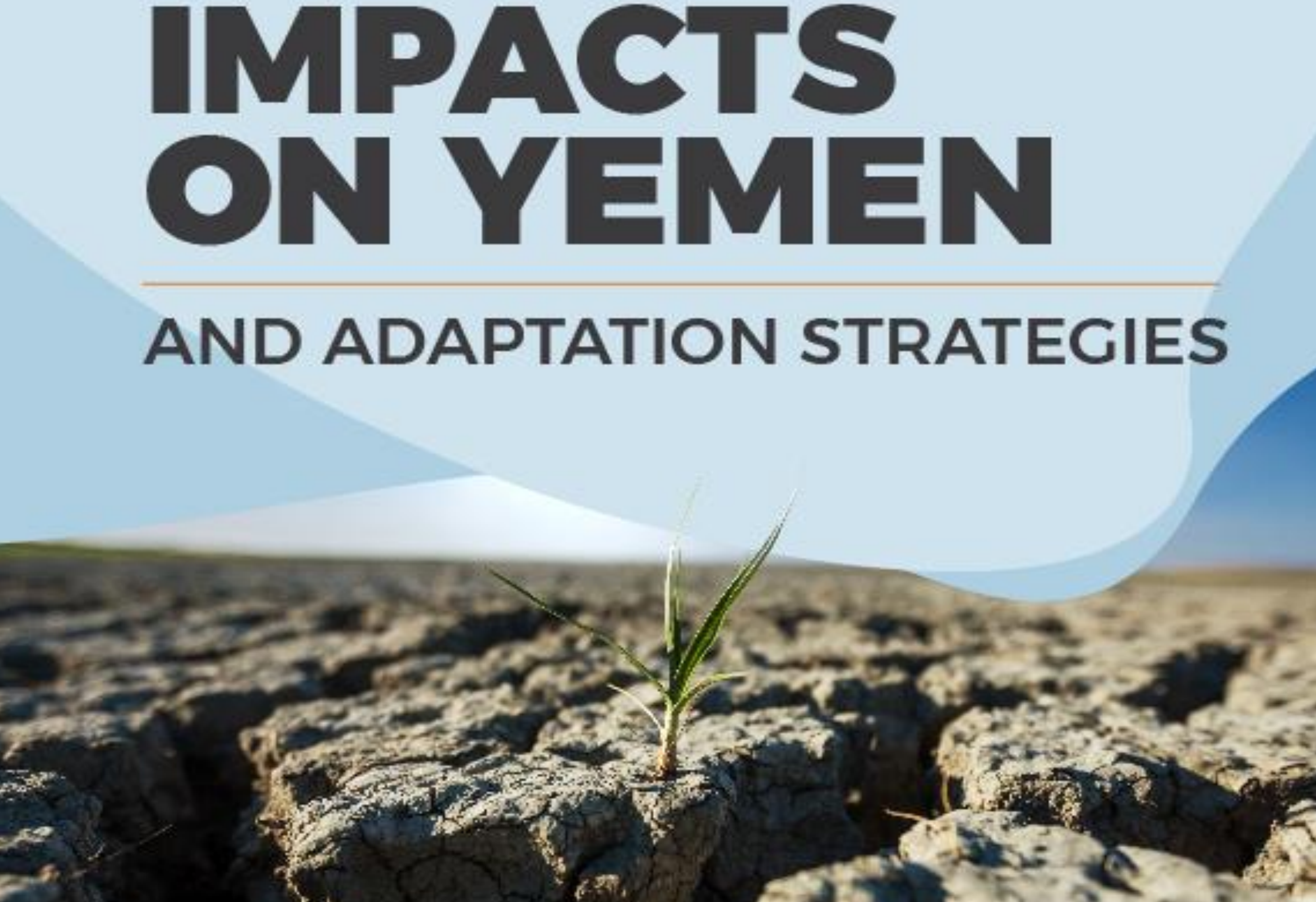
CLIMATE CHANGE IMPACTS ON YEMEN

AND ADAPTATION STRATEGIES



Climate Change Impacts on Yemen and Adaptation Strategies

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Acronyms

LDC	Least Developed Countries
CEOBS	The Conflict and Environment Observatory
CIA	Central Intelligence Agency
CIVIC	Center for Civilians in Conflict
CPI	Consumer Price Index
EPA	Environmental Protection Authority
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
GERICS	Climate Service Center Germany
GFDRR	Global Facility for Disaster Reduction and Recovery
GHG	Greenhouse Gas
Ha	Hectare
ICRC	International Committee of the Red Cross
IDP	Internally Displaced People.
IPCC	Intergovernmental Panel on Climate Change
IPC	Integrated Food Security Phase Classification
LPG	Liquefied petroleum gas
MENA	Middle East and North Africa
MFA	Ministry of Foreign affairs
ND-GAIN	Notre Dame Global Adaptation Initiative
NWRA	National Water Resources Authority
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
UNDP	United Nations Development Programmer
UNF	United Nations Foundation.
UN-Habitat	United Nations Human Settlement Programmer.
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development.

Abstract

The objective of this research is to highlight the climate-related hazards and their impacts on different sectors such as water, agriculture, coastal areas, livelihoods, and food security, and their impacts on vulnerable groups such as women, girls, children, people with disabilities, and elder people. It also sheds light on the climate-related conflicts, and mitigation and adaptation solutions that can be implemented to alleviate the impacts of climate change on the country. The methodology utilized in this research involved a combination of primary and secondary data sources. To ensure accuracy and reliability, the research team met with specialized experts and referred to authentic sources throughout the data collection process.

Yemen is among the world’s most vulnerable countries to climate change, and among the least prepared to mitigate or adapt to its impacts. As for climate vulnerability Yemen ranks 171st out of 181 countries in the ND-GAIN Index (2022). It is the 22nd most vulnerable and the 12th least ready country. Despite being one of the least countries contributing to GHG emissions, Yemen is highly vulnerable to climate change-related impacts such as drought, extreme floodings, pests, sudden disease outbreaks, changes in rainfall patterns, increased storm frequency/ severity, and sea level rise that threatens the already fragile state of the country.

Exposure to cyclones and floods has been worsening in recent years as a result of climate change and global warming. Rainfall in Yemen is characterized by seasonally intense and short-lived heavy storms that often lead to flash floods with implications for landslides, soil erosion, uprooting vegetation, and degradation of agricultural terraces. Occasionally, these floods have caused significant economic damage and loss of crops and lives.

Drought conditions were coupled with an unprecedented rise in temperature affecting all cropped regions of the country, and as a result of that desertification and deforestation increased from 90% in 2014 to 97% in 2022”.

Yemen is considered one of the top five most vulnerable low-income countries to sea level rise, sea level in Yemen is expected to increase by 0.3 to 0.54 meters by 2100. Sea level rise will also result in saltwater intrusion, rendering coastal aquifers brackish and undrinkable and exacerbating the country’s already serious water scarcity issues. Aden for example is the sixth most vulnerable city in the world to sea-level rise and storm surges.

Climate change has specific impacts on water resources, agriculture, food security, coastal zones, health, and vulnerable communities. As for water resources, the impacts of climate change have been obvious, as air temperature increases resulting in increasing evaporation, declining precipitation, and changing weather patterns that are contributing to water scarcity. Flooding also causes contamination to both surface and groundwater as it carries different pollutants such as wastewater and chemical trash into water resources. Climate change is influencing the recharging of aquifers due to the change in the precipitation in terms of amount and distribution, all of these effects have put Yemen as the seventh most water-scarce country in the world with dwindling groundwater levels ranging between 3 to 8 meters per year in critical basins.

The agriculture sector in Yemen has been affected by floods, drought, and pests, all contributing to reduced crop yields. Desertification caused by drought has resulted in a yearly loss of 3-5% of arable land. Moreover, water scarcity remains the biggest obstacle to improving agricultural productivity in Yemen, and the depletion of water resources could lead to a 40% reduction in agricultural productivity. Floods have also led to soil erosion and loss of agricultural land, resulting in a decrease in cropland from 1.6 million hectares in 2010 to 1.2 million hectares in 2020. The impact of climate change on Yemeni agriculture is expected to worsen in the future, especially with more intense rainfall and longer droughts.

The impact of climate change on a global level poses a significant threat to Yemen's food security, which can further worsen food insecurity, undernourishment, and reliance on external aid. This can have severe consequences for Yemen's prospects. Currently, it is estimated that around 19 million Yemenis (about 62% of the population) face food insecurity, with 161,000 people living in famine-like conditions (IPC 5). In the 2022 Global Hunger Index, Yemen ranks 121st out of 121 countries with a score of 45.1, indicating that Yemen has a level of hunger that is alarming.

Regarding the health sector, many of the endemic and epidemic diseases in Yemen are affected by climate events. The spread of cholera, for example, is affected by heavy rain and drought events. Increased storm surges and floods have led to displacement, injuries, and loss of life. Additionally, drought and flood are associated with an increased risk of malnutrition, vector-borne diseases, and waterborne diseases. Extreme heat can increase morbidity and mortality of the most vulnerable such as older people, especially those above 65 years of age; people with pre-existing health conditions, such as heart disease, respiratory illness, and diabetes.

