The Cholera Crisis in Yemen: Case Studies on Vulnerability and Resilience in Sana'a, Al Hudaydah, and Ma'areb

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The Cholera Crisis in Yemen: Case Studies on Vulnerability and Resilience
in Sana'a, Al Hudaydah, and Ma'areb

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GLOSSARY

Anchor Institutions
Anchor institutions are Universities, hospitals, and local organizations that are important and integral to local communities and their economies. These institutions are thought to play a role in improving the health and well-being of the local residents that they serve (Maurrasse, 2016).

Attack Rate
Attack rate is a measure of Morbidity, or disease. The term is synonymous with Incidence Proportion and Risk. Its value is a reflection of the risk of contracting a disease within a specified time interval. The Overall Attack Rate, used in this research project, can be calculated by dividing the total number of new cases by the total population (CDC, 2012a).

Formula:
Overall Attack Rate =

\[
\frac{\text{New cases of disease during time period of interest}}{\text{Total population at the beginning of the time period of interest}}
\]

Case Fatality Rate (CFR)
CFR, also referred to as case fatality risk or case fatality ratio, is a way to measure the severity of a condition. It is the proportion of people diagnosed with a certain disease that die as a result of the disease during a specified time period. CFR can be calculated by dividing the number of deaths among diagnosed cases during a specified time period by the total number of incident cases. This quotient is multiplied by 100 in order to transform the proportion into a percentage (CDC, 2012a).

Formula:
CFR =

\[
\frac{\text{Number of deaths among incident cases}}{\text{Total number of cases}} \times 100
\]

Endemic
Endemic is a term used to refer to the persistent prevalence of disease in a population within a geographic area, usually at relatively low case numbers (CDC, 2012b).
Epidemic

Epidemic is a term used to refer to a rise in the cases of a disease that exceeds the expected case numbers in a geographic area. An epidemic usually manifests suddenly and rapidly (CDC, 2012b).

Governorate

The Republic of Yemen features two administrative divisions, larger governorates and smaller districts within them. The country is organized into 21 separate governorates and 1 municipality of Amanat Al Asimah (Encyclopedia Britannica, n.d.).

Improved Water Source

An improved water source is a term developed for monitoring purposes which refers to a water source that is protected from contamination by fecal matter. Such sources include piped water, public taps, tube wells, protected dug wells, protected springs, and rainwater collection (Water, Sanitation and Hygiene: UN-Water, 2020).

OCHA Population Size Estimates

The population size estimates used in this study were based on OCHA’s Yemen population estimates from 2019, which calculated population by district. The estimates took into account the Central Statistics Office (CSO) 2019 population projections and accounts for the internally displaced people (IDP) that entered and exited each district (OCHA Yemen, 2019).

Formula:

Estimated Population =
CSO projected population (2019) - IDP’s who left district + IDPS who entered district

Political actor

Political actors are individuals or groups that wield political power or authority in a society and through their actions have the ability to impact the decisions, policies, reporting, and outcomes of a conflict (Wolfsfeld, 2015).
INTRODUCTION

The largest recorded cholera epidemic in history is happening right now in Yemen, a country which has reported 2,309,859 cases of cholera as of February 2020 (“Cholera worldwide overview”, 2020). Yemen has a history of endemic cholera, but prolonged conflict in the country has led to deteriorating conditions that have triggered massive outbreaks of the disease (“Endemic in Yemen, cholera still hits Yemenis hard,” 2019). The purpose of this study is to investigate the direct and indirect causes of the cholera epidemic in Yemen by proposing factors that may confer vulnerability and resilience in Yemeni governorates.

Case studies were compiled on three governorates: Sana’a and the inner municipality of Amanat Al Asimah; Al Hudaydah; and Ma’areb. As part of each case study, information about political governance, water and sanitation services, healthcare, nutrition level, displacement, and humanitarian aid is presented, and used to situate 2017-2018 epidemiological data on cholera and 2016-2018 infrastructure destruction data in the context of the conflict. The situation in these three governorates speaks to a larger humanitarian crisis that has affected virtually every facet of life, from livelihood and mobility to health, for people all across the country. The impact of these factors on civilians is important to consider and can inform international policy about war, humanitarian response during conflict, and the process of rebuilding and fortifying Yemen in a post-conflict context. This kind of investigation into Yemen’s vulnerability is more relevant than ever as the population, already challenged by a massive public health crisis and crumbling healthcare system, confronts the added threat of the COVID-19 virus. In order to better understand these issues and their relationship to cholera, the underlying history and politics of the current conflict and the biological basis of cholera must be examined.
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War and Politics

The ongoing conflict in Yemen is fueled by tensions that existed long before war broke out in 2015. Prior to unification in 1990, two separate states existed: the northern Yemen Arab Republic (YAR) and the southern People’s Democratic Republic of Yemen (PDRY) ("Mapping the Yemen conflict", 2019). Post-unification, historical and religious differences were apparent, spurring on unsuccessful secession efforts by southern separatists in 1994 ("World Report 2019: Rights Trends in Yemen", 2018). Ali Abdullah Saleh governed North Yemen starting in 1978 and remained in power when the two states became one. In the 1990’s, the Houthi movement known as Ansar Allah organized to oppose Saleh on account of wide-spread corruption and nepotism, as well as his relationships with Saudi Arabia and the U.S. Ansar Allah draws its support largely from the Zaydi tribal groups in the northern highlands of Yemen. Saleh, with backing from Saudi-Arabia, launched attacks against the Houthis in 2003, but fell short of defeating them (Riedel, 2017).

In 2011, widespread uprisings took place across Yemen; separatists from the South as well as Houthis in the North organized pro-democracy demonstrations which pushed Saleh to step down from his post as President. In 2012, the Gulf Cooperation Council (GCC), and more specifically Saudi Arabia organized Yemen’s transition to President Abd-Rabbu Mansour Hadi, who formerly served as Saleh’s Vice President. Hadi was set to serve a term of two years while the nation made a democratic transition. Many regarded Hadi as a weak and corrupt leader, whose interests were tightly intertwined with those of Saudi Arabia. Saleh supporters actively opposed Hadi (McDowall & Ghantous, 2020). In 2014, army forces loyal to Saleh aided the Houthis in the seizure of Sanaa, who continued to expand their territory farther ("Mapping the Yemen conflict", 2019). In January of 2015, Hadi, after being arrested by the Houthis, resigned.
Come March, he fled to Aden and rescinded his resignation. Hadi was taken to Riyadh, Saudi Arabia, where he has lived in exile since. His government is still internationally recognized (Alshuwaiter, 2020).

To restore Hadi’s government to power and subdue the joint efforts of the Iranian-backed Houthis and the Saleh-affiliated military forces, Saudi Arabia led the formation of a coalition backed by the United States and the United Kingdom. Members included the other GCC nations of Qatar, the United Arab Emirates (UAE), Kuwait and Bahrain, as well as Egypt and Sudan ("Mapping the Yemen conflict", 2019). The coalition’s military operations, including an intensive airstrike campaign, provoked retaliation from the Houthis in the form of missile attacks targeting Saudi Arabian assets and territories.

At the conclusion of 2017, the alliance between the Houthis and Saleh was fractured. The result was the death of Saleh and the defeat of his forces. The remainder of his allies redirected their efforts to join the battle against the Houthis ("War in Yemen: Global Conflict Tracker", 2020). From the South, Yemeni secessionists have formed groups backed by the UAE. In 2018, secessionist forces clashed with the Yemeni government in Aden ("World Report 2019: Rights Trends in Yemen", 2018). As it stands, the dynamics of the conflict have progressed past a central struggle between Saleh and Hadi. The International Crisis Group identifies 5 cantons of political and military control in Yemen. The Southern Transition Council, advocating for Southern secession, has a hold on the important port city of Aden (“Rethinking Peace in Yemen,” 2020). Houthis command the capital city of Sana’a and a large part of the country’s northern highlands. ("Mapping the Yemen conflict", 2019). The Yemeni government maintains its control in Ma’areb, Al-Jawf, Al-Mahra, Shabwah, Abyan, the city of Ta’iz, and the northern portion of Hadhramaut. The Joint Resistance Forces, a militia loyal to Tariq Saleh, is located in
the districts along the Red Sea coast. Local authorities control the coastal region of Hadhramaut ("Rethinking Peace in Yemen," 2020). A relentless five years of conflict have resulted in a significant number of civilian casualties, destroyed essential infrastructure, and created a massively devastating humanitarian crisis.

**Biological Basis of Cholera**

Cholera is a waterborne disease caused by the ingestion of a contaminated food or water source. The causative agent is bacterium *Vibrio cholerae*, for which the only known natural reservoir is humans. This gram-negative bacillus features a single polar flagellum that confers high motility. *V. cholerae* has hundreds of serogroups, but only two have been identified as pathogenic: O1 and O139. The latter serogroup was discovered in Bangladesh in 1992 and has never been identified outside of the Asian continent (World Health Organization, 2019). Infections of both have been shown to cause the same illness and share a similar pathophysiology.

*V. cholerae* has a high infectious dose of $10^8$ (Rodriguez & Kahwaji, 2020). Upon the ingestion of contaminated food or water, in order to successfully infect a person, *V. cholerae* must first cross the gastric acid barrier in the stomach. Then, it must colonize the small intestine. The toxin coregulated pili (TCP) at their surfaces interact with receptors at the surface intestinal mucosal cells. Utilizing motility and chemotaxis, the bacteria penetrate through the mucosal layer of the small intestine. Upon colonization, the bacterial cells divide and secrete toxins, among them an enterotoxin known as cholera toxin (CT) (Mekalanos et al., 1997).

Released CT is endocytosed by intestinal epithelial cells. CT is an AB toxin in which the B subunit binds to GM1 ganglioside receptors on the epithelial cell surface. This facilitates the
endocytosis of the A subunit. Inside the cell, the A subunit is cleaved into A1 and A2. A1 functions in the catalysis of the ADP ribosylation of GTP-binding G proteins. This leads to the constitutive activation of the adenylate cyclase enzyme, which increases cAMP levels within the cells. This drives the release of chloride ions into the lumen on the intestine and simultaneously inhibits sodium absorption. This causes an imbalance which causes an influx of water from the intravascular spaces of the body to flood the small intestine. This is the cause for the clinical manifestation of effusive watery diarrhea experienced by patients with cholera (Wernick et al., 2010).

The bacteria excreted into the environment allows for a 24-hour hyper-infective period during which time high rates of fecal-oral transmission can occur. This is one of the reasons why cholera outbreaks can happen so rapidly (Rodriguez & Kahwaji, 2020). Cholera is often diagnosed based on clinical suspicion when patients experience what is called rice water diarrhea. This can be confirmed by the presence of *V. cholerae* in stool samples, identified using laboratory culture or PCR (World Health Organization, 2019).

In addition to what is known as rice water diarrhea, cholera has a number of clinical signs that can be observed anywhere between 12 hours to 5 days after ingestion. Most symptoms manifest after 2-3 days. Most cases are mild or asymptomatic, but some, about 10%, are severe. Symptoms include vomiting, leg cramps, and dehydration. Severe dehydration can lead to shock or death ("General Information | Cholera | CDC", 2020). Mortality rate is very low, less than 1%, when treated. However, left untreated the mortality rate can be as high as 25-50% (Fournier & Quilici, 2007).

Treatment primarily takes the form of rehydration therapy. The WHO calls for the administration of oral rehydration solution (ORS). The standard mixture consists of sugar and
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Salts dissolved in 1L of water. As many as 6L may be needed to adequately rehydrate a patient. For severe cases, patients undergo intravenous fluid replacement. The general guideline is that patients are rehydrated with 1.5 to 2 times the amount of fluid they lost in stool. It is important that treatment is easily accessible and is administered early on in the infection. Delays in treatment can lead to serious consequences (World Health Organization, 2019).

Populations most vulnerable to cholera are those who lack access to safe drinking water and proper sanitation systems (World Health Organization, 2019). Other risk factors include people with blood type O and those with achlorhydria, or a deficiency of hydrochloric acid in their gastric secretions ("General Information | Cholera | CDC", 2020).

