



Perspectives of local public officials on the health hazards of compound flooding in Eastern North Carolina

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ABSTRACT

The recurrence of compound flooding in Eastern North Carolina (ENC) leads to place-based short- and long-term health effects in a predominantly rural coastal region. Findings from focus groups with planners, emergency managers, and public officials in 2020 (41 participants) and 2022 (24 participants), show that ENC communities experience place-based health effects that fall under three areas including healthcare access for special needs and aging populations, respiratory and water-borne diseases, and stress and mental health. While, the lack of quantifiable data and indicators of health impacts creates barriers to appropriate responses, greater investments to improve primary care and better data collection tools can mitigate the health challenges of compound floods in rural ENC.

1. Introduction

Compound hazard events, defined as sequential or combined occurrence of extreme weather events (IPCC, 2013; Leonard et al., 2014), can have severe impacts to human health and the environment (Raker et al., 2020). They can disrupt healthcare system operations, namely their surge capacity and in turn their ability to meet the needs of impacted populations. Hick et al. (2009) define surge capacity as the ability to absorb an unusual demand for health services. This can include the ratio of healthcare provider to affected population, adequate medical equipment and hospital bed capacity, and the ability to refill prescription medication (Runkle et al., 2012). Ryan et al. (2016) identify food, health services, power, sanitation, and shelter as part of the Public Health Infrastructure (PHI). The challenges of healthcare systems and infrastructure during compound events are thus multi-faceted.

The impacts of compound hazard events are more significant than that of a single event in isolation (Kruczkiewicz et al., 2022, Leonard et al., 2014; Zscheischler et al., 2018; Muñoz et al., 2020; Fang et al., 2021). The cumulative impacts of a compound event were evident after hurricanes Katrina (2005), Sandy (2012), Matthew (2016), and Harvey

(2017) (Nofal & van de Lindt, 2020). During Hurricane Sandy, for example, the loss of more than USD 50 billion and a death toll of 233 people was attributed to pluvial flooding, high wind speed, storm surge, and ocean waves (Nofal & van de Lindt, 2020; Zscheischler et al., 2018), a combination of water and wind hazards leading to a compound flood event (Kruczkiewicz et al., 2022).

Impacts of compound hazards on the healthcare system can be felt by people with chronic health conditions, by medical facilities, by those seeking access to medical treatments and to a medical professional, and especially by vulnerable populations such as the elderly and premature infants (Powell et al., 2012; Raulji et al., 2018; Rodríguez & Aguirre, 2006). After Hurricane Katrina struck the US Gulf Coast in 2005, for instance, approximately 200,000 people with chronic health conditions were displaced by the floodwaters and unable to access their medications and medical treatment. In Jefferson and Orleans Parishes, 23 percent of the population had no access to medical care and about nine percent had difficulty accessing prescription medications due to pharmacy closures. Fifty percent (8) of the medical facilities in New Orleans were shut down and about 2000 of the region's 3500 practicing doctors were displaced, exacerbating the lack of medical expertise in the area.

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Hurricane force wind caused electric power failure at medical facilities resulting in stoppage of air conditioning systems. Temperatures exceeded 92 °F with consequent malfunctioning of lab machines such as Magnetic Resonance Imaging (MRI). Emergency generators also stopped working as floodwaters inundated the basements of medical facilities that stored food, fuel, and water (CDC, 2006; Raulji et al., 2018; Rodríguez & Aguirre, 2006; Runkle et al., 2012).

In the US, only Florida has more direct hurricane strikes among Atlantic coastal states than North Carolina (NC) (Platt et al., 2002). As climate change exacerbates extreme weather events, studies show that rural Eastern North Carolina (ENC) is experiencing recurring storms with increased frequency and severity (e.g., Curtis et al., 2022; Gori et al., 2020; Horney et al., 2014). These storms are thus compounded spatially, temporally, and because they contain multiple hazards (Zscheischler et al., 2020). Several hurricanes including Fran (1996), Floyd (1999), Irene (2011), Matthew (2016), and Florence (2018) to name a few have hit the ENC region in the past decades causing compound floods and widespread devastation. In 1999, Hurricane Floyd made landfall and moved over watersheds in ENC, including lower Cape Fear, Neuse, Tar-Pamlico, lower Roanoke, and Chowan River, leading to flooding in the 500-year floodplain (Bales, 2003). Floyd was associated with 52 recorded deaths, an estimated 2.1 million people affected, and an estimated total damage of USD 6 billion (Bales, 2003; Bin & Polasky, 2004; CDC, 2000; Platt et al., 2002). Hurricane Matthew, the fourth costliest and the fifth deadliest tropical cyclone in NC history made landfall on October 7, 2016. Matthew caused significant damage in central NC and ENC, leading to over 28 deaths and about 100,000 structures and businesses worth USD 10.3 billion destroyed state-wide by the floodwaters (Musser et al., 2017; Spialek et al., 2019). After two years, Hurricane Florence made landfall in Wrightsville Beach, NC in September 2018 as a Category 1 hurricane. The slow pace of Florence generated a 5-day continuous rainfall in the Carolinas, making it the wettest hurricane in the state’s history (Aly et al., 2021; Tanz et al., 2019). Florence led to 15 direct and 25 indirect lives lost in NC and an estimated economic damage of USD 24 billion to make it the ninth most destructive hurricane ever to make landfall in the United States (Callaghan, 2020).