Climate change has specific impacts on vulnerable communities, including women, IDPs and refugees, children, and older people. Women are particularly impacted by water scarcity, it is usually their job to fetch water, even where it is kilometers away. In addition to the challenges women face stemming from their responsibility to fetch water, early marriage has increased. As climate change continues to slowly degrade rural communities' abilities to produce, Yemeni women bear the burden of food insecurity and caring for malnourished children while facing increasing malnutrition themselves. Climate change has also increased the number of female-headed households and gender-based violence. Climate change produces more IDPs and refugees as the degradation of land and water sources displaces people in search of vital resources, where displaced people are more vulnerable to climate change and extreme weather events including flood events that can quickly destroy the limited infrastructure in the camps as well as heat waves that leave people with few options for cooling and shelter. Children are also affected by climate change as diseases including diarrheal diseases and dengue fever affect many children during flooding periods. Older people including particularly older persons with disabilities and older women are among those most affected by climate-related harms such as the increasing spread of vector-borne diseases, heat stress, and the increasing frequency and intensity of sudden and slow onset disasters which can impact their physical and mental health and wellbeing.

In conclusion, climate change has already had severe impacts on Yemen, affecting all sectors and resources as well as communities across the country. Yemen's situation serves as a warning to the rest of the world of what could happen if climate change is not effectively and rapidly addressed. Government entities, civil society, community leaders, and the international community must work together to tackle climate change and environmental issues in Yemen before it is too late. The future of Yemen and its people depend on these collective efforts to mitigate and adapt to the impacts of climate change and protect the environment.

1. Introduction

Climate change is a serious global issue with implications in every domain of human life.[1] The evidence suggests that global warming and a change in precipitation patterns will be experienced as a result of ongoing changes in the climate. It is expected that the global average temperatures may rise by 1.4 – 5.8 ◦C by the end of 2100.[2] It is also predicted that the frequency and intensity of extreme weather events like drought and flooding will also increase given weaker coping capacity and poor adaptation planning particularly in Least Developed Countries (LDC).

Although the historical and current GHG emissions by Yemen are evidently trivial compared to GHG emissions from developed countries,[3] it is on the other hand, highly vulnerable to climate change-related impacts such as drought, extreme flooding, pests, sudden disease outbreaks, changes in rainfall patterns, increased storm frequency/severity and sea level rise that threatens the already fragile state of the country. These are serious concerns as Yemen's economy largely depends on its rural natural resources. Climate change is also a contributing factor in exacerbating the gender-based violence against women and girls, which Yemeni women and girls suffer especially at displacement sites and rural areas.

Yemen is among the world's most vulnerable countries to climate change, and also among the least prepared to mitigate or adapt to its impacts. Temperatures are rising more rapidly than the global average, and water resources, agriculture, food security, coastal areas, and coastal infrastructure are at risk in a country already ranked as the world's most fragile state. A lack of adequate environmental management policies (among other factors) which has been exacerbated by the ongoing devastating war positions Yemen at a great disadvantage in facing the future impacts of climate change. A lack of adequate natural resources management, weak governance, and awareness about climate change impacts as well as other factors seriously hinder Yemen's ability to address the current and future impact of climate change. Additionally, Yemen's projected GDP is expected to decrease by 24% by 2050 due to the effects of climate change.

2. Methodology

In order to understand the impacts of climate change on Yemen. Many trusted resources have been collected and interviews either in person or via phone call were performed with specialists and government officials at NWRA-Sana'a Branch, EPA, and Sana'a University as primary data. Some secondary data sources were also collected from reliable websites, research, and reports as cited throughout the report.

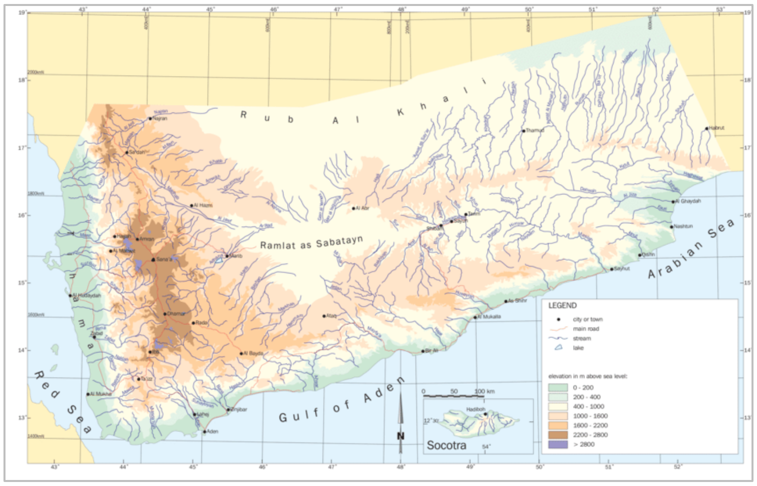
YFCA focused on its research particularly on the impacts of climate change on sectors such as water resources, agriculture, coastal areas, food security, and health sector, in addition to its impact on specific vulnerable groups, including women and girls, youth, older people, people with disabilities and minorities. It also focused on conflicts that emerged between groups and tribes as a result of climate change.

The research also focused on climate change adaptation and mitigation measures that have been applied worldwide and proved their success in topography and situation like Yemen.

3. Objective

The objective of this research is to highlight the climate-related hazards and their impacts on different sectors such as water, agriculture, coastal areas, livelihoods, and food security, and their impacts on vulnerable groups such as women, girls, children, people with disabilities, and elder people. It also sheds light on the climate-related conflicts and mitigation and adaptation solutions that can be implemented to alleviate the impacts of climate change on the country.

4. Country Overview



Map 1: Yemen geography. *(Source:* www.mapsland.com *)*

Yemen is a country located in the Arabian Peninsula and occupies an area of 527,970 square kilometers (km^2). The topography of Yemen is characterized by a diversity of terrain. It is divided into five main regions: mountain heights, plateaus, coastal plains, deserts, and islands. (Map1) The population of Yemen as of November 10, 2022, was 31,371,026 million.[4]

The ongoing conflict, a lack of adequate natural resources management, weak governance as well as other factors seriously hinder Yemen's ability to address the current and future impact of climate change.[5] In addition to being one of the poorest countries in the world and it is a low-income country with about 40% of the population below the poverty line, Yemen has been facing food insecurity and water scarcity, gender inequality, and slow economic growth challenges that are intensified by climate change.[6]

As for climate vulnerability Yemen ranks 171st out of 181 countries in the ND-GAIN Index (2022). It is the 22nd most vulnerable and the 12th least ready country- meaning that it is extremely vulnerable to, yet very unready to address climate change effects. Therefore, it has both a great need for investment and innovations to improve readiness and a great urgency for action.

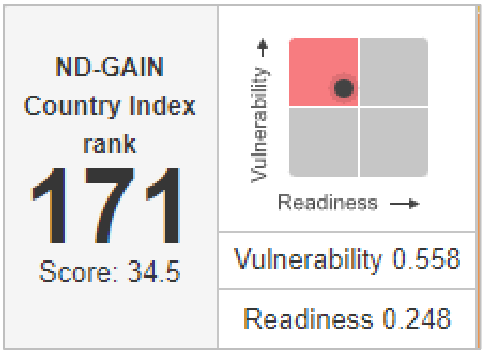


Figure 1: Yemen's ND-GAIN Ranking (ND-GAIN 2022).

5. Climate overview

Yemen has a semi-arid to arid-tropical climate with significant variability geographically, but the climate has changed throughout the country as a result of global climate change. The table below gives a comparison between the historical and projected climate of the country.

Historical Climate	Projected climate
Temperature	
In general, Yemen's temperatures have been rising steadily for the last three decades; rising at a rate faster than the global average. In many places in Yemen, temperatures are 2°C higher than they were before climate change (USAID 2016).	Research shows that temperatures will likely rise further; with estimates of 1.2–3.3°C by 2060, depending on the rate of climate change (UNFCCC 2013). Temperature extremes will also continue to rise. By the end of this century, they might reach 5.1 °C and the hottest day of the year is projected to be 3–7°C hotter than it is today. Using a heat index, scientists estimate that there are about 14 extremely uncomfortable days per year at present, and there could be over 100 such days by the end of the century (World Bank 2014).
Precipitation and water	
Trends in precipitation are more difficult to identify for the entire country. A study by USAID,2016 indicates that the average precipitation has decreased by about 1.2 mm per month per decade, while others show an increase in some areas (Climate Service Center Germany (GERICS) 2015).	The country will likely face more extreme weather, with stronger and more intense flooding and droughts. The frequency of storms is expected to increase as well (USAID 2016). There is a wide range of potential projections for whether rainfall will increase or decrease overall, with models showing different results. Very heavy precipitation events will likely increase in the late summer and autumn seasons in September–November (MFA 2018).

