



Published in final edited form as:

Int J Disaster Risk Reduct. 2021 August ; 62: . doi:10.1016/j.ijdr.2021.102415.

Assessing the effects of disasters and their aftermath on pregnancy and infant outcomes: A conceptual model

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Abstract

Although many studies have examined broad patterns of effects on pregnancy and infant outcomes after disasters, the causes of adverse outcomes are not always clear. Disasters cause interrelated exposure to environmental pollutants, psychological stressors, and lack of health care, and interacts with other social determinants of health. This topical review examines the short- and long-term effects of disasters on pregnancy and how they are mediated by social, behavioral, and environmental effects. In the short term, disasters are associated with physical trauma, adverse environmental exposures, and unstable housing. In the longer term, disasters may lead to relocation, changes in family functioning, and negative economic effects. These aspects of disaster exposure, in turn, lead to lack of access to health care, increased stress and negative mental health outcomes, and negative behavioral changes, including smoking and substance use, poor nutrition, physical overexertion and limited activity, and reduction in breastfeeding. All of these factors

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

interact with social determinants of health to worsen effects on the most vulnerable women, infants, and communities. Few interventions after disasters have been tested. With the increase in disasters due to climate change and the ongoing coronavirus pandemic, the models of effects of disasters and their human health consequences need increasing refinement, and, more importantly, should be applied to interventions that improve disaster prevention, mitigation, and response.

Keywords

disaster; pregnancy; environment; tropical cyclones; birthweight

Introduction

The natural world and human influences work together to create the devastation that follows a major disaster such as a hurricane. Although many studies have examined broad patterns of effects on pregnancy outcomes after disasters,¹ the causes of adverse outcomes are not always clear, as there are interrelated environmental pollutant exposures, psychological stressors, lack of health care, all moderated by social determinants of health. Without understanding which aspects of disaster exposure are the most meaningful contributors to adverse outcomes, it will not be possible to establish proactive disaster responses that efficiently target the most important factors and protect pregnant women. This topical review examines the traditionally expected short-term disaster exposures such as storm damage, health care closures as well as environmental and longer-term effects on pregnancy-related outcomes. In this review, we follow the World Health Organization's definition of disaster, "A serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources,"² with a particular focus on the short- and longer term effects of natural and technological disasters. Several possible downstream effects of disaster exposure on pregnant women have been identified, including adverse birth outcomes, pregnancy loss, birth defects, and adverse child development, all of which have potential long-term or lifelong effects.^{3, 4} Surveillance after Hurricane Katrina found that 3% of evacuees had an emergency room visit for obstetric reasons and 13–15% of evacuees had a need for WIC (Special Supplemental Nutrition Program for Women, Infants and Children) services or birth control,⁵ suggesting this is not a small population of public health concern. Figure 1 depicts the multidimensional nature of the impact of disasters on pregnant women and infants. The conceptual model demonstrates the complex interactions among physical, chemical, and non-chemical stressors and the impacts on prenatal and perinatal health. Furthermore, the model takes into account the short-term, often more identified effects, as well as the more protracted long-term consequences closely connected to existing burdens of health- and socio-economic disparities.

Proposed Framework

Short-term effects

Physical trauma—Disasters bring several inherent risks, such as those associated with structural damage and vegetation collapse, involving increased risk of injury for anyone

directly exposed. Pregnant women are less likely to be injured than some groups as they are more likely to limit their exposure and are not likely to be called upon for physical labor if others are available.⁶ Still, reduced mobility and changed reflexes and balance associated with pregnancy may create vulnerability to hazards that might otherwise be avoided.^{7, 8}

Environmental exposures—Many disasters are accompanied by secondary environmental exposures. Hurricanes, earthquakes, or extreme precipitation and/or flooding may cause ruptures of storage tanks of chemicals or other hazards, such as animal waste and heavy metals.⁹ This was vividly shown when the recent landfall of Hurricane Laura (2020) caused a major fire at a chlorine production plant in Lake Charles, LA.¹⁰ Flooding is frequently accompanied by mold infestation, especially in hot and humid climates such as the U.S. Gulf Coast where summer temperatures can reach three digit levels (Fahrenheit).^{11, 12} Chemical exposure (see¹³ for review), heat, and mold may cause short and long-term effects on pregnancy health, including increases in congenital anomalies, low birthweight, and preterm birth.^{14–17}