The health hazards of compound flooding can be acute in rural ENC due to its geography and environmental factors. This is especially the case for water borne illnesses due to the presence of concentrated animal feeding operations (CAFO), a point source pollutant, in or close to the floodplain. NC is one of the major producers of hogs, turkeys, and broiler chickens in the United States. There are 142 CAFOs located within our focus group participant counties (see Fig. 1 and Table 1) posing risk of water contamination. Pitt County has by far the greatest number of CAFOs at 52. A buffer analysis of the animal feeding operations in ArcGIS application shows that 121 of the 142 CAFOs are within 1 mile of the Special Flood Hazard Area (SFHA), and 91 of those 121 CAFOs are within just 0.5 miles of the SFHA (Fig. 1). While the spillover from CAFO wastewater lagoons was catastrophic during Hurricane Floyd with 50 lagoons flooded and six breached, it was more controlled during Hurricane Matthew with flooding limited to six lagoons and two breaches (Davis, 2021).

The location of CAFOs intersect with the counties designated by the NC Department of Commerce as economically most distressed (Tier 1), less distressed as Tier 2, and the least distressed as Tier 3. CAFOs in the ENC region are heavily concentrated in the Tier 1 counties. In 2020, NC

Table 1
Number of concentrated animal feeding operations and tier designations in focus group participant counties.

County	Number of CAFOs	Tier Designation
Beaufort	13	Tier 2
Bertie	6	Tier 1
Chowan	9	Tier 1
Edgecombe	35	Tier 1
Gates	10	Tier 2
Martin	2	Tier 1
Perquimans	9	Tier 2
Pitt	52	Tier 1
Tyrell	1	Tier 1
Washington	5	Tier 1
Total	142	

Data Source: North Carolina Department of Environmental Quality (NC DEQ) & North Carolina Department of Commerce.

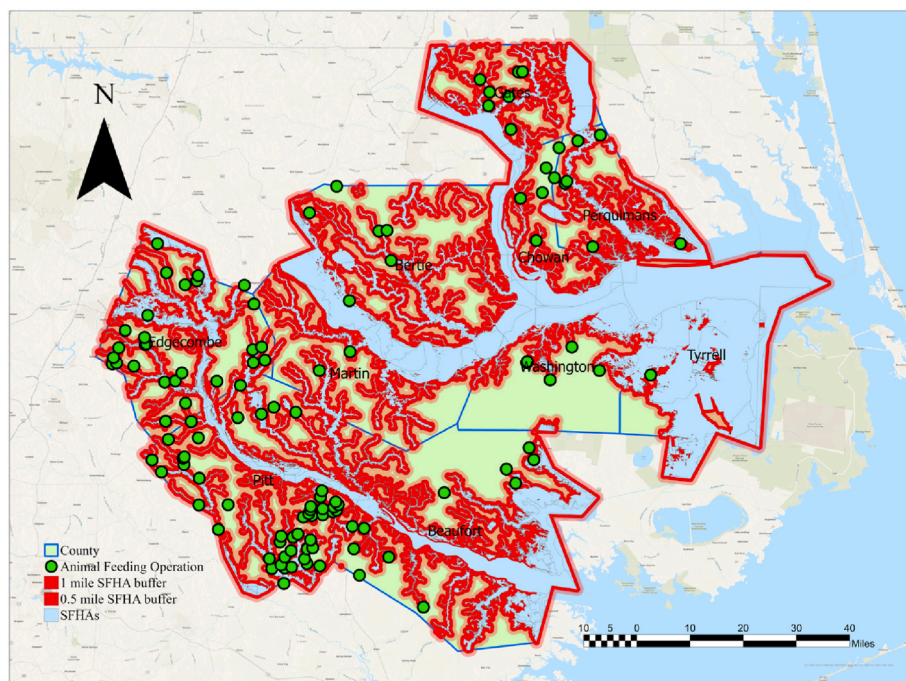


Fig. 1. Location of concentrated animal feeding operations in the counties represented in the 2020 and the 2022 focus groups. Map created by co-author using ArcGIS Pro 2.9.5 and ArcGIS Online.

