia. Once again, the indefatigable Roger Glass was at the forefront of this trend (Glass, Nieburg, & Cates, 1980). Subsequently, the CDC published a comprehensive monograph edited by Drs. Glass and Nieburg, which documented the context, health services organization, disease control programs, public health surveillance, and other aspects of the refugee crisis in eastern Thailand between 1979 and 1982 (Allegra, Nieburg, & Grabe, 1983).

During the same period, a relatively young journal called *Disasters* published an entire issue devoted to refugees (1981), and the first textbook on refugee health was written (Simmonds, Vaughan, & Gunn, 1983). During the early 1980s, international public health was heavily influenced by the Alma Ata Declaration by UNICEF and WHO, which promoted primary health-care (PHC) as the most effective approach to addressing the developing world's health problems. Stephanie Simmonds and Bruce Dick from the *London School of Hygiene and Tropical Medicine* were particularly active in suggesting that refugee health programs should be based on the PHC model and should give refugee communities a greater role in planning and implementation (Dick & Simmonds, 1985). Perhaps the most successful attempt to apply PHC principles to a large-scale refugee health program took place in Somalia in the early 1980s. An estimated 700,000 ethnic Somali refugees fled armed conflict in Ethiopia and were dispersed in 35 camps. With the support of UNHCR, international NGOs, and the CDC, the Somali Ministry of Health's Refugee Health Unit (RHU) developed a program that stressed disease prevention, health education, standard treatment protocols, and essential drugs, and the training of more than 2,000 refugee community health workers and traditional birth attendants. The

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program was outlined in a manual that was among the first of its kind (Somali Ministry of Health, Refugee Health Unit, 1982).

Throughout the 1980s and 1990s, CDC published regular bulletins through its widely disseminated *Morbidity and Mortality Weekly Report* (*MMWR*). These articles still comprise the most comprehensive summary of the public health impact of refugee emergencies during this two-decade period and include reports from refugee populations in Thailand, Somalia, Pakistan, Sudan, Malawi, and Ethiopia, as well as famine situations in Mauritania, Mozambique, Niger, and Burkina Faso. One effect of these reports was an increased emphasis on the use of epidemiological assessments to develop program priorities.

A series of technical manuals were also published providing detailed guidelines for various aspects of refugee and emergency nutrition. The first manual on applied nutrition in emergencies was published in 1978 (De Ville de Goyet, Seaman, & Geijer, 1978). Then, in the mid-1980s, *Oxfam* published a manual on selective feeding procedures (Lusty & Disket, 1984). During the same period, some progress was made in standardizing methods of assessing the nutritional status of populations through anthropometric surveys. Consensus on definitions of acute and chronic malnutrition was greatly assisted by a Working Group convened by WHO, which established the NCHS/WHO reference population as the standard comparison group for nutrition surveys (World Health Organization Working Group, 1986). In the first half of the 1990s, UNHCR and UNICEF published emergency guidelines that included extensive sections on health, nutrition, water, and sanitation, while one of the first extensive clinical manuals for emergencies was published by MSF (Desenclos, 1988). A second textbook on refugee health was also published focusing on the clinical management of diseases (Sandler & Jones, 1987). In the 1990s, the major sources of articles published in respected peer-reviewed journals on the public health impact of disasters came from three organizations—the CDC in Atlanta in the United States, MSF, and the Paris-based humanitarian health think-tank, Epicentre.

CDC medical epidemiologists during the decade of the 1990s wrote prolifically on virtually every aspect of health consequences of natural disasters, from water and sanitation to war surgery, including a monumental series of 12 articles summarizing the major causes of mortality in refugee and displaced populations and proposing strategies to reduce excess mortality (Centers for Disease Control, 1992). The CDC studies clearly documented evidence that mortality rates among refugee populations were sometimes 10 to 20 times higher than death rates in their countries of origin. Several widely cited papers were also published by the *Journal of the American Medical Association* in its annual Hiroshima commemoration issue (Toole & Waldman, 1990). Meanwhile, several articles in the *Bulletin of the World Health Organization* provided detailed guidelines for the prevention and control of specific diseases (e.g., vitamin-A deficiency, measles, and

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meningitis). The article on measles control was noteworthy in that it proposed a strategy that deviated from standard measles prevention policies in non-refugee populations (Toole, Steketee, Waldman, & Romero, 1989). Thus, a sub-specialty of emergency public health was rapidly developing that had its own methods, policies, and practices appropriate for post-disaster settings. This development was given impetus by the First International Health and Humanitarian Aid conference, sponsored by Georgetown University in Washington, DC in 1988.