Communities often suffer a double burden of vulnerability associated with exposures to natural disasters and environmental contaminants. Figure 2 illustrates the geography of recent overlapping hazards in Florida. The figure shows the location of hurricanes Irma and Michael that made landfall in Florida in 2017 and 2018 respectively,¹⁸ and their interaction with environmental hazards: the U.S Environmental Protection Agency’s regulated abandoned and current hazardous waste facilities^{19, 20} and the *Karenia brevis* (“red tide”) algal bloom formed and spread during this period.²¹ Harmful algal blooms (HAB) are an example of an environmental exposure that has increased in recent years,^{22, 23} and is of concern to pregnant women given the associations with spontaneous abortions and premature births in animals.^{24–27} Combined exposures to natural disasters and environmental contaminants increase vulnerability, not only because these increase the overall burden of health-harming exposures, but also because the exposures may interact (i.e., hurricane storm surge may increase community exposure to HAB) possibly potentiating or synergistically impacting the adverse health outcome of concern, in this case adverse birth outcomes.

Exposure to disasters is also often co-extensive with exposure to extreme temperatures. Extended periods of extreme heat are not historically considered as emergencies under the Pandemic and All Hazard Preparedness Act of 2006 (amended as the Pandemic and All-Hazards Preparedness and Advancing Innovation Act of 2019), although such events would frequently meet the definition of disaster given above. High heat has been associated with placental abruption,²⁸ preterm birth and low birthweight,^{29, 30} birth defects,^{31, 32} and stillbirth.³³ In many locations, extreme heat co-occurs with high air pollution (PM_{2.5}, O₃) levels which are consistently linked to preterm birth, low birthweight, and stillbirth.³³ About half of the published extreme heat and air pollution studies found health disparities, where Black mothers faced higher risks of negative birth outcomes from heat exposure than white mothers.³³ Lower-income households are less likely to have central air conditioning and more likely to struggle to pay electric bills or repair cooling equipment and experience heat-related illness symptoms.^{34, 35}

Extreme precipitation events in both the cold and warm seasons may also influence birth outcomes. Disasters in winter, such as ice storms, may increase exposure to cold,³⁶ which has sometimes been associated with adverse birth outcomes.^{37–40} Flooding from tropical storms and hurricanes can lead to increases in disease transmitting mosquitoes, with concomitant increase in the risk of diseases like Zika, dengue, and malaria;^{41, 42} droughts and flooding can affect triatomine prevalence, leading to changes in risk of Chagas disease.⁴³ These effects on vector-borne infection can be long-term rather than short-term,⁴⁴ and are associated with congenital anomalies (Zika),⁴⁵ pre-eclampsia, preterm birth (dengue),⁴⁶ and vertical transmission of infection (Chagas).⁴⁷

A defining characteristic of disaster is disruption of housing. Temporary housing is often limited or substandard and may increase exposure to heat and cold. After Hurricane Irma, non-white and poorer households were much less likely to have a generator and backup electricity.⁴⁸ In addition, lack of electricity means many people use generators, which may lead to carbon monoxide exposure.⁴⁹ Carbon monoxide poisoning during pregnancy is associated with fetal demise, severe neurological complications, intrauterine growth retardation, preterm delivery, and birth defects.⁵⁰ Evacuation offers risk of its own – transportation accidents, dehydration, malnutrition, and lack of access to medications or medical care, in some cases requiring evacuation during labor or birth.⁵¹ Depending on the severity of disaster and location, quality of housing during the evacuation or in new locations may be poor or nonexistent. All of these are risky for pregnant women; for instance, preterm labor may be triggered by acute trauma,⁵² physical exertion, environmental exposures, or heat.