ranked in the bottom half at 45 among 50 states in the country in terms of spending on public health per person. The state spends \$76 per person, where Alaska (ranked one) spends \$449, and New Mexico (ranked two) spends \$265 per person (America's Health Rankings, 2023). Furthermore, public health governance in NC is decentralized and administered at the County level for the most part, along with a few districts that govern multiple counties. As a result, local public health departments in ENC counties are at the frontline of overseeing and managing the public health impacts of compound flood hazards. Nevertheless, economic downturn in previous decades have resulted in multiple rounds of budget cuts for local health departments and reduced the capacity of counties to provide public health services.

The recurrence of extreme weather events in ENC is an impetus to examine health hazards in rural coastal communities facing what De Polt (2021, p. 98) terms as Compound Coastal Water Events (CCWEs). There is no clear definition of the term rural or a clear delineation of the bounds of rurality in the literature (Jerolleman, 2020). Instead, the term is ambiguous and is used to represent that which is not urban (Miller, 2013; US Census Bureau, n.d.). According to the US Census almost 20% of the US population (about 60 million people) live in areas considered rural (Ratcliffe, n.d.). In this work, we look at health hazards of CCWEs in ENC through the perspectives of local public officials. Contributions to the literature are threefold. First, we focus on the rural communities of ENC along the coast and those adjacent to it that share estuarine environments or linked riverine systems. Though water hazards can cause health hazards, the health impacts of CCWEs are rarely examined in rural regions (e.g., Brackbill et al., 2014; Raulji et al., 2018; Rodríguez & Aguirre, 2006; Sullivent et al., 2006). The current scholarship on CCWEs is limited and focuses mostly on urban coastal areas (e.g., Lian et al., 2013; Lv et al., 2020). A second related aspect is that most studies on health hazards focus on a single acute disaster, or one type of health hazard as opposed to the cumulative health effects of CCWEs. A post-Irene study of health impacts in the ENC region focusing mainly on the injuries sustained (Miller et al., 2013) is but one example. Compound hazards are physically complex and nonlinear with feedbacks that can lead to short-, medium-, and long-term health consequences. An earlier study found that a lack of understanding of CCWEs by hazard professionals, and poor communication of risk, can exacerbate a disaster (Curtis et al., 2022). Third, while the health hazards of CCWEs in rural areas are usually place based, defined as specific to a community or region due to its geography, environment, economy, and other factors, studies that look at rural health hazards are situated largely in the Global South and rarely examined in the context of the rural United States. Chanda Shimi and colleagues (2010), for instance, have investigated flood impacts on water supply, sanitation, and health of rural communities in Goalanda Upazilla in the Rajbari District of Bangladesh.

We begin with an overview of the health hazards of compound events noting their short- and long-term health effects. We then introduce our research methods, based on two full-day focus group workshops held in February of 2020 and 2022 on the East Carolina University (ECU) campus. Interview questions in February 2020 asked participants about the health hazards of CCWEs and the indicators of health hazards in rural ENC communities. The 2022 follow-up workshop asked about the health metrics and resources that would be most useful to ENC communities to respond to the health hazards. Results from qualitative analysis of the interview transcripts indicate that the health effects of CCWEs in ENC are highly place based. Rural areas such as ENC are more isolated with lower access to health infrastructure (Lal, Alavalapati, & Mercer, 2011) and "tend to have older, less affluent, and less educated populations, limited financial and human resources, and weaker relationships with state and federal agencies than urban areas" (Consoer & Milman, 2018, p.142). Furthermore, rural communities in ENC with shared estuarine environments or linked riverine systems are also often located close to or downstream from CAFOs that are in or around the floodplain. Such place-based factors inform health and healthcare challenges in rural ENC in three broad areas - healthcare access for

special needs and aging populations, respiratory and water borne diseases, and stress and mental health issues. While, the lack of quantifiable data and specific indicators of health impacts creates barriers to adequate and appropriate response, greater investments to improve primary care and better data collection tools can mitigate the health challenges of CCWEs in rural ENC.

