A black and white sign

Description automatically generated with low confidence

August 2023

# Water Waste and Mismanagement in Yemen

Haile Terry

## Summary

The water crisis in Yemen is caused by three main factors: the breakdown of the national government due to a civil war, the increasing prevalence of weaponization of water as a war tactic, and the domination of the agricultural sector by a plant, known as qat (which has no nutritional value or export potential, requiring a disproportionate amount of water year-round). The crisis has led to a number of devastating and life-threatening consequences, including poor WASH practices and the worst cholera outbreak in human history; some of the worst malnutrition rates in the world, particularly in children; and a general public health crisis including the spread of diseases like diphtheria, helminthiasis, and schistosomiasis. One potential solution to the crisis is the widespread adoption of rainwater harvesting techniques to increase individual water supplies and decrease reliance on communal systems and infrastructure.

## Key Terms

**Aquifer—**“A body of rock or sediment that holds groundwater.”1

**Cholera—**A diarrhoeal infection caused by ingesting food or water contaminated with a bacteria called Vibrio cholerae. It can cause severe acute watery diarrhea leading to extreme dehydration, and kill within hours if untreated.2

**Diphtheria—**A serious infection caused by Corynebacterium strains. It can lead to “difficulty breathing, heart rhythm problems, and even death” due to the toxins it creates.3

**Groundwater abstraction—**A decrease in water stored in groundwater aquifers generally caused by human water use and well drilling. Groundwater abstraction is also referred to as depletion.

**Groundwater replenishment—**An increase in water stored in groundwater aquifers, caused by a natural process by which water percolates through the soil, avoiding evaporation by the sun until it reaches an aquifer. As water generally moves through the soil at a rate of 10 feet per year, this process can take hundreds or thousands of years.

**MENA region—**Middle East and North Africa, this paper’s preferred term for the geographic region in which Yemen is located.

**Moderate acute malnutrition—** A weight-for-height indicator that lies below the global median for a person of that height.4 In a traditional bell curve, 2.2% of a given population is expected to fall in this range.

**Rainwater harvesting—** A weight-for-height indicator that lies well below the global median for a person of that height.5 In a traditional bell curve, 0.1% of a given population is expected to fall in this range.

**Stunting—** Also known as height-for-age, indicating a lower-than-average height for a given person’s age. Results from chronic malnutrition and is not life-threatening.6

**Underweight—**Also known as height-for-age, indicating a lower-than-average height for a given person’s age. Results from chronic malnutrition and is not life-threatening.6

**WASH—** An acronym commonly used to refer to Water, Sanitation, and Hygiene health and safety practices.8

**Wasting—** Also known as weight-for-height, indicating a lower-than-average weight for a given person’s height. Results from acute malnutrition can be life-threatening if not treated.

## Context

### Q: What is a water crisis, and how is it measured?

**A:** Several typical measurements or statistics are commonly used in determining a water crisis, including availability, usage, and deficit (which is measured both as a whole and per capita). Availability refers to how much and how frequently water is available to those who need it, particularly regarding renewable resources. Usage, referring to how much water is used by humans before it can evaporate, drain, or be absorbed by the ground, is defined into two subcategories: surface and groundwater usage. Surface water usage refers to the usage of above-ground water, such as rainfall, waterways, or reservoirs. Groundwater usage refers to the usage of below-ground water, such as wells, drills, and pumps; often, there is a distinction between groundwater and deep groundwater, but the data in Yemen is limited, so this paper will not differentiate between the two. Deficit refers to how much extra water is being used beyond the supply from renewable resources; in other words, the deficit is defined by how much is being taken from non-renewable resources and how long until those non-renewable resources are depleted. There are also additional measures of water that can be used to measure a water crisis, such as waste or infrastructure. This paper is aware of no field studies on water resources in Yemen conducted after 2010, the last being in 2008.9 As a result, many of the numbers used in this paper are likely outdated to an unknown extent. However, in 2021, the United Nations Development Programme and its partners attempted to create updated datasets for Yemen despite needing field studies, deriving new estimates from satellite data.10 These numbers will also be used occasionally.

### Q: What does Yemen's water crisis look like?

**A:** Yemen’s water availability is extremely low. Availability measurements are often meant to include all water used in a person’s life, meaning drinking water and any water used in their food, sanitation, appliances, and even more indirect things like water used to manufacture or ship any goods they purchase. A country's benchmark for being considered “water scarce” is anything below 1000 m3 of water per person per year. Absolute scarcity is anything below 500 m3.11 The most recent measurements in Yemen put water availability around 78–85 m3 per person yearly.12,13 This means Yemen citizens have access to around 16% (or one-sixth) of the benchmark of absolute scarcity. The World Health Organization says the amount of water the average Yemeni subsists on is one-fifth of what is considered “adequate” for good health.14 As a whole, the country has 2.5 billion m3 of renewable water resources per year; this figure will be revisited shortly in the context of Yemen’s deficit.15



**Photo by NASA Johnson on Flickr**

Yemen’s total water usage is extremely high, especially given the extremely low availability. The most recent concrete data is from 2000, showing a total usage of 3.4 billion m3 that year and an estimate of 3.97 billion m3 in 2010; this estimate is the most recent figure from any major study. Yemen’s usage is predicted to rise to 4.5 billion m3 by 2025.16,17,18 In terms of surface water, 80% of the population was exposed to high levels of water stress in 2018. This study measured areas where surface water withdrawals exceeded 40% of total supplies. However, the study clarified that in Yemen’s case, these regions had withdrawals exceeding 80% of total supplies.19

The total surface water supply is insufficient to meet Yemen’s water needs. The difference is currently being supplemented by extreme and unsustainable withdrawals from groundwater, causing water levels to drop rapidly. Groundwater aquifers, which are extremely difficult and slow to replenish, are declining 3–7 meters per year.20 In 2012, it was necessary in some areas of Yemen to drill 800 m (0.49 mi) to reach any water.21 Wells in many urban regions, such as Sana’a and Taizz, have run dry; for example, one study found that 55% of wells in Sana’a had dried up between 2000 and 2010.22,23 In 2003, most water basins were expected to be depleted by 2053 at the latest.24 In 2021, a similar prediction was made with a deadline of 2041, moving the deadline up 12 years.25

The total deficit is calculated from the availability and usage figures. As mentioned above, the most recent number for each is 2.5 billion m3 and 3.9 billion m3, respectively. This means that Yemen has a deficit of 1.4 billion m3.26 This deficit is currently being covered by extracting water from deep aquifers that have formed over hundreds or thousands of years and are not a highly renewable resource. This is equivalent to receiving a salary for $1000 and immediately spending the entire paycheck plus an additional $560 from savings, and then doing that every payday for 20 years.27

### Q: What is the current political situation in Yemen, and how does it impact the water crisis?

**A:** The ongoing civil war is a multifaceted, complex conflict with multiple national and international actors. In 1990, following the collapse of the Soviet Union and the end of the Cold War, the two states of North and South Yemen were unified into one sovereign state, from which Ali Abdullah Saleh was president for 21 years until 2011.28 Saleh was ousted in 2011 due to the Arab Spring, a period of significant political upheaval in the larger Middle East and North Africa region.29 He was succeeded by his vice president, Abdrabbuh Mansur Hadi, who was the only candidate in the 2012 election.30 The Houthi rebels, who helped depose Saleh in 2011, were dissatisfied with Hadi’s leadership and joined forces with Saleh in 2014.31 That fall, the Houthis took over Sana’a’s capital and briefly signed a unity agreement with the government.32 However, in January 2015, the brokered peace fell apart, and the civil war began.33 As of 2023, the war has not stopped. It is also worth noting that there have been several peace treaties and brokered ceasefires during the war, with the longest and most recent occurring in 2022; none has led to lasting peace.34

A map of the country

Description automatically generated

### Q: Who is uniquely impacted by the water crisis?

**A:** Several demographics are most impacted by the water crisis are children, refugees, and women.

Gender roles and culture in Yemen dictate that women are largely responsible for gathering and retrieving water. In many developing countries, as resources grow scarcer, women and girls must spend more time traveling to retrieve water at the expense of their education and freedom.35 During these journeys, women risk injury, harassment, kidnapping, and sexual violence. If they do not obtain the necessary quota for water, they may face domestic violence at home.36 Water is essential for female reproductive health and hygiene during menstruation, pregnancy, and birth; several studies found a correlation between water insecurity and female reproductive health issues in developing countries.37 Breastfeeding mothers dealing with water insecurity are more likely to be dehydrated or malnourished, decreasing the quality or quantity of breast milk their body can produce and resulting in malnourished infants. In Yemen, 1.3 million pregnant or breastfeeding women require treatment for acute malnutrition.38