Long-term effects

Relocation—Short-term relocation may become long-term relocation, or, in some cases, refugee status. Relocation is associated with worse mental health⁵³ and physical health indicators.⁵⁴ Pregnant women who are displaced are less likely to access prenatal, delivery, and postnatal care.⁵⁵ Refugee status is associated with worse mental health,⁵⁶ maternal mortality, and preterm birth.⁵⁷

Family functioning—Family functioning is often affected adversely by disasters, starting with basic family structure. Divorce has been found to increase in the aftermath of some disasters (Hurricane Hugo, Southeastern United States, 1989).⁵⁸ Disasters with a high death toll are likely to lead to an eventual rise in remarriage among widowed people (Wenchuan earthquake, China, 2008),⁵⁹ and in some cases marriage rates have risen after less severe disasters (Hurricane Hugo).⁵⁸ Unmarried women and women without partners are at higher risk for pregnancy-related morbidity and adverse birth outcomes,^{60, 61} as are women who are in abusive or unsupportive relationships.⁶² Several sociologists and gender theorists have drawn attention to increases in intimate partner violence and child abuse after disaster,^{63–67} and severe experience of disasters is also often associated with worse self-reported family functioning.^{68, 69} Women who experience intimate partner violence are at higher risk for pregnancy complications and adverse birth outcomes,⁷⁰ while women who experience abuse as children may be at higher risk for pregnancy-related morbidity.^{71–73} Worse family functioning is also associated with worse birth outcomes.^{73, 74} On the broader scale,

disasters impact both individual and community resilience and can disrupt social networks; the National Academies of Sciences, Engineering, and Medicine in its report “Building and Measuring Community Resilience” identified social cohesion as a key factor influencing community resilience.⁷⁵

Economics—Disasters cause short- and long-term economic effects on the micro and macro scales.⁷⁶ Job loss is common after disasters (although in some cases rebuilding provides jobs, or changes the composition of the workforce, as the influx of Hispanic workers to New Orleans post-Hurricane Katrina (2005) demonstrated. This tends to be more relevant to men, as many of the positions are in construction, although a growing number of women have also joined the construction sector.). Even among those employed and insured, the money required to replace possessions and to mitigate the disaster through evacuation or, for example, generator purchase, can be substantial. The disparities in pregnancy outcomes between lower- and higher-income families are well-known, as is the association between financial stress and adverse outcomes,^{77, 78} which may be exacerbated by the negative financial consequences of the disasters.

Short- and long-term mediators

Health care access—Post-disaster, health care providers often close temporarily or permanently. If jobs or savings are lost, lack of insurance or money for services may also make accessing care difficult. Even if care providers are available, the stress of the disaster, evacuation, and demands of recovery and rebuilding may mean that women do not access care as promptly as would be optimal. Access to medications may be limited post-disaster, either from supply chain or economic reasons. Reproductive healthcare is often deprioritized post-disaster by clinicians, disaster agencies, and the general population, which may lead to lack of availability of birth control.^{79, 80} Relief agencies’ values may conflict with communities’ beliefs: contraception may be counter to local cultural or religious norms and its provision, especially to adolescents or unmarried people, controversial. Combined with the common post-disaster increase in the need to prevent pregnancy (as many families tend to avoid a pregnancy in the immediate aftermath), this can lead to a large unmet contraceptive need, which may manifest in increases in unplanned pregnancy, as was seen after Hurricane Katrina.⁸¹ Unplanned pregnancies, especially under difficult conditions, are associated with worse health outcomes for mothers and babies.⁸²

Prenatal clinics usually close, at least in the short term, after a disaster. Thus, many pregnant women are likely to miss prenatal care visits. Studies post-disaster tend to find an increase in the proportion of women receiving late or inadequate prenatal care (Hurricane Katrina and Michael),^{83, 84} although the effect is not as consistent as might be expected (Red River flooding, North Dakota, 1997; El Niño floods, Ecuador, 1997–8).^{85, 86} The likely effect of lapses in prenatal care after disasters is not altogether clear. Some studies indicate that the number of prenatal care visits can be reduced for low-risk women without significant harm to maternal or infant health,⁸⁷ and prenatal care has not been conclusively demonstrated to reduce low birthweight, although the correlation is strong.⁸⁸ More directly tied to the ability to access care is treatment for complications such as gestational diabetes, infectious conditions such as HIV and syphilis,^{89, 90} and potential indications for delivery such as pre-

eclampsia and reduced fetal growth. In countries without universal health care, concerns about cost and insurance coverage are barriers to receiving care, even though access to insurance is often expanded post-disaster.⁹¹