2. A review of the short and long-term health effects of compound events

Health effects of compound events can be short-term such as death, acute trauma, injuries, and infectious diseases, and long-term such as non-communicable diseases, psychosocial health deterioration, and mental health issues (Ahern et al., 2005; Alderman et al., 2012; Bozick, 2021; Du et al., 2010; Paterson et al., 2018; Saulnier et al., 2017). Previous studies on health impacts during extreme weather events have focused on the resulting injuries and diseases (e.g., Ahern et al., 2005; Shukla et al., 2018), water contamination during floods or from oil spills (e.g., McCann et al., 2011), toxic exposure (e.g., Alderman et al., 2012), and carbon monoxide (CO) poisoning (e.g., Daley et al., 2001). In a systematic review of global flood health impacts Ahern and colleagues (2005) identified a high risk of fecal-oral, vector-borne, and rodent-borne diseases among survivors. Another study of infectious diseases observed viral infections such as norovirus among the survivors of Hurricane Katrina that were evacuated to a mega-shelter in Houston, Texas, with over 1000 of the 27,000 evacuees infected (Shukla et al., 2018). For non-fatal injuries, Sullivent and their research team (2006) show that 29 percent of those who visited hospitals (8) and non-hospital (20) acute-care medical treatment facilities (7543 of 26,192 visits) after hurricanes Katrina and Rita in the greater New Orleans area were there for injury related care. The main injuries were laceration/abrasion (27 percent), sprain/strain/dislocation (17 percent), and bruise/contusion (10 percent). Similarly, Brackbill and colleagues (2014) reported that after Hurricane Sandy, 10.4 percent (231) of the 2224 respondents in a study by the NYC Department of Health and Mental Hygiene, had sustained a physical injury, specifically, arm/hand cuts, back strain, and leg cuts. Extreme weather event power outages and disruptions in air conditioning, heating and ventilation systems also lead to the use of gasoline powered generators for emergency power and potential CO poisoning. Studies show CO poisoning has led to more annual deaths among all toxicants in the US (e.g., Daley et al., 2000) and occurred mainly among healthy, working-aged men after a flood event (e.g., Daley et al., 2001). Power outages may further exacerbate the concentration of indoor contaminants leading to poor indoor air quality.

The most devastating health impact of extreme weather events in the short-term, however, is mortality, mainly attributed to drowning inside automobiles while navigating flooded roads, and to trauma when hit by objects in fast moving flood waters. (Ahern et al., 2005; McCann et al., 2011; Paterson et al., 2018). Rappaport (2014) reports that 76 percent of fatalities in the United States from tropical cyclones are related to drownings. There were 971 deaths documented in Louisiana and New Orleans associated with Hurricane Katrina (Brunkard et al., 2008) and 4645 deaths assessed after the 2017 Hurricane Maria in Puerto Rico (Kishore et al., 2018).

The disruptions in social, economic, and physical systems following extreme weather events can have long-term health impacts too, such as increased susceptibility to mental health conditions or triggering an existing mental health condition (Lane et al., 2013). Mental health conditions can include an increase in illnesses such as common mental disorders, post-traumatic stress (PTS) syndrome, and suicide susceptibility (Ahern et al., 2005; Bevilacqua et al., 2020; Galea et al., 2007; Peek-Asa et al., 2012). A study (LaJoie et al., 2010) on the long-term well-being of evacuees after Hurricane Katrina found that more than 50 percent of the respondents suffered from post-traumatic stress disorder (PTSD). Another study (Bevilacqua et al., 2020) evaluated the presence of mental illness in the survivors of Hurricane Harvey after 5

months. Thirty percent of the 161 enrolled participants had a history and were being treated for mental illness. Similarly, Fitzpatrick and Spialek (2020) assessed suicide ideation among 316 Harvey survivors and observed that approximately 10 percent of the respondents thought of committing suicide, which is 2.5 times higher than the national average. Care workers are also susceptible to mental health conditions such as depression, anxiety, and PTSD. Following the 2016 Great Flood in Louisiana, a study evaluating the mental health of social work students in two universities identified 186 students who had survived the Great Flood event, of which 60 percent were identified as depressed upon surviving the event (Lemieux et al., 2019b).

CCWEs disproportionately disrupt the lives of vulnerable populations such as households composed of women, the aged, and households with a family member with chronic illness or disability (Okaka & Odhiambo, 2019). Though knowledge of health disparities associated with extreme weather events is inadequate, the limited set of studies indicate more adverse experiences in the United States for racial/ethnic minority communities and immigrant groups such as households among Latino communities without US citizenship (e.g., Collins et al., 2013). Jimenez and colleagues (2013) find that Latino households with lower socio-economic status are at a greater risk of post-flood respiratory health problems and exposure to mold, and experience increased family conflict. Vulnerable groups such as pregnant women also exhibit negative outcomes of flood impacts. A study of women in North Dakota after the Red River catastrophic floods show an increase in the proportion of women with more than one medical risk factor (Tong et al., 2011).