The water crisis caused a food crisis, resulting in some of the highest malnutrition rates in the world by which children are most impacted.39 Several recent studies have found an extremely high prevalence of various diseases and health problems in Yemeni children, including respiratory infections, diarrhea, diphtheria, edema, rickets, and measles correlate to low water availability or high malnutrition.40,41 Eleven million children in Yemen (which is more than 80% of the total youth population) require humanitarian assistance, and more than half are experiencing life-threatening acute malnutrition.42

Due to the conflict, Yemen has many refugees or internally displaced persons (IDPs). These refugees are significantly more likely to be impacted by the water crisis in several ways. Refugees are particularly susceptible to poor WASH practices, such as the use of open standing water receptacles or lack of access to sanitary bathrooms. Additionally, refugees are much more likely to experience the negative consequences of the water crisis, including malnutrition and waterborne disease. Many refugees attempt to move in with relatives only to find themselves and their families ostracized or even driven out by communities who fear their limited water resources will be stressed further by unwanted guests; in this manner, many refugees become doubly victimized. More than 75% of refugees are women or children, indicating that they are inherently at higher risk because of the issues discussed above.43

### Q: When did the situation in Yemen transition from water scarcity to a water crisis?

**A:** Yemen has a millennia-long history of sustainable water use and management. Historically, Yemenis were very conscious of their tenuous water situation, and the culture valued water and preservation of their limited resources. They were careful never to waste water or overtax their water sources.44

However, in the 1990s and early 2000s, due to increased migration of Yemenis to neighboring Gulf countries in search of work and better pay, the Yemen economy grew as migrant workers began sending home their earnings.45 This caused rapid growth in the agricultural sector; many new technologies previously unused in Yemen agriculture, such as tractors, tube wells, and chemical agents, were developed and introduced.46 At the same time, the Yemen government began implementing policies to promote agricultural growth and development, such as low-interest loans, cheap diesel pricing, unregulated drilling of wells, and subsidized irrigation.47 These policies encouraged water use by making farming an extremely affordable and accessible option for individual Yemenis and made the economy heavily dependent on the agricultural sector with no regard for the desert climate in which it operated.48 Together, these factors caused a slow but noticeable shift in the overall attitude towards water resources as traditional farming methods and systems of water management were replaced with unsustainable profit-motivated practices.

### Q:  Where is water the most scarce in the Middle East?

**A:** The Middle East as a whole is one of the driest regions in the world and therefore struggles with water scarcity. However, Yemen’s water situation is far worse than any other country in the Middle East. In Yemen, each person has access to an average of 140 mm of water per year. The average in the Middle East is 1250 mm of water.49 In 2018, the World Bank found that Yemen had the highest levels of year-to-year water variability in the MENA region.50 Yemen does not follow the regional trends of increased water availability; from 1990 to 2004, the World Bank estimated that the average water availability in the MENA region rose from 87.5% of the population to 89.5% while in Yemen, these numbers fell from 71% to 67% in the same period.51

While much of the Middle East is fed by several major rivers, including the Nile, Tigris, Euphrates, Jordan, Orontes, and Yarmouk Rivers, the Arabian Peninsula, Yemen’s location is such that no rivers and very few permanent water sources of any kind exist.52 Yemen has no permanent water sources outside a few man-made reservoirs. Additionally, Yemen is one of two countries on the Arabian Peninsula that does not supplement its freshwater with desalinated water, leaving its citizens reliant on surface water from rainfall and groundwater aquifers.53

### Q:  How does geography impact water scarcity within Yemen?

**A:** Yemen is typically divided into three or four major geographic regions (depending on the academic study): the coastal plains in the west and southwest; the Sarawat mountains; the eastern plateau; and the central and northern deserts. The latter two are sometimes combined, as they are both very large in area, very small in population density, and share many geographic similarities. Additionally, precipitation in Yemen drains through four major watersheds (Red Sea, Gulf of Aden, Arabian Sea, and Rub al-Khali Interior) through seasonal waterways called wadis, a primary water source for many rural Yemenis.54 Water is only available from wadis during and immediately following the rainy season in the highlands.

A diagram of weather forecast

Description automatically generated

The Sarawat mountains are a massive outlier, receiving the most rainfall of the entire Arabian Peninsula. This is due to Yemen’s position on the northern edge of the Intertropical Convergence Zone (ITCZ), the meteorologic zone along the equator where the global trade winds converge. During the summer, the ITCZ winds blow moist air off the Red Sea and the Arabian Sea, combining with the high elevations of Yemen’s Sarawat mountains to produce enormous amounts of orographic precipitation.55,56 The rest of the country experiences almost no rainfall and relies heavily on runoff from the mountains as a water source. As a result, the distribution of rainfall and water throughout the country is extremely uneven. Regarding overall land area, most land receives less than 100 mm (3.93 in) of rain per year. In one study, 53% of land received around 100 mm or less per year, and an additional 20.72% received no more than 200 mm (7.87 in) per year.57

The other important factor to consider about geography and water scarcity in Yemen is population density, particularly the urban divide. While water availability is higher in urban areas, it is also decreasing rapidly in these areas. From 1990 to 2004, water availability in rural areas fell by 3% while urban areas fell by 13%.58 Studies consistently show a large water cleanliness and sanitation disparity between rural and urban areas.59 Rural areas are almost entirely reliant on wadis, while urban areas have more infrastructure for water distribution and conservation; however, there are many problems in urban areas. Urban areas are subject to scheduled restrictions of public water network deliveries, and citizens in some cities receive water once every 40 days.60 In the highland plains where most of the urban population lives, the ratio of water use to recharge in groundwater aquifers is 5:1, meaning the cities are using 5 times their renewable water resources; specifically, water use is 500 million m3 compared to a 100 million m3 recharge per year.61

## Contributing Factors

***Qat***

Cultivation of the qat crop is the primary driver of the water crisis because it’s responsible for a staggeringly large portion of water usage and waste in Yemen. The leaves of the qat plant contain a stimulant (alkaloid cathinone), and its use is illegal in many countries, including the US and much of Europe.62,63 Chewing qat leaves is particularly common among Yemeni men.64 Unlike most crops, the plant can be harvested four times a year and requires little maintenance other than water and sunlight.65 In 2015, the income per hectare from growing qat was 3 times greater than other crops.66 All this makes it an extremely appealing crop to the average poor Yemeni farmer—it’s popular, profitable, easy to sell, and can be harvested year-round.67,68 To families experiencing desertification and loss of livelihoods, qat farming is a safe investment with limitless demand. Qat is “a cornerstone of the Yemeni economy," representing nearly a third of Yemen’s GDP from agriculture.69,70,71

Unfortunately, qat cultivation, particularly nationally, has a significant downside: the crop’s disproportionately large water needs are not suited to a desert environment. One bag of harvested qat requires 130 gallons of water to grow, and the water use does not stop after harvesting. The stimulant the plant is known for, alkaloid cathinone, decomposes if the leaves dry out, being replaced by the weaker stimulant cathine. As a result, the leaves are kept moist in their packaging through shipping, sale, and storage up until consumption. This is done by refrigeration, wrapping the qat leaves in moist banana leaves, and frequently spraying them with water.72



**Photo by Rod Waddington on Flickr**

Additionally, qat farmers often use wasteful or unsustainable water practices that damage long-term water resources in favor of short-term economic gains and increased crop yields. Approximately 67% of the water used for irrigation is supplied by drilling wells into groundwater aquifers,73,74 which are extremely difficult to replenish and are not a highly renewable resource. In the highlands, some wells are more than half a mile deep75, and the water tables fall more than 20 feet yearly.76 A report from the Yemeni government in the early 2000s found that qat was frequently irrigated with “more water than it needs” due to inefficient irrigation techniques.77 Farmers do not want to risk plants being under-watered and experiencing a breakdown in cathinone. As a result, they practice inefficient irrigation techniques such as flood irrigation to ensure all plants get sufficient water.78 Flood irrigation, in particular, leads to water waste and runoff, meaning almost none of the excess water from flood irrigation is returned to groundwater aquifers; instead, most water drains into the ocean. Drilling water from these aquifers may yield a more favorable harvest but is not sustainable.