The FDA recently approved the use of the Vaxchora®, a live cholera vaccine administered orally in a single dose to people travelling to areas where cholera is endemic or epidemic ("General Information | Cholera | CDC", 2020). Existing vaccines approved by WHO are killed whole cell (KWC) vaccines Dukoral®, ShanChol®, and Euvichol-Plus®/Euvichol®. These vaccines are often deployed to areas of outbreaks in order to limit spread and susceptibility, but this presents its own logistical challenges. Dukoral®, for example, is an oral vaccine requiring cold storage, trained staff, and is kept suspended in a buffer (Sedaghat et al., 2019). This means that vaccines are expensive and difficult to transport. It is important to remember that vaccination does not confer 100% protection from illness. Preventative measures such as building and maintaining proper water and sanitation systems are the most effective barrier against cholera ("General Information | Cholera | CDC", 2020).
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The Cholera Epidemic

Prior to the outbreak of war, cholera was endemic to Yemen. But since 2015, cases have skyrocketed to unprecedented numbers. As coalition airstrikes damaged and destroyed Water, Sanitation and Hygiene (WaSH) facilities, water borne diseases proliferated (Federspiel & Ali, 2018). The outbreak has manifested in waves. The first cases were confirmed in Sana’a in September 2016, the start of what the World Health Organization (WHO) identified as the first wave (Al-Mandhari et al., 2018). As of October 2016, 2,241 cases had been reported, and 47 people had died, conferring a case fatality rate (CFR) of 2.4%. At this point, 11 of the 23 governorates reported cholera cases ("Situation update for cholera for Yemen, October 2016", 2016). The second wave commenced in April 2017 during the rainy season (Dureab et al., 2018). This time, incidence was much higher and effects more devastating. Between April 2017 and October 2018, cholera infected an estimated 1.2 million people, the majority of them, 58%, children. At the time, the overall CFR was 0.21% ("Yemen Cholera Response Weekly Epidemiological Bulletin Week 26 2018", 2018).

The COVID-19 virus presents a whole host of new logistical and biological challenges to managing the cholera crisis in Yemen. Thus far in 2020, all but one governorate has reported cases of cholera. Between January and June, the WHO reports that a cumulative total number of 1.3 million people are suspected of being infected. The overall CFR is 0.11%, and children under 5 make up 24% of the cases in the country ("Outbreak update – Cholera in Yemen, 28 June 2020", 2020). In the past five years, the state of cholera in Yemen has escalated to become the largest epidemic in modern history. Data indicates that Yemen is experiencing an epidemic that is three times larger than the next largest on record, which occurred following Haiti’s 2010 earthquake (Potter, 2020). A more in-depth discussion about the epidemic, its causes, and impact
in Sana’a, Al Hudaydah, and Ma’areb will be presented in this study. The methods used to compile these case studies are discussed in the following section.

**METHODOLOGY**

This investigation draws upon two main datasets. The first comes from OCHA’s Humanitarian Data Exchange initiative and provides case totals, CFR’s, and attack rates (per 1,000 people) by governorate from May 2017 to February 2018. This epidemiological data was manually extracted from the WHO’s Yemen Situation Reports page (WHO regional Office for Mediterranean, n.d.). Experts working for the WHO on Yemen post daily and weekly updates which include important cholera information.

The second dataset utilized comes from the Targeting of Infrastructure in the Middle East (TIME) project (Duke University & University of New Hampshire, n.d.). This project tracks discrete incidents in which civilian and environmental infrastructure is targeted by actors involved in a number of selected conflicts in the Middle East and North Africa. Among the conflicts documented is that of Yemen. Researchers collect information from primary and secondary sources including news sources, human rights reports, and NGO and International Organization (IO) documents pertaining to the conflict in Yemen (Duke University & University of New Hampshire, n.d.). The Yemen data spans from 2010 to the present, the coded information including categories such as the date and location of the incident, the infrastructure targeted, the means by which it was targeted, the actors involved, infrastructure operationality, injuries/casualties, and human/environmental impact.

Upon examination of the available data and initial visualizations, it was determined that the governorates of Sana’a, Al Hudaydah, and Ma’areb had the potential to tell different and
interesting stories about the crisis’s toll on human health and well-being, especially considering that different political dynamics existed in each governorate. In the Sana’a case study, data for the governorate of Sana’a and Amanat Al Asimah, the municipality that lies within its borders, are distinguished from one another. Outside of the case study, Sana’a is used to refer to the region that contains both the municipality and the larger governorate together.

Using both the cholera and infrastructure destruction data, three smaller datasets were created for the governorates of Sana’a, Al Hudaydah, and Ma’areb. In the case of the TIME project data, a time period of interest was selected. Considering the timeline of the cholera epidemic in Yemen, which began in 2016, and the availability of epidemiological data from 2017 to 2018, it was determined that infrastructure destruction documented from 2016 to 2018 would be helpful in expanding upon the context of the human crisis. Graphs were produced based on these subsets of data in order to visualize the changes in the state of cholera and damage to infrastructure over time.

Three case studies, one for each governorate of interest, were conducted. Each case study was constructed using a combination of quantitative and qualitative methods. In order to situate the data in the context of the governorate’s place in the conflict, the following 4 categories, which were identified as having the potential to contribute to the governorate’s vulnerability and/or resilience to cholera, were researched: population/displacement, malnutrition, access to healthcare, and access to water. This process drew upon a variety of sources, including reports by the UN, the WHO, The World Bank, humanitarian organizations, news agencies, and scientific research papers. This was followed by an analysis of the epidemiological cholera data and the infrastructure destruction data. The purpose of this study was to shed light on the convergence of
vulnerability and resilience factors contributing to the health and humanitarian crisis in the three governorates as well as in the country as a whole.

SANA’A/AMANAT AL ASIMAH

Military and Political Dynamics

Sana’a has been a landscape of political turmoil since 2014, when armed Houthi forces took control of Sana’a from President Hadi’s Yemeni government in September. They have established themselves as the de-facto authority in the area. Uniquely, the city of Sana’a’s local council has continued to exercise their role, though in a more restricted capacity and with limited resources. They meet regularly, retain some decision-making authority, and oversee public service operations for the city. This comes with the ruling authorities’ condition that they appoint Houthi representatives within the existing structures to serve as supervisors. The result is that two parallel structures govern the city. Beyond the city's limits, in the governorate of Sana'a, no such council activities take place (Sana'a Center for Strategic Studies, 2016). Since 2015, the Saudi-led coalition has operated primarily from the sky over Sana’a, perpetrating airstrikes. Other actors in Sana’a include Tribesmen, Islamic militants, Political militias (National Resistance Forces, Military forces of Yemen 2016, Military forces of Yemen 2012)

What factors confer vulnerability to cholera infection in Sana’a?

Population/Displacement

In 2019, the governorate of Sana’a was estimated to have a population of approximately 1.5 million (OCHA Yemen, 2019). Sana’a, the country's most densely populated city (Madhok, 2016), is not a part of the governorate of Sana’a, though geographically it lies inside its borders.
Instead, it forms the administrative and political district that makes up the municipality of Amanat-al-Asimah (The World Bank, 2009). In 2019, the population of Amanat Al Asmiah was approximately 3.4 million. In 2019, there were an estimated 997,397 children under 5 years old and 90,896 adults over 60 years old in Amanat Al Asimah and Sana’a (OCHA Yemen, 2019). These demographics are particularly important to note as people belonging to these age groups typically have weaker immune systems. This renders them especially vulnerable to infectious diseases like cholera.

Since the start of the conflict, the city has taken in droves of refugees. The UN estimated that as of March 2018, more than 2 million people had been displaced by the conflict. Many of these displaced people made their way to Sana’a, driven by the promise of humanitarian assistance once they got there. Thousands of internally displaced families reside in camps outside Sana’a (Al-Sakkaf, 2018). Lack of protective shelter, maintenance and sanitation, a shortage of employment opportunities, inadequate food and water supplies, and dangerous conditions for women and children make for a poor living situation in these camps and increases the risk of cholera infection (The New Humanitarian, 2010).

**Malnutrition**

Contributing to the humanitarian crisis in Yemen is widespread food insecurity. The people of Yemen are suffering from severe food insecurity. A number of factors have driven the dissemination of hunger throughout the population in Sana’a. Amanat Al Asimah’s urban landscape means it relies heavily on food grown in other governorates and from goods entering from the country’s major ports, namely Al Hudaydah, which is the nearest port to the city (City Development Strategy, 2010). However, as a result of the conflict, delivering food to the city has
become more costly. High fuel prices and damage to transportation infrastructure have made it even more difficult to transport food to Sana’a. In August 2016, the Saudi-led coalition bombed a major bridge located on the road from Al Hudaydah to Sana’a. The destruction of this bridge was akin to cutting off a lifeline for the capital, as the 155-mile road was the main supply route, including 90% of the World Food Program’s (WFP) aid delivered to Sana’a (Oxfam, 2016).

Ports like that of Al Hudaydah are often key means by which international actors like the Saudi-led coalition put pressure on the Houthi Forces. For example, when Houthi forces fired a missile targeting the airport in Riyadh, Saudi Arabia, in November of 2017, Saudi officials retaliated by closing the entirety of Yemen’s air, sea, and land ports (Oxfam, 2017). This deprived the country of 500,000MT of food and fuel, and 1,476MT of humanitarian aid. Though some ports reopened 10 days later, the port of Al Hudaydah as well as the airport in Sana’a remained closed until November 23rd. Markets in Sana’a had little to sell to its residents during that time, who struggled to feed themselves and their families. Once people became malnourished, it may take an extended amount of time and a consistent food supply to recover. The 16 days of blockade meant that even after points of entry had reopened, prices soared to unaffordable amounts. This was true of fuel prices as well, which in Sana’a increased by more than 100%, and consequently made transportation even more expensive (Oxfam, 2017).

Houthi forces have also played a major role in obstructing WFP aid from reaching Sana’a. In 2019, after repeated incidents of Houthi forces seizing medical and humanitarian supplies, it was revealed that they were systematically abusing aid in the city and diverting resources. The WFP decided to halt general food distribution in Houthi-controlled areas. The program was cut for two months before being re-implemented after the WFP and the Houthis
settled on an agreement that ensured that their aid would be allocated to those in Sana’a with the most need (Physicians for Human Rights, 2020).

Further complicating the issue of food accessibility is unemployment in Sana’a. Pre-conflict, Sana’a was an important economic center. The city was home to more than half of the entire country’s hotels and attracted tourists from everywhere around the world. It was also here that 30% of the total commercial and industrial areas in Yemen were located (Soltanzadeh & Moghaddam, 2015). The conflict certainly eliminated the tourism industry, and plunged Sana’a into a dire economic situation. Many were rendered jobless as a result of things like danger, destruction, and a lack of pay. Factories based in Sana’a were forced to close their doors and let go of thousands of workers after airstrikes damaged their buildings and equipment in 2015. Former workers from the city’s two major textile factories can be found sitting on sidewalks (Murdock & Mojalli, 2015). Today, men clutch tools and wait on sidewalks for an opportunity to earn money by working odd jobs (Murdock & Mojalli, 2015). Unemployed people have turned to dangerous ways to secure income, like looking to earn some money in exchange for fighting on the battlefield. Many families rely on food donations from NGO’s and the kindness of local businesses and community members to sustain themselves (Al-Sakkaf, 2018). The intersections of blockade, infrastructure destruction and economic strains culminate to the breakdown of the city’s market system and reveal a devastating feedback loop which is characteristic of the nature of the malnutrition crisis in Yemen during this conflict, posing a very real and dire threat to the well-being of the people in Sana’a.

One survey performed in 2019 examined malnutrition in children belonging to the governorates of Ibb and Sanaa. The majority of households in Sana’a depended on purchasing food from markets. The second most utilized source of food was Agriculture, apparent in 30.5%
of households overall, followed by humanitarian assistance, which accounted for the sourcing habits of 16.6% of households in Sana’a (Fekri et al. 2019). At this point in the crisis, according to the World Food Program’s Integrated Food Security Phase Classification (IPC) scale, the situation in Sana’a had escalated from “crisis level” in September of 2016 to “famine” in 2019 (United Nations World Food Programme, 2020). Data from these same households were used to discern the extent of the food insecurity issue as it pertains to children below 5 years of age (Fekri et al. 2019). Global Acute Malnutrition, also known as wasting, was found in 13.3% of the children considered. This percentage is quite alarming, falling under the UNHCR’s label of ‘Very High’ Emergency Standard. (UNHCR, n.d.) 4.9% suffered from Severe Acute Malnutrition (SAM) and 8.44% were afflicted with Moderate Acute Malnutrition. Findings also indicated a clear association between malnutrition and other adverse health effects. This included a higher occurrence of measles, fever, cough, and diarrhea. In fact, 37.7% of children surveyed in Sana’a and Ibb presented with diarrhea, a symptom associated with cholera. Wasting has been demonstrated to heighten children’s risk of death from infectious diseases (World Health Assembly, 2014).

Malnutrition confers heightened biological susceptibility to other illnesses and infectious diseases, including cholera, mainly by subduing the immune system. This is evidenced in part by the prolonged healing process that malnourished patients present after incurring surgical wounds. Nutrient deficiencies affect the immune system’s cell mediated response, and impair phagocytosis, cytokine expression, and complement pathways (Saunders & Smith, 2010). Additionally, undernutrition is hypothesized to effect nutrient metabolism, and in turn gut microbiota, in a way that triggers pathogenesis. Malnutrition can have far-reaching cross-generational consequences. For example, dietary deficient mothers facing higher rates of
morbidity and mortality give birth to children with lower birth weight. These children are more likely to suffer from type 2 diabetes, hypertension, cardiovascular diseases, and obesity when they grow older. The ramifications of this food crisis could continue to impact the health and wellbeing of the Yemeni population for generations to come.