In rural areas, the reproductive health services of women can be negatively impacted after a CCWE (Kamal et al., 2018), food can be scarce, and vulnerability to water borne diseases increase (Shimi et al., 2010). Flood events are also a stressor and cause of disease outbreaks that disproportionately impacts pregnant women and children. In-utero exposure to floods especially in conflict affected regions is detrimental for the fetus due to the release of stress hormones in the mother (Nasir, 2021). CCWEs can also cause deterioration in the mental health status of impacted populations with a high rate of depression among adults (e.g., Heo et al., 2008; PremarajanAshok et al., 2019) and psychological effects on children (Vranda & Sekar, 2012).

In this study, we offer a contribution toward identifying the specific place-based health hazards and the cumulative aspect of health effects of CCWEs in rural coastal communities in ENC in the United States. We explain our approach in the next section.

3. Methodology

Results presented in this work is part of a larger study that assessed the perceived risks and needs of the hazard management and planning community in ENC. The study objective also included examining the perspectives of local public officials on the physical nature and the economic and health effects of CCWEs from 2010 to present and using this information to co-produce knowledge for better preparation, response, and mitigation plans. Data collection for this study took place through two full-day focus group workshops, both conducted at the ECU campus in Greenville, NC. The first workshop took place in February 2020 and the second in February 2022. The 2020 workshop took place 2-weeks before the COVID-19 shutdown came into effect across the state of North Carolina and did not impact data collection. IRB approval (#UMCIRB 19-002099) for the research was obtained from the ECU IRB and informed consent was obtained from all subjects during the workshop. Participants for both workshops included emergency managers, planners, elected officials, and other public officials (e.g., county manager, public services director, health director, floodplain manager) from the ENC region. In all, there were 41 participants in 2020 and 24 in 2022 from 12 counties representing jurisdictions under two Regional Councils of Government (CoG), the Mid-East Commission (Region Q) and the Albemarle Commission (Region R) in ENC. Each workshop had seven groups with up to seven participants in each group during the 2020 focus

group interviews and up to four in each during the 2022 focus groups. Workshop participants were recruited through the Mid-East Commission, our project partner, and the Albemarle Commission. A breakdown of the participants is provided in Table 2.

For both workshops, participants were divided according to their CoGs for Session 1 held in the morning to examine geographically clustered flood risks perceptions. For Session 2 held in the afternoon, participants were divided according to their profession to examine the economic and health effects of CCWEs according to different stakeholders such as planners, emergency managers, and other public officials who have differing roles during CCWEs. During the 2020 workshop, Session 1 focus group questions asked about flooding and perceptions of flood risk, for Session 2A (i.e., emergency managers & elected officials) on economic and health effects of floods and barriers to response during flood events, and for Session 2B (i.e., planners) on the economic and health effects of floods and barriers to flood mitigation. In 2022, study findings from the 2020 workshop were presented to the ENC community during Session 1. Feedback from the participants was overwhelmingly in agreement with our findings, thus strengthening its validity and rigor. During Session 2, participants were asked about health metrics and resources that would be most useful to ENC communities.

Each interview team consisted of a facilitator and a recorder. The facilitator asked a pre-determined set of questions of each group. All sessions were audio recorded. The recorder took handwritten notes to document key points. The recorded focus group sessions were transcribed into text documents and uploaded into NVivo, a qualitative analysis software, for coding. A code in qualitative inquiry "is most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based on visual data" such as "interview transcripts, participant observation field notes, journals, documents, photographs, video ... and so on" (Saldaña, 2009, p. 3).

Two cycles of qualitative coding were completed for transcribed texts from both the 2020 and 2022 focus groups. Descriptive coding technique which, "summarizes in a word or short phrase the basic topic of a passage" (Saldaña, 2009, p. 70), was used for the first cycle coding in NVivo. An undergraduate student conducted the first cycle coding for the 2020 focus group data and a graduate student for the 2022 data. Both students were trained in qualitative coding and worked closely with the first author on the first cycle coding. The second cycle coding used pattern coding technique which helps to "identify emergent theme or explanation (...) it is a way of grouping summaries into sets or themes" (Miles & Huberman, 1994, p.69), and was completed in MS Word. The themes that emerged during the second cycle pattern coding are the key study findings that we present in the next section.

4. Results: local officials' perspectives on the health hazards of CCWEs in ENC

Our first focus group in Feb 2020 began by asking participants about their perception of flood risk in ENC. Participants agreed that the flood risk in ENC is high, happens more frequently now than ever before, and

Table 2
Breakdown of focus group participants according to profession and gender.