As a whole, agriculture represents a massive portion of water usage in Yemen, with many estimates placing the percentage above 90% or even 95% of all water use in the country.79,80 Agriculture is typically the sector with the largest water usage in any given country, but the proportions in Yemen are still disproportionate after this is taken into consideration. For comparison, in 2018, the average proportion of agriculture’s water usage in the MENA region was 83%, and the global average was 70%.81 Yemen had the largest agricultural water withdrawals out of every MENA country in the 2018 study.82 A large amount (around 30–40%) of the water used in agriculture is used for just one crop: qat, a lucrative but extremely thirsty plant.83,84Together, this indicates that qat alone is responsible for approximately 27% of all water use in Yemen; though this is not a majority, it is the largest single use of water in the country.

### Weaponization of Water

Over the years, combatants have taken full advantage of the tensions that arise from water scarcity, creating and exacerbating situations of scarcity in hopes of gaining a strategic advantage. These tactics have included blocking humanitarian aid deliveries, restricting access to water sources, destroying infrastructure, and polluting or contaminating potable water.

Humanitarian aid providing water to combat disease, famine, and drought has been blocked in numerous cases. Reuters reported in 2016 that the Saudi Arabia coalition and the Houthi rebels were restricting humanitarian aid throughout the country. The article explains that Houthis “were inconsistent in allowing access and movement” of humanitarian aid, and Saudi airstrikes forced the United Nations and international aid groups to evacuate and abandon aid efforts.85 Tribal leaders have also been known to use water to gain power in small-scale power struggles with other tribes, using their influence and relationships with humanitarian organizations to “deprive those of different tribes of assistance,” damaging the credibility of humanitarian organizations and reducing aid availability.86 Even within local communities and family groups, there have been efforts to restrict access to humanitarian aid. For example, a community in Amran, a small city on the western side of Yemen, was forced to host internal migrants and refugees from the water crisis (often referred to as IDPs), and after tensions escalated, the host community successfully blocked assistance to the IDP camp for 6 months, beginning in July 2016.87

Taizz is one of the largest cities in Yemen and has been the focus of protracted military campaigns from both sides of the conflict since 2015. The city has become increasingly important as it sits on the border of Houthi-controlled North Yemen and Hadi-controlled South Yemen; both sides view Taizz as a strategic stronghold. One of the longest and most important conflicts involving Taizz occurred in 2016 when pro-government forces recaptured a portion of the city from the Houthis. Many reports noted Houthi and pro-government soldiers’ treatment of civilians during this conflict, including denying or restricting humanitarian aid for non-combatant civilians.88 Citizens of Houthi-controlled Taizz reported frequent Houthi guards blocking civilians from bringing water into neighborhoods controlled by opposing forces, sometimes confiscating the water.89 Houthi soldiers also prevented civilians from leaving to access wells outside the city.90 Five years later, military campaigns in Taizz have mostly subsided, but the city has failed to recover from the protracted fighting and water availability is decreasing rapidly.

Another tactic for weaponizing water is destroying infrastructure such as sanitation plants, desalination facilities, freshwater pipes, and drinking reservoirs. The Saudi-led coalition has been bombing Yemen since March 2015; as of 2016, the UN classified 119 of these as violations of international law, many of which damaged or targeted water infrastructure.91 Accounts in February 2016 reported the Saudi-led coalition had “bombed and destroyed a reservoir that served as a source of drinking water for thirty thousand people.”92 Bombings like these also increase local tensions and force internal displacement in search of other water sources.93 Numerous airstrikes were reported throughout 2015, with targets including a water tank and an Oxfam warehouse in Sa’ada City, an al-Jumhouria hospital, a Shamlan mineral water warehouse in Taizz, and a bottling plant in Hajjah where 34 people died.94

There are also countless unverifiable reports of criminal attacks on water sources perpetrated by both sides, but insufficient infrastructure, lack of government records, and political tensions often make it very difficult to determine the veracity of such claims. For example, the Saudi coalition was accused of bombing a desalination plant near Mokha in 2016. However, since all reports occurred after the incident, it was impossible to determine whether the plant was functioning before the attack or where it was providing water. However, the Bellingcat site, which reported on the alleged incident, provided compelling evidence from open-source intelligence (OSINT) resources, including social media, metadata, and website dating to prove that the plant was likely in operation before the attack and was targeted because it was a water source for nearby Houthi-controlled cities.95 Many alleged but unconfirmed reports of water weaponization from Yemen are similar, with little conclusive proof but sufficient circumstantial evidence to accept their validity. If most of these reports are taken as fact, it’s clear that the targeted destruction of water infrastructure is a widespread problem in Yemen.

### Failure of Government



**Photo by Rod Waddington on Flickr**

Over the last 30 years, the government has failed to properly prioritize, regulate, and enforce issues surrounding water usage in Yemen, which has only been exacerbated during the war. The 1990s were a period of great agricultural development in Yemen, and the government thoroughly supported this growth as a means to economic development. Many of its policies during this time, including low-interest loans, cheap diesel, unregulated drilling of wells, and subsidized irrigation, meant that water use and irrigation became significantly underpriced.96

As a result, rather than being treated as the limited and valuable resource it is, water was frequently used and wasted in extreme excess because there was no immediate economic penalty for doing so. The government also instituted several agricultural import bans on fruits, vegetables, and coffee, supposedly to boost the economy and increase the domestic cultivation of these water-intensive crops.97 Given the extreme desert climate of most of Yemen’s land area, the government prioritized short-term economic growth over long-term sustainability leading directly to the current crisis.

Besides changing priorities, the government must still regulate its priorities. In 2005, there were around 800 active well drilling rigs and more than 50,000 active wells in Yemen, yet only 70 rigs and 1000 wells were registered and licensed by the government. That means the government properly regulated about 9% of rigs and less than 2% of wells.98 Numerous other studies have made similar findings.99,100 Even before the war, there was little investment in infrastructure construction and maintenance from the government, resulting in dangerous flooding during the rainy season and severe drought for the rest of the year. The few existing desalination plants were generally disused due to lack of upkeep; the remaining were destroyed in the war.

Yemen’s urban population has experienced exponential growth over the last 30 years, and the government did not invest in properly scaling the infrastructure to withstand the increased demand. Citizens in Taizz, Yemen’s third largest city, receive piped city water once every 45 days.101 Many pipes have leaks, with some resulting in a loss of as much as 60% of all water that passes through them.102 This continues to perpetuate the water crisis in Yemen.

## Consequences

### WASH Practices

Yemen’s water crisis has significantly impacted sanitation facilities and access with disastrous results, most notably waterborne illness. The most impactful waterborne illness in Yemen in recent years has been cholera, of which there was an epidemic from 2016–18. The first peak was from October 2016 to February 2017, and the second was from April 2017 to July 2018. During the second peak, there were nearly 1 million suspected cases and over 2,200 deaths.103 This was the largest cholera outbreak in history.104 At the start of the second peak, all Yemeni cities had some level of contamination from sewage in their groundwater, and many water treatment plants shut down.105 Two-thirds of the Yemen population did not have access to clean drinking water, identified as a principal cause of the epidemic.106 There are also reports that in the capital city Sana’a, one of the cities hit worst by the epidemic, the sewer system stopped working entirely just a few days before the second peak began.107

Several parasitic diseases thrive in poor sanitation practices that have seen an increased presence in Yemen during the height of the water crisis, including schistosomiasis (SCH), soil-transmitted helminthiasis (STH), and malaria transmitted via anopheles stephensi. Both SCH and STH are parasitic diseases endemic to Yemen that tend to affect populations with limited access to water, sanitation, and health services. In 2010, both diseases were endemic in more than 80% of Yemeni districts, and over 10 years, the rates fell to around 60%, largely due to drug campaigns and treatment programs. But the same findings also warn that “treatment alone is unlikely to lead to the elimination of SCH or STH infections, which is thought to also require health education, improved access to safe water, and adequate sanitation facilities.”108 In another case, many IDPs displaced by the conflict or water scarcity reside in temporary shelters with no infrastructure for sanitation and, as a result, are often forced to rely on open water containers. These open containers are a prime breeding ground for the invasive species Anopheles stephensi, a mosquito that prefers to lay its eggs in man-made containers and is known for spreading malaria in urban areas where malaria rates are typically low. In some countries, the species has been associated with “an over 30-fold increase in malaria.”109 The exact spread of An. stephensi across Yemen is unknown, as its presence in the country was only recently confirmed, but it is believed that it is more widespread than currently reported. The confirmation of An. stephensi in Yemen is a concerning development and is a direct result of the poor sanitation situation faced by thousands of displaced Yemenis.110 The complete lack of sanitation services and facilities caused by insufficient water resources has made the population vulnerable to waterborne illnesses and parasitic diseases, and the water crisis must be addressed first or in conjunction with these diseases if any progress is to be made.