Beginning in the early 1990s and continuing to the present day, emergency surveillance bulletins published in the *Morbidity and Mortality Weekly Report* (*MMWR*) included reports from the genocide in Rwanda, eastern Zaire, the famine in Somalia, refugee camps in southern Sudan, the rapid collapse of the largest public health system in the world following the disintegration of the Soviet Union in the winter of 2001–2002, and episodes of staggering violence, atrocities, and genocide not seen in Europe since World War II in Bosnia and Herzegovina, following the dissolution of the Federal Republic of Yugoslavia. The term “ethnic cleansing” entered the lexicon of public health challenges faced by relief workers. CDC summarized its vast experience and rapidly accumulating knowledge of the public health consequences of humanitarian emergencies in a special 1992 *Recommendations and Reports* issue of the *MMWR* (Centers for Disease Control, 1992) and in a companion publication, *The Public Health Consequences of Disasters* (Noji, 1997). Despite the passage of many years, this volume continues to remain the authoritative and most widely used educational textbook on the human impact of natural hazards, disasters, and humanitarian crises (Noji, 1997). MSF was particularly active in publishing timely reports on cholera, dysentery, meningitis, leishmaniosis, scurvy, and pellagra outbreaks in various emergency settings (Moren, Stefanaggi, & Antona, 1988). These articles played a key role in establishing epidemiology as a routine field tool and in developing a more professional approach to the practice of public health in emergency settings. Reports on scurvy and pellagra epidemics reinforced the notion that public health and nutrition in emergency settings had its own unique characteristics (Malfait, Moren, & Dillon, 1993). Other NGOs such as *Save the Children*, *Concern*, and *Oxfam* routinely used the letters section of *The Lancet* to release information and debate refugee health policy issues. Recognition of the unique circumstances of emergencies led several NGOs to develop specific training courses for their public health workers (*Health Emergencies in Large Populations*, ICRC; *Populations en Situations Precaires*, MSF). In April and May 1994, one million Rwandan refugees fled into the eastern Zaire province of North Kivu, there was a remarkable degree of co-operation and standardization of information-gathering methods among the agencies present. This was reflected in a landmark article jointly authored by 24 epidemiologists from the Zaire Ministry of Health, WHO, UNHCR, CDC, MSF, the French Army, and the Red Cross (Goma Epidemiology Group, 1995).

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A series of papers published from 1978 through 2008 clearly documented the major public health priorities in emergencies resulting from forced migration were: malnutrition, diarrheal diseases, measles, malaria, and acute respiratory infections. Guidelines and manuals ensured a relatively standard approach to public health in emergency settings. Adequate food rations, clean water, sanitation, and shelter were recognized as the major relief program priorities. Consensus was reached on minimum caloric and micronutrient requirements (at least 2,150 kilocalories per person per day), as well as the minimum quantity of clean water (20 liters per person per day). Measles immunization was identified as the most urgent and cost-effective medical intervention. Reflecting this, while extensive measles outbreaks were the norm in refugee camps in the 1980s, they were relatively rare 10 years later and virtually unheard of today. Technical guidelines were published on a broad range of public health issues affecting refugees and displaced persons, including reproductive health, mental health, HIV/AIDS and STD prevention and control, tuberculosis control, water, sanitation, and preventable childhood communicable diseases. In addition, the concerns of earlier authors such as Simmonds and Dick that refugee health programs take a PHC approach were accepted and acted upon by many relief organizations. While our understanding of the public health problems of refugees and the displaced has steadily improved, the causes of—and response mechanisms to—man-made emergencies have become significantly more complicated. The focus of assistance programs in the 1970s and early 1980s was on refugees who had crossed borders to escape armed conflicts; in the late 1990s and continuing to the present day, it was often necessary to provide assistance to civilians still in the proximity of the conflict or displaced within their own countries. Violence and forced migration of huge numbers of people in southern Sudan, Afghanistan, the former Yugoslavia and Soviet Union, Lebanon, Palestine, East Timor, Iraq, and the flow of people forced to leave their homes continues unabated in Colombia, Libya, Syria, and Yemen have had profound effects on the long-term health of local civilian populations and reconstruction of the health infrastructure. Increasingly, civilians, health care workers, and hospitals have become the intentional target of violence. Hundreds of thousands of civilians have been trapped in urban enclaves in Syria, Kurdistan, and Iraq by Islamic State fighters (ISIS), resulting in siege-like environments where public utilities have been destroyed and basic medical services have collapsed (Brown, 2014). The provision of humanitarian assistance in these settings has proven to be extremely difficult and dangerous, and oftentimes absolutely impossible. Fortunately, the public health impact of recent humanitarian crises beginning in 2003, following Operations Iraqi and Afghan Freedom, to the present day has been extensively documented. *The Lancet* and *JAMA* have both published reports on emergencies in northern Iraq, Yemen, Congo, Sudan, Afghanistan, Myanmar, and Bangladesh (Boss, Toole, & Yip, 1994). One useful article that appeared following the Darfur emergency documented the different approaches to the collection of public health information among various agencies (Lawry, 2005).