Focus Group	Planner	Emergency Management	Elected Official	Other Official	Private Entity
2020					
Female	6	2	4	4	-
Male	7	8	-	7	3
Total	13	10	4	11	3
Focus Group 2022					
Female	3	1	3	2	-
Male	4	-	2	5	4
Total	7	1	5	7	4

that the increase in flood risks has health effects. Our results from the focus group data show that the health hazards of CCWEs in ENC fall under three main areas –healthcare access for special needs and aging populations, respiratory and water-borne diseases, and stress and mental health. Participants described these hazards as both short- and long-term. The lack of access to healthcare for special needs and an aging population during and immediately after a flood event is a short-term hazard, albeit one that carries high risks. Long-term hazards include respiratory and water-borne diseases, stemming from standing flood waters, that communities must live with. Ongoing stress and mental health issues in communities repeatedly hit with CCWEs are also long-term hazards.

Our findings also show that though health effects are significant, there is a lack of quantifiable data that could provide an accurate indicator for such health hazards. This broader issue compounds the health effects in rural coastal communities. Focus group participants were unsure if they had access to health impact indicators and were largely unaware of whether the information was recorded. Some suggested that the local health department might have data as they could see a spike in clients or hospital visits. Participants of one county stated that their health department compiles post-flood or post-event data, although the information was limited. One participant remarked:

I don't know if that [health data] is tracked in any way, maybe through social services or the health department. I don't know if they have any way to do that, or who it would be reported to. So, I just don't have that kind of information.

The lack of accurate, complete, and useable data on the health effects of CCWEs leave rural coastal communities in ENC without the tools and information to adequately prepare for and respond to the health impacts of flooding. Participants suggested greater investments to improve primary care and better data collection tools can mitigate the health challenges of CCWEs in rural ENC.

4.1. Healthcare access for special needs & aging population

Disruption to infrastructure when roads flood or are washed away impacts assisted living facilities and nursing homes. It is difficult to conduct evacuations and meet medical needs as emergency services cannot get through and access to the hospital is cut off. A participant explained. "We don't have any doctors, we don't have any hospitals, so we have to go to other places to receive those things normally. But flooding causes travel impacts, that we can't get to places." Another elaborated:

We've got, like, 28% senior population. When you start trying to look at needs, medical needs that these people have, and you've got a crisis situation, you've got people on oxygen, and you've got people on home dialysis, and you've got all kinds of things going on, and then you've got all this on top of it (...) It becomes massive.

Other participants stressed that without access to healthcare, CCWEs pose a big risk to nursing homes that often house dementia patients. Some nursing homes are automatically evacuated during storms, but evacuations cannot take place when routes are cut off. Similarly, hospitals can face a critical shortage of blood without access. A participant from Bertie County told us:

Bertie County is an aging population, and it's a declining population. So, us trying to look at our high-risk and look at our special-needs [population], we have a lot of impact to the health of our community because they're a sickly community, they're aging.

Participants also remarked on other vulnerable populations within their communities such as those who required respirators but were at risk of losing electricity during flood events.

4.2. Respiratory & water borne diseases

Mold related health effects shadow communities in ENC. Participants told us that mold and mildew are significant problems in their communities with households living in moldy homes for years. One participant explained:

The truth is the impact is very large especially with the slowness of federal and state response and people out, you've got people from Matthew who are still in moldy homes, people from Florence who were about four years out, still in moldy homes. So, and they're breathing that every day, and even though trying to clean it, it's still in the wall. It's still in the floor so it impacts cognitively.

Household members may also not be able to get back to their properties immediately after a flood event to air out the building and dry it causing mold. Mold mitigation is expensive and contractors for mold remediation are not always available, which can lead to a lack of mold removal. Even after mold mitigation, the mold can come back. Deferred maintenance and repairs can also compromise a property and lead to mold and mildew years after a flood event.

We still have a lot of buildings that are uninhabitable because of the mold issue. We just haven't been able to get contractors in there to remediate the mold, and now it's gotten to the point that it's past remediation. So, we're going to have to tear them down. But the problem with that is we can't get the contractors in to do the demolition. So, we're stuck with buildings that are full of mold and whatnot.

Mold related respiratory cough is increasingly seen in ENC communities and respiratory diseases have risen among children.

You can talk to any teacher from elementary through high school, in Beaufort County, Pitt County, and they will tell you they have never - these are teachers who've been teaching twenty, twenty-five years or more - they have never seen so many kids with asthma, bronchitis, unexplained rashes related to respiratory distress.