6. Yemen's Greenhouse Gas (GHG) Emissions

Yemen is one of the least countries contributing to GHG emissions. Looking at Yemen's annual emissions in Figure 2 reflects that the average annual share is about 0.03 % of the global total GHG emission.

Recently, the elevated level of GHG emissions in 2008 and 2013 reached 0.08% of the global total GHG emission, but continuously declined from that year until 2018 with only 0.03% and raised a bit in 2019 and 2020 and then decreased in 2021 with the same percentage 0.03% of the global total GHG emission.[7]

CO_2 emissions in Yemen are dominated by the burning of fossil fuels for energy production and industrial production of materials such as cement and agriculture. For instance, in 2019 agriculture sector was the dominant sector by emitting about 7.2 million tons as illustrated in figure 4.

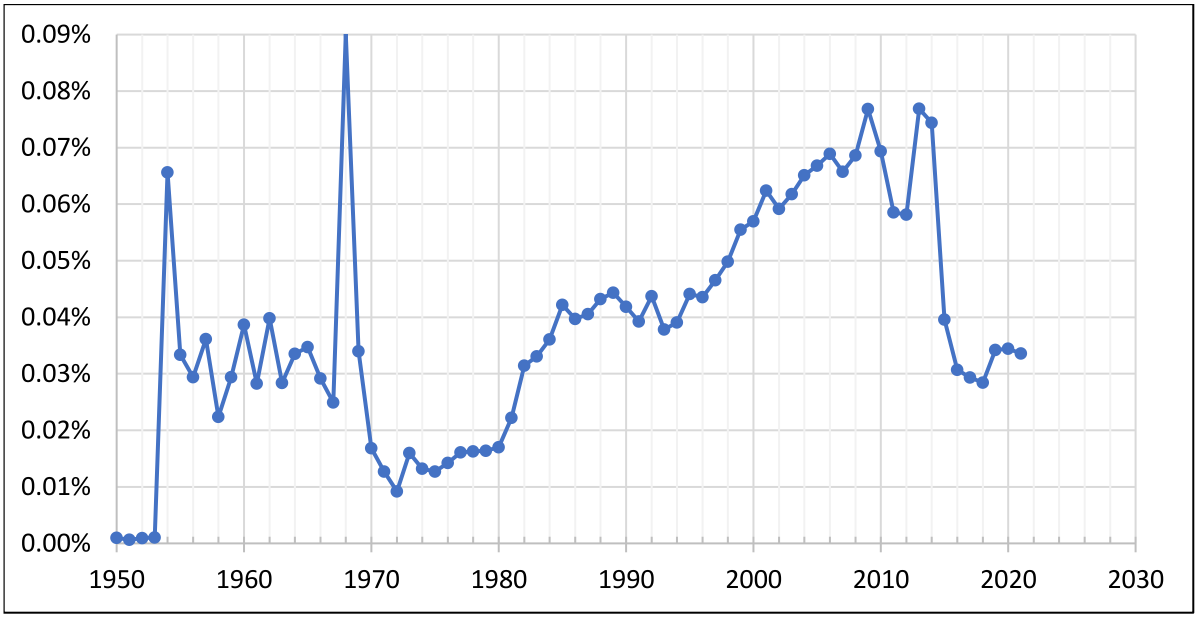


Figure 2: Annual share of global CO_2 emissions. (Our World in Data based on the Global Carbon Project (2022))

Carbon dioxide (CO_2) emissions from fossil fuels and industry. Land use change is not included.

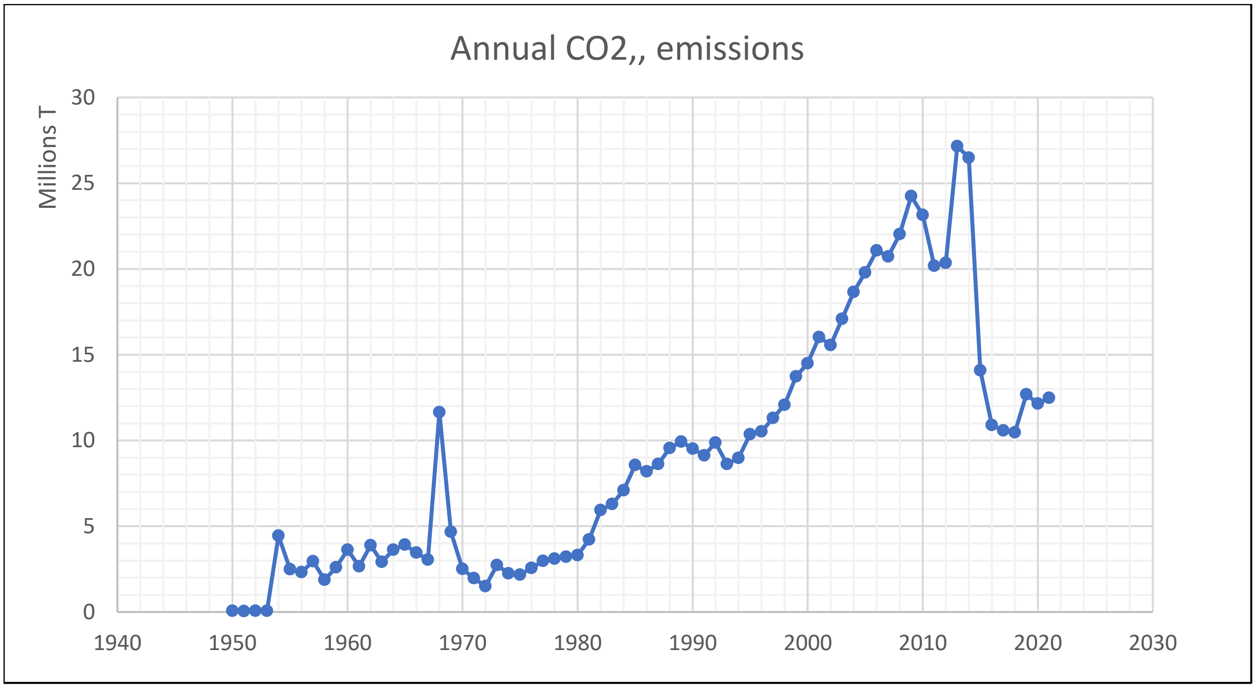


Figure 3:Annual carbon dioxide (CO2) emissions from fossil fuels and industry. Land use exchange is not included. (Our World in Data based on the Global Carbon Project (2022))

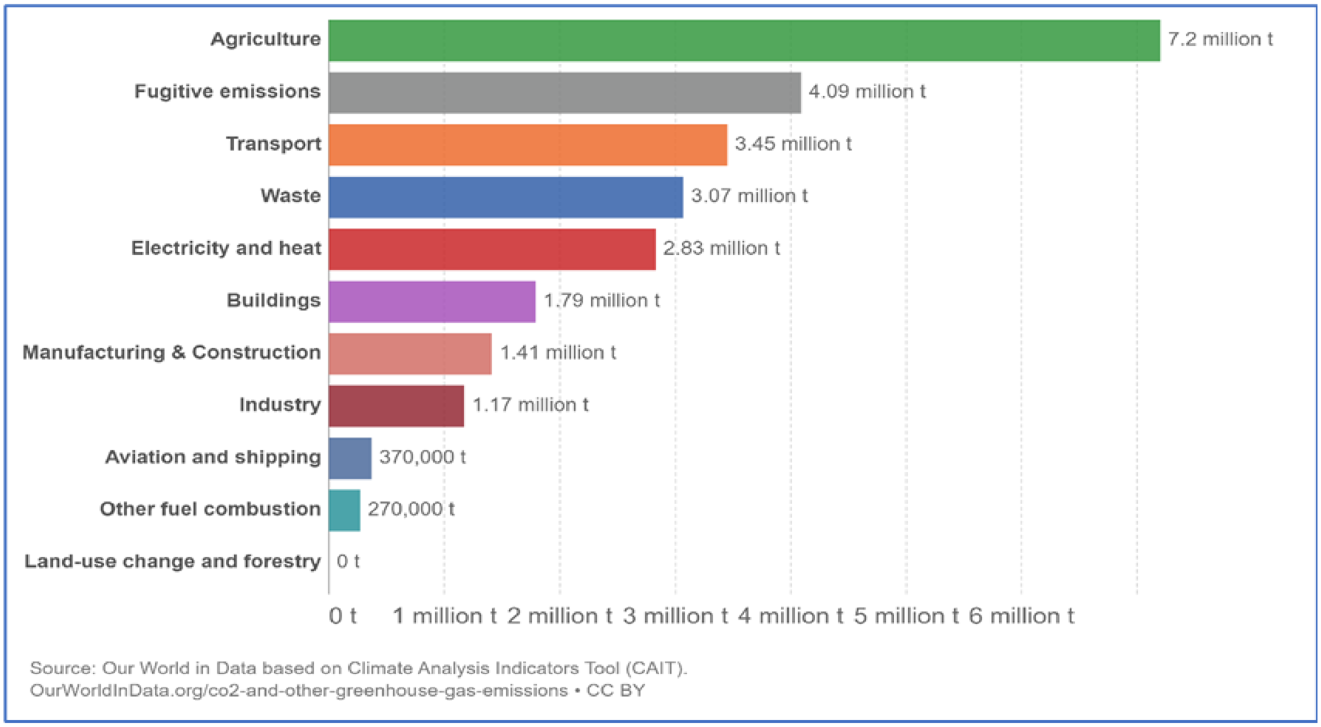


Figure 4:Greenhouse gas emissions by sector, Yemen,2019. (Our world in data, 2019).