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Lessons From Other Disasters

On September 11, 2001, the United States experienced the worst terrorist attack in its history. As the nation sought to deal with this tragedy, it would soon face a second wave of terrorism, perhaps more diabolical and insidious than the terrifying events of 9/11—this time, in the form of a biologic attack. There should be no doubt by now that the challenge of terrorism has left an indelible mark on the world as we know it, spanning all inhabited continents, crossing all cultures, and penetrating the borders of all countries. Unfortunately, a disaster caused by the intentional release of biologic weapons would be very different from other natural or technologic disasters, conventional military strikes, or even attacks with other weapons of mass destruction (e.g., nuclear, chemical, or explosive). The initial responders to a biologic disaster will most likely include county and city health officers, hospital staff, members of the outpatient medical community, and a wide range of personnel in the public health system, and not traditional first responders such as police, fire, rescue, and ambulance services. Expanded public health laboratory capacity, increased surveillance (disease monitoring), early alert, warning and outbreak response capacity, and health communication and training are critical for an effective response to bioterrorism, with the focus of such public health preparedness resources and expertise at the state and local levels. It is likely that recognition of the nature of and appropriate response to future bioterrorist attacks and natural epidemics, such as West Nile virus, hantavirus, pandemic influenza, and the international outbreak of severe acute respiratory syndrome (SARS) in 2003, MERS (a coronavirus related to the causative agent of SARS that has proven to be difficult to control in Saudi Arabia the past three years), and last but most certainly not least, the global spread of the dreaded Ebola virus of “Hot Zone” notoriety in 2015 (with cases reported for the first time in hospitals in Europe and the United States) will also unfold in the very near future. Information management, working with the media and sharing the results of epidemiologic investigation of disease outbreaks has been quite challenging to public health authorities and community leaders in this new age of 24-hour media coverage and expectations of instant answers. It is critical that public health authorities familiarize the communities they serve and the media with the likelihood that reliable answers to questions arising in future attacks will take time to assemble and validate.

Furthermore, the public must understand that messages (including medical advice, recommendations about who is at risk, treatment) conveyed at one given point in time, although based on the best available information, are subject to change when new facts become known. The myth that things go back to normal within a few weeks is especially pernicious. The truth is that the effects of a disaster last a long time (Pan American Health Organization, 2009; ASTHO, 2007). Disaster-affected countries deplete many of their financial and material resources in the immediate post impact phase. The bulk of the