**Access to Healthcare**

The governorate of Sana’a is a mountainous region with a semi-arid climate. The capital city of Sana’a sits high in altitude, at about 2,300 meters in an upland basin (City Development Strategy Team, 2010). This terrain complicates travel even outside of the context of the conflict. Sana’a is home to the highest number of healthcare facilities in the country, leading in both public and private institutions. This includes 333 private health centers, 46% of the country’s total private health centers, and 62 private hospitals, accounting for 34% of Yemen’s private hospitals, were located in Sana’a city in 2014 (McMaster, 2019). Rising fuel prices, destruction of roads and bridges, and potential danger associated with travel not only made it difficult to transport food, but also obstructed people from physically reaching healthcare facilities in Sana’a.

Hospitals and medical facilities in Sana’a have been increasingly burdened by an influx of patients. This began in 2014, when the Houthi armed group, in partnership with the military forces loyal to previous President Saleh forcibly took over the Capital city, clashing with the forces allying themselves with President Hadi. As fighting intensified, hospitals in Sana’a scrambled to treat scores of injured people (Physicians for Human Rights, 2020). Among the facilities facing shortages in supplies were Al-Kuwait public hospital, Al-Moayad private hospital and Dhula Hospital (Medicins Sans Frontieres, 2020).
The burden only intensified once the Saudi-led coalition launched their campaign against the Houthi forces in 2015, at which point hospitals, clinics, and mobile vaccination and medical centers in Sana’a became targets of airstrikes. Houthi forces and other armed groups also began occupying these spaces. For example, in May of 2015, a Saudi-led coalition airstrike hit Ghadran Health Center in the governorate of Sana’a. People in the area warned the Houthi forces using the vital treatment center as a military base that their occupation would put a target on the building, but the warnings went unheeded. As a result, the facility was destroyed and 8 civilians lost their lives (Physicians for Human Rights, 2020).

Actors in Sana’a have disregarded the protected status of these health facilities, and done harm to the structures, equipment, and workers on the ground. At least nine different attacks on medical staff in Sana’a have been recorded by Mawatna, a Yemeni organization for human rights. Such attacks, ranging from threatening behavior to physical assault, have been perpetrated by a range of groups, including actors identified as pro-government, Emirati-backed Security Belt Forces, Houthis, and al-Qaeda-affiliated groups. Unpaid for weeks on end, in 2016 and 2017, a group of doctors, nurses, technicians, and midwives at Al-Thawra Hospital in Sana’a assembled to protest for compensation and benefits. The medical personnel that participated came under fire. Many were fired, arrested and threatened by the Houthi authorities that controlled the area (Physicians for Human Rights, 2020).

Healthcare workers in Sana’a are therefore operating under intense pressure and a lack of personnel and resources as they take on the challenge of caring for an increasing population of displaced people along with native residents that are wounded or plagued by malnutrition and infectious diseases like cholera. While cholera is easily treatable through rehydration therapy,
cholera patients that seek medical attention in Sana’a are met with a number of logistical challenges that delay their treatment. This delay could prove fatal for immunocompromised and vulnerable members of the population like children. As a result, access to healthcare is a major determining factor in the disease outcome of an infected person. The population’s access to healthcare in Sana’a is reflected in the governorate’s death total and CFR throughout the cholera epidemic.

Access to WASH

Prior to the conflict, Sana’a was already positioned to become the first capital city to exhaust their water supply. In 2010, it was observed that water was being extracted from the Sana’a basin four times faster than it was replenished (New Agriculturist, 2010). The water supply was also inconsistent. Some residents received piped water from the city’s system only once every nine days. Moreso, others did not receive this service at all. Water for the city is primarily sourced from wells, which were quickly drying up. Whereas in 2000, Sana’a had 180 wells, only 80 remained operational by 2010. These wells were projected to dry up by 2015 (Glass, 2010). Considering that the city’s population was growing at a rate of 7% each year, Sana’a was hard pressed to find a solution for their water problem, which was projected to become catastrophic within the next decade (New Agriculturist, 2010).

In the “Water, Sanitation and Hygiene Review for 2020,” the UN WASH Cluster and the ACAPS Yemen Analysis Hub found that Sana’a city had the highest estimated number of people in need (PIN) of WASH assistance. Of all the districts in Yemen, 5 out of 9 which had the highest PIN belonged to Sana’a and Amanat Al Asimah governorates. Bani Harith in Sana’a city had an estimated 257,000 PIN. This is 56% of the district’s population. These numbers are
consistent with trends that have persisted throughout the duration of the conflict, which place Sana’a at the forefront of the WASH crisis (WASH Cluster, 2020).

Before the first wave of cholera swept through the country, the entire northern portion of Sana’a city and all 1.5 million of its residents shared a single wastewater treatment plant designed to serve only 500,000 people (Al-Assadi, 2016). The work of overwhelmed public WASH services is vital to keeping the environment clean and protesting people from the spread of infectious diseases. Damage incurred by this plant in 2015 halted operations, leaving untreated water to run through neighborhoods and creating an opportunity for cholera infection to proliferate. The district of Bani Harith suffered as a result, and is still dealing with the repercussion of this blow to WASH services (WASH Cluster, 2020). And so, exacerbating the issue of water scarcity, the conflict has damaged and impaired public services in Sana’a, resulting in the contamination of water supplies. Residents have little access to safe water sources, driving unsanitary drinking behavior. Of course, consumption of contaminated water is the means by which V. cholerae gains access to the body and causes infection. The combination of these factors creates the potential for a public health crisis which started in Sana’a and took on the shape of a cholera epidemic in 2016.

**Infrastructure Destruction**

**Targeted Infrastructure**

Since the beginning of the conflict in March 2015, when the Saudi-led coalition began to engage in military operations in Yemen, the civilian infrastructure in Sana’a has incurred damage that is devastating to the health and wellbeing of its people. It became apparent that civilian lives and buildings were not exempt from the list of potential targets in the conflict. An airstrike
carried out at an airport in Sana’a on March 26, 2015 prompted the employees of a wastewater treatment plant across the way to leave the lights on in the facility at all times in order to alert coalition forces in the air that it was a civilian building. They feared that any damage could result in widespread and dangerous water contamination for the 500,000 people they served. This tactic proved ineffective a few days later, when a coalition airstrike targeted a crane at the same facility. This was just the beginning of the damage that civilian infrastructure would incur in Sana’a.

The interconnectedness of the water and energy sectors is important to acknowledge when considering the repercussions of damage to municipal facilities. The water treatment plant in Sana’a relied on electricity in order to power its operations. The bombing of Sana'a’s central electricity grid in April 2015 resulted in an extensive loss of power that posed an immediate threat to the water plant’s operationality. The plant turned to diesel fuel supplied by UNICEF. This source of energy was exhausted by May 2015, at which point all activities ceased, and wastewater was left untreated for a long period of time after. Later, the United Nations Children’s fund provided funding to reopen the plant, which began to operate at reduced capacity to service the growing population of the city as more displaced people arrived. By 2016, almost 3 million people resided in the city, burdening the city’s WASH systems with waste (Allana, 2017). Such conditions allowed *V. cholerae* to flourish in Sana’a, which became the epicenter of the country’s cholera epidemic in 2016.

Among the districts affected by this incident was Bani Harith, which also suffered from other targeted attacks throughout the conflict. The TIME data denotes that on April 3rd, 2017, a Saudi-led coalition airstrike hit a farm in the Bani Harith district of Amanat Al Asimah (ACLED, 2020). In 2017, 53 incidents involving the agriculture sector in Sana’a and Amanat Al Asimah
were captured in the database. In the year 2018, 23 attacks on agriculture infrastructure can be observed in the TIME data. Incidents in Sana’a tracked by the TIME project revealed that Agriculture was the most frequently targeted sector in both 2017 and 2018, constituting 65% and 70% of the total incidents for each year respectively (Fig. 1). This is partly because there are many more farms, farm equipment, and markets to target than there are other types of infrastructure such as health facilities, power stations, or water treatment plants. Damage to farms in districts like Bani Harith introduced yet another strain on resources by slowing food production. Combined with high food prices and a crippled market system, this created the potential for malnourishment to proliferate as an additional vulnerability to cholera. By 2020, the crisis in Bani Harith had escalated, rendering it the district with the single highest estimated number of people in need (WASH Cluster, 2020). This is just one example of how communities in Sana’a are dealing with pressures caused by attacks on multiple infrastructure sectors.

While Agriculture is the most targeted, the sectors which confer the most immediate vulnerability to cholera are Water and Energy. Damage to water and energy infrastructure often results in reduced access to electricity and safe water for large swaths of the population. The year 2016 had few corresponding entries in the TIME data. In the case of Amanat Al Asimah and Sana’a, collectively 7 total incidents were included in the database. Of those 7, 5 of them involved targeting of water infrastructure. In 2016, 5 instances of damage to water infrastructure were recorded (Fig. 1). One such event, which took place on February 7th, 2016, was the Saudi-led coalition’s bombing of water storage tanks in Al-Nahdain (Asiri, 2016). These tanks were reportedly totally destroyed and rendered non-operational. As a result, the 30,000 people who had previously relied on the tankers lost access to the safe water it supplied. The task of replacing the tanks would prove costly, as the tanks were valued at 4 million dollars (Asiri,
2016). Attacks like these continued through 2017 and 2018, manifesting the same effects across the two governorates. In Sana’a and Amanat Al Asimah, 4 attacks on water and 6 on energy were recorded in 2017. In 2018, 1 attack on water infrastructure and 4 on energy were captured in the database (Fig. 1). With power down, and consequently obstructed access to clean water, many in Sana’a likely turned to unsafe water sources, the consumption of which could cause cholera infections.

Cholera patients seeking treatment encountered challenges in seeking out and receiving treatment. Targeting of transportation infrastructure has a hand in obstructing people from benefiting from both food and health services. In the case of Sana’a and Amanat Al Asimah, there were 18 recorded incidents in which bridges, roads, and airports were targeted from 2016 to 2018 (Fig. 1). While damage to roads like the main road in Al Manakhah on January 19th, 2017 by Saudi-led coalition airstrike restricted travel to hospitals and care facilities (Yemen Data Project, 2020), airstrikes on Sana’a airport were repeatedly perpetuated by the Saudi-led coalition in 2017, once on April 9th and again on April 12th. Attacks on airports have the potential for widespread devastation by depriving thousands of people from benefiting from life-saving medical equipment that is shipped internationally to Sana’a.

Damage to health infrastructure is directly related to cholera patients’ access to life-saving treatment. In 2017, Sana’a and Amanat Al Asimah, 2 incidents involving health facilities were recorded. On April 5th, 2017, a hospital in Amanat Al Asimah was the target of a Saudi-led airstrike (Yemen Data Project, 2017). In 2018, 4 attacks on health facilities were perpetrated in these two governorates (Fig. 1). On April 27th, 2018, a Saudi-led airstrike hit the National Blood Transfusion and Research Center of Al Sabeen Hospital (Humanity & Inclusion, 2018). Harm
done to patents, medical personnel, facilities, and equipment could prove fatal to those battling severe cases of cholera.

**Actors Involved in Incidents**

The actors responsible for carrying out targeted attacks against civilian infrastructure in Sana’a and Amanat Al Asimah reflect the adversarial tensions between the forces who control the area and those struggling against them. As previously illustrated, the governorate of Sana’a and the Capital City are both under the de-facto control of the Houthi forces and have been since 2014. The Saudi-led coalition is carrying out a campaign against the Houthi forces to restore the Yemeni government’s control of Sana’a under Hadi. Aerial attacks there began in 2015, and, according to the TIME data, account for a majority of the incidents in which civilian infrastructure was targeted. All of Sana’a and Amanat Al Asimah’s recorded attacks for 2016 were attributed to the Saudi-led coalition. In 2017, the Saudi-led coalition was responsible for 80 incidents, 99% of the total, and in 2018, for 30 incidents, 91% of the total (Fig. 2). The Saudi-led coalition was the only actor that perpetuated any air attacks in Sana’a and Amanat Al Asmiah during this time period. These airstrikes resulted in extensive damage and destruction as well as numerous civilian casualties and injuries. One airstrike carried out on August 23, 2017, targeted a Qat Farm housing unit and resulted in the death of 41 civilians, all of which were identified as farmers (ACLED, 2020). In this example, not only is the human toll apparent, but the agricultural/economic one as well. It is important to note that the Saudi-led coalition issued a statement denying responsibility, attributing the attack to Houthi combatants instead.

Other actors targeted civilian infrastructure through the use of other means like explosive weapons and shelling. Political militias, namely pro-Hadi military forces, who opposed Houthi
control, were responsible for two attacks (Fig. 2). One transpired on December 25, 2017 when forces fired more than 37 rockets into farms in Sana’a city’s Nihm district (ACLED, 2020). The other took place on September 6, 2018, on which day pro-Hadi military forces fired artillery at farms and houses in the same district (ACLED, 2020). It was reported that 2 civilians were injured.