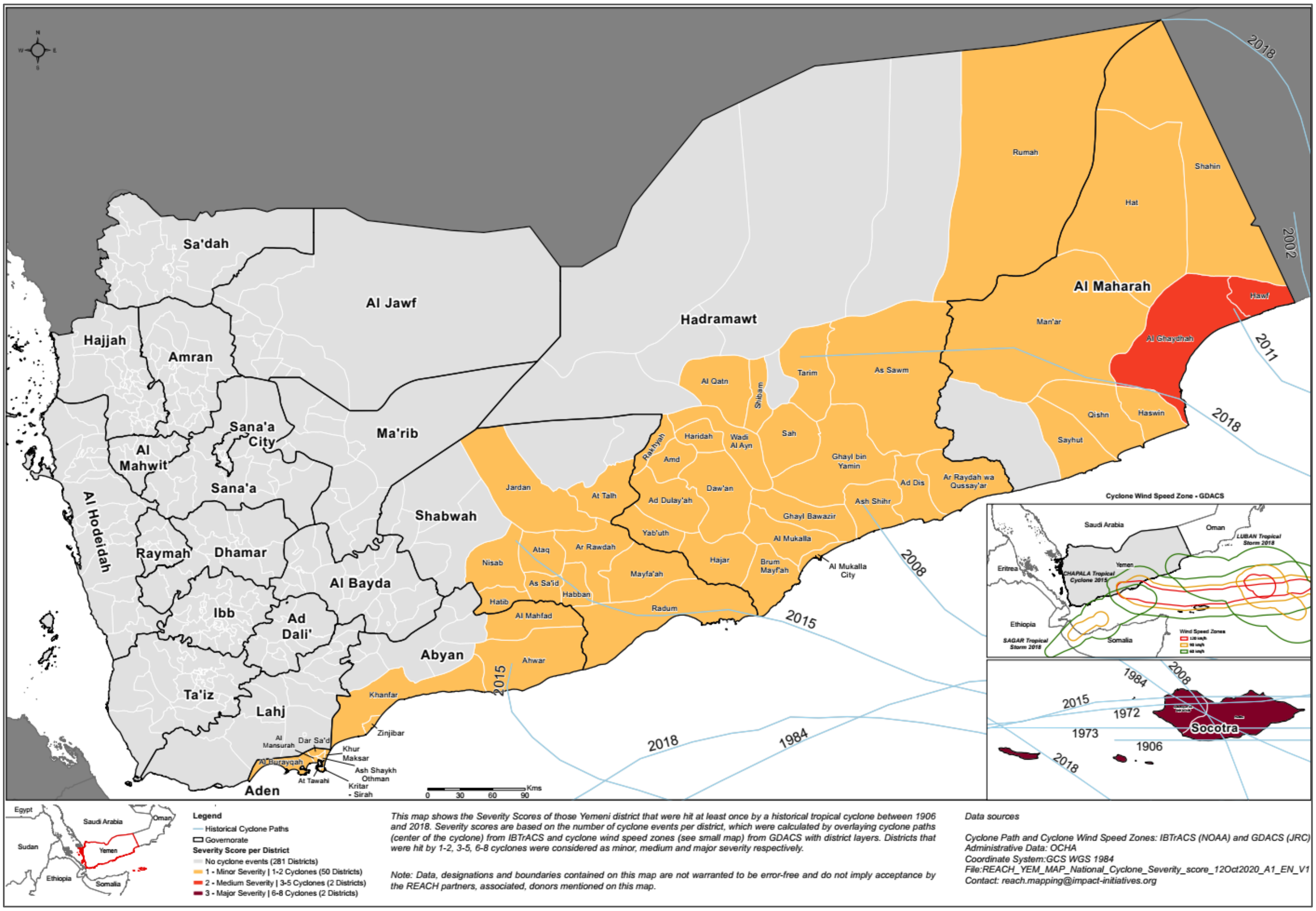
7. Climate-related Hazards

"Climate-related hazards in Yemen have become more frequent including extreme temperatures, catastrophic cyclones and floods, landslides, sea level rise, and droughts."[8] While these hazards are a natural occurrence in Yemen, they nevertheless pose serious constraints on development and food security, and their intensity and frequency are likely to increase under a changing climate. The causes and impacts of these natural hazards across Yemen are discussed below:

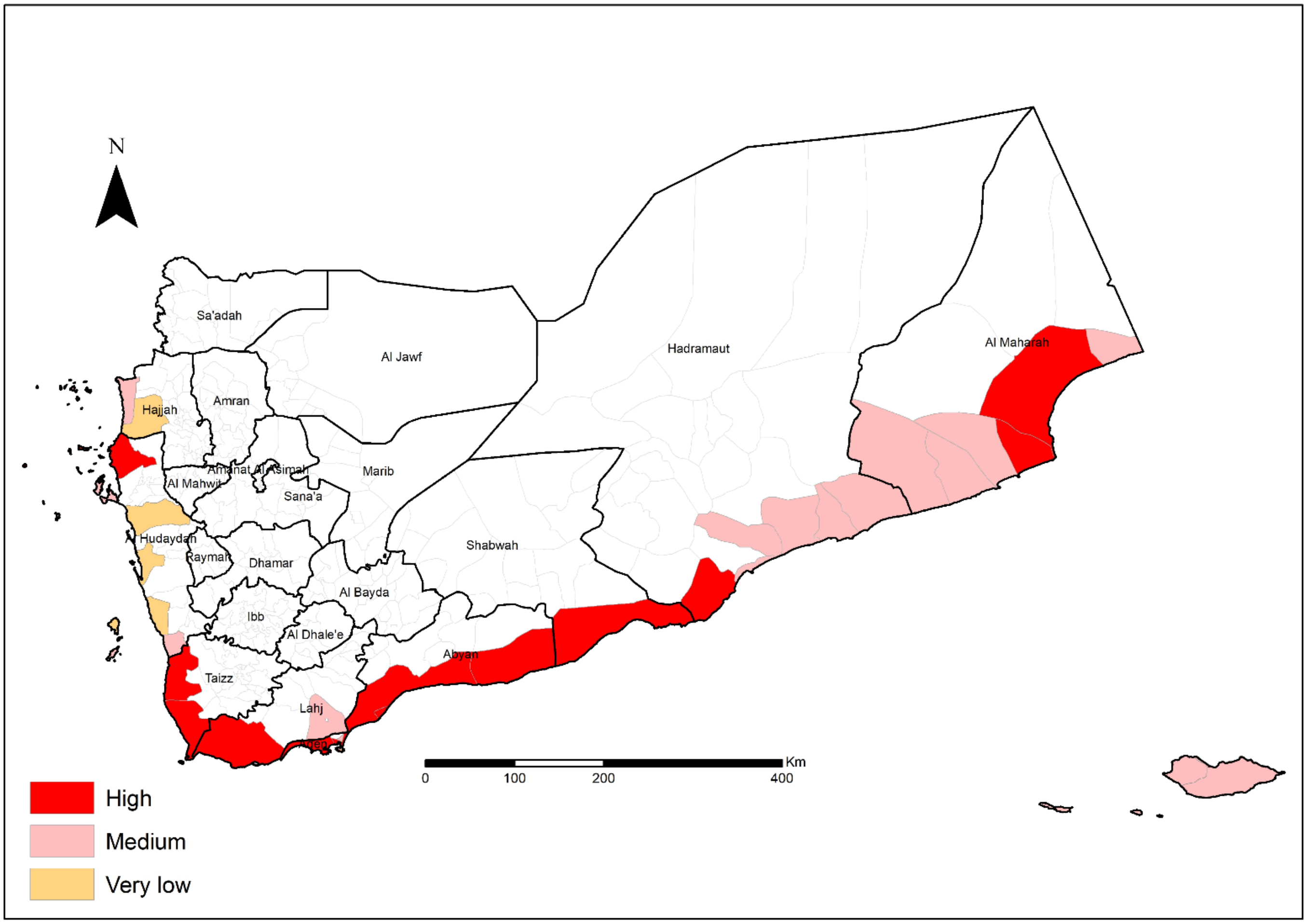
7.1- Cyclones and floods

As a result of climate change and global warming, rainfall in Yemen is characterized by seasonally intense and short-lived heavy storms that often lead to flash floods with implications for landslides, soil erosion, uprooting vegetation, and degradation of agricultural terraces. Occasionally, these floods have caused significant economic damage and loss of crops and lives.