### Food Crisis

Scant water resources inevitably impact the quantity and quality of food that a country can independently produce, causing an overwhelming food crisis in Yemen. As water resources dwindle, desertification intensifies, and arable land shrinks, Yemen grows significantly less food. In 2007, cereal grains comprised the vast majority of Yemen’s agricultural land use, at more than 90,000 hectares, with the next highest usage being around 40,000 hectares of qat.111 Just 10 years later, in 2017, cereals had fallen by more than two-thirds to approximately 30,000 hectares; all other crops remained about the same.112 As a result, the vast majority of Yemen’s food is imported—up to 90%. Recently, this reliance on imports has become a major stressor for Yemenis as food access is restricted due to many factors, including price spikes, a blockade of southern shipping ports, and the war in Ukraine, a country from which Yemen usually receives more than 40% of its total grain imports.113

Malnutrition rates in Yemen are among the worst in the world. Yemen ranked last among the 121 countries with sufficient data to appear on the Global Hunger Index (GHI) in 2022.114 Yemen is one of two countries whose GHI rating deteriorated rather than improved since 2000, with the other being Venezuela.115 The GHI calculated a rate of 45.1% malnutrition, meaning nearly half the population experiences either acute or chronic malnutrition. This is an increase of 3.4 percentage points from 2014, when the war began, and 6.7 from 2007.116 Over 370,000 children in Yemen suffer from severe life-threatening malnutrition, and 9.8 million children require some nutritional assistance.117 Considering the total population of children is approximately 11.7 million, this represents 84% of the children.118 There are three anthropomorphic indicators generally used to assess malnutrition: stunting, underweight, and wasting. In 2021, the rates of each type of malnutrition in Yemen were 47%, 39%, and 16%, respectively.119 These numbers surpass all three of the World Health Organization’s benchmarks for critical child malnutrition: 40%, 30%, and 15%, for the same indicators.120 Out of all countries ranked by GHI, Yemen was first in the world in stunting, third in wasting, and fifth in underweight.121

The situation is particularly bad for children under 5. As of 2023, of the two types of acute malnutrition, 2.2 million children under 5 experienced moderate acute malnutrition and 540,000 experienced severe acute malnutrition.122 Given an estimated under-5 population of 3.925 million, approximately 56% and 13.8% of the total under-5 population in each category.123 For comparison, given a population resembling the standard distribution of a bell curve, one would expect to see 2.2% and 0.1% of the population in each category, meaning the prevalence in Yemen is 25x and 138x higher than expected for moderate and severe acute malnutrition, respectively.124



**Photo by Julien Harneis on Flickr**

The effects of malnutrition are particularly extreme for children, who have a higher risk of long-term health conditions or even death from malnutrition, and it is estimated that a child dies from malnutrition every 10 minutes in Yemen.125 Aside from the direct effects of malnutrition, including edema, low weight, stunting, and death, this also has a large impact on overall public health, as malnutrition decreases the body’s ability to fight infections and can lead to high morbidity, particularly in children.126 The full scale of the health crisis is discussed in greater detail below. The resulting malnutrition and death, particularly in children, have created one of the worst humanitarian crises in the world.

### Public Health

Yemen is currently facing several health concerns, epidemics, and crises, all negatively impacted by the water crisis. The effects of waterborne illnesses and parasites have already been discussed, including the cholera epidemic and the direct link between poor sanitation and an increase in morbidity and mortality for all such illnesses. There are also several significant health concerns not directly caused by the water crisis, which are still exacerbated by it, including the diphtheria outbreak of 2019. High diphtheria morbidity is closely tied to sanitation and water. More importantly, the rapid population movement of IDPs due to water insecurity is a major factor in the spread of diphtheria, as seen in the Ibb governorate, a governmental region in Yemen, which had a disproportionately high number of both IDPs and diphtheria cases.127



***Photo by Julien Harneis on Flickr***

Some poor health outcomes result from malnutrition caused by the water crisis, particularly in children. Malnutrition weakens the immune system, and increased severity of malnutrition is directly correlated to an increased risk of illness and severity of illness. One study selected Yemeni children under 5 at random, asked about symptoms of illness in the past week, and found that 27% had diarrhea, 31% of children had a fever, and 31% had a respiratory infection.128

Respiratory infections are most common in malnourished children and are one of the leading causes of death for children in developing countries worldwide. In Yemen, along with diarrhea, they are responsible for more than a quarter of deaths of children under 5.129 Malnutrition has associations with many other diseases in Yemen, including measles, which is 3 times more common in malnourished children; diphtheria, which is 5% more likely to cause death in malnourished children, and rickets, a weakening of the bones caused by nutrient deficiencies (estimated at 51.4% prevalence in Yemen).130,131 Whether through waterborne illness, the diphtheria outbreak, or the many adverse health effects of malnutrition, the water crisis has had a widespread impact on the issues and barriers of Yemen’s public health.

## Practices

Rainwater Harvesting

Most water management strategies can be categorized as either hard or soft. Hard path management refers to strategies that are large in scale, expensive, and often take a centralized, top-down approach. Conversely, soft path management refers to strategies that are more individualized, focused on sustainability and renewable resources, and similar to existing processes.132 Most of Yemen’s water management in recent years could be classified as a hard path, with large dams and reservoirs, expensive wastewater treatment and desalination plants, pipelines that carry water over vast distances, and extensive regulation on water use. Hard path management is necessary in many situations, but with the conflict, the weak and fractured governance, and the poor infrastructure, it is insufficient to improve Yemen’s current water situation. This paper posits that adding the soft path strategy of rainwater harvesting (RWH) is currently one of the best practices for Yemen water management.

Many civilizations in arid and semi-arid environments have developed RWH methods. And though several basic types of RWH are common worldwide, including cisterns, terracing, and dams, the actual implementation of these methods is always slightly different due to environmental and cultural differences.133 Yemen is no exception and has a long history of rainwater harvesting practices. These include naqab, karfaan, and jawaabi, which are all variations on the cistern method utilizing the surrounding geography to divert and direct water flow to storage structures, and shurooj, a type of rainfed agriculture based on natural depressions in the land.134,135 Other generic types of RWH with a historical basis of practice in Yemen include contouring, terracing, in situ practices, spate water diversion, ponds, reservoirs, dams, and rooftop harvesting.136,137

Many of these are particularly suited to address some of the biggest concerns of the water crisis in Yemen discussed in this paper. In situ practices, a Latin term that refers to practices designed to decrease the amount of water lost to evaporation by improving storage and absorption by the soil, could improve the replenishment rates of groundwater aquifers that are currently being depleted at unsustainable rates.138 Rooftop harvesting is particularly suited to Yemen’s cities, as it can mitigate the flash floods that follow rainstorms in the cities. Additionally, it provides a decentralized solution for water scarcity that does not depend on the insufficient and inconsistent infrastructure in the cities.139 Contouring and terracing are extremely common and effective in Yemen’s highland agricultural regions, as they reduce erosion and runoff waste, decrease reliance on groundwater, and increase irrigation efficiency.140 Lastly, spate irrigation, where floodwater is diverted from riverbeds for irrigation, is suited to environments like Yemen’s, where sporadic high rainfall often causes flooding, and it is nearly ubiquitous across the whole country, having many different regional names including oqmas, ogmas, obars, saqiya, and rozzum.141