**Cholera in Sana’a**

Sana’a is the epicenter of Yemen’s cholera epidemic. It is in Amanat Al Asimah that the first cases manifested that would eventually lead to widespread infection. On October 6th, 2016, 11 confirmed cases of cholera were reported in one neighborhood in Sana’a city. As there were no reports of cases anywhere outside of this cluster, officials did not yet foresee the potential spread of the disease. Omar Saleh, an official from the WHO held a press conference in Sana’a following the reports, noting that “All the suspected cases are from the same area, they are all interconnected, there is no spread of the disease” (UNICEF, 2016) The WHO would later come to view these cases as triggering the start of the first wave of the cholera epidemic in October 2016 (Al-Mandhari et al., 2018).

Around the start of the second wave of infection on April 27th, 2017, news agencies reported a strike by sanitation workers and water engineers in Sana’a, who had gone unpaid for weeks as a result of the conflict (Gladstone, 2017). The internationally recognized Yemeni government under Abdel Mansour al-Hadi had stopped compensating public workers in places like Sana’a because they were under rebel control. As a result, the streets of Sana’a were littered with garbage and municipal sewage drains were clogged (Kennedy, 2017). This increased the likelihood of water contamination and infection from cholera.

Following 2 weeks of a devastating outbreak, on May 14th, 2017, The Health Ministry of
The Cholera Crisis in Yemen

the Houthi government declared a state of emergency in Sana’a. The following day, at a press conference in Aden, the International Committee of the Red Cross (ICRC) announced that since April 27th, 184 deaths from cholera had been reported. The outbreak, originating in Sana’a and Aden, had led to suspected cases in 14 of the 23 governorates (Al Jazeera, 2017). At this point, Sana’a and Amanat Al Asimah had been the most impacted, reporting 4,000 cases. The dataset obtained from OCHA shows that this total increased to 6,224 cases and 50 deaths by the end of that same month in the governorate of Sana’a and 13,700 cases and 36 deaths in Amanat Al Asimah. From May 22nd to June 10th, together these two areas led the other governorates in case totals (Fig. 3).

The city’s hospitals were overwhelmed by cholera patients. While typically it might be relatively easy to treat and control cholera, the circumstances of these outbreaks were challenging. The city had incurred damage to healthcare facilities during the past few years of the conflict. Hospitals were ill-equipped and short-staffed to meet the demands of thousands of patients. Médecins Sans Frontières (MSF) alone had taken on 1,670 of the city’s patients (Allana, 2017).

While Sana’a experienced a resurgence of cases, other governorates began to observe a rise in incidence. Over the course of the next few weeks, 22 of the 23 governorates had cases to report, all except Socotra Island. Those most affected were children, including people younger than 18 years old, who made up approximately 60% of suspected cases. Within that demographic, children 5 years and younger constituted 29% of total estimates. For some, namely people over 60 years old, infection conferred a higher risk of death. This demographic made up about one third of cholera associated deaths at this point in the epidemic (Al-Mekhlafi, 2018).
Cases & Attack Rate

In regard to the governorate of Sana’a, the data shows a steady rise in cases from June 2017 to August 2017, at a rate of about 8,326 cases per month (Fig. 4). Similarly, the Sana’a governorate’s attack rate per 1000 people rose steadily from May 2016 through August 2017, climbing from 4.110 to 22.805 (Fig. 4).

This is followed by a sharp spike in cases in the month of September by roughly 17,250 cases accompanied by a jump in the attack rate to 41.437. Another significant jump in cases occurs in October, in which the total case count rises by approximately 16,250 (Fig. 4 & 5). This is indicative of the highly infectious nature of the disease, and its ability to rapidly spiral out of control. Likely contributing to this sudden spike is Yemen’s rainy season, particularly in the northern part of the country. Rain typically begins in mid-April and continues through the end of August. During the spring rainy season, a number of factors contribute to making the environment particularly hospitable to *V. cholerae*, among them the contamination of water sources, the proliferations of zooplankton, from and on which the bacteria derives its carbon source (Jia & Zhang, 2020), and changing iron levels in water conducive to the organism’s survival. There has been an observed lag between the rainy season and cholera risk. As a result, the effects of the beginning of this rainy season during the months of April and May manifested in the later months of September and October in the year 2017 (BBC News, 2017).

The city of Sana’a did not demonstrate the same spike in cases during this time. In Amanat Al Asimah, incidence started much higher at 13,700 cases in May 2017. The attack rate, however, closely mirrored that of Sana’a governorate for that same month, measuring 3.573. The case total continued its upward trend, but the rate at which it did so decreased each month. From May to June, cases increased by 22,540. From July to August, the same time period in which
Sana’a governorate experienced a jump in case totals, Amanat Al Asimah’s rate of case increase slowed, moving up by 12,548 cases in one month. The attack rate in Amanat Al Asmiah and Sana’a matched almost exactly in August 2017. At 23.345 in Amanat Al Asimah, only 0.917 separated the two governorates. The two diverged from one another when Sana’a’s attack rate surged the following month (Fig. 4 & 5).

The divergence may be due in part to the efforts of Health and WASH clusters, who scaled up their response in Sana’a city. By June, an emergency operations center was actively surveilling the spread of Cholera throughout the city and coordinating the response on the ground (Health, WASH Cluster, 2017). Their campaign focused on preventing infection with Cholera through sanitation and education. As a result, 2 million people in the cities of Aden and Sana’a received information about water safety. Additionally, water supplies were chlorinated at both the household and system levels, providing 5 million people in the cities of Sana’a and Aden with access to safe water. Nearly half also benefited from water storage disinfection (Health Cluster, 2017).

We would expect to observe a similar spike in later months in the governorate of Sana’a as a consequence of the summer rainy season, which spanned from July to August 2017. Instead, cases continued to rise, though at a slower rate month after month from October 2017 to February 2018. From the month of December 2017 to January 2018, only 2,877 new cases had been reported. By February 2018, Sana’a reported 76,250 total cases. From October 2017 to February 2018, the attack rate continued to rise, but at a much slower rate than it did previously. By February 2018, the attack rate had reached 51.607 (Fig. 4 & 4). The elevated risk of cholera following the Summer rainy season was partly mitigated and subdued by WASH initiatives that
were carried out, which reportedly tripled between the Spring and Summer seasons (London School of Hygiene & Tropical Medicine, 2018).

By January 2018, Amanat Al Asimah’s case curve showed signs of plateauing, increasing by only 3,259 cases since the previous month. The attack rate had risen to 51.607 in February 2018. At this point in time, the trend in the Sana’a and Amanat Al Asimah had started to look more similar, though Sana’a city certainly led in overall totals, reaching 103,184 cases by February 2018 (Fig. 4 & 5).

**Deaths & CFR**

The death toll as a result of cholera in Sana’a started at 50 in May 2017 at the beginning of the second wave, and followed a logarithmic pattern from then until February 2018. A steep climb in deaths can be observed between May and June 2017 to a total of 99 deaths, followed by a slower rate of increase to 117 deaths in July 2017, before the death totals plateau, remaining at roughly 122 for the remainder of the data collection period in February 2018. The CFR in Sana’a, indicative of the fatality of the disease in the governorate over time, starts off very high in May of 2017 at 0.9% (Fig. 6 & 7). At this point, the beginnings of the second wave were tearing through the governorate and healthcare workers found themselves and their facilities severely ill-equipped to handle the staggering number of incoming patients.

In Amanat Al Asimah, 36 deaths were recorded in May 2017. The logarithmic pattern can be recognized here as well. There is an initial steep climb from May to June 2017, the death toll increasing by 17. The curve quickly plateaus following this, nearly leveling by February 2018 at 71 deaths. The CFR in Amanat Al Asimah follows a similar overall trend. It is important to note that the death and CFR measures in Sana’a are higher than those in Amanat Al Asimah
overall (Fig. 4 & 5). One factor contributing to this may be the residents of Amanat Al Asimah’s proximity to healthcare facilities. The city of Sana’a has more hospitals than anywhere else in the country. Logistically, it would be much easier for a cholera patient to seek treatment in the city, especially considering the lack of security and damage to roads one may encounter in travel.

Following the onset of the second wave, on May 25th 2017, three airplanes chartered by the WHO landed in Sana’a carrying 80 metric tons of aid, approximated to have the potential to serve 10,000 patients. Around the same time, UNICEF contributed by flying 40 metric tons of medical and WASH supplies to Sana’a as well. In the case of cholera, treatment has a tremendous effect on mortality rate (USAID, 2017). Therefore, this supply of cholera treatment kits and intravenous fluids likely made the difference between life and death for hundreds of patients. By June, interventions and initiatives had been put in place by the Yemen Health Cluster in Sana’a and Amanat Al Asimah to treat cholera infections, including 311 oral rehydration points, opened to receive patients with mild and moderate symptoms. For severe cases, 2,351 Cholera Treatment Center (CTC) beds, supplies, and medical personnel were allocated to treat those most affected by the disease (Health, WASH Cluster, 2017). As access to treatment increased, rates of change in deaths and CFR decreased.

In Sana’a governorate, the CFR dropped drastically to 0.434 come June 2017, and continued to decrease steadily from August 2017 to October 2017, at which point the CFR was estimated to be 0.2. Sana’a continued to experience a CFR of roughly 0.2 from October 2017 to February 2018. The CFR in Amanat Al Asimah was estimated to be 0.33 in May 2017, and then dropped rapidly in a span of two months to 0.1 in July 2018. From July to December, CFR remained relatively stable. There is a dip to 0.035 in January 2018 before it increases slightly in February 2018, returning closer to the previous measure of 0.1 (Fig. 4 & 5).
AL HUDAYDAH

Military and Political Dynamics

Houthi forces seized control of Al Hudaydah city in 2014. In 2017, the Saudi-led coalition imposed a blockade on the port in retaliation to a Houthi missile strike on the Saudi airport Riyadh (European Strategic Intelligence and Security Center, 2018). Al Hudaydah and Al Saeef ports were previously responsible for the processing and entry of 80% of Yemen’s commercial imports. The blockade, in violation of International Humanitarian Law (IHL), prevented millions in Yemen from benefiting from the commercial imports and humanitarian aid (Artrip, 2017). Control of the Red Sea port therefore confers a strategic advantage for all sides of the conflict.

After Houthi forces refused the demand to withdraw peacefully from the port by June 12th 2018, the Saudi-led coalition escalated their efforts to retake Al Hudaydah from Houthi forces on June 13th, when they launched a joint campaign with the United Arab Emirates and pro-Hadi military forces known as the Golden Victory Offensive. This was the largest battle of the war as of 2018 (European Strategic Intelligence and Security Center, 2018). Fighting between the Houthi forces, pro-government groups, and the Saudi-led coalition over Al Hudaydah has escalated since 2018, particularly in the port city (European Strategic Intelligence and Security Center, 2018).

What factors confer vulnerability to cholera infection in Al Hudaydah?

Population/Displacement

Al Hudaydah governorate was estimated to have a population of approximately 3,000,000 in 2019. Adult females (18+) make up approximately 24% of the population at
705,528 individuals. Adult males constitute about 25% of the population, with a total of 725,638 people. Of this total, it is particularly important to note that 563,172 are children and 63,552 are people over the age of 60 (OCHA Yemen, 2019). These two demographics are typically more vulnerable to infection and serious/fatal health outcomes from cholera.

Since the start of the conflict in 2015, many people from Al Hudaydah have been driven from their homes multiple times over, becoming refugees in their own country. Over 1 million Yemenis were internally displaced in the first six months of the conflict (Gardner, 2015). A number of factors contribute to displacement in Al Hudaydah, the most direct of which is the violence the governorate has become increasingly subject to, including air raids, and attacks by means of explosive weapons on the ground.

Al Hudaydah city is the fourth largest city in the country with a population of approximately 600,000 people. Upon the launch of the Golden Victory Offensive, more than half of the city's 600,000 residents were forced to leave. This brought the number of displaced people to 333,846 people (International Organization for Migration, 2018). From December 2017 to March 2018, more than 21,000 people previously residing in Al Hudaydah fled South to Abyan. Others went to other governorates including Sana’a, Lajh, Al Maharah, Aden, Idd, Dhamar. One heavily affected district was Hays, which went from a population of 67,000 to 40,000 (ACAPS, 2018). As attacks continued to damage infrastructure and endanger lives, many found themselves living in an unsanitary and unsafe environment which left them vulnerable to poverty, harm, injury, and illness.
**Malnutrition**

The blockade of Al Hudaydah port has had immediate and severe consequences for food security in Al Hudaydah. Attacks have caused extensive damage to the port’s infrastructure, further slowing the shipment process. Residents are facing not only food shortages but also fuel shortages. A growing need for fuel is a result of both the Saudi-led blockade of the port as well as the actions of Houthi forces, who are selling fuel on the black market (Artrip, 2017). Transportation of food also became increasingly difficult. The roads and bridges connecting the port to local markets in Al Hudaydah have been damaged, and numerous security checkpoints have been installed along the routes. For example, the road between the districts Hays and Al Garrahi remained blocked for several months according to reports in February 2018, complicating trade logistics between the two districts (ACAPS, 2018). Obstacles at virtually every point in the food delivery system have made access to food both complicated and costly. The people of Al Hudaydah are ill-positioned to pay skyrocketing expenses to feed themselves and their family.