Stress and mental health—Disasters are a cause of trauma and severe stress, which have been directly linked to several pregnancy complications.⁹² Stress can raise blood pressure during pregnancy,⁹³ which is an issue in itself and also predisposes to reduced fetal growth and preterm birth.⁹⁴ Altered levels of stress hormones such as cortisol and CRH have been associated with pregnancy complications,⁹⁵ particularly preterm birth.⁹⁶ Stress may also increase vulnerability to infection;⁹⁷ infections including bacterial vaginosis,⁹⁸ group B strep,⁹⁹ chlamydia, and gonorrhea¹⁰⁰ all have negative effects on birth outcomes. Disaster exposure is also a risk factor for postpartum depression,¹⁰¹ one of the most common perinatal mental health disorders, and associated with maternal impairment, poorer quality parenting, negative child behavior, and poorer cognitive development.¹⁰²

Behaviors

Smoking: Tobacco use is well-known to be associated with pregnancy complications, most notably reduced fetal growth and birthweight, but also preterm birth. In the aftermath of disasters, smokers may smoke more as a response to stress; those who have quit may relapse; and intentions to quit may be postponed.¹⁰³ Similar considerations apply to other types of substance use,^{104, 105} and addiction treatment, seldom tailored for pregnant women, may be even less available than usual.

Diet: Malnutrition in various forms may follow in the aftermath of disasters. In areas where the food supply is insecure, disasters may lead to limited food supplies or even famine; in addition, access to foods rich in essential micronutrients may be limited. For instance, hurricane effects on folic acid-containing foods were believed to be related to a subsequent spike in neural tube defects (Hurricane Gilbert, Jamaica, 1988).¹⁰⁶ In settings where food availability is generally good but sometimes uneven, low-income women have been found to be particularly vulnerable to post-disaster food insecurity (Hurricane Katrina).¹⁰⁷ In other cases, food quality rather than overall energy intake may be affected. People are likely to prioritize practical (nonperishable) and affective (appetizing, varied) considerations over strictly nutritional ones,¹⁰⁸ which can lead to weight gain.¹⁰⁹ Severe nutrient restriction is associated with fetal growth restriction and preterm birth, while excessive weight gain is associated with pregnancy complications such as gestational diabetes and pre-eclampsia, as well as labor and delivery complications (shoulder dystocia, caesarean section).¹¹⁰

Physical activity: Physical overexertion, which may be caused by assisting in disaster cleanup, can trigger preterm birth. Leisure or health-related physical activity, which generally improves health, is likely to be deprioritized post-disaster and exercise facilities, such as gyms or even safe streets or parks for walking or running, may be unavailable (Hurricane Harvey, Texas, 2017).¹¹¹ Lack of leisure-time activity may negatively affect birth and obstetric outcomes¹¹² and raise the risk of gestational diabetes and hypertension.

Breastfeeding: Breastfeeding is associated with better health for infant and mother,¹¹³ and in a disaster setting, avoids the need for powder and potable water to mix formula. Breastfeeding has sometimes been found to decline post-disaster and formula feeding increase (Great East Japan Earthquake, 2011).¹¹⁴ Many women find breastfeeding difficult without support, which may not be available post-disaster; in addition, milk supply may also be reduced.¹¹⁵ Women may fear breastfeeding if there are chemical exposures.¹¹⁶ Post-disaster, formula is included in relief provisions, which inadvertently may discourage breastfeeding.¹¹⁷

Effects of disasters on maternal and infant outcomes

We have explored the multiple pathways of effects of disasters, which converge on worsened outcomes for mother and infant in the short and long term. Major drivers of maternal morbidity and mortality include pregnancy complications such as hypertensive disorders and gestational diabetes; complications of labor; and cardiovascular conditions. The degree to which these conditions and complications cause sickness and death is strongly predicted by access to quality care. Disasters limit this care directly, by closing clinics and hospitals, and indirectly, by restricting employment possibilities and health insurance. Beyond maternal complications, which directly affect fetal outcomes, major drivers of infant morbidity and mortality are reduced fetal growth and lower gestational age. These are the major focus of our discussion, because other indicators of maternal and infant morbidity are less-studied, in part due to lack of routine data collection or insufficient power to address rarer outcomes, such as maternal and infant mortality.^{118, 119} These are also strongly affected by maternal exposures, which may include physical trauma and environmental exposures, as well as maternal behaviors and moods that may be worsened by disasters, including health behaviors such as smoking and increased stress levels as noted earlier. The effects of disasters do not, of course, end at birth, and continue to negatively affect maternal postpartum mental health¹ and child development.¹²⁰