A key reason for the health hazards of CCWEs is due to standing water in residences, buildings, and ditches after an event that becomes a breeding ground for mosquitoes as the water sits for weeks on end. This water is often contaminated by spills from hog lagoons, flooded wastewater treatment plants, and failing septic systems in low-lying areas under the water table. Building damage from contaminated water influences indoor environments increasing indoor dampness and humidity, which in turn contributes to mold, dust mites, bacteria, and other indoor bio-contaminants. One participant said:

And you mentioned what's coming downstream; we've got a lot of sewer treatment plants, but we've also got a lot of large animal facilities, and all that is coming downstream, and it just sits in these homes. And you mentioned mold and mildew; it's beyond mold and mildew. It's a lot of other effects that come with it.

4.3. Stress & mental health

Though community mental health does not receive much attention in the aftermath of a hazard event due to other pressing needs, communities in ENC suffer from hazard related stress that has long-term health effects. Stress impacts both those affected by CCWEs, and the first responders who are on the frontline of emergency preparedness and response work. One participant put it succinctly, "mental health would be my biggest one [impact] (...) not just the victims of flooding (...) but the first responders (...). I know people that have walked away from this profession." Another said, "just the mental and emotional health of those of us who have been in the game for so long. We're just exhausted."

Participants explained that repeated hits from flooding have caused despair and severe stress among their populations. "Flooding has had a

long-term continuous impact. Not just the economy and lives, but the stress. The mental stress.” The stress is especially acute among households living below the poverty threshold, “The despair is only exacerbated with an event. We already have some of the poorest people. And anything that happens to these people (...) they’re barely hanging on as it is and surviving (...) so (...) the despair is gonna happen.” Other participants added that they are “seeing all kinds of mental health issues” in their community and that “every time it’s a small flood, a hurricane, it brings back all that anxiety, all those feelings from previous times. And these folks are not well.” Another person elaborated:

The biggest single health issue (...) relating to flood recovery (...) [is] (...) stress. I mean, we have people come in that are sick, and they’re sick from nothing but stress. And part of that stress is the confusion, and the indecision about what’s gonna happen, how, and when, and what you just said about - What am I supposed to do?

Participants expressed frustration that the political leadership does not comprehend the depth of health problems in rural coastal communities facing CCWEs, leading to policies that do not meet their needs.

And part of the problem with all of this (...) and it adds to the stress and the health issues, is that our congress doesn’t understand that they may throw out a pot of \$200 million, and it comes out of CDBG money (...) the rules and regulations that surround it aren’t friendly to flood recovery.

4.4. Mitigating health effects of CCWEs in ENC

Participants articulated that in rural communities, long-term efforts to mitigate health effects must include investments in primary care and data collection tools. Opportunities for improving primary care fell into three categories. First, there is a need for robust training for primary care physicians (PCPs) and sharing with them information about post-disaster health issues such as the effects of mold. Participants observed that they were seeing a significant percentage of people in ENC counties “complaining about similar symptoms, but nobody can figure out what’s wrong with them, but when you look at the symptoms they do match up to mold.” Mold exposures and dampness in buildings are linked to allergy and respiratory illnesses. Second, there is a call for increasing mental health vulnerability assessments through the Hope4NC program that goes door to door and has assisted with suicide prevention after Hurricane Matthew in ENC and conducted “compassion burnout training” for first responders. Third, expanding the community care medicine program is proposed. As a participant explained:

The community care medicine program, where we essentially are combining some of our telehealth with the paramedics who can go and check on individuals in their homes, and it does a lot. It looks at some primary care issues, getting them to primary care and looking at ED admission rates and other needs that we have in our communities.

Participants also stressed the need for a system of data collection, that looks at “not only the data itself, but our systems of collection (...) how do we even know how accurate or what are we missing?” Tools are acutely needed to collect longitudinal health information prior to and immediately after flood events in the ENC region and to conduct follow-up data collection at certain intervals. For example, following up a year after an event, when households are still waiting on federal housing assistance funds, could shed light on mental health issues such as stress and other health aspects such as the long-term effects of living in the presence of mold, while also making connections with pre-existing health conditions. As one participant stated: *I think, part of the reason you don’t have data too, is how it’s coded, because I come in and I’ve got anxiety or I’ve got depression, I’ve got PTSD, it gets coded as that. It doesn’t necessarily get coded as secondary to Floyd or secondary to Matthew or whatever the event might have been.*

5. Discussion, conclusions and recommendations

In this study, we conduct focus group workshops with public officials in the ENC region to identify specific place-based health effects of CCWEs and the indicators of such impacts. Participants point to three broad areas of health effects - healthcare access for special needs and aging populations, respiratory and water-borne diseases, and stress and mental health. Though not all effects are unique to rural ENC, place-based elements such as the presence of CAFOs in ENC can increase exposure to microbial and chemical contaminants in water and the likelihood of waterborne infections and gastrointestinal illnesses. Participants also observed that a lack of quantifiable data and accurate indicators of health impacts creates challenges to addressing those impacts and compounds its effects in rural and resource poor communities within ENC.