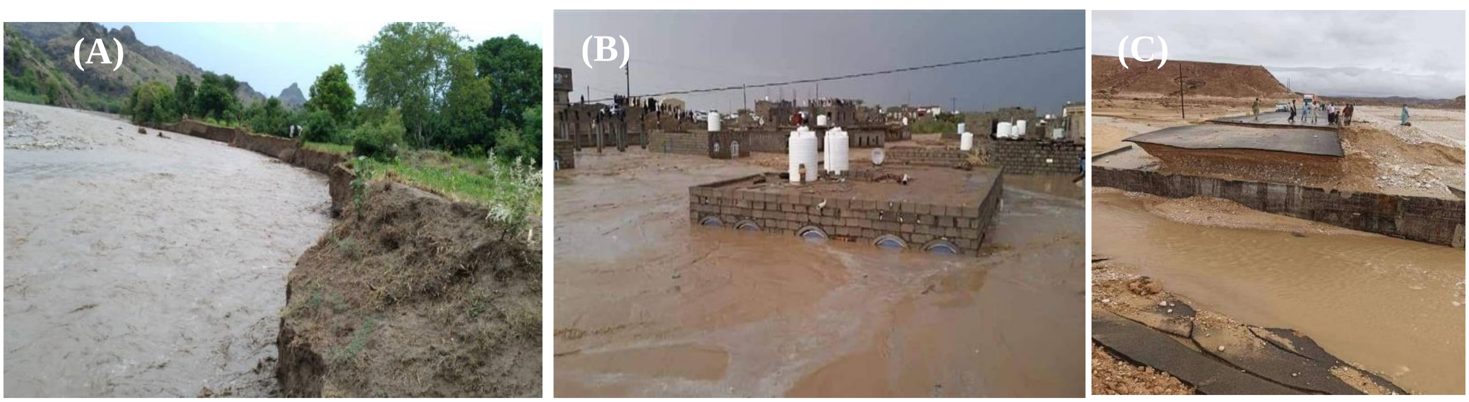
Exposure to cyclones and floods has been worsening in recent years. Tropical cyclones Chapala and Megh in 2015, cyclones Sagar, Mekunu, and Luban in 2018, and cyclone Gati in 2020 are examples of such extreme events that have caused loss of lives and livelihoods along with displacement and extensive damage to and destruction of houses, properties, farmlands, fishing equipment, and infrastructure. In 2019, at least 130,000 people were affected by flooding between June and August, and at least 17,000 in September / October (OCHA). In 2020, flash floods killed more than 170 people and affected thousands of Yemeni families across the country. In 2022 the period between June and August was characterized by heavy rain and widespread flooding across the country, destroying property and livelihoods, including damage to critical infrastructure such as roads, bridges, and in some areas, loss of lives, about 73,854 families were affected across the country (OCHA,2022). Stagnant floodwater during flooding periods creates a suitable environment for the outbreak and growth of water and vector-borne diseases such as cholera and malaria. Cyclones also can create favorable breeding conditions for locusts which were evident after Mekunu and Luban struck in 2018.[9]



Map 2:Historical cyclone severity score in Yemen - Oct 2020. Source. Reach.mapping@impact-initiatives.org



Map 3: Coastal flood hazard susceptibility which is classified as High. (Data source: GFDRR)



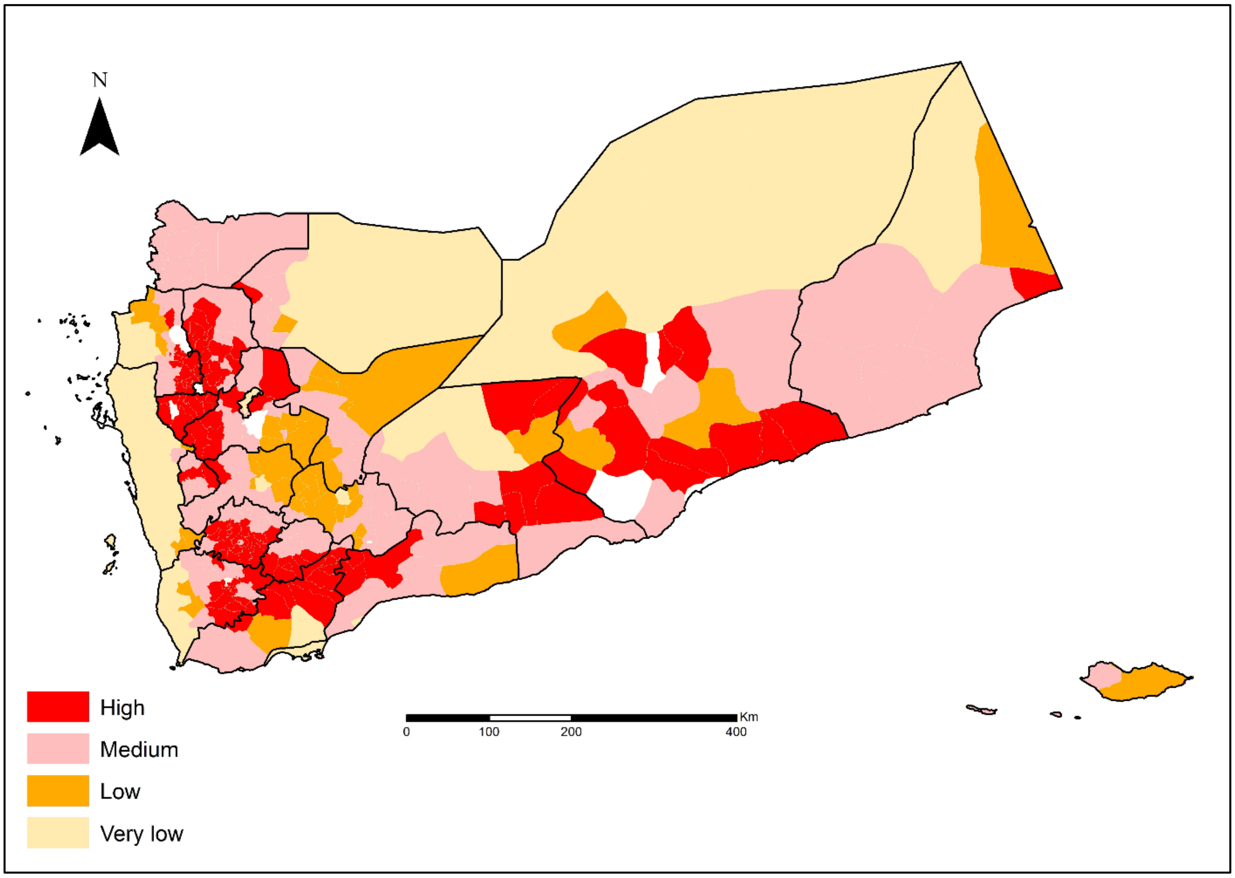
Examples of flood impacts on Yemen. (A): Flood destroys arable lands (Almusaymeer, Lahj Gov.2021) (B): Flood destroys residential places at Marib Gov. (independentarabia.com, 2020). (C): Flood destroys infrastructures at Al-Mahrah. (almahrahpost.com.2022)

7.2- Landslides

The natural topography of Yemen contains about 70% of its land as mountains made it highly susceptible to landslides, and a large percentage of Yemen's population lives on the tops or the bottom of these mountain slopes that are places related to the phenomena of rockslides, all of these factors increase the number of mortalities and economic losses. According to the study implemented by Dr. Adnan Baraheem,2008, the number of human deaths due to rockslides in Yemen ranges from 2 to 60 people annually, and the economic losses of homes, roads, agricultural terraces, water, and electricity exceed one billion riyals annually. For instance, on December 28, 2005, more than 65 people were killed and about 31 houses were destroyed at Al-Dhafeer Village, Bani-Matar District[10].

Climate change is likely to alter slope and bedrock stability through changes in precipitation and/or temperature.[11] Landslides can be initiated in slopes already on the verge of movement by rainfall, snowmelt, changes in water level, stream erosion, changes in groundwater, earthquakes, volcanic activity, disturbance by human activities, or any combination of these factors.

Landslides can be avoided by planting ground cover on slopes to stabilize the land, improving water channels to drain rainwater, building retaining walls at the base of slopes, turning slopes into terraces, avoid construction near steep cliffs.