Social determinants of health

Although this topic review focuses on downstream effects of disasters, the pre-existing burden of disparities and other social determinants of health cannot be ignored. The National Academies of Science, Engineering, and Medicine identified natural, built, financial, human and cultural, social, and political capitals as social determinants of health (SDH) domains impacting a community's ability to "bounce back" following disasters (Table 1).⁷⁵ These six SDH domains influence the ability of a community and its members, including pregnant women, to absorb the impact and recover from disasters.

As an example of how these social determinants can influence disaster effects, one study, conducted 5–7 years after Hurricane Katrina, showed African-American pregnant women were more likely than women of other race/ethnicities to have had severe experiences of the hurricane and less likely to perceive that there had been progress in recovery. Severe experiences of Katrina still affected birth outcomes 5–7 years later.¹²¹ Analyses of spatial hazards data across the US¹²² and of hurricane data over 13 years concluded that disasters affected gestational age most in counties classified as socially vulnerable by the CDC.¹²³

Public health implications for disaster planning, response, and resilience

Few controlled trials have addressed health after disasters in pregnant women. Exceptions are interventions after the Fort McMurray fires in Alberta, Canada, which included a randomized trial of bundled interventions including expressive writing exercises.¹²⁴ However, a similar intervention after Hurricane Harvey was not effective in improving mental health.¹²⁵ Data collected includes questionnaire data on stress and mental health, and analysis of biomarkers. In other populations, there is increasing use of m-health and E-health interventions, including online interventions after Hurricane Ike (Texas, 2008) to improve mental health and self-efficacy (My Disaster Recovery)¹²⁶ and Bounce Back Now! after tornadoes in Missouri and Alabama (2011).¹²⁷ Other programs focus on children rather than mothers, either online (BRAVE online for earthquake, Canterbury, New Zealand, 2011)¹²⁸ or school-based.

Pregnant women have specific needs, including prenatal care; and infants have needs such as diapers, potential supplemental feeding, and childcare. However, interventions that benefit the community as a whole are likely to benefit them, and vice versa – pregnant women and children serve as a concrete symbol of hope and the future.¹²⁹ Effective financial, community, and services recovery are as likely to be beneficial to physical and mental health in pregnancy as anything else. Supporting communities and helping people support each other is valuable; such support builds self-efficacy, which improves disaster preparedness and recovery as well as mental and physical health,^{130, 131} including birth outcomes.¹³²

Regardless of type, disasters share common potential adverse outcomes and impacts for pregnant women and infants. Although these results appear quite similar in terms of morbidity and mortality, the pathways have many differing contributing factors. The conceptual model (see Figure 1) illustrates the often synergistic interaction among the different pathways and the resulting impact on maternal and infant morbidity and mortality. This approach allows for opportunities to further delve into the short term, longer term, and overlapping mediators of maternal and child health related to disasters. Our proposed model is supported extensively by the current disaster literature. Nonetheless, research is warranted that allows the individual contributing factors to be assessed, controlling for other factors. Heretofore this has been challenging, absent a viable framework. Our intent is to further the development of in-depth study of disasters on pregnant women and infants by promoting additional perspectives regarding the composition of contributing risk factors. We are currently applying this model to address the effects of Hurricane Michael and associated exposures to HAB, CO, and health care services loss, on pregnant women.

The present coronavirus pandemic provides a unique opportunity for researchers to test our model utilizing international, national, and state level maternal and child health laboratories. Now is also the optimal time to develop data collection instruments that can capture the full breadth of data this conceptual model undergirds. The Gulf of Mexico Research Institute recently published a report outlining a potential system for monitoring human health in the Gulf region;¹³³ such systems should incorporate the ability to examine effects on pregnancy. We welcome the input and feedback of colleagues who accept our challenge to take the study of disasters and their human health consequences to the next stage of refinement, and,

more importantly, apply it to interventions that improve prevention, mitigation, and response.