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need for external assistance is in the restoration of normal primary health-care services, water systems, housing, and income-producing work. The longer-term recovery and rehabilitation needs in the affected areas are more poorly understood than the short-term needs, but they may be even more important. Many of the large relief agencies have substantial capacity for both relief and development, but effecting a transition from relief activities to sustainable and meaningful reconstruction activities is neither a simple nor a straightforward task. Relief organizations still have much to learn about shifting from short-term medical-aid efforts to productive, sustainable interventions that promote the development of a local health-care system (PAHO, 1981). In particular, social and mental health problems will appear when the acute crisis has subsided and the victims feel (and often are) abandoned to their own means (Khachadourian, Armenian, Demirchyan, Melkonian, & Hovanesian, 2016). Unfortunately, with a few exceptions, the mental health and psychological consequences of disasters have not drawn the attention they deserve from epidemiologists and disaster health researchers in the public health literature (especially when compared with the extensive research that has been done and the large body of knowledge accumulated and documented in the social and behavioral sciences literature). Post-disaster follow-up studies on populations affected by disasters (whether due to civil conflict, or chemical releases, or volcanic eruptions) have revealed that these populations may have to cope with widespread depression, anxiety, and post-traumatic stress for years after the disaster (Benedek, 2007). Successful relief programs have generally incorporated long-term mental health-care services in their overall planning for disaster relief, recovery, and reconstruction. The physical health of survivors may also be adversely affected for years, particularly in technological catastrophes, that is, involving chemicals or radiation. According to the landmark WHO report, “Chernobyl’s Legacy: Health, Environmental, and Socio-Economic Impacts,” the most pressing threats to community health associated with nuclear reactor incidents are the delayed effects from long-term exposure to low levels of radiation (UN Chernobyl Forum, 2006). Such threats to public health may not manifest themselves until many years after the initial exposure. If the total radiation exposure over time cumulatively exceeds known thresholds levels (e.g. “maximal allowable dose”), we should be able to predict that a certain percentage of the population will have suffered significant genetic damages (e.g., broken or damaged chromosomes) that may only become clinically apparent when such exposed individuals develop conditions related to both humoral and cellular immune-deficiencies. Such conditions would run the gamut, from thyroid cancer, to several different types of lymphomas and leukemias, to exposed individuals experiencing frequent and difficult-to-treat infections. Release of radiologic material into the environment or nuclear disasters are unique in that the potential exists to cause harm to our children and perhaps even generations to come. The affected communities, and perhaps adjacent regions, would begin to see significantly higher prevalence of rare and unusual birth defects among

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offspring of those exposed who in turn would pass the same damaged genetic material to their children, and so on and so forth (UNSCEAR, 2001).

WHO is currently working to translate the latest scientific information on the consequences of the Chernobyl accident into sound practical advice for residents of the affected territories. This work is part of the *International Chernobyl Research and Information Network* (ICRIN) project; a joint effort by the International Atomic Energy Agency (IAEA), the United Nations Development Programme (UNDP), the United Nations Children's Fund (UNICEF), and the WHO (UN Chernobyl Forum, 2006).

Recent Developments

The number of epidemiologic studies on the adverse health impact resulting from all types of natural hazards and disasters has unquestionably increased during the past 15 years, especially in the university and academic community. The number of papers submitted and published on topics such as disaster medicine and public health effects of natural hazards has undergone an explosive acceleration since September 11, 2001. And there certainly has not been a dearth of disasters to study during this particularly rich period for disaster researchers, especially if one considers that every major disaster, if studied, has the potential to provide further important lessons to the natural hazards "Book of Knowledge"—knowledge critical for developing effective death and injury prevention strategies. Many important studies have taken place, and the results of long-term research have now been published on such catastrophic events as the 2004 South Asian tsunami and Hurricane Katrina, which devastated the city of New Orleans in September 2005.

As Professor Susan Cutter and colleagues recently wrote in the editorial in the journal *Nature*: "Improved disaster-risk management and resilience is essential for sustainable societies. But the science of natural hazards is too fragmented to influence policy effectively" (Cutter et al., 2015). Unfortunately, in most parts of the world, even if good research is conducted, the results of that research rarely inform policy that directs government actions. A good example of the latter unfortunate situation is China. On May 12, 2008, an earthquake struck Sichuan prefecture in central China, killing over 70,000 people, leaving about 4.8 million people homeless though the number could have been as high as 11 million, with 18,000 people remaining unaccounted for. It was the deadliest earthquake to hit China since the 1976 Tangshan earthquake, which killed at least 240,000 people. China has some of the finest earthquake scientists and structural engineers in the world. Chinese seismologists, for example, had long warned in specialist journals that this region of China was due to have a very large earthquake and very soon.

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Local politicians and the business community (who generally do not read scientific publications) did not strengthen construction codes, reinforce old buildings, or inform the population about potential risks. Had such measures been implemented—as they have in Japan, California, and Chile—the death toll would have been lower.