### Impact

Much research has been done about the impact of RWH, both in the world and in Arab countries with geographic and environmental similarities to Yemen. One of the most famous and impactful studies on RWH was conducted in Negev, Israel, from 1960–1984. They found that RWH had significant potential for causing increased food production in arid regions.142 Conducted just a few years after one of the most extreme droughts in the region’s history, the experiment harvested sufficient rainwater to grow several field crops, including wheat, barley, and sunflowers.143 Over a 10-year period beginning in 1986, a community in Gopalpura, India, used RWH techniques to significantly improve the groundwater situation; most notably, groundwater levels increased by 23 feet on average. Their practices were reproduced throughout the Alwar region, and in 2006, a survey found that 82% of previously dry wells across 120 villages had water again.144 More recently, a study in Sudan proved rooftop RWH could provide an additional source of drinking water in urban areas experiencing climate change due to significant population growth.145 In Palestine, RWH caused a 40% reduction in the environmental impact of household water use.146 Two studies recommended RWH as a future water management strategy for neighboring Saudi Arabia, which has many geographic and environmental similarities with Yemen, including the east-west elevation pattern, extreme climate change, prevalence of flash floods following rainfall, and significant variability of rainfall and water availability.147,148

Recent studies have found that more than 50% of rainfall, which would otherwise be lost to inefficient water use, could be recovered through RWH practices. Many studies are showing the positive impact of RWH on irrigation for agriculture.149 RWH has been found to have a significant impact not just on water availability but also on several negative consequences of water scarcity, including increased crop yields, less time spent by women and children fetching water, reduced fuel expenses, decelerated climate change, and reduced poverty levels.150

### Gaps

A lack of data is likely the biggest obstacle to the successful and effective implementation of RWH practices in Yemen. Determining the efficacy of RWH in a specific environment requires knowledge of several data points for which Yemen needs more recent data. These include wet durations, when an area can reasonably expect consistent rainfall, and surplus rainfall, referring to the total amount of rainfall exceeding a set threshold during a wet duration.151 Due to the conflict, there have not been many surveys collecting data of this kind in the last 15 years, and what data does exist is too outdated to be reliable due to the rapid climate change that has occurred throughout Yemen. RWH practices are most successful when they are adapted to the specific geographic, environmental, and cultural distinctions of a given area—what works in India, Mexico, or even other Arabian Peninsula countries may not work in Yemen, and what works in one region of Yemen may not work elsewhere in the country. Some of this gap may be bridged with knowledge of the extensive history of RWH in Yemen, as modern efforts could be based on traditional practices. But due to rapid climate change, what worked in the past may not be the best today. This is why it is essential to conduct an updated water survey throughout Yemen to ensure the best and most up-to-date data for implementing RWH practices.