Between November 2017 and March 2018, the average cost of a food basket in Al Hudaydah increased by 15% (ACAPS, 2018). Unemployment breeds food insecurity in the governorate. Pre-conflict, Al Hudaydah’s location and landscape allowed people to make a living farming, raising livestock, and fishing. Farms and farm equipment have been damaged by airstrikes and violent clashes on the ground. Farmers still operating in the region have stopped growing staple crops and taken up qat farming instead because it allows them to generate more profit in the difficult economic circumstances. This transition means that the population must rely more heavily on imports. In fact, 90% of the staple foods are now imported (Artrip, 2017) compared to 75% in 2010 (New Agriculturist, 2010).
Livestock holders face a number of challenges. Pastures and shelters have been damaged. Veterinary care has become out of reach. Restricted movement and reduced access to water and grazing grounds have made it difficult to continue raising and livestock. Poor environmental conditions may also affect the health of livestock, which is interconnected with human health. Close contact between animals and humans may provide the opportunity for disease to spread (CDC, 2018). Economic hardship has forced many to sell their livestock in order to provide for their families. In December 2017, livestock sales increased by more than 50% in the districts of Al Garrahi, Hays, and Jabal Ras 2017 (ACAPS, 2018). In coastal districts such as Tuhayat, the fishing and agriculture industries were the primary source of income for about 102,000 people prior to the conflict in 2015 (ACAPS, 2018). Attacks on the fishing industry have targeted fishing boats and equipment in the Red Sea and killed many fishermen. The average income in Al Hudaydah plummeted more than 50% between 2014 to August 2017 (ACAPS, 2018).

The situation as a whole has resulted in widespread food insecurity across Al Hudaydah. By 2018, the situation in the governorate was designated a crisis at an IPC level of 3 (Famine Early Warning System, 2018). Even with humanitarian food assistance, 1,685,000 people were characterized as experiencing Phase 3 crisis or Phase 4 emergency levels of food insecurity (IPC Global Support Unit, 2019). In 2018, the governorate had a malnutrition rate of 25%, the highest in Yemen (“Health Conditions,” 2020). Malnourished communities are at a heightened risk of becoming sick and suffering from severe symptoms.

**Access to Healthcare**

With rising levels of malnutrition, and an environment conducive to the spread of cholera, healthcare accessibility was more important than ever in Al Hudaydah during the war.
But the crumbling healthcare system has become overwhelmed by a soaring number of patients, many of whom require treatment for cholera and diphtheria, both of which the governorate witnessed through massive outbreaks starting in 2016 (ACAPS, 2018). Import restrictions have barred medical supplies from facilities in need. The facilities are underfunded as a result of the conflict. Because Al Hudaydah is under Houthi control, the Yemeni government stopped compensating public servants on account of accusations that the Houthi forces were putting their fighters on the government payroll. Healthcare professionals in Al Hudaydah are therefore operating as unpaid workers (ACAPS, 2018). In addition to this lack of capacity, the health sector has been subject to damage and destruction. For example, Hays hospital provided healthcare for 10,000 households before an airstrike shut the hospital down in December 2017.

Damage to infrastructure like roads and bridges has obstructed patients’ travel to healthcare facilities. For the health hubs still operating, the fuel shortage has many running at reduced service, with insufficient electricity to run the lighting and equipment needed for surgery, deliveries, and other procedures. This continued despite a promised fuel donation from Saudi Arabia in January 2018. By mid-February, the donation remained undelivered. At this point in the conflict, it was determined that 17% of Yemen’s fuel requirement was focused in Al Hudaydah and Taizz. Of the 22 governorates, Al Hudaydah’s fuel needs were the second highest in the country during this time (ACAPS, 2018).

Collectively, these factors have collapsed the healthcare system. Al Hudaydah is a governorate which falls significantly short of the WHO’s standards for healthcare (WASH Cluster, 2020). The number of hospital beds per population in the governorate missed the WHO’s requirement by approximately 40% in and by 50% in 2018 (WASH Cluster, 2020). Additionally, a shortage of medical personnel means that the health sector can only cover 45% of
the population in Al Hudaydah (WASH Cluster, 2020). In one survey conducted in 2020, 10
districts in Al Hudaydah received a vulnerability score of 6 out of 6 and a designation of ‘critical
vulnerability’. These districts were among the 12 districts across the country where internally
displaced people were most vulnerable to communicable diseases like cholera (WASH Cluster,
2020).

**Access to WASH**

Pre-conflict, the governorate of Al Hudaydah already lacked adequate water and
sanitation water infrastructure, although water supplies were comparably higher than in much of
Yemen. In 2007, Al Hudaydah city’s water supply covered 96% of the population, and sanitation
services reached a mere 55% of the population (Ward, 2015). Rural towns had poorer service
and higher costs. Before the attacks on Al Hudaydah escalated in June 2017, most of the
households in the governorate were serviced by a piped water network. An estimated 88% of the
Al Hudaydah governorate’s population enjoyed access to improved water sources (ACAPS,
2018). The energy sector is inextricably intertwined with the water sector, as fuel and electricity
determine which parts of the governorate receive clean water and which did not. Piped water
systems require electricity to pump water into households (ACAPS, 2018). When fuel is
unavailable, clean water cannot be extracted from deep wells, and transportation of water to
vulnerable communities, such as those with a high number of displaced people, is also
obstructed. In November 2017, The Red Cross declared that the city of Al Hudaydah had
exhausted its clean water stores and issued a warning about another potential cholera outbreak
(Kasinof, 2017).
Direct damage to water infrastructure made clean water even more inaccessible. For example, in December 2018, the desalination plant in Al Khawkhah, located in the Hays district, operated at only half capacity after the plant’s generator was severely damaged (ACAPS, 2018). WASH evaluations in 2019 and 2020 revealed that Al Hudaydah was among the governorate with the consistently highest severity scores. Severity scores were based on a 7 point scale ranging from 0-6, the criteria for which included the core indicators of access to improved water sources, access to functional and improved sanitation, access to functional handwashing facilities, and broader indicators such as global acute malnutrition rate, cholera attack rate, infrastructure access rate, and flood susceptibility rate. Five districts in Al Hudaydah led the country in severity scores close to 6 in 2020 (WASH Cluster, 2020). The conflict therefore increased the likelihood of exposure to, and contact with, contaminated water for people in Al Hudaydah, positioning the governorate to be the site of one of the most devastating outbreaks in the country.

Infrastructure Destruction

Targeted Infrastructure

The TIME project includes 373 total incidents from the years 2016 to 2018. The database features only 7 entries for the governorate of Al Hudaydah in 2016. In addition to attacks on farms and markets, which were numerous, the fishing industry was also categorized under the agriculture sector. Two of the incidents in 2016 were categorized as attacks on fishing boats. On February 1st, 2017, a Saudi-led airstrike hit fishing boats off the coastline of Al Khawkah (Yemen Data Project, 2020). The UN’s Sustainable Development Goal #14 draws the connection between ocean health and human health. Fisheries play an important role in
livelihood, nutrition, and by extension, health and wellbeing (United Nations, n.d.). Attacks on fisheries in Al Hudaydah could have negative consequences for communities that rely upon them. Cumulatively in 2017, there were 33 instances in which the agricultural sector was targeted in Al Hudaydah, constituting 38% of the governorate’s entries that year. Comparatively, a majority, 72% of the incidents in 2018 were agriculture-based attacks in Al Hudaydah. This is 201 of the total 373 entries for the three-year period in the governorate. While farms were the most common targets, 2018 featured a number of attacks on food aid infrastructure. On May 8th, a missile from an unknown party struck in Al Mina, setting fire to a World Food Program warehouse containing food aid (Civilian Impact Monitoring Project, 2018). On August 13th, a Saudi-led airstrike was carried out targeting a food distribution point in Durayhimi (Civilian Impact Monitoring Project, 2018). These are examples of intentional attacks that demonstrate a growing disregard for the protected status of humanitarian aid from all sides of the conflict (Fig. 8).

According to the TIME database, in 2017, the infrastructure category most frequently targeted in Al Hudaydah was transportation, constituting 52% of the incidents in the governorate that year. The 45 incidents include repeated attacks on Al Hudaydah Airport, Al Hudaydah Port, Al Khawkhah Port, as well as roads and bridges. Al Hudaydah Airport, located in Ad-Durayhimi district, was targeted repeatedly from January 2017 to July 2018. Over the course of 2017, 4 Saudi-led airstrikes were carried out on Al Hudaydah Port. There was 1 documented Saudi-led airstrike on the port in 2018 (OCHA, 2018a) (Fig. 8). Considering Al Hudaydah Port is an important anchor institution, serving as the country’s point of access to the rest of the world, damage to the port brings with it serious and implications such as the obstruction of food, fuel, and medical supplies, as well as rising import expenses, all of which put those not only in Al
Hudaydah, but by extension people across the country, in a particularly vulnerable position (Fig. 8).

Moreover, attacks on transportation infrastructure such as roads and bridges directly impact the civilian and health worker travel as well as transportation of food and medical aid. On August 6th, 2017, the Sana’a-Al Hudaydah road, the primary route of exchange and travel between the two cities, was subject to an airstrike perpetrated by the Saudi-led coalition (Yemen Data Project, 2020).

The interdependence of water and energy infrastructure is important to recognize when considering the effects of infrastructure destruction in Al Hudaydah. In the year 2016, two events involved energy and water infrastructure respectively (Fig. 8). Targeted energy infrastructure included an oil refinery operated by Houthi forces in Jabal Ras district. A Saudi-led airstrike on January 21st, 2016 rendered the facility non-operational and resulted in the deaths of 9 people, among them oil workers, and injured 20 more. This reportedly disrupted fuel distribution, which only exacerbated fuel shortages and soaring prices (Yemen Data Project, 2020).

Water infrastructure was harmed in 2016 when Saudi-led coalition airstrikes were carried out on the island of Kamaran on December 10th (Yemen Data Project, 2020) and again on the 15th (Al-Mrasel, 2016), resulting in extensive damage to water storage tanks on the island. As a result, the people on the island experienced a reduction in and pollution of their water supply. It may have become more difficult for people of the island to access clean water, especially considering they are removed from the mainland, where alternative water sources may be available. In 2017, 6 attacks on water infrastructure were reported in the governorate, two of which also transpired on Kamaran Island. Nearly 7 months following the destruction of water tanks, a water desalination plant was bombed twice in the span of two days (Al Motamar, 2017).
On an island, where freshwater is limited, desalination plants play an integral role in providing purified water to the community. This could have exacerbated the pre-existing strain on the island’s resources. In 2018, 5.4%, or 15, of the incidents recorded for Al Hudaydah involved water infrastructure and 1.4%, or 4 incidents, involved energy infrastructure. On July 27th, 2018, a UNICEF-supported sanitation center in the Zabid district of Al Hudaydah was targeted by the Saudi-led coalition in an airstrike which damaged the facility’s fuel tank (*Yemen: Attacks on Water, 2017*). As a result, the facility was only partially operational. This incident exemplifies the extent to which water infrastructure is heavily dependent upon energy and the Saudi-led coalition’s disregard for humanitarian aid. Already that year, Zabid had been subject to attacks which damaged its roads, farms, markets, and factories (Fig. 8). This blow compounded this violence and destruction by leaving untreated sewage in the environment, creating the ideal conditions for cholera infection to proliferate through the population.

As for the direct targeting of the health sector, Al Hudaydah’s health facilities incurred damage and destruction during this three-year period. The TIME database documents 2 events in which health facilities were targeted in the governorate during the year 2017. The first took place on December 10th when Hays Hospital was the target of a Saudi-led coalition airstrike (OCHA, 2018b). Tens of casualties and injuries were reported, along with extensive damage to the building and supplies within it including medicine. At this point, the hospital remained partially operational. Just a few weeks later, on December 28th, a second airstrike rocked Hays Hospital, killing 5 civilians, among them an ambulance driver, and halting all operations. This prevented 10,000 households and countless patients suffering from injuries, malnutrition, and infectious diseases-- including cholera-- from benefiting from healthcare at this hospital (*Yemen Data Project, 2020*). In 2018, attacks on health infrastructure accounted for 8.6% of the reported
incidents in Al Hudaydah. The 24 entries included targeted rural hospitals like urban hospitals, a mental hospital, ambulances, a health office, lab, and pharmacy. In the port city of Al Hudaydah, the Saudi-led Coalition’s offensive against the Houthi rebels in the city led to damage of a water and sanitation station as well as health centers on July 30th, 2018 (Saudi Airstrikes in Yemen, 2018). The conditions in the city following this attack left the community particularly vulnerable to cholera infection. Just 4 days later, on August 2nd, Al Thawra Hospital, a major healthcare provider in the city, was bombed in an airstrike (Fresh Yemen hospital attack, 2018). At least 20 casualties were reported. In November 2018, as fighting intensified, bombs and gunfire moved closer and closer to Al Thawra Hospital. This endangered the lives of healthcare workers and patients, particularly children, 59 of whom were being cared for at the time, 22 of them in the intensive care unit (Mekki, 2020). These attacks stripped the city of its most important defenses against cholera infection: access to medical treatment (Fig. 8).