Map 4: illustrates the hazard of landslides in Yemen. (Data source: GFDRR)

Figure 5:landslides destroy a number of buildings in Hadramout.(https://www.aljazeera.net.2012)

Figure 6: landslides destroyed some houses in two villages at Al-Sadah (https://almawqeapost.net.2019)

7.3- Drought and desertification

In Yemen, drought directly hit rain-fed agriculture which constitutes around 60% of the total cultivable lands (47% rain-fed, 17% run off and 3% irrigated through check dams and small dams). This means that the impacts of drought affect almost 65% of the population who are living in hilly areas and valleys and depend mainly on rain-fed agriculture. In addition to agriculture and farmer, the drought impact affects the ranges and Yemen’s herders who possess 1.3 million livestock heads.[12] For instance, 2022 was recorded as the third driest year in the past four decades, following 2014 (driest) and 2000.[13] Rainfall is decreasing at an average of 0.3mm per annum, and extreme patterns, more droughts, and more floods are expected in the future. “In the first half of the year (2022), most farmers lost the first season of planting, with a third of households reporting reduced area planted. Most farmers temporarily suspended most agricultural activities and those who planted lost inputs and incomes”.[14] Drought conditions were coupled with an unprecedented rise in temperature affecting all cropped regions of the country. “Desertification and deforestation increased from 90% in 2014 to 97% in 2022”.[15]

Additionally, the increasing demand for wood has prompted a wave of deforestation, according to Islamic Relief about five million trees have been cut down since 2018 with more than 889,000 felled annually to fuel bakeries and restaurants in the capital, Sana’a, alone. People and cattle are at risk of dying from the lack of water and fodder across Yemen, and the shrinking coverage of arable land also strips those reliant on it of a stable means of supporting themselves and their families. 75% of Yemen’s population live in rural settings and rely heavily on stable climate conditions to maintain their livelihoods. Without this, households and communities are forced to relocate, adding to what is already one of the world’s largest internal displacements, for example; some families in various governorates including Dhamar, Al-Mahwit, Hajja, Taiz, Lahj, and Al-Dhal’e have already left their homes in search of greener pastures and wetter lands.[16]

Climate change also affected the ancestral honey production in Yemen which according to UN figures forms a source of income for about 100,000 Yemeni households. Climate change disturbs the bee’s ecosystem which is impacting the pollination process.

For instance, in 2022 there have been lower-than-usual precipitations with water tables falling and increased desertification, areas previously engaged in agricultural activities and bee-keeping no longer sustain these livelihoods.[17] Flash floods are also slashing honey production, said Fuad Ali, the head of the UNDP’s Economic Development Unit in Sanaa City, “Farmers and beekeepers used to have a traditional method of warning each other when a flood was coming in, which was to shoot into the air in particular patterns, but now the floods are too sudden for them to have enough time to warn each other,”. Abdullah Nasher, the head of Yemen’s Beekeeping Association also said “In 2016, numerous beehives were destroyed by flash floods that occurred in seven governorates.

Figure 7:Drought impacts on Yemen 2022. **A**: Serar District Abyan Gov (after shabwahalyoum.com,2022).

B: People are suffering from water scarcity Lahj Governorate (after almushahid.net, 2022)

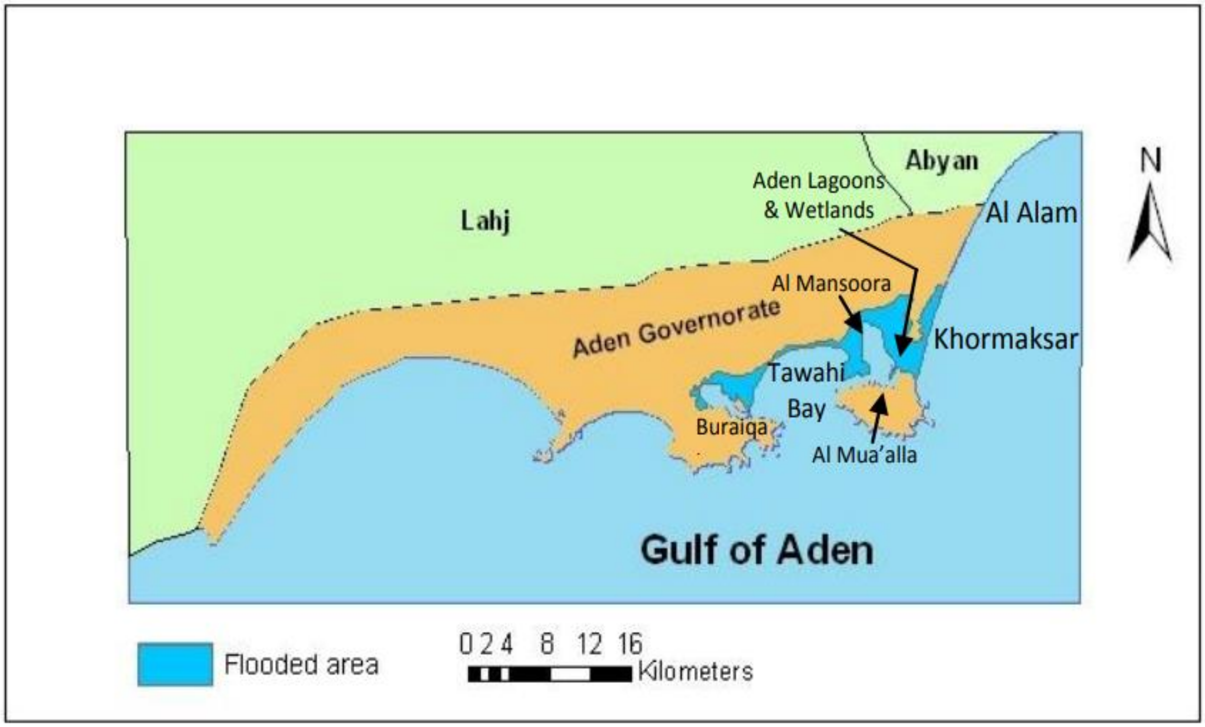
7.4- Sea level rise

Accelerated global sea-level rise is considered one of the more certain consequences of global climate change, which will intensify the stress on many coastal zones, particularly those where human activities have diminished natural and socio-economic adaptive capacities. Satellite observations available since the early 1990s provide more accurate sea level data with nearly global coverage. This decade-long satellite altimetry data set shows that since 1993, the sea level has been rising at a rate of around 3 mm/year, significantly higher than the average during the previous half-century (Bindoff et al., 2007). The Intergovernmental Panel on Climate Change (IPCC) fourth assessment report suggested a rise in sea level globally by 18-59 cm by the end of this century.

Yemen is considered one of the top five most vulnerable low-income countries to sea level rise, with more than 50% of their coastal areas at risk, for exposed populations, and more than 50% of coastal urban areas lie within the potential impact zones (Dasgupta et al., 2009). According to Unnikrishnan and Shankar (2007), using stations from the northern Indian Ocean, the sea level at Aden rises by about 2 mm/year, which is similar to that of the global estimate.

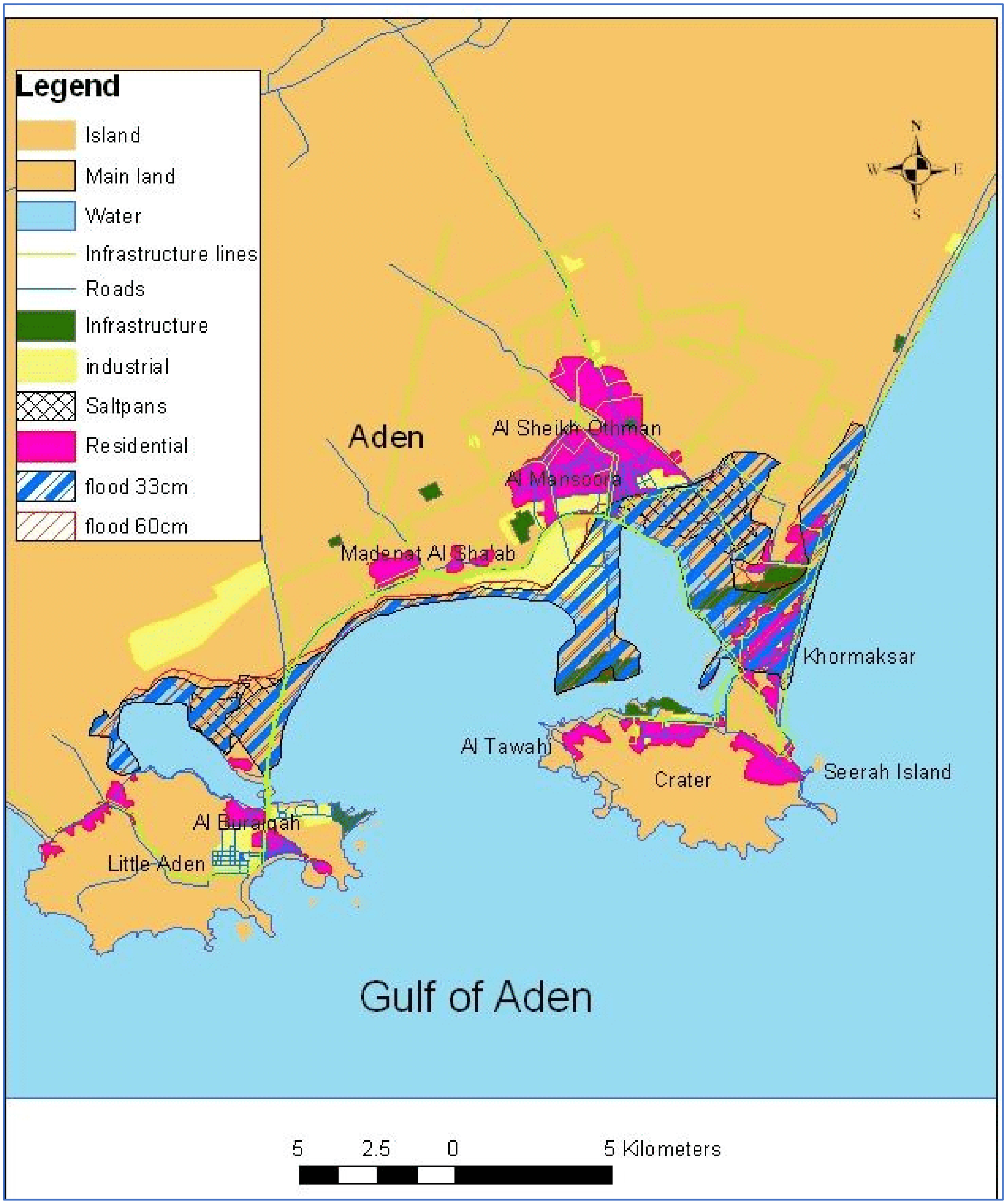
The sea level in Yemen is expected to increase by 0.3 to 0.54 meters by 2100 (Mohamed, 2017). This rise in sea level would put more than 50% of Yemen's coastal areas at risk and affect more than 55% of the country's coastal population (USAID, 2016). Sea level rise will also result in saltwater intrusion, rendering coastal aquifers brackish and undrinkable and exacerbating the country's already-serious water scarcity issues (Harazi, 2014).