## Endnotes

1. “Aquifers,” *Education,* National Geographic, accessed July 27, 2023, https://education.nationalgeographic.org/resource/aquifers/.
2. “Cholera,” *World Health Organization*, accessed July 19, 2023, https://www.who.int/news-room/fact-sheets/detail/cholera.
3. “Diphtheria,” *Center for Disease Control and Prevention*, accessed July 18, 2023, https://www.cdc.gov/diphtheria/index.htm.
4. “Types of Acute Malnutrition,” *Action Against Hunger*, accessed April 13, 2023, https://actionagainsthunger.ca/what-is-acute-malnutrition/types-of-acute-malnutrition/.
5. Ibid.
6. “Malnutrition,” *World Health Organization*, accessed April 13, 2023, https://www.who.int/health-topics/malnutrition.
7. Ibid.
8. “WASH,” *World Health Organization*, accessed July 19, 2023, https://www.who.int/health-topics/water-sanitation-and-hygiene-wash.
9. “Country Profile – Yemen,” *Food and Agriculture Organization of the United Nations*, accessed July 21, 2023, https://www.fao.org/3/ca0352en/CA0352EN.pdf.
10. “Water Availability in Yemen,” *United Nations Development Programme*, accessed October 10, 2022, https://www.undp.org/sites/g/files/zskgke326/files/migration/ye/Water-Availability-Study-in-Yemen.pdf.
11. Grace Kam Chun Ding and Sumita Ghosh, “Sustainable Water Management - A Strategy for Maintaining Future Water Resources,” *Encyclopedia of Sustainable Technologies* (2017): 93, https://doi.org/10.1016/B978-0-12-409548-9.10171-X.
12. Peter H. Gleick, “Water as a Weapon and Casualty of Armed Conflict: A Review of Recent Water-Related Violence in Iraq, Syria, and Yemen,” *Water* 6, no. 4 (June 2019), https://doi.org/10.1002/wat2.1351.
13. “Water Availability in Yemen,” *United Nations Development Programme*, accessed October 10, 2022, https://www.undp.org/sites/g/files/zskgke326/files/migration/ye/Water-Availability-Study-in-Yemen.pdf.
14. Nicole Glass, “The Water Crisis in Yemen: Causes, Consequences and Solutions,” *Global Majority E-Journal* 1, no. 1 (June 2010): 23, https://www.american.edu/cas/economics/ejournal/upload/glass\_accessible.pdf.
15. “Water Availability in Yemen,” *United Nations Development Programme*, accessed October 10, 2022, https://www.undp.org/sites/g/files/zskgke326/files/migration/ye/Water-Availability-Study-in-Yemen.pdf.
16. A.M. Al-Asbahi and Qahtan Yehya, “Water Resources Information in Yemen,” *National Integrated Water Resources Management Program*, United Nations, June 20, 2005, https://unstats.un.org/unsd/environment/envpdf/pap\_wasess3a3yemen.pdf.
17. Ibid.
18. Mohammed Hezam Al-Mashreki, “Characterization of Soil and Water Resources in Yemen,” in *Global Degradation of Soil and Water Resources*, ed. Rui Li (Singapore: Springer, 2022), http://dx.doi.org/10.1007/978-981-16-7916-2\_12.
19. “Beyond Scarcity: Water Security in the Middle East and North Africa,” *Open Knowledge Repository*, (2018): 28, https://openknowledge.worldbank.org/handle/10986/27659.
20. “Water Availability in Yemen,” *United Nations Development Programme*, accessed October 10, 2022, https://www.undp.org/sites/g/files/zskgke326/files/migration/ye/Water-Availability-Study-in-Yemen.pdf.
21. Nicole Glass, “The Water Crisis in Yemen: Causes, Consequences and Solutions,” *Global Majority E-Journal* 1, no. 1 (June 2010): 22, https://www.american.edu/cas/economics/ejournal/upload/glass\_accessible.pdf.
22. “Water Availability in Yemen,” *United Nations Development Programme*, accessed October 10, 2022, https://www.undp.org/sites/g/files/zskgke326/files/migration/ye/Water-Availability-Study-in-Yemen.pdf.
23. Nicole Glass, “The Water Crisis in Yemen: Causes, Consequences and Solutions,” *Global Majority E-Journal* 1, no. 1 (June 2010): 25, https://www.american.edu/cas/economics/ejournal/upload/glass\_accessible.pdf.
24. Mohammed Hezam Al-Mashreki, “Characterization of Soil and Water Resources in Yemen,” in *Global Degradation of Soil and Water Resources*, ed. Rui Li (Singapore: Springer, 2022), http://dx.doi.org/10.1007/978-981-16-7916-2\_12.
25. “Water Availability in Yemen,” *United Nations Development Programme*, accessed October 10, 2022, https://www.undp.org/sites/g/files/zskgke326/files/migration/ye/Water-Availability-Study-in-Yemen.pdf.
26. Ibid.
27. (3.9 billion) / (2.5 billion) = 1.56 billion, or 156% of what they have each year. This is equivalent to spending a $1000 paycheck + $560 extra with each paycheck. We used 20 years because both of these numbers come from the 2000s and they are definitely worse today.
28. Megan Jenkins, “Yemen: The Worst Humanitarian Crisis in the World, Ignored,” *MUNDI: Global Studies Society Undergraduate Research Journal* 1, no. 1 (May 2020): 2, https://tuljournals.temple.edu/index.php/mundi/article/view/384.
29. Ibid.
30. “Republic of Yemen: Election for Yemeni Presidency,” *Election Guide*, February 21, 2012, https://www.electionguide.org/elections/id/2224/.
31. “Timeline: Yemen War Began in 2014 When Houthis Seized Sanaa,” *AP News*, February 11, 2021, https://apnews.com/article/joe-biden-saudi-arabia-ali-abdullah-saleh-united-arab-emirates-coronavirus-pandemic-7a1c185cbd6cfb815dfbf7c21df1c0e1.
32. “The Peace and National Partnership Agreement,” *Saba.net*, September 22, 2014, https://web.archive.org/web/20150924114647/http://www.sabanews.net/en/news369204.htm.
33. Charles Schmitz, “Yemen’s Ansar Allah: Causes and Effects of Its Pursuit of Power,” *The Middle East Institute*, February 14, 2015, https://www.mei.edu/publications/yemens-ansar-allah-causes-and-effects-its-pursuit-power.
34. “Saudi Ambassador Says Talks With Houthis Aim To Revive Yemen Ceasefire,” *Eurasia Review*, April 11, 2023, https://www.eurasiareview.com/11042023-saudi-ambassador-says-talks-with-houthis-aim-to-revive-yemen-ceasefire/.
35. “Water and Gender,” *United Nations*, UN Water, accessed July 6, 2023, ​​https://www.unwater.org/water-facts/water-and-gender.
36. “The Impact of the Water Crisis on Women & Girls,” *Well Aware*, March 6, 2023, https://wellawareworld.org/blog-the-latest-the-impact-of-the-water-crisis-on-women-girls/.
37. Molly Allen et al., “Women and Water in the Developing World: Linking Water Insecurity and Gender Disparities,” *CSIS Journalism Bootcamp*, September 30, 2020, https://journalism.csis.org/women-and-water-in-the-developing-world-linking-water-insecurity-and-gender-disparities/.
38. “Yemen Crisis Explained,” *United Nations High Commissioner for Refugees*, accessed April 13, 2023, https://www.unrefugees.org/news/yemen-crisis-explained/.
39. “Global Hunger Index Scores by 2022 GHI Rank,” *Global Hunger Index (GHI)*, Concern Worldwide & Welthungerhilfe, accessed July 25, 2023, https://www.globalhungerindex.org/ranking.html.
40. Fekri Dureab et al., “An Overview on Acute Malnutrition and Food Insecurity Among Children During the Conflict in Yemen,” *Children* 6, no. 6 (June 2019): 82, https://doi.org/10.3390/children6060077.
41. Ruan Neto Pereira Alves et al., “The Silence of the Lambs: Child Morbidity and Mortality from Malnutrition in Yemen,” *Journal of Pediatric Nursing* 65 (2022): e13, https://doi.org/10.1016/j.pedn.2021.12.006.
42. “8 Years of Crushing Conflict in Yemen Leave More than 11 Million Children in Need of Humanitarian Assistance,” *UNICEF*, accessed March 24, 2023, https://www.unicef.org/press-releases/8-years-crushing-conflict-yemen-leave-more-11-million-children-need-humanitarian.
43. “Yemen Crisis Explained,” *United Nations High Commissioner for Refugees*, accessed April 13, 2023, https://www.unrefugees.org/news/yemen-crisis-explained/.
44. Mohammed Hezam Al-Mashreki, “Characterization of Soil and Water Resources in Yemen,” in *Global Degradation of Soil and Water Resources*, ed. Rui Li (Singapore: Springer, 2022), http://dx.doi.org/10.1007/978-981-16-7916-2\_12.
45. Ibid.
46. Ibid.
47. Ibid.
48. Ibid.
49. Ibid.
50. “Beyond Scarcity: Water Security in the Middle East and North Africa,” *Open Knowledge Repository*, (2018): 28, https://openknowledge.worldbank.org/handle/10986/27659.
51. Mohammed Hezam Al-Mashreki, “Characterization of Soil and Water Resources in Yemen,” in *Global Degradation of Soil and Water Resources*, ed. Rui Li (Singapore: Springer, 2022), http://dx.doi.org/10.1007/978-981-16-7916-2\_12.
52. Diptarka Ghosh, “Major Rivers of the Middle East,” *World Atlas*, May 18, 2021, https://www.worldatlas.com/rivers/major-rivers-of-the-middle-east.html.
53. Benjamin E. Sawe, “Countries Who Rely on Desalination,” *World Atlas*, April 25, 2017, https://www.worldatlas.com/articles/countries-who-rely-on-desalination.html.
54. Mohammed Hezam Al-Mashreki, “Characterization of Soil and Water Resources in Yemen,” in *Global Degradation of Soil and Water Resources*, ed. Rui Li (Singapore: Springer, 2022), http://dx.doi.org/10.1007/978-981-16-7916-2\_12.