Recent history has shaped our understanding of the health and medical impacts of tsunamis. Notable earthquakes causing massive tsunamis and life loss include the December 2004 earthquake in the Indian Ocean and the March 2011 Japan seismic event. The latter unleashed massive tsunami waves that crashed into Japan's northeastern coast of Honshu, the largest and main island of Japan, resulting in widespread damage and destruction, including at least 10,000 confirmed deaths and 18,000 missing persons (Diep, 2011). What made this event so tragic, even poignant, is that all search, rescue, and relief operations, evacuations, and international humanitarian assistance were conducted within the framework of the possibility of significant radiation release and a nuclear meltdown resulting from fires and explosions at a coastal nuclear power plant facility. One year after the catastrophe, radioactive contamination of soil, coastal waters, and groundwater still emitted radiation levels as high as 10,000 times maximum government standards (Harmon, 2012). Japan's social, technical, administrative, political, legal, health care, and economic systems were tested to their limits by the nature, degree, and extent of the socioeconomic impacts of the tsunami and the possibility of a "nightmare nuclear disaster." Recovery from this disaster will take many years, perhaps well into the next century if lessons from the 1986 Chernobyl nuclear reactor explosion apply here. Return to economic strength will require the same degree of national will and sacrifice that produced the "Japanese Economic Miracle" following the utter devastation of World War II (International Federation of Red Cross and Red Crescent Societies, 2015).

The Growing Role of Social Media in Public Health Disasters

On January 12, 2010, a devastating earthquake struck Port-au-Prince, Haiti. After this natural disaster, a powerful new tool was widely used to reduce disaster-related morbidity and mortality risk. The ways in which people used social media to inform and to assist quake victims and responders has reshaped the ways in which we will confront disaster-related challenges in the future.

Social media are forms of information and communication technology (ICT). Created using highly accessible and scalable publishing techniques, social media are designed for dissemination through social interaction. Social media are also collaborative,

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decentralized, networked, and community-driven. They support the democratization of knowledge and information, transforming people from content consumers into content producers and analysts. Popular networking sites such as Facebook, Twitter, and Google are the social media most commonly used for connecting with friends, relatives, and employees. During the immediate aftermath in Haiti, much of what people around the world were learning about the earthquake originated from social media. These sites have taken on a new role: assisting disaster-affected populations to build resilience and reduce vulnerabilities in real-time. During the Haiti disaster, the online communication (micro-blogging) site Twitter played an especially large role as it quickly relayed disaster-related information. During the immediate quake aftermath, much of what people around the world were learning about the Haiti earthquake originated from social media sources.

Independent from its use as an effective emergency response tool, Twitter itself became a main topic of extended electronic discussion long after immediate relief efforts, such as search and rescue and the acute need for emergency trauma surgery, had ended. Users in Haiti provided live earthquake coverage, including pictures and information about damaged areas. Furthermore, social media and social networks galvanized during the world response to the plight of the Haitian people. While most online consumers relied on traditional media for quake coverage, those consumers then turned to Twitter and blogs to share information, to react to situations, and to rally support. Millions throughout the globe joined Facebook discussion groups to share information, donate money, and offer comfort and support. Within hours of the Haiti quake, “Haiti” was a trending word on Twitter, which became central to the effort that raised millions of dollars in new and innovative ways. For example, during the first two days following the earthquake alone, texting mobile phone users donated over $5 million to the American Red Cross (Wortham, 2010). Social media became a new forum for collective intelligence, social convergence (Hughes, Palen, & Sutton, 2008), and community activism related to the Haiti disaster.

This trend has continued and grows in sophistication and in innovative uses of existing technologies. After recent earthquakes in Chile and Mexico, both public and private response agencies used Google Maps extensively. Just minutes after a deadly earthquake struck coastal areas of Chile, Pacific islanders thousands of miles away immediately used their mobile phones and access to VOIP (voice over internet protocol) services such as Skype to monitor hazard-prone beaches on their islands for signs of an impending tsunami. Cyber traffic was not limited to individual users; social as well as traditional media mega-outlets such as CNN shared these feeds.

Sutton et al. accurately predicted that emergent uses of social media would broadly change disaster management models (Sutton, Palen, & Shklovski, 2008). Studies of social media use in response to the Virginia Tech shootings and Southern California wildfires in 2007, as well as during the 2008 Democratic National Convention and Hurricanes Gustav

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and Ike revealed that during disasters, the public used social networking to verify facts, coordinate information, bring together resources, and make communities more resilient (Sutton et al., 2008).

The 2011 Joplin tornado was a catastrophic EF5 multiple-vortex tornado that struck Joplin, Missouri, late in the afternoon of Sunday, May 22, 2011. It was the third tornado to strike Joplin since May 1971. Overall, the tornado killed 158 people (with an additional four indirect deaths), injured some 1,150 others, and caused damages amounting to a total of $2.8 billion. It was the deadliest tornado to strike the United States since the 1947 Glazier-Higgins-Woodward tornadoes, and the seventh-deadliest overall. It also ranks as the costliest single tornado in U.S. history. As we saw in the aftermath of the Haiti earthquake the year before, this tornado highlighted the extensive use of social media to support the local, regional, and national response. News outlets began aggregating images and video from eyewitnesses shared through social media. Public citizen-led Facebook groups and web sites, such as Joplin Tornado Info, coordinated information, needs, and offers (Curley, 2012). The results were so effective the project became a finalist in the 2011 Mashable Awards for Best Social Good Cause Campaign. FEMA (Federal Emergency Management Agency) has now included this form of communication in its Communication Emergency Support Function, where it is now known as Social Media Emergency Management.