Aden is the sixth most vulnerable city in the world to sea level rise and storm surges, according to a 2009 study by the Center for Global Development, a nonprofit think-tank. According to the study by M.A. Al-Saafani et all, 2015 which aimed to evaluate the impact of sea level rise and climate change on Aden city, two plausible future sea-level rise scenarios were adopted (33cm and 60cm). The study revealed that for both scenarios, sea level rise will affect the highly populated coastal area and floodplain zone of Aden. Inundation will unevenly affect Aden Governorate's coastal area. Aden lagoons and wetlands will be permanently inundated since their propagation towards the land is restricted by urbanization. Erosion will result in the loss of sandy beaches, which will affect the tourism and recreation activities in coastal communities. The total socio-economic impacts include loss in both infrastructures and livelihoods. It has been estimated that the total economic losses due to sea level rise by 33cm and 60cm are about 410,233 and 459,461 million YR (1,908 and 2,137 million US$), respectively. Various adaptation options were suggested including hard protection (Dike), setback between 300-500 m, and beach nourishment. As the sea level rises, fresh groundwater and surface water could be displaced by saline water, which could have substantial adverse impacts on the drinking-water supply and agriculture.



Map 4:Map of Aden Governorate shows the expected inundated area due to the SLR of 33 and 60 cm.

(After M. Alsafaani, et al,2015)



Map 5:Map of important sectors in the Governorate of Aden which are subjected to inundation (33 & 60 cm).

(After M. Alsafaani, et al,2015)

8. Sector impacts and vulnerabilities

Climate change has specific impacts on water resources, agriculture, food security, coastal zones, health, and vulnerable communities, as will be discussed below.

8.1- Water resources sector

Surface water and groundwater form the main source of water in Yemen. Although rainfall is limited, being less than 50 mm along the coast and inland desert areas and between 250-800 mm in the western mountainous regions, times of heavy rain bring about violent spate torrents and occasionally catastrophic floods causing damage to vital (irrigation) water infrastructure. During these floods, only rapid recharge of shallow groundwater occurs due to the often-steep slopes, sparse vegetation, and limited soil permeability. In major wadis, the rush floods ultimately drain into the sea[18].

Yemen is considered one of the world's most water- scarce countries where about 18 million people lack access to safe water and adequate sanitation services, and providing drinking water will likely be one of the biggest problems that people will encounter in the coming years (OCHA,2022). Moreover, in July 2022, UNOCHA and UNICEF stated that "over 61% of Yemenis have no access to safe water,"[19] and as climate change continues to worsen year by year, Yemeni civilians remain at significant risk of being unable to access water and food.

Several underlying causes are contributing to exacerbating the water crisis in Yemen, including the high population growth, misguided agricultural development, and policies, the proliferation of Qat as a cash crop which consumes more than 40% of Yemen's total renewable water resources, and 32% of all groundwater withdrawals, and the high vulnerability to climate change. The rate of groundwater overdraft is currently much higher (twice) than the recharge rate, and is increasing, bringing depletion of water reserves, inequity, and shortages[20].

The impacts of climate change have been obvious, as air temperature increase is resulting in increasing evaporation, declining precipitation, and changing weather patterns that are contributing to water scarcity. Flooding also causes contamination to both surface and groundwater as it carries different pollutants such as wastewater and chemical trash into water resources. Water ecosystems, particularly shallow aquifers, the water of wadies, natural springs, and traditional dam reserves are contaminated primarily by industrial and residential waste, wastewater effluents, and inappropriate agricultural practices. High population results in high production of liquid waste from domestic and commercial sectors, particularly under the absence of water quality monitoring, groundwater monitoring, and monitoring of disposal of sewage and untreated wastewater into water-ecosystems under lack of national water quality standards and wastewater treatment[21].

Yemen is experiencing an absolute scarcity of water resources with an average share of 82 m^3 per year per capita (NWRA, 2020) which is well below the average water share in the MENA[1] region as illustrated in figure 8. Additionally, Yemen is currently the seventh most water-scarce country in the world[22] with dwindling groundwater levels ranging between 3 to 8 meters per year in critical basins.[23] The country receives limited rainfall ranging between 19 to 600 mm/year and has no permanent rivers. Thus, overexploitation of groundwater resources has been on the rise to respond to the different water needs.

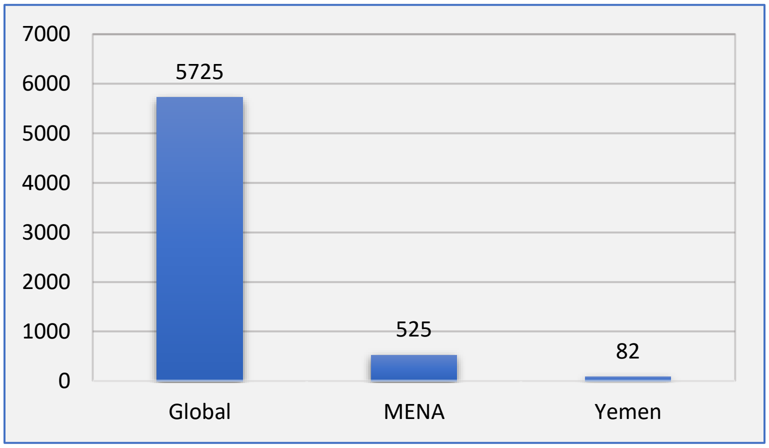


Figure 8:Water availability per capita (in cubic meters). (Source, World Bank & MENA (2017), NWRA Yemen (2020).

[1] Middle East/ North Africa

According to the National Water Resources Authority (NWRA), estimates of water use in 2020 were 80.4% for agriculture to irrigate a total area of 0.52 million hectares (with 32% coming from groundwater), 14% for domestic use and 5.6% for industrial use mainly in the food, chemical, pharmaceutical, and beverage industries.

Regarding Yemen's renewable water resources, they reach 2.5 billion cubic meters/year while used water is 5.1 billion cubic meters/year; this reflects an alarming water deficit situation of around 2.6 billion cubic meters/year (NWRA, 2019), which means that groundwater withdrawal rate is currently more than twice the recharge ratio with a presence of more than 800 rigs and more than 100,000 wells most of which were drilled illegally (NWRA, 2021).

Among the 15 water basins in Yemen, 5 basins are classified as critical, which have recorded the highest drop in groundwater levels as a result of low basin recharge and high extraction rate; for instance, in Sana'a Basin, the water deficit reached (271 million m^3 per year), in Sa' dah basin (85 million m^3 per year), in Amran basin (79 million m^3 per year), in Taiz basin (39 million m^3 per year), and in Rada' Basin (28 million m^3 per year. Furthermore, these basins face pressures in terms of quantity and quality.[24]

Table2 :Average of Groundwater Level Decline in Yemen (NWRA,2021)

Groundwater Basin	Decline Level (meters per year)
Sana'a	**6.0 - 8.0**
Taizz	**1.5 - 2.0**
Amran	**3.0**
Sa'adah	**5.0 - 6.0**
Rada 'a	**5.0**
Tuban-Abyan	**0.02 – 1.0**
Tehama	**1.0 – 3.0**

Table 1:The current water situation and water stress by basin/ withdrawal and recharge rate (Million m^3/year).