55. F. A. Farquharson, D. T. Plinston, and J. V. Sutcliffe, “Rainfall and Runoff in Yemen,” *Hydrological Sciences Journal* 41, no. 5 (1996): 797–811, https://doi.org/10.1080/02626669609491546.
56. Mohammed Hezam Al-Mashreki, “Characterization of Soil and Water Resources in Yemen,” in *Global Degradation of Soil and Water Resources*, ed. Rui Li (Singapore: Springer, 2022), http://dx.doi.org/10.1007/978-981-16-7916-2\_12.
57. Ibid.
58. Ibid.
59. “Beyond Scarcity: Water Security in the Middle East and North Africa,” *Open Knowledge Repository*, (2018): 76–7, https://openknowledge.worldbank.org/handle/10986/27659.
60. Hadil Al-Mowafak, “Yemen’s Water Crisis: A New Urgency to an Old Problem,” *PeaceLab*, Global Public Policy Institute, April 6, 2021, https://peacelab.blog/2021/04/yemens-water-crisis-a-new-urgency-to-an-old-problem.
61. Mohammed Hezam Al-Mashreki, “Characterization of Soil and Water Resources in Yemen,” in *Global Degradation of Soil and Water Resources*, ed. Rui Li (Singapore: Springer, 2022), http://dx.doi.org/10.1007/978-981-16-7916-2\_12.
62. “Khat Fast Facts: Questions and Answers,” *National Drug Intelligence Center*, United States Department of Justice, July 2006, https://www.justice.gov/archive/ndic/pubs5/5116/index.htm.
63. “Khat Use in Europe: Update and Policy Implications,” *European Monitoring Center for Drugs and Drug Addiction*, July 4, 2011, https://www.emcdda.europa.eu/news/2011/3\_en.
64. Hammoud Mounassar, “Qat Habit Drains Yemen's Precious Groundwater,” *Middle East Eye*, February 12, 2015, https://www.middleeasteye.net/news/qat-habit-drains-yemens-precious-groundwater.
65. Ali Abulohoom, “Desertification a Threat to Millions of Yemenis,” *Yemen Times,* July 1, 2014, https://reliefweb.int/report/yemen/desertification-threat-millions-yemenis.
66. Hammoud Mounassar, “Qat Habit Drains Yemen's Precious Groundwater,” *Middle East Eye*, February 12, 2015, https://www.middleeasteye.net/news/qat-habit-drains-yemens-precious-groundwater.
67. Ali Abulohoom, “Desertification a Threat to Millions of Yemenis,” *Yemen Times,* July 1, 2014, https://reliefweb.int/report/yemen/desertification-threat-millions-yemenis.
68. Hammoud Mounassar, “Qat Habit Drains Yemen's Precious Groundwater,” *Middle East Eye*, February 12, 2015, https://www.middleeasteye.net/news/qat-habit-drains-yemens-precious-groundwater.
69. Collin Douglas, “A Storm Without Rain: Yemen, Water, Climate Change, and Conflict,” *The Center for Climate & Security*, August 3, 2016, https://climateandsecurity.org/2016/08/a-storm-without-rain-yemen-water-climate-change-and-conflict/.
70. Ibid.
71. “Agriculture, Forestry, and Fishing, Value Added (% of GDP) - Yemen, Rep.,” *World Bank Data*, accessed July 25, 2023, https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=YE.
72. Lenard Milich and Mohammed Al-Sabbry, “The ‘Rational Peasant’ vs Sustainable Livelihoods: The Case of Qat in Yemen,” *Development* 38, no. 3 (1995), accessed October 1, 2022, https://cals.arizona.edu/~lmilich/yemen.html.
73. A.M. Al-Asbahi and Qahtan Yehya, “Water Resources Information in Yemen,” *National Integrated Water Resources Management Program*, June 20, 2005, https://unstats.un.org/unsd/environment/envpdf/pap\_wasess3a3yemen.pdf.
74. “Water Availability in Yemen,” *United Nations Development Programme*, accessed October 10, 2022, https://www.undp.org/sites/g/files/zskgke326/files/migration/ye/Water-Availability-Study-in-Yemen.pdf.
75. Nicole Glass, “The Water Crisis in Yemen: Causes, Consequences and Solutions,” *Global Majority E-Journal* 1, no. 1 (June 2010): 22, https://www.american.edu/cas/economics/ejournal/upload/glass\_accessible.pdf.
76. Hammoud Mounassar, “Qat Habit Drains Yemen's Precious Groundwater,” *Middle East Eye*, February 12, 2015, https://www.middleeasteye.net/news/qat-habit-drains-yemens-precious-groundwater.
77. Mohammed Hezam Al-Mashreki, “Characterization of Soil and Water Resources in Yemen,” in *Global Degradation of Soil and Water Resources*, ed. Rui Li (Singapore: Springer, 2022), http://dx.doi.org/10.1007/978-981-16-7916-2\_12.
78. Ali Abulohoom, “Desertification a Threat to Millions of Yemenis,” *Yemen Times,* July 1, 2014, https://reliefweb.int/report/yemen/desertification-threat-millions-yemenis.
79. “Beyond Scarcity: Water Security in the Middle East and North Africa,” *Open Knowledge Repository*, (2018): 46, https://openknowledge.worldbank.org/handle/10986/27659.
80. Erika Weinthal and Jeannie Sowers, “The Water-Energy Nexus in the Middle East: Infrastructure, Development, and Conflict,” *Water* 7, no. 4 (April 2020), https://doi.org/10.1002/wat2.1437.
81. “Beyond Scarcity: Water Security in the Middle East and North Africa,” *Open Knowledge Repository*, (2018): 46, https://openknowledge.worldbank.org/handle/10986/27659.
82. Ibid.
83. Nicole Glass, “The Water Crisis in Yemen: Causes, Consequences and Solutions,” *Global Majority E-Journal* 1, no. 1 (June 2010): 22, https://www.american.edu/cas/economics/ejournal/upload/glass\_accessible.pdf.
84. Ali Abulohoom, “Desertification a Threat to Millions of Yemenis,” *Yemen Times,* July 1, 2014, https://reliefweb.int/report/yemen/desertification-threat-millions-yemenis.
85. Reuters Staff, “Saudi Coalition, Houthi Rebels Restricting Yemen Aid Access: U.N.,” *Reuters*, February 16, 2016, https://www.reuters.com/article/us-yemen-war-saudi-un/saudi-coalition-houthi-rebels-restricting-yemen-aid-access-u-n-idUSKCN0VP2Q6.
86. Ghaidaa Motahar and Mohammed Al-Sabahi, “Tension Among Local Yemeni Communities Due to Aid Imbalance,” *Atlantic Council*, July 12, 2017, https://www.atlanticcouncil.org/blogs/menasource/tension-among-local-yemeni-communities-due-to-aid-imbalance/.
87. Ibid.
88. Hadil Al-Mowafak, “Yemen’s Water Crisis: A New Urgency to an Old Problem,” *PeaceLab*, Global Public Policy Institute, April 6, 2021, https://peacelab.blog/2021/04/yemens-water-crisis-a-new-urgency-to-an-old-problem.
89. “Yemen: Houthis Block Vital Goods into Taizz,” *Human Rights Watch*, January 31, 2016, https://www.hrw.org/news/2016/01/31/yemen-houthis-block-vital-goods-taizz.
90. Milena Caye, “The Weaponization of Water Amidst Yemen’s Humanitarian Crisis,” *Crossfire KM*, August 19, 2020, https://www.crossfirekm.org/articles/the-weaponization-of-water-amidst-yemens-humanitarian-crisis.
91. Brendan Clifford and Christiaan Triebert, “Yemen’s Bombed Water Infrastructure: An OSINT Investigation,” *Bellingcat*, February 5, 2016, https://www.bellingcat.com/news/mena/2016/02/05/yemens-bombed-water-infrastructure/.
92. Margaret Suter, “Running Out of Water: Conflict and Water Scarcity in Yemen and Syria,” *Atlantic Council*, September 12, 2017, https://www.atlanticcouncil.org/blogs/menasource/running-out-of-water-conflict-and-water-scarcity-in-yemen-and-syria/.
93. Milena Caye, “The Weaponization of Water Amidst Yemen’s Humanitarian Crisis,” *Crossfire KM*, August 19, 2020, https://www.crossfirekm.org/articles/the-weaponization-of-water-amidst-yemens-humanitarian-crisis.
94. Brendan Clifford and Christiaan Triebert, “Yemen’s Bombed Water Infrastructure: An OSINT Investigation,” *Bellingcat*, February 5, 2016, https://www.bellingcat.com/news/mena/2016/02/05/yemens-bombed-water-infrastructure/.
95. Ibid.
96. Nicole Glass, “The Water Crisis in Yemen: Causes, Consequences and Solutions,” *Global Majority E-Journal* 1, no. 1 (June 2010): 20, https://www.american.edu/cas/economics/ejournal/upload/glass\_accessible.pdf.
97. Ibid.
98. Mohammed Hezam Al-Mashreki, “Characterization of Soil and Water Resources in Yemen,” in *Global Degradation of Soil and Water Resources*, ed. Rui Li (Singapore: Springer, 2022), http://dx.doi.org/10.1007/978-981-16-7916-2\_12.
99. Nicole Glass, “The Water Crisis in Yemen: Causes, Consequences and Solutions,” *Global Majority E-Journal* 1, no. 1 (June 2010): 22, https://www.american.edu/cas/economics/ejournal/upload/glass\_accessible.pdf.
100. Ali Abulohoom, “Desertification a Threat to Millions of Yemenis,” *Yemen Times,* July 1, 2014, https://reliefweb.int/report/yemen/desertification-threat-millions-yemenis.
101. Nicole Glass, “The Water Crisis in Yemen: Causes, Consequences and Solutions,” *Global Majority E-Journal* 1, no. 1 (June 2010): 25, https://www.american.edu/cas/economics/ejournal/upload/glass\_accessible.pdf.
102. Laura Kasinof, “At Heart of Yemen’s Conflicts: Water Crisis,” *The Christian Science Monitor*, November 5, 2009, https://www.csmonitor.com/World/Middle-East/2009/1105/p06s13-wome.html.
103. Daihai He et al., “Modeling the 2016–2017 Yemen Cholera Outbreak with the Impact of Limited Medical Resources,” *Journal of Theoretical Biology* 451 (August 2018): 80, https://doi.org/10.1016/j.jtbi.2018.04.041.
104. Maria Francesca Carfora and Isabella Torcicollo, “Identification of Epidemiological Models: The Case Study of Yemen Cholera Outbreak,” *Applicable Analysis* 101, no. 10 (March 2020): 3745, https://doi.org/10.1080/00036811.2020.1738402.