**Actors Involved in Incidents**

The majority of the incidents located in Al Hudaydah captured in the TIME database listed the Saudi-led Coalition as the actor responsible. All 7 attacks recorded for the governorate for the year 2016 were attributed to the Saudi-led coalition. The year 2017 had 87 recorded incidents, all of which implicated the Saudi-led coalition. The year 2018 featured the most recorded incidents during this time period. Seventy-eight percent, 217 out of 279 in Al Hudaydah that year, attributed the attacks to the Saudi-led Coalition. This actor mainly perpetrated attacks on civilian infrastructure through airstrikes, which often resulted in more casualties than clashes and attacks from the ground. For example, in 2016, the bombing of an oil facility controlled by Houthi forces resulted in the deaths of a reported 9 people (Yemen Data Project, 2020). On
August 2nd, 2018, a strike on a fish market located in Al Hudaydah city killed 55 people, many of whom were women and children (OCHA, 2018c). While other actors in the area focused their attacks on agriculture infrastructure, the Saudi-led Coalition additionally targeted other types of infrastructure which more directly impacted water safety and access. Of 23 total attacks on water infrastructure recorded from 2016 to 2018, 20 of them involved the Saudi-led coalition (Fig. 9).

Political militias were responsible for 9% of the incidents in Al Hudaydah recorded in the TIME database in 2018. The National Resistance Forces, a private militia loyal to Tareq Salih, was implicated in 14 of attacks on civilian infrastructure in 2018. The other political militia operating in Al Hudaydah during this time were the Military Forces of Yemen, to which 11 incidents were attributed. All targeted local farms, either through seizure or the use of explosive weapons (Fig. 9). In one instance, on July 22nd 2018, the Saudi-led Coalition and the National Resistance Forces engaged in a joint attack on farms in Zabid, where Houthi forces were positioned. The Saudi-led airstrike allowed the National Resistance’s Giant Brigade on the ground to overtake the Houthi forces, who lost 35 of their fighters in the process (ACLED, 2020).

Houthi forces engaged in 6 of the attacks recorded in Al Hudaydah, all of which took place during 2018, constituting 2% of the attacks tracked that year (Fig. 9). In November and December of 2018, 2 of these incidents involved the forced occupation of hospitals in the governorate, accomplished by means of armed attacks. When Houthi forces take over health facilities, not only do they obstruct cholera treatment, they also make the facility vulnerable to attack by the Saudi-led Coalition, who could target the location in their efforts to subdue the Houthi forces inside. Houthi forces also targeted markets, factories, and fishing boats.
**Cholera in Al Hudaydah**

The first signs of a cholera epidemic manifested in Sana’a. As case numbers began to climb, the WHO officially declared the epidemic in October of 2016. The WHO joined with various partners to handle the outbreaks on the ground, among them the Ministry of Public Health and Population, UNICEF, OCHA, and other NGO’s (“Cholera Cases in Yemen,” 2016) including Action Contre la Faim (ACF), which the medical response and WASH interventions in Al Hudaydah city (Altman, 2017). By mid-November 2016, Al Hudaydah governorate reported 693 cases of cholera, 242 of which were children under 5 years old (Yemen Cholera Taskforce, 2016). The first wave peaked in December, after which cholera cases decreased until April 2017, when the second wave began. In July 2018, the WHO reported that Al Hudaydah city had the highest incidence of cholera cases in the country (Keir, 2020).

**Cases & Attack Rate**

At the start of data collection, the WHO reported 6,865 cases of cholera in the governorate of Al Hudaydah. Al Hudaydah therefore started as one of the most highly impacted governorates in the country, second only to the combined statistics of Sana’a/Amanat Al Asimah (Fig.1). As the second wave progressed, cases in Al Hudaydah surged, making it the governorate with the single most cases from 2017 to 2018. From May to October 2017, case totals rose sharply. In a single month, cases rose by 23,169 from May to June 2018. This steep upward trend persisted as cases rose to 53,803 in July, 74102 in August, 97193 in September, increasing at a steady rate of around 20,000 cases per month. In October 2017, cases rose even more sharply, at a rate of approximately 30,000 cases in a single month, bringing the case total up to 127, 366.
In this same month, water tanks on Kamaran Island were hit, once on October 11th and then again on October 28th. Following the month of October, cases began to accumulate at a much slower rate. From October to November 2017, Al Hudaydah reported 11,779 new cases. The rate of increase continues to slow. By January 2018, the case total had reached 153,446, a change of about 4,400 from the month prior. A cumulative number of 155,908 cases were reported in Al Hudaydah in February 2018 (Fig. 10).

The attack rate, measured per 1000 people, followed a similar path into 2018. In May 2017, the attack rate in Al Hudaydah started at 1.070. It climbed rapidly from May to October 2017 at an increasingly faster rate. From May to June 2017, the rate of change was about 5 per 1000 people in a single month. From June to September 2017, the attack rate increased by a rate of approximately 7 each month. The attack rate in September was 26.880. From September to October, this measurement climbed even more rapidly, demonstrating a rate of change closer to 8 over the course of that month. Starting in October 2017, the attack rate continued to increase, though at an increasingly slower rate, increasing by approximately 5 each month from October to December 2017. From December 2017 to January 2018, the attack rate increased by 1.398. The final month of data collection, February 2018, featured an attack rate of 47.909 (Fig. 11).

Deaths & CFR

At the start of data collection in May 2017, Al Hudaydah reported 49 deaths from cholera. From then, the death toll rose at a very rapid rate before generally slowing from August 2017 to February 2018. The month of June 2017 had the highest reported number of deaths during this time period, 123, and brought the death toll to 172. From June to July 2017, 59 more deaths were recorded. Come August 2017, deaths continued to accumulate, though the rate at
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which they did slowed significantly. 8 deaths were recorded for the month of August, and 15 for the months of September and October. The rate continued to slow, at a pace of about 3 deaths per month from November to January. By February 2018, 282 total deaths had accumulated during the period of data collection (Fig. 12).

The CFR started high and quickly decreased as time progressed. In May 2017, the CFR in Al Hudaydah was reported to be at 1.5%. This quickly plummeted during the month of June, dropping to 0.585%. From then on, CFR maintained a general downward trend from June 2017 to January 2018. CFR dropped to 0.490 in July, 0.363 in August, 0.282 in September, 0.227 in October, 0.203 in November, 0.190 in December, 0.093 in January, each month dropping at a faster rate. In February 2018, CFR picked up slightly, returning to 0.180, a value close to what it was back in December 2017 (Fig. 13).

MA’AREB

Military and Political Dynamics

The governorate of Ma’areb seems to be an exception in Northern Yemen as a governorate not under Houthi control. The Houthi expansion in 2015 was resisted by tribal forces loyal to the Yemeni government in the governorate, who forced advancing forces to fight in the mountains, directing them away from more densely populated areas. This strategy was successful and drove Houthi forces to retreat from the provincial capital. Following this show of resistance, the Saudi-led coalition established a relationship with the governorate, sending in military forces, weapons, and financing the governorate to support security efforts and establish it as a resistance center in the North.
Ma’areb has since been jointly governed by a number of actors, including military officials from Saudi Arabia and the UAE, tribal leaders, and local prominent politicians. While friction exists between the various actors, some of which have manifested as small skirmishes, they have generally maintained peace and governed successfully. Ma’areb is therefore one of the last strongholds for the Hadi government in northern Yemen. Further from the city, in the surrounding districts like Qaniah and Sirwah in the western part of the governorate, clashes between the Saudi-led coalition, pro-government, and Houthi forces persist (Nagi, 2019). Recently, in 2020, Houthi forces have begun pursuing control of Ma’areb more aggressively. A Houthi victory in Ma’areb could change the dynamics of the war and give them the upper hand in the conflict (“Preventing a Deadly Showdown,” 2020).

**What factors confer vulnerability to cholera infection in Ma’areb?**

**Population/Displacement**

Ma’areb is a northern governorate of Yemen located 17 kilometers east of the Capital Sana’a (Al-Monitor, 2020). The governorate had a population of approximately 500,000 in 2019. Adult females and males (18+) account for about 25% and 28% of the population respectively. There are an estimated 37,927 children under 4 years old and 7,783 adults over 60 years old. Children make up approximately 8% of the population in Ma’areb compared to 18% in Al Hudaydah and 20% in Sana’a and Amanat Al Asimah (OCHA Yemen, 2019).

Because Ma’areb is located relatively far from the violent battles being waged across the rest of Northern Yemen against the Houthi forces, it has become a safe haven for thousands of internally displaced people and non-Yemeni refugees who began arriving in 2015 (Nagi, 2019). By 2017, nearly 1.5 million displaced people had passed through the governorate. The majority
who settled did so in the district of Ma’areb, which lies in the eastern portion of the general governorate. Prior to the conflict, the district of Ma’areb had a population of 40,000 (Al-Rawhani, 2017), which surged to 85,000 by 2019 (OCHA Yemen, 2019). Ma’areb also acts as a transit point for migrants from Somalia and other African countries transiting Yemen to seek entry into neighboring nations like Saudi Arabia (Nagi, 2019).

People also come seeking economic opportunity. In fact, the governorate, especially the provincial capital, is a thriving economic and socio-political center compared to the governorates surrounding it, which are comparatively greatly burdened by war and violence (Baron, 2018). Prior to the conflict, the people of Ma’areb earned their living by working in a number of different fields. Ma’areb was considered a leader in agricultural engineering and many local tribes led an agrarian lifestyle, working as farmers across the rural parts of the governorate. Ma’areb is the third highest food governorate in food production, growing 7.6% of the crops in Yemen (The Republic of Yemen, 2018). The region is also oil-rich, and its oil refineries fulfilled a large proportion of Yemen’s oil requirements and employed thousands of people within the governorate. Within the city, residents run and work for businesses which continue to operate, produce profit, and expand as the population grew following 2015 (Nagi, 2019). In the case of Ma’areb, the conflict has not stifled economic activities.

Of course, the influx of displaced people has also stretched the governorate’s capacity. Ma’areb is experiencing greater need for food, transportation, housing, and public services to support its displaced population (Al-Rawhani, 2017). These needs have triggered massive urban expansion in order to house the displaced population. Even so, many still struggle to secure housing on account of low availability and high costs. The average rental cost in Ma’areb increased by 500% from 2015 to 2019 (Abdul-Malik, 2020). Living conditions deteriorate as
displaced people get farther from the city. Camps situated near the mountains are faced with flimsy tent shelters, refused access to clean water, healthcare, and food insecurity, all of which confer vulnerability to diseases like cholera (Nagi, 2019).

**Malnutrition**

Despite Ma’areb’s unique position in the context of the conflict, the governorate is not immune to the effects of the country’s crumbling food production and delivery system. In places like Sirwah, where battles continue to be waged between warring parties, malnutrition is especially prevalent. In 2015, as part of a survey of people in 26 villages in Sirwah, upwards of 97% of participants reported that living conditions had deteriorated in the past year and 92% of those surveyed identified malnutrition as an issue plaguing their community. Movement in the district had been restricted considerably by the threat of armed conflict, curfews, checkpoints, damaged transportation infrastructure, and high fuel prices. This consequently reduced mobility. In fact, 82% of respondents reported difficulty in reaching community structures and 92% expressed a lack of freedom to travel between places like from their homes to markets and back. This made it more difficult for people to secure food for their households. Many in Sirwah have also lost their livelihoods on account of the conflict. Farming and pastoralism have become an unsustainable means to earn money, exacerbated by destruction of agricultural infrastructure and a decline in purchasing power. This made it difficult to afford to buy food (The Humanitarian Forum of Yemen, 2015).

The governorate at large began to encounter similar challenges as the conflict continued. An assessment by the Famine Early Warning System (FEWS) (2016) based on data from 2015 and 2016 revealed that acute food insecurity in Ma’areb was at crisis level (IPC Phase 3). A later
assessment by the same organization revealed that the situation had remained at crisis level three years into the conflict. Though the local economy in the governorate may be in better shape comparatively, the macro-economy of the country plays a role in inflating food prices and rendering staple foods harder to access, especially for IDP populations who are typically more financially insecure (Famine Early Warning Systems Network, 2018). The Ministry of Public Health and Population released a report on the nutritional status of Ma’areb in 2018. Both urban and rural households were surveyed. Sixteen percent of households in both urban and rural zones experienced a lack of food security and 5 to 9% suffered from severe food insecurity (Republic of Yemen Ministry of Public Health and Population, 2018).