Research on the health effects of CCWEs in rural America is limited. Studies focused on urban regions have identified short-term effects such as deaths, injuries, and lack of access to health care for vulnerable populations (Powell et al., 2012; Raulji et al., 2018; Rodríguez & Aguirre, 2006), and long-term health challenges such as non-communicable diseases (e.g., from water contamination) and mental health issues (Ahern et al., 2005; Alderman et al., 2012; Bozick, 2021; Du et al., 2010; Paterson et al., 2018; Saulnier et al., 2017). Our results reinforce these findings albeit within a place-based rural context and add to this scholarship by highlighting the place-based nature of health effects. First, for an aging rural population with pre-existing health issues, healthcare access for special needs and aging populations is a significant health effect. Second, in a rural coastal region dotted with CAFOs in the floodplain and where seven of the ten participant counties are designated as Tier 1, susceptibility to respiratory and water-borne diseases is also a key health hazard. Third, mental health is an insidious long-term consequence of the recurrent and spatially extensive impacts of CCWE in ENC. For example, Matthew affected a large portion of ENC at the same time (spatial compounding, Curtis et al., 2021), which stressed first responders and slowed recovery, exacerbating the impacts of Hurricane Florence two years later (temporal compounding). Fourth, unlike previous studies on health effects, and though NC has seen flood related fatalities, our findings do not show mortality as a major health effect. In NC, 25 people died after Fran, 52 after Floyd, 28 after Matthew, and 15 direct and 25 indirect deaths were recorded after Florence in NC (Bales, 2003; Platt et al., 2002; Spialek et al., 2019; Tanz et al., 2019). However, fatalities and injuries, possibly seen as an immediate destructive outcome of a hazard, are not considered among the short- or long-term health effects of flood events in rural ENC communities.

More broadly, while the existing literature presents the short- and long-term health impacts of CCWEs, it is clear from our study that such health effects are place-based and depend on a set of unique local factors related to geography, environment, socio-economic, and other aspects of a community. The findings also indicate that health effects can be cumulative and intersect with vulnerability. For instance, long-term exposure to mold in living environments and its health effects can lead to stress and especially impact vulnerable groups such as children in ENC. This supports current studies that show adverse health experiences in the US for minority households of lower socio-economic status and for vulnerable populations that include pregnant women, children, and the elderly (Collins et al., 2013; Okaka & Odhiambo, 2019; Tong et al., 2011). The findings also highlight barriers in rural areas from the perspective of ENC public officials, specifically the lack of accurate, complete, and useable data on the health effects of CCWEs, that compound the challenges of mitigating health hazards in rural communities. The study results reveal an urgent need to invest in appropriate support for low-resource rural communities to bolster rural adaptive capacities.

Because the study focuses mainly on the perspectives of local public officials to understand health hazards of CCWEs in rural ENC, we caution that further research is needed with other stakeholders such as

residents and local health workers before concrete conclusions can be drawn. Moreover, although we did not build a complete demographic profile of our participants, representatives at our workshops were predominantly White, and thus do not share the cultural context and lived experiences of the majority African American residents they serve. Finally, future research that looks at a wider geographical area can fill knowledge gaps on the health hazards of CCWEs beyond rural coastal regions.

Our findings point to the necessity for specific policy approaches that are sensitive and appropriate to the health care needs of rural coastal communities. This must include ways to assess long-term physical and mental health vulnerabilities and connect them with existing rural health challenges. As a participant observed, “when we think about flooding and runoff and everything, how’s that impacting our cancer rates, how’s that impacting our neurodegenerative conditions and everything else like that. We definitely don’t have a good handle on all of that.” Another participant stated:

I mean, when we think of our community health assessment, cancer is always leading cause in our rural farm communities. And are we really looking at the impacts of pesticide runoff and salinity levels in water and lead in water and so many different other things that we’re just not making those different connections.

Participants suggested improving data collection strategy and increasing data accuracy, which in turn could help identify vulnerable populations and prioritize aid such as shelters. One participant stated that “we need to be able to know who is the most vulnerable health-wise, so we know to prioritize them, to get to them first, what do they need first. Are they the ones that need to be evacuated to the shelter; do we have space for them.” The findings also indicate a need for greater investments to improve primary care through training for PCPs, increasing mental health vulnerability assessments, and expanding the community care program in ENC.

Given the backdrop of economic challenges and the increasing impacts of CCWEs in NC, particularly in the ENC region, our findings and recommendations in this work seek to provide future policy directions as the state navigates a complex environment.

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Declaration of competing interest

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

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