Social Media Challenges

Widespread use of social media to promote disaster risk reduction involves several important challenges, including but not limited to awareness, content accuracy, public policy, security issues, and personal privacy. In November 2015, in the hours after Paris, France experienced a series of coordinated terrorist attacks, a number of social-based technologies reached out to help survivors and those who cared about them. AirBnB and Twitter helped find shelter for those dislocated, communication services such as Skype, Sprint, and Verizon provided free calls, and Uber relaxed its pricing. Among the most discussed of these efforts, though, was Facebook's *Safety Check* feature (D'Onfro, 2015). The company activated its year-old feature, which prompts those physically in a disaster area to answer the question, "Are you safe?" While the activation was likely altruistic and useful to users (within 24 hours of the attacks 4.1 million had checked in as safe, while another 360 million users received notices their friends were okay), it also spawned a rash of speculation about the ethics and application of the service (Chappellet-Lanie, 2015).

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Chief among reasons for this speculation is the fact that it was the first time it had been activated for a human-generated hazard. Before the Paris attacks, *Safety Check* had only been activated five times—three times for large-scale earthquakes such as the one in Nepal, once for Cyclone Pam, and once for Typhoon Ruby. The Paris attack activation immediately drew criticism from detractors who asked—why Paris?—when a day earlier, 80 people were killed in terrorist bombings in Beirut. The insinuation was that Facebook cared more about European lives than those in the Middle East (Waxman, 2015). But that in turn brought up more questions—namely, in a world plagued by daily terrorism, what is deemed worthy of alert activation? That has led to even more speculation about the feature's usefulness if applied inconsistently. Most recently, preliminary reports coming out of Haiti, Florida, South Carolina, and North Caroline in the aftermath of Hurricane Matthew in early October indicate that user inconsistency is already posing some communications challenges. For example, while a safe check-in can provide reassurance to friends and families, a lack of check-in is less meaningful. Users in Haiti and Florida who have chosen to ignore the prompt or have access issues have left family, friends and loved-ones guessing about their status. Those with location services turned off have obviously not even received the prompt (UN Office for the Coordination of Humanitarian Affairs, 2016).

While tech experts have pointed out that this lack of information is unlikely to cause panic, others wonder about the deeper implication of the messages, especially when used for terrorist attacks. Unwittingly reinforcing terrorism is another concern experts have about the Facebook service (and social technology in general). There's worry that that terrorists could use the information to monitor and increase the chaos they seek to generate (D'Onfro, 2015). Still, even normal uses of these media can be appropriated, and we know that crowdsourcing, social media monitoring, and crisis mapping benefits emergency agencies and relief organizations, as well. Insights from local communities and traditional societies with experience and with historical continuity can enrich scientific understandings of complex adaptive systems. Augmentation of scientific understanding with traditional knowledge and community-based participation is an important research tool. In the end, there's still a lot to learn about what effect services such as Facebook's Safety Check will have on how people communicate in disaster (UN Office for the Coordination of Humanitarian Affairs, 2016).

Conclusion

Epidemiology, as the applied instrument of public health interventions, can provide much needed information on which a rational, effective, and flexible policy for the management

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of disasters can be based. In particular, epidemiology provides the tools for rapid and effective problem solving during public health emergencies, such as natural and technologic disasters and emergencies from terrorism. Drought in the African Sahel, refugee crises in Zaire and the former Yugoslavia, floods in Bangladesh, and earthquakes in Mexico City and Armenia may not have much in common, but in the investigation of all, the epidemiologic approach has proved powerful. Results of epidemiologic research on disasters have formed the scientific basis for increasingly effective prevention and intervention strategies to decrease mortality in several different types of disaster situations. The influence of the publications reviewed here on the conduct of disaster relief and humanitarian assistance and the methodology of disaster research have been profound, and all continue to serve as important desk references for health professionals responsible for preparing for and responding to public health emergencies.

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