**Access to Healthcare**

Of the 120 attacks on healthcare in Yemen documented by Physicians for Human Rights (PHR) from April 2015 to June 2018, only two were located in Ma’areb. The first took place in April 2015, when the Saudi-led coalition carried out four airstrikes on Al-Watan General Hospital in the Harib district. The facility was completely destroyed. The second took place nearly a year later when Houthi-Saleh forces fired a grenade at Ma’areb General Hospital. The report claims that two people were injured, but the hospital was unimpeded from carrying on operations (2020). Unlike other governorates, Ma’areb health infrastructure was not subject to repeated and devastating attacks.

The healthcare system in Ma’areb has experienced less financial strain than other governorates. Medical personnel in Ma’areb continued to be compensated as employees under the Yemeni government in a non-Houthi controlled area. Additionally, the governorate received continued financial support from the Saudi-led coalition. This allowed humanitarian aid
organizations easier access to conduct relief efforts on the ground. Saudi-funded hospitals can be found in Ma’areb, taking care of both injured soldiers and civilians (Gambrell, 2018). Therefore, the health sector was better equipped to handle and control the spread of cholera in the governorate.

Access to WASH

Because a large part of Ma’areb has been sheltered from the armed conflict since 2015, most of the existing water infrastructure has been spared from damage and destruction. This is not the case in conflict centers like the district of Sirwah, where 88% of those surveyed by the Humanitarian Forum of Yemen and the UNHCR reported that they struggled to access safe water for drinking, cooking, and personal hygiene. One factor contributing to this is that a lack of security has prevented water trucks from transporting clean water to villages, which 55.56% of respondents were affected by. Additionally, 44.44% reported that water collection required them to travel long distances in unsafe conditions (2015). The WASH cluster’s mapping of water sources in June of 2017 reported that only 50% of Sirwah’s water sources were functional. This stands in stark contrast to the district of Ma’areb, where 95% of the water facilities remained functional (Wash Cluster, 2017).

Though parts of the governorate have managed to avoid targeted attacks and collateral damage to water and energy infrastructure, water safety and sanitation is still lacking. A Nutritional Status and Mortality Survey of Ma’areb in 2018 revealed that 4 out of every 5 households in Ma’areb’s cities do not use improved water sources. In rural locations, two-thirds of households do not use improved water sources and 30% do not use latrines. Water sanitation
is therefore lacking, increasing the risk of water-borne diseases (Republic of Yemen Ministry of Health and Population, 2018).

As the heavy fighting approaches closer and closer to the densely populated areas of Ma’areb in 2020, there are major concerns about how this could impact the health and wellbeing of civilians. Many have been displaced recently as a result of armed conflict and flooding, some for the third or fourth time, and are living in overcrowded tents with inadequate access to food, water, and healthcare (International Organization for Migration, 2020). Less than 5% of those living in these makeshift camps have access to a latrine (International Organization for Migration, 2020). This creates the opportunity for water contamination. Now, not only do these conditions render thousands more susceptible to Cholera, but also to COVID-19, which has spread rapidly through vulnerable populations (International Organization for Migration, 2020).

**Infrastructure Destruction**

**Targeted Infrastructure**

There were a total of 166 incidents collected for the governorate of Ma’areb by the TIME project. Only a single incident was documented for the year of 2016 (Fig. 14). On February 7th, a few months before the first wave of the cholera epidemic commenced, the Soqam dam located in the district of Sirwah was hit three times by Saudi-led coalition airstrikes. The dam incurred heavy structural damage which led to flooding in the area (Press TV, 2016). When heavy rainfall arrived in April, the damaged dam acted as an added vulnerability for people in the district, particularly those internally displaced, 1,600 of whom were affected by the floods (OCHA, 2016). Floods also affected the agriculture industry in the district. This flooding swept contaminated water into the environment, increasing the risk of water-borne diseases. No other
attacks on water or energy infrastructure in Ma’areb were recorded in the span of this three-year period (Fig. 14). This is one factor that likely contributed to the governorate’s resilience to cholera, which will be discussed in the coming sections.

The bulk of the incidents in Ma’areb, 109 out of 166, were categorized as targeting the agriculture sector. Sixty-five of these incidents took place in 2017, and 44 in 2018, accounting for 100% of the incidents in 2018. Farms in the governorate were targeted by airstrikes and explosive weapons. Farms and markets in Sirwah were among the most frequent targets, which were reportedly affected in 32 separate incidents. For example, an air raid by the Saudi-led coalition on April 20th, 2017, during the rainy season, destroyed a farm and damaged several houses. The farm was rendered non-operational, resulting in loss of livelihood, displacement, and a decrease in food availability (ACLED, 2020). Much of the same was reported in 2018, where 41 of the 44 attacks on infrastructure were located in the district of Sirwah (Fig. 14).

All documented damage to transportation infrastructure in Ma’areb was concentrated in the year 2017 and consisted mainly of attacks on roads. The Saudi-led coalition was responsible for 4 of the 5 incidents targeting main roads in Sirwah (Fig. 14). The remaining case was a bridge strike by the Saudi-led coalition in Sirwah on November 21st, (Yemen Data Project, 2020). Damage to these routes affected the food system in the governorate. These conditions contributed to conferring food insecurity experienced by residents of the area. People plagued with malnourishment are also more susceptible to suffering from infectious diseases.

There was one documented event in which health infrastructure was targeted in Ma’areb throughout this three-year period (Fig. 14). On December 11th, 2017, five Saudi-led coalition airstrikes were carried in Al Ali. Among the targets was a health facility. No information about the operationality of the facility following the strike was available (Yemen Data Project, 2020).
Actors Involved in Incidents

The TIME project implicated a number of political and military actors in the targeting of infrastructure in Ma’areb from 2016 to 2018. Seventy-seven of the events recorded in 2017 identified the Saudi-led coalition as the actor involved in infrastructure destruction. The majority of these 55 incidents were aerial attacks targeting the agriculture sector, particularly farms in Sirwah. 64% of the incidents in 2018 were attributed to the Saudi-led coalition, with the primary means of destruction also being airstrikes (Fig. 15).

Another prominent actor category was political militias, namely the Military Forces of Yemen loyal to Hadi. They accounted for 20% of the incidents in 2017. In total, they were responsible for 18 of the events. All were by means of explosive weapons. Though none of the incidents documented identify the Houthi rebels as perpetrators during this three-year period, there were 14 incidents for which the actors involved were unknown (Fig. 15). Considering most of them afflicted damage by means of mortar shells and explosive weapons, it is very possible that the Houthi forces participated in these attacks.

Cholera in Ma’areb

Cases & Attack Rate

The data for the governorate of Ma’areb demonstrates a curve of increasing cholera cases that rose steadily from May to November 2017 before the rate slows and approaches a plateau by February 2018. There were 114 cases reported at the start of data collection in May 2017. This total increased by 844 cases in June 2017, and by 1,527 in July. From August through November, case totals continued to increase at a rate of approximately 1000 cases per month. In December, this rate slowed significantly, with 380 new cases reported. The total plateaued from
then on, increasing by only 9 cases in January. There were 7,288 total cases reported by February 2018 (Fig.16).

The attack rate followed a very similar pattern, starting at 0.163 per 1000 in May 2017 and increasing steadily until December before taking on the shape of a plateau. In the month of June 2017, the attack rate increased by 1.257 compared to the previous month. The rate at which the attack changed picked up following the reported 1.42 in June 2017. In July, the attack rate increased by about 3.5, and then by approximately 4 in August. September through December 2018, the attack rate changed an average rate of 2.722 per month. In January, the reported attack rate only differed from the previous month’s report by 0.54. In February 2018, the attack rate was 20.323 per 1000 (Fig.17).

Ma’areb featured lower case numbers and attack rate than Sana’a and Al Hudaydah. Unlike the other governorates, people in Ma’areb benefited from access to water sources, which remained largely intact and operational throughout the majority of the governorate. In 2017, an inventory of the governorate’s water sources revealed that 72% of them retained functionality (Wash Cluster, 2017). The city of Ma’reb, home to the highest cholera attack rate in 2017, is the most densely populated of the governorate’s districts, and contains a particularly vulnerable population of IDP’s. Eighty-two percent of the city’s water facilities, and 95% of those in the neighboring district, were categorized as operational (Wash Cluster, 2017). This could have played a part in preventing the situation in Ma’areb city from escalating to catastrophic levels.

Deaths & CFR

Deaths in Ma’areb remained extremely low throughout this period of time. A single death had been reported in the month of May 2017. This rose to 4 in June and remained there for the
duration of July. The total rose slightly once again to 7 in September 2017, after which point the death toll remained the same for the rest of the data collection period until February 2018 (Fig. 18). The CFR is Ma’areb quickly plummeted from the reported value of 0.9% in May 2017. In June, the CFR rapidly decreased by 0.385 percentage points to 0.515%. CFR dropped to 0.248% in July, then to 0.139 in August. In September, there was a slight increase to 0.169, only by about 0.03 percentage points, before returning to 0.133 in October. From then on, the CFR stabilized, remaining close to 0.1% from November 2017 to February 2018 (Fig. 19).

The death toll and CFR from cholera in Ma’areb was relatively low compared to those of Sana’a and Al Hudaydah. Access to healthcare and humanitarian aid during this time period likely aided the governorate in limiting adverse effects and reducing severe outcomes. The King Salman Humanitarian Aid and Relief Center funded 20 flights into Ma’areb as of February 2018, the military transport planes stocked with food, medical aid, and shelter materials to relieve stresses experienced by local and displaced people (Gambrell, 2018). Fast and easily accessible treatment greatly reduces the mortality rate associated with cholera infection (Fournier & Quilici, 2007) and sufficiently nourished patients are less likely to suffer from severe symptoms that could lead to debilitating complications and death (Ovchinnikov, 2018).

CONCLUSION

A number of key observations emerged from the case studies of Sana’a, Al Hudaydah, and Ma’areb. Among the most prominent is that the cholera epidemic, and the humanitarian crisis as a whole, is not the result of a single factor, but the amalgamation of a number of drivers, all of which can be traced to the conflict.
One study conducted by researchers at the Center for Sustainable Development at Qatar University examined the resilience of Yemen’s basic water and energy infrastructure throughout the conflict (Al-Saidi et al., 2020). They defined vulnerability as the result of the properties which weaken and reduce an infrastructure system’s ability to function normally and persist when threatened or challenged. They defined resilience as an infrastructure system’s ability to resist, adapt, and retain functionality when subject to a disturbance. In the case of Yemen, the study identified armed conflict as the main force disrupting infrastructure operationality.

I propose that this framework of vulnerability and resilience would be valuable in my discussion on the manifestation of the cholera epidemic in each of the three governorates. While the infrastructure-specific definitions are certainly applicable to these case studies, the broader concepts of vulnerability and resilience can also be used to understand a population’s experience with cholera infection and disease outcomes, and a community’s ability to control and respond to the epidemic.

The governorates each experienced the conflict differently, and these experiences rendered them more vulnerable or resilient to the conflict’s many crises, among them the cholera epidemic. Ma’areb, as a government-aligned area, was subject to a combination of resilience and vulnerability factors. Under joint Yemeni government and Saudi military control, Ma’areb experienced the vulnerabilities that existed in other governorates at a reduced degree of severity. Therefore, one clear vulnerability factor is living in a Houthi-controlled area, such as Sana’a and Al Hudaydah.

Sana’a and Al Hudaydah, both under de-facto Houthi control, were subject to a much more aggressive military campaign at the hands of the Saudi-led coalition. Sana’a, as the previous government Capital, and Al Hudaydah, home to the country’s main port, are both
governorates that confer a certain strategic advantage for the actors that can control them. The presence of Houthi actors, who occupied civilian centers such as hospitals, exercised control over infrastructure such as energy plants, or settled near places where civilian infrastructure was located, made these areas increasingly susceptible to attack. Saudi-led airstrikes were the main means by which such attacks were perpetrated. Often, the damage and destruction that followed rendered important facilities incapable or ill-equipped to provide for civilians in the area, preventing people from benefiting from water, energy, transportation, healthcare, and agriculture services.

The districts on the frontlines of the conflict were the same ones experiencing high levels of water scarcity and unsanitary conditions (WASH Cluster, 2020). The interconnectedness of the energy and water sectors proved important in studies of Sana’a and Al Hudaydah. When fuel and electricity became scarce, unavailable, and expensive as a result of infrastructure damage and blockades, water delivery and sanitation systems were impaired. As a result, untreated waste polluted the environment, and residents, left with limited options, were likely driven to partake in the consumption of contaminated water from unsafe sources, leading to cholera outbreaks, and high case numbers. From May 2017 to February 2018, Sana’a and Amanat Al Asimah reported 179,434 cases, and a final attack rate of 51.607 per 1000 people. Al Hudaydah reported 155,908 cases and an attack rate of 47.909 per 1000 during this same time period.