Funding

This project was funded by NIEHS grant, R21ES031020.

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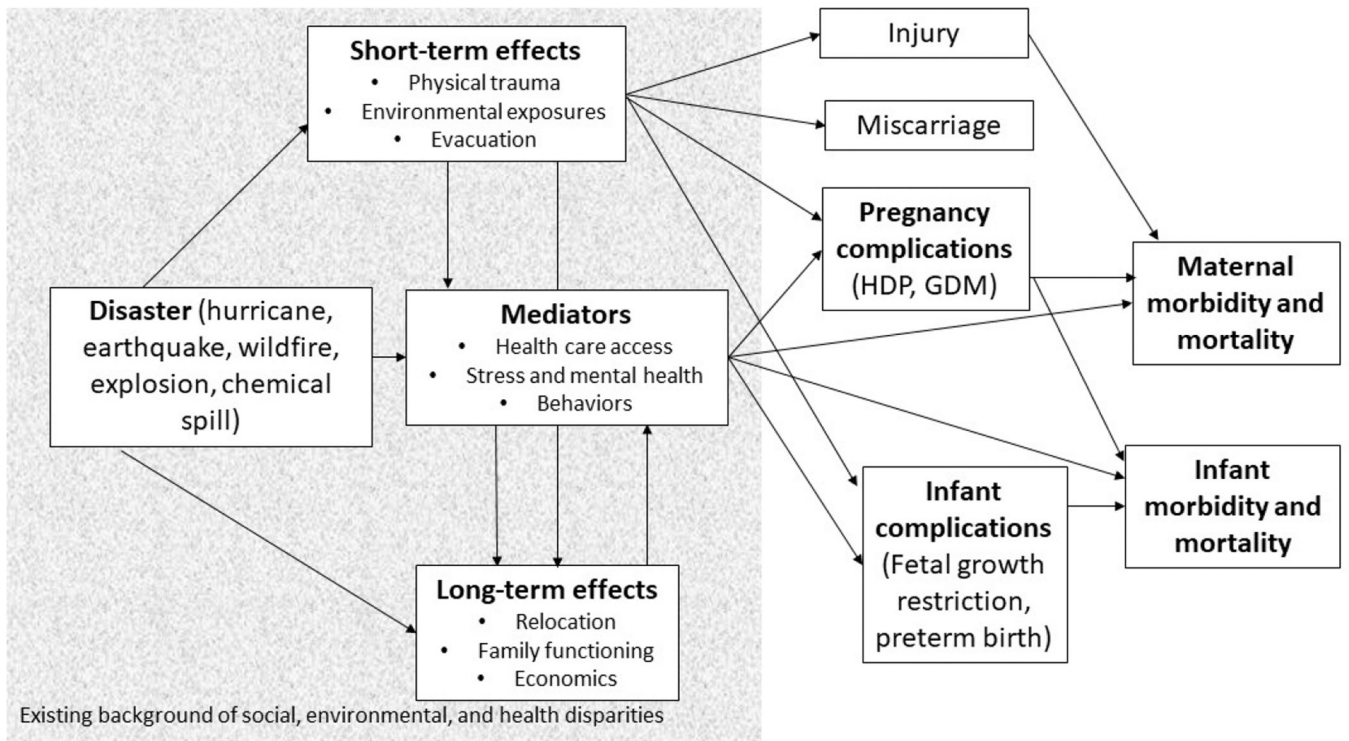


Figure 1. Conceptual model representing the short- and long-term effects of disasters on pregnant women and their infants. Arrows represent causal relationships. HDP, hypertensive disorders of pregnancy; GDM, gestational diabetes mellitus