Region	Recharge (Million M3/year)	Withdrawal (Million M3/year)	Water Stress (%)
Southern Highlands	25	28	112%
Al-Jawf Vally	47	56	119.1%
Taiz	20	59	295%
Northern Highlands	31	121	390.3%
Ahwar-Mayfa'a	150	225	150%
Ramlat Al-Sab'atien	180	253	140.6%
Sana'a	80	332	415%
Tuban-Abyan	87	352	404.6%
Central Highlands	88	391	444.3%
Western Highlands	304	428	140.8%
Tihama	524	1140	217.6%

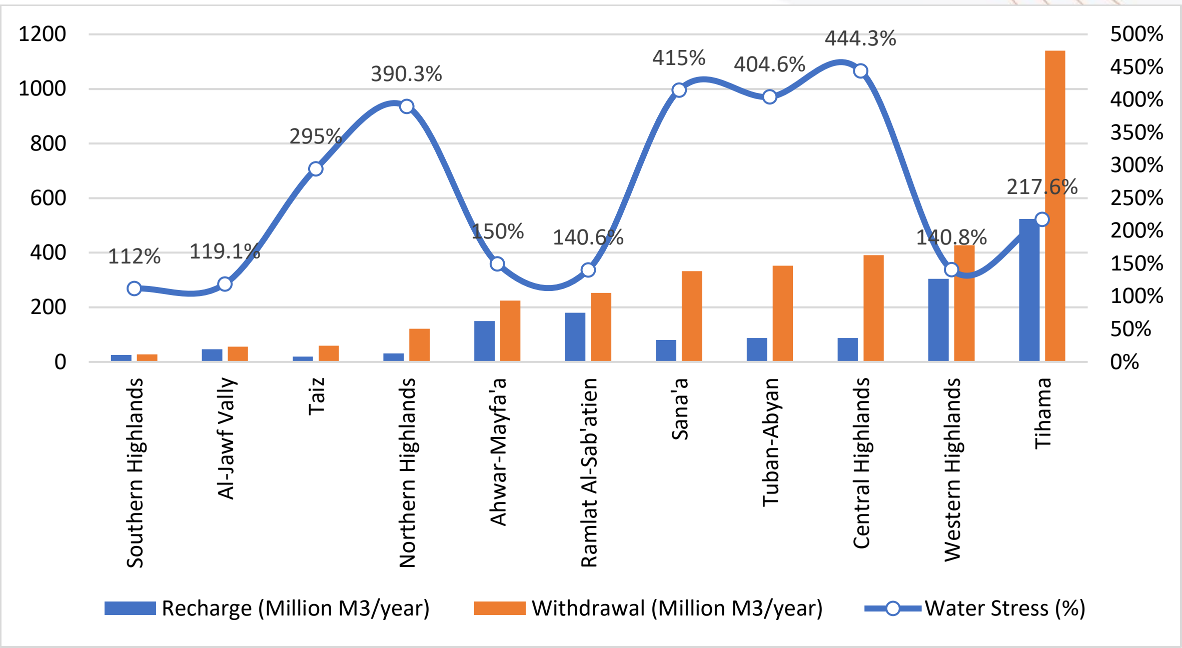


Figure 9 Water Situation, Water Stress by Basin (Withdrawal/Recharge) (million M3/year).

Source: Prepared by the Economic Studies and Forecasting Sector, based on: MoWE, Water Sector in Yemen, Resources and Services, 2019.

In coastal zones, overexploitation of groundwater leads to saltwater intrusion. A study conducted by the Tehama Development Authority (2004) reported that the electrical conductivity increased from 225 to 3,480µs/cm (at 25°C) in the Al-Jar area as a result of seawater intrusion. Another study was conducted by UNDP, and the government of the Netherlands and Yemen in 2001 and 2002 on Wadi Hadramout and Tuban Abyan deltas, the study showed that seawater intrusion has heavily impacted well fields in both deltas. The seawater intrusion front in the Abyan delta was geophysically mapped as far as 15 km inland. The seawater intrusion front in the Tuban delta was mapped 10 km inland. Sea water intrusion changes soil salinity in coastal farmlands, leading to crop yield declines and reduced resilience of coastal lands to climatic events.

Additionally, poor water management strategies have exacerbated the water scarcity problems. Water is wasted through old irrigation techniques where flood irrigation is still the dominant method used. In addition, the poor sanitation system causes contamination of surface water and groundwater aquifers. Moreover, the random drilling of wells and extensive pumping of groundwater resulted in drying up some aquifers and seawater intrusion as is happening in coastal zones of the country.

8.2- Agriculture sector

Agriculture accounts for 17.18% of the national GDP (World Bank,2018). "Approximately 75% of Yemen's population lives in rural areas and agriculture is the main source of employment for 55% of Yemeni" (FAO,2019). Moreover, agriculture consumes 93% of Yemen's surface and groundwater resources."[25]

Cultivated food crops include cereals, fodder, fruits, vegetables, and legumes. Cash crops include Qat and coffee, although coffee production has declined somewhat. Yemen's agricultural sector is dominated by small, subsistence farms and derives from a terrace system with one planting season from July to August. Rainfall during these months can be intense, leading to flooding that causes soil erosion and loss of agricultural land. Agriculture activities in the coastal plains and deserts are most vulnerable to floods. During other months, dry periods and drought lead to desertification, accounting for a 3-5% annual loss in arable land. Both floods and drought have contributed to diminishing crop yields. Water scarcity continues to be the largest hindrance to agricultural productivity in Yemen, and groundwater reserves are likely to be mainly exhausted, irrespective of climate change, reducing agricultural output by up to 40 percent by 2030 (World Bank, 2010). In addition, the production of Qat consumes almost 40% of the available water resources. Qat uses 38% of Yemen's irrigated land, contributing further to a decline in land area for food cultivation. Overall, future climate change impacts on Yemeni agriculture are expected to worsen, especially with more intense rainfall and prolonged droughts. However, future climate change impacts on agriculture vary among regions given Yemen's regional climate variability. For example, higher temperatures may increase crop yields in the highlands, whereas significant decreases in crop yields are expected in the south. (USAID,2016). Arable land is estimated at around 1.6 million hectares, of which the cultivated area is estimated at 1.3 million hectares. The agriculture land represents 2% of the total area of Yemen.[26] Moreover, the rapidly growing population at the rate of 3% annually is increasing the demand for scarce natural resources water resources, foodstuffs, and other products. People exploit soil, vegetation, and water without paying adequate attention to the sustainability of these resources. Unplanned expansion of urban centers in some areas exceeds the capacities of the available resources to meet new demands.

Yemen has experienced increasingly frequent floods from extreme rainfall events causing terraces deterioration, erosion of fertile soil from the banks of wadis. Frequent droughts and flooding events have also affected the sources of income of most of the population. Moreover, many households are facing the destruction of their crops by pests and diseases, sandstorms of which all desertification threatens their food production and security.[27] Climatic changes in recent years have greatly affected the seasonal crop output. The size of agricultural land, including farm output, has declined over the years, as a result of erratic rainfall, frequent drought waves, and changing temperatures in Yemen. During the last decade 2010-2020, and due to climatic changes in addition to the repercussions of war and conflict, the cropland in Yemen declined from about 1.6 million hectares in 2010 to its lowest in 2018, and then rose again slightly during the years 2019 and 2020, to stabilized at about 1.2 million hectares.

Table 3: Decrease of cropland in Yemen during 2010-2020 (Hectare):

Year	Cropland (ha)
2010	1,579,855
2011	1,411,929
2012	1,500,973
2013	1,499,404
2014	1,351,560
2015	1,172,185
2016	1,092,848
2017	1,084,001
2018	1,064,812
2019	1,124,486
2020	1,154,762

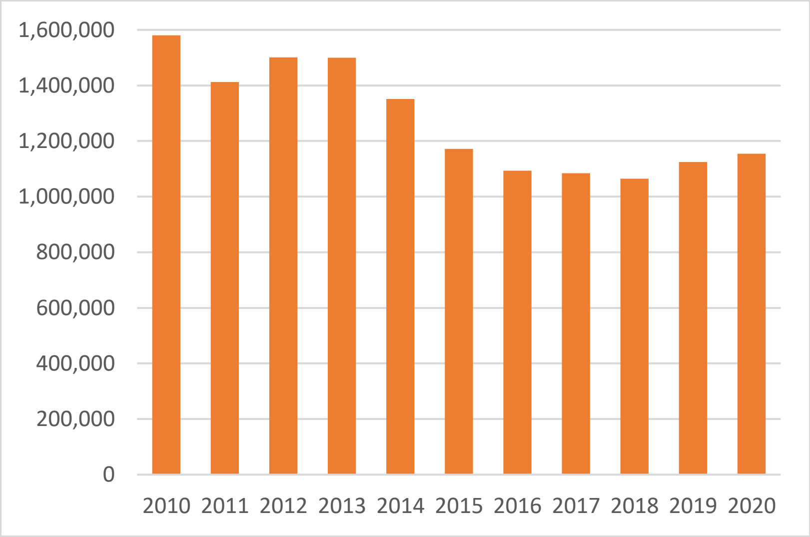