In Ma’areb, very few attacks on water and energy infrastructure took place from 2016 to 2018. Only a single incident was coded for this time period in Ma’areb, when a dam in the district of Sirwah was subject to airstrikes by the Saudi-led coalition in 2016. Unlike the majority of the governorate’s districts, Sirwah was an active conflict zone. Armed conflict between the Saudi-led coalition, the Houthis, Yemeni Military, and tribal forces set the context for
surrounding districts including Sirwah and Qarniah to more closely resemble conditions in Sana’a and Al Hudaydah than they do the rest of Ma’areb. For the majority of the governorate, water and energy infrastructure was protected from damage and destruction. These systems continued to service the most populous districts. It would be plausible to assume that people living in Ma’areb generally benefited from better water and sanitation conditions than those living in Sana’a and Al Hudaydah, meaning there were less opportunities to contract cholera. Ma’areb did indeed showcase significantly less cholera cases from May 2017 to February 2018, reporting about 7,288 cases and an attack rate of 20.323 per 1000 patients by the end of the time period. It is important to note that these reports from Ma’areb also demonstrate that the governorate was not completely protected from the spread of cholera.

Infected people with severe cases had a difficult time seeking medical treatment in Sana’a and Al Hudaydah. Destruction to roads and bridges, high fuel prices, and armed conflict meant the journey to healthcare facilities posed logistical challenges at multiple levels. Healthcare buildings and equipment were subject to targeted attacks which damaged them and reduced operationality. Under Houthi control, healthcare workers were also denied government wages. This meant that the hospitals that did operate did so understaffed. As a result, people in Sana’a and Al Hudaydah with severe cases of cholera had less access to life-saving treatment. This is reflected in the death and CFR data. Sana’a and Amanat Al Asimah jointly accumulated 194 cholera-related deaths in the time period from May 2017 to February 2018, the CFR starting at 0.9% and decreasing to 0.16 over the course of 9 months. Al Hudaydah accumulated 282 cholera-related deaths from May 2017 to February 2018, the initial CFR reported as 1.5%, the highest of the three governorates of interest, and decreasing to approximately 0.18% over the course of 9 months.
In conflict zones of Ma’areb, roads and bridges were damaged, and armed conflict threatened the security of traveling from one place to another. As a result, it could have been more difficult for infected people to seek out medical attention. However, this was not true for most places in the governorate, where roads remained safe and unimpeded. Additionally, Ma’areb’s health infrastructure did not incur the same damage and destruction as that in Sana’a and Al Hudaydah. Only a single such incident was reported in the TIME data between 2016 and 2018. Moreover, healthcare workers continued to be compensated as employees of the Yemeni government, and hospitals benefited from the financial backing of Saudi Arabia. As a result, Ma’areb had comparably more capacity and resources to control the cholera epidemic and respond to the needs of those affected. As a result, Ma’areb reported only 7 deaths in the time period of May 2017 to February 2018, and a CFR that quickly fell from approximately 0.9% to 0.1% in a period of 3 months, the most rapid reduction of the three governorates examined.

Agriculture was the most commonly targeted sector in all three governorates. The Saudi-led coalition was the main perpetrator of such attacks as part of their aerial campaign. Farms were most frequently targeted, followed closely by markets. The intersection of the agriculture and transportation sectors was another important relationship that emerged throughout this study. The transport of food between farms, ports, and markets, and consumers was disrupted by damage to routes and unsafe conditions. The Saudi-led coalition has continued to employ blockades and slowed operations at the main port of Al Hudaydah as a strategy to put pressure on the Houthi-controlled areas of the country, which relied heavily on imports of food, supplies, and fuel, leading to soaring expenses. The breakdown of Yemen’s internal market system was therefore exacerbated by skyrocketing food prices, especially in Sana’a, Al Hudaydah, and the rural and conflict-center districts of Ma’areb. All three governorates were characterized by the
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WFP according to the IPC scale as experiencing crisis level food insecurity by 2018 (IPC Global Support Unit, 2019). Food insecurity led to widespread malnutrition, which would subdue the immune response’s ability to combat cholera upon infection. In this way, food insecurity is another vulnerability factor shared by all three governorates.

In the conflict zones of Ma’areb, including Sirwah, many people relied on agriculture and animal husbandry as their main source of livelihood prior to the onset of conflict in 2014, but have since been forced to find alternative employment. As a result, people living in rural settings are likely those that struggle to afford food. Beyond this, the governorate is oil rich and employs thousands of people in the energy sector. In the city, people work at and run growing businesses, which were unstifled by the distant conflict. Financial support from the Yemeni and Saudi governments has bolstered the governorate’s economy and created a sort of socioeconomic oasis in the middle of a poverty-stricken country. This has likely helped to buffer the adverse effects of soaring food prices, and protected thousands from malnutrition and severe outcomes from cholera infection.

While a thriving economy acted as a resilience factor for Ma’areb, a crippled economy was a vulnerability factor for those in Sana’a and Al Hudaydah. Similarly to the rural areas of Ma’areb, the majority of those in Al Hudaydah led an agrarian lifestyle. Food production in Al Hudaydah has become an increasingly unsustainable means of livelihood on account of targeted attacks on farms and farm equipment. Additionally, thousands of the cities’ residents were internally displaced from the governorate, taken away from their urban jobs. In Sana’a city, thousands earned their livelihood working factory and manufacturing jobs. These industries were threatened in 2014 when the Houthi forces overtook the Capital, the damage and destruction escalating following the beginning of the Saudi-led airstrike campaign in 2015. Rising levels of
unemployment increased the burden felt by individuals and families struggling to afford shelter, food, transportation, and safe water, rendering them more susceptible to poor health and cholera infection.

Humanitarian aid acted as a resilience factor for people living in both Houthi-controlled and government-aligned governorates, but the extent to which aid efforts were impeded or enabled varied based on their political context. In places rife with armed conflict, humanitarian workers worked in dangerous conditions, and were often injured, harmed, killed, or kidnapped while serving in needy communities. In Sana’a, repeated closure of the main airport limited the medical supplies, food, and aid workers that entered the governorate. In Al Hudaydah, similar limitations were experienced at Al Hudaydah port. For example, in November 2017, Saudi officials closed both of these points of entry in retaliation for a missile strike on Riyadh by the Houthi forces. What followed was a 16-day closure that barred 500,000MT of food and fuel, and 1,476 MT of humanitarian aid from entering the country (Oxfam, 2017). Additionally, the aid that did make it into the governorate did not always come to the aid of the most vulnerable members of the population. In Sana’a, it was found that Houthi forces were diverting food and medical aid from civilians (Physicians for Human Rights, 2020). Ma’areb, on the other hand, received ample humanitarian aid, especially in response to the cholera epidemic. The King Salman Humanitarian Aid and Relief Center, for example, funded 20 flights to Ma’areb. The planes carried food, medical equipment, shelter materials, and healthcare workers (Gambrell, 2018). The case of Ma’areb demonstrates clearly that humanitarian aid has the potential to improve the living conditions, health, and overall well-being of those living in Yemen. The result is that the governorate was more successful in preventing both infection and death from cholera.
Among those most vulnerable to cholera infection in all three governorates were internally displaced people. The UN estimates that the conflict had driven more than 2 million people from their homes by the beginning of 2018 (Al-Sakkaf, 2018). In places like Al Hudaydah, which has been continuously bombarded with airstrikes and explosive weapons, some have been displaced many times over. Al Hudaydah city, which has witnessed an escalation of clashes over the port, is the fourth largest city in the country, with a population of 600,000 in 2018 (European Strategic Intelligence and Security Center, 2018). In Sana’a, thousands flocked to the capital in the hopes of accessing humanitarian aid. Make-shift camps were established on the outskirts of the city. There, lack of protective shelter, poor sanitation, and a shortage of food and water supplies created a particularly dangerous environment for displaced families (The New Humanitarian, 2010). A similar scene could be observed in Ma’areb, where an estimated 1.5 million IDP had passed through the governorate by 2017. The governorate offered the unique promises of employment opportunities and stability that were hard to come by elsewhere. Maareb city’s population had more than doubled by 2019. Many were relegated to camps located near the mountains, where the poor living conditions mirrored those in Sana’a (Nagi, 2019). It is here that the conditions were ripe for cholera to proliferate and spread throughout the internally displaced population (Nagi, 2019). Additionally, increasing population placed further stress on the water, energy, food, health, and housing capabilities of the governorates. In Sana’a and Al Hudaydah, partially operational and non-operational civilian infrastructure likely failed to meet rising demands. Overcrowding in cities and IDP camps conferred vulnerability across all three governorates.

It is important to recognize that this study had a number of limitations. The ongoing conflict makes it particularly difficult to collect accurate data and reports from the ground. In
displacement camps, for example, errors occur often in classifying causes of deaths. Contributing to this phenomenon is a shortage of staff operating in high-pressure situations. Major causes of death include measles, respiratory infections, diarrheal diseases, malaria, and malnutrition (UNHCR, 1995). Similarly, it is challenging to accurately collect and report epidemiological data related to cholera on a governorate-scale. It is plausible to assume that there were gaps and errors in the data considered in this analysis.

This study uncovered harsh cycles of human suffering, in which a crippled economy, crumbling healthcare system, disruption of public services and anchor institutions, and threats of armed conflict led to displacement, poverty, malnutrition, and cholera infection, and vice versa. It is important to recognize that these feedback loops are very much the result of the actions of political actors, and did not arise naturally from the environment. The process of identifying political, economic and environmental drivers of the cholera epidemic direct our attention to a larger humanitarian crisis in Yemen. Currently, as the COVID-19 pandemic stretches the country’s capacity to respond to the health needs of its most vulnerable members, the question of how Yemen can adapt and recover is more crucial than ever.

One research study conducted at the Center for Sustainable Development at the University of Qatar approaches this question by examining how communities and public entities worked to adapt water and energy infrastructure during the conflict. Figure 1 in their paper outlines a conceptual framework for resilience assessment, proposing underlying causes contributing to vulnerability and adaptation, and outlining the connections between armed conflicts, resilience, and post-conflict rehabilitation (Al-Saidi et al., 2020). Their insights about how to confer conflict resilience of infrastructure systems provides a template for how to think proactively about what communities can do to better protect these systems in the future (Al-Saidi
et al., 2020). My own study, in suggesting and diagnosing the drivers of the cholera epidemic, sets the stage for the development of preventative measures which can be used to fortify the country in a post-conflict context, and ensure that the people do not find themselves in a situation as dire as this once again.
APPENDIX

Table 1

*OCHA 2019 Population Estimates of Yemen Governorates*

<table>
<thead>
<tr>
<th>Governorate</th>
<th>Total</th>
<th>Children under 0-4 years</th>
<th>Adults 60+ years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sana’a</td>
<td>1,469,960</td>
<td>266,436</td>
<td>26,977</td>
</tr>
<tr>
<td>Amanat Al Asimah</td>
<td>3,406,643</td>
<td>730,961</td>
<td>63,919</td>
</tr>
<tr>
<td>Al Hudaydah</td>
<td>2,985,122</td>
<td>563,172</td>
<td>63,552</td>
</tr>
<tr>
<td>Ma’areb</td>
<td>495,634</td>
<td>37,927</td>
<td>7,783</td>
</tr>
</tbody>
</table>

(OCHA Yemen, 2019)

Figure 1

*Case Totals By Governorate 5/22/2017 - 2/18/2018*
Figure 2

Infrastructure Types Targeted in Sana’a and Amanat Al Asimah

Figure 3

Actors Involved in Destruction in Sana’a and Amanat Al Asimah
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Figure 4

*Case Totals in Sana’a and Amanat Al Asimah*

![Graph showing case totals in Sana’a and Amanat Al Asimah over time.](image)

Figure 5

*Attack Rate Per 1000 in Sana’a and Amanat Al Asimah*

![Graph showing attack rate per 1000 in Sana’a and Amanat Al Asimah over time.](image)
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Figure 6

Death totals in Sana’a and Amanat Al Asimah

Figure 7

CFR in Sana’a and Amanat Al Asimah
Figure 8

*Infrastructure Types Targeted in Al Hudaydah*

![Infrastructure Types Targeted in Al Hudaydah](image)

Figure 9

*Actors Involved in Destruction in Al Hudaydah*

![Actors Involved in Destruction Al Hudaydah](image)
Figure 10

*Case Totals in Al Hudaydah*

![Graph showing case totals in Al Hudaydah]

Figure 11

*Attack Rate Per 1000 in Al Hudaydah*

![Graph showing attack rate per 1000 in Al Hudaydah]
Figure 12

**Death Totals in Al Hudaydah**

![Graph showing death totals in Al Hudaydah](image1)

Figure 13

**CFR in Al Hudaydah**

![Graph showing CFR in Al Hudaydah](image2)
Figure 14

*Infrastructure Types Targeted in Ma’areb*

![Graph showing infrastructure types targeted in Ma’areb over years 2016, 2017, and 2018.](image)

Figure 15

*Actors Involved in Destruction in Ma’areb*

![Graph showing actors involved in destruction in Ma’areb over years 2016, 2017, and 2018.](image)
Figure 16

Case Totals in Ma'areb

Figure 17

Attack Rate Per 1000 in Ma’areb
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Figure 18

Death Totals in Ma'areb

Figure 19

CFR in Ma'areb
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