105. Alice Klein, “Unprecedented Cholera Outbreak Tears through War-Torn Yemen,” *New Scientist*, May 23, 2017, https://www.newscientist.com/article/2132070-unprecedented-cholera-outbreak-tears-through-war-torn-yemen/.
106. Maria Francesca Carfora and Isabella Torcicollo, “Identification of Epidemiological Models: The Case Study of Yemen Cholera Outbreak,” *Applicable Analysis* 101, no. 10 (March 2020): 3745, https://doi.org/10.1080/00036811.2020.1738402.
107. Daihai He et al., “Modeling the 2016–2017 Yemen Cholera Outbreak with the Impact of Limited Medical Resources,” *Journal of Theoretical Biology* 451 (August 2018): 80, https://doi.org/10.1016/j.jtbi.2018.04.041.
108. Nur Alia Johari et al., “National Mapping of Schistosomiasis, Soil-Transmitted Helminthiasis and Anaemia in Yemen: Towards Better National Control and Elimination,” *PLOS Neglected Tropical Diseases* 16, no. 3 (March 2022), https://doi.org/10.1371/journal.pntd.0010092.
109. R. Allan et al., “Confirmation of the Presence of Anopheles Stephensi among a Conflict-Affected Host Community in Aden City, Yemen,” *Malaria Journal*, August 23, 2022. https://doi.org/10.21203/rs.3.rs-1977582/v1.
110. Ibid.
111. Alhasan Ahmed Aljawzi et al., “Assessment of Water Resources in Sana’a Region, Yemen Republic (Case Study),” *Water* 14, no. 7 (March 2022): 1039, https://doi.org/10.3390/w14071039.
112. Ibid.
113. “Unprecedented Spike in Food Prices Puts Yemenis at Risk of Extreme Hunger,” *Oxfam International*, July 27, 2022, https://www.oxfam.org/en/press-releases/unprecedented-spike-food-prices-puts-yemenis-risk-extreme-hunger.
114. “Global Hunger Index Scores by 2022 GHI Rank,” *Global Hunger Index (GHI)*, Concern Worldwide & Welthungerhilfe, accessed July 25, 2023, https://www.globalhungerindex.org/ranking.html.
115. “Global Hunger Index Scores by 2022 GHI Rank,” *Global Hunger Index (GHI)*, Concern Worldwide & Welthungerhilfe, accessed July 25, 2023, https://www.globalhungerindex.org/ranking.html.
116. Ibid.
117. Ruan Neto Pereira Alves et al., “The Silence of the Lambs: Child Morbidity and Mortality from Malnutrition in Yemen,” *Journal of Pediatric Nursing* 65 (2022): e13, https://doi.org/10.1016/j.pedn.2021.12.006.
118. Aaron O'Neill, “Yemen - Age Structure 2011-2021,” *Statista*, August 31, 2022, https://www.statista.com/statistics/524184/age-structure-in-yemen/.
119. Khaled Al-zangabila et al., “Alarmingly High Malnutrition in Childhood and Its Associated Factors,” *Medicine* 100, no. 5 (February 2021), https://doi.org/10.1097/md.0000000000024419.
120. “Nutrition Landscape Information System (NLIS) Country Profile Indicators: Interpretation Guide,” *World Health Organization*, 2010, http://apps.who.int/iris/bitstream/handle/10665/44397/9789241599955\_eng.pdf?sequence=1&isAllowed=y.
121. “Global, Regional and National Trends,” *Global Hunger Index (GHI)*, Concern Worldwide & Welthungerhilfe, accessed July 25, 2023, https://www.globalhungerindex.org/ranking.html.
122. “8 Years of Crushing Conflict in Yemen Leave More than 11 Million Children in Need of Humanitarian Assistance,” *UNICEF*, March 24, 2023, https://www.unicef.org/press-releases/8-years-crushing-conflict-yemen-leave-more-11-million-children-need-humanitarian.
123. “Estimated Under-5 Population,” *World Health Organization Regional Office for the Eastern Mediterranean*, Child and Adolescent Health, https://www.emro.who.int/child-adolescent-health/data-statistics/yemen.html.
124. (56% of the population experiencing moderate acute malnutrition) / (2.2 % of the population experiencing moderate acute malnutrition) = a proportion 25x higher. Similarly, (13.8% of the population experiencing severe acute malnutrition) / (0.1% of the population experiencing severe acute malnutrition) = a proportion 138x higher.
125. “8 Years of Crushing Conflict in Yemen Leave More than 11 Million Children in Need of Humanitarian Assistance,” *UNICEF*, March 24, 2023, https://www.unicef.org/press-releases/8-years-crushing-conflict-yemen-leave-more-11-million-children-need-humanitarian.
126. Ruan Neto Pereira Alves et al., “The Silence of the Lambs: Child Morbidity and Mortality from Malnutrition in Yemen,” *Journal of Pediatric Nursing* 65 (2022): e13, https://doi.org/10.1016/j.pedn.2021.12.006.
127. Fekri Dureab et al., “Diphtheria Outbreak in Yemen: The Impact of Conflict on a Fragile Health System,” *Conflict and Health* 13, no. 1 (May 2019), https://doi.org/10.1186/s13031-019-0204-2.
128. Fekri Dureab et al., “An Overview on Acute Malnutrition and Food Insecurity Among Children During the Conflict in Yemen,” *Children* 6, no. 6 (June 2019): 82, https://doi.org/10.3390/children6060077.
129. Ruan Neto Pereira Alves et al., “The Silence of the Lambs: Child Morbidity and Mortality from Malnutrition in Yemen,” *Journal of Pediatric Nursing* 65 (2022): e13, https://doi.org/10.1016/j.pedn.2021.12.006.
130. Fekri Dureab et al., “An Overview on Acute Malnutrition and Food Insecurity Among Children During the Conflict in Yemen,” *Children* 6, no. 6 (June 2019): 82, https://doi.org/10.3390/children6060077.
131. Ruan Neto Pereira Alves et al., “The Silence of the Lambs: Child Morbidity and Mortality from Malnutrition in Yemen,” *Journal of Pediatric Nursing* 65 (2022): e13, https://doi.org/10.1016/j.pedn.2021.12.006.
132. David B. Brooks, “Beyond Greater Efficiency: The Concept of Water Soft Path,” *Canadian Water Resources Journal* 30, no. 1 (January 2013), 84, https://www.tandfonline.com/doi/pdf/10.4296/cwrj300183.
133. Ezgi Akpinar Ferrand and Fatima Cecunjanin, “Potential of Rainwater Harvesting in a Thirsty World: A Survey of Ancient and Traditional Rainwater Harvesting Applications,” *Geography Compass* 8, no. 6 (June 2014), https://doi.org/10.1111/gec3.12135.
134. “Water Availability in Yemen,” *United Nations Development Programme*, accessed October 10, 2022, https://www.undp.org/sites/g/files/zskgke326/files/migration/ye/Water-Availability-Study-in-Yemen.pdf.
135. Ibid.
136. Ezgi Akpinar Ferrand and Fatima Cecunjanin, “Potential of Rainwater Harvesting in a Thirsty World: A Survey of Ancient and Traditional Rainwater Harvesting Applications,” *Geography Compass* 8, no. 6 (June 2014), https://doi.org/10.1111/gec3.12135.
137. M.T. Amin, A.A. Alazba, and U. Manzoor, “Soft Path Water Management in Dry and Arid Regions of the Arabian Peninsula by Rainwater Harvesting,” *American Journal of Environmental Sciences* 9, no. 2 (2013): 159, https://doi.org/10.3844/ajessp.2013.156.163.
138. Ezgi Akpinar Ferrand and Fatima Cecunjanin, “Potential of Rainwater Harvesting in a Thirsty World: A Survey of Ancient and Traditional Rainwater Harvesting Applications,” *Geography Compass* 8, no. 6 (June 2014), https://doi.org/10.1111/gec3.12135.
139. M.T. Amin, A.A. Alazba, and U. Manzoor, “Soft Path Water Management in Dry and Arid Regions of the Arabian Peninsula by Rainwater Harvesting,” *American Journal of Environmental Sciences* 9, no. 2 (2013): 159–62, https://doi.org/10.3844/ajessp.2013.156.163.
140. “Water Availability in Yemen,” *United Nations Development Programme*, accessed October 10, 2022, https://www.undp.org/sites/g/files/zskgke326/files/migration/ye/Water-Availability-Study-in-Yemen.pdf.
141. Ibid.
142. Ezgi Akpinar Ferrand and Fatima Cecunjanin, “Potential of Rainwater Harvesting in a Thirsty World: A Survey of Ancient and Traditional Rainwater Harvesting Applications,” *Geography Compass* 8, no. 6 (June 2014), https://doi.org/10.1111/gec3.12135.
143. Ibid.
144. Ibid.
145. M.T. Amin, A.A. Alazba, and U. Manzoor, “Soft Path Water Management in Dry and Arid Regions of the Arabian Peninsula by Rainwater Harvesting,” *American Journal of Environmental Sciences* 9, no. 2 (2013): 157, https://doi.org/10.3844/ajessp.2013.156.163.
146. Ibid.
147. Mansour Almazroui et al., “Rainwater Harvesting Possibility Under Climate Change: A Basin-Scale Case Study Over Western Province in Saudi Arabia,” *Atmospheric Research* 189 (2017): 11–22, https://doi.org/10.1016/j.atmosres.2017.01.004.
148. M.T. Amin, A.A. Alazba, and U. Manzoor, “Soft Path Water Management in Dry and Arid Regions of the Arabian Peninsula by Rainwater Harvesting,” *American Journal of Environmental Sciences* 9, no. 2 (2013): 162, https://doi.org/10.3844/ajessp.2013.156.163.
149. Ezgi Akpinar Ferrand and Fatima Cecunjanin, “Potential of Rainwater Harvesting in a Thirsty World: A Survey of Ancient and Traditional Rainwater Harvesting Applications,” *Geography Compass* 8, no. 6 (June 2014), https://doi.org/10.1111/gec3.12135.
150. Ibid.
151. Mansour Almazroui et al., “Rainwater Harvesting Possibility Under Climate Change: A Basin-Scale Case Study Over Western Province in Saudi Arabia,” *Atmospheric Research* 189 (2017): 22, https://doi.org/10.1016/j.atmosres.2017.01.004.