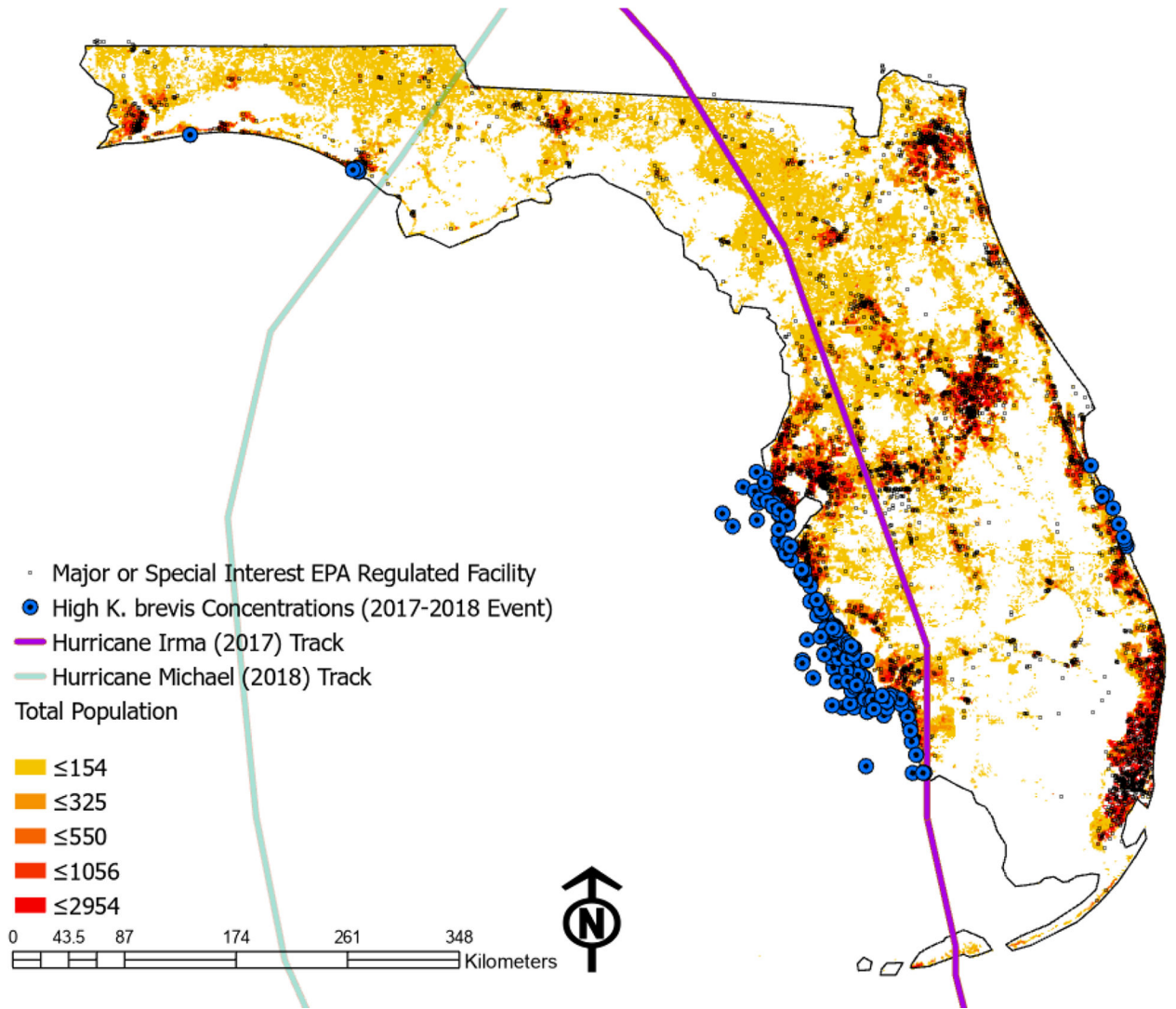


Figure 2. Joint environmental hazards and disasters, Florida, 2017–2018.

Table 1.Domains of community capital and resilience (after⁷⁵)

Domain	Examples
Natural	ecosystem assets: air, land, water, general environmental quality
Built	critical support facilities, residential housing, health facilities, electricity and transportation infrastructure
Financial	income levels and equality, employment
Human and cultural	demographic characteristics, language competencies, cultural assets and belief systems
Social	social networks and connectivity; political, religious, community, and volunteer engagement; sense of belonging
Political	access to resources and ability to engage external entities; disaster experience and response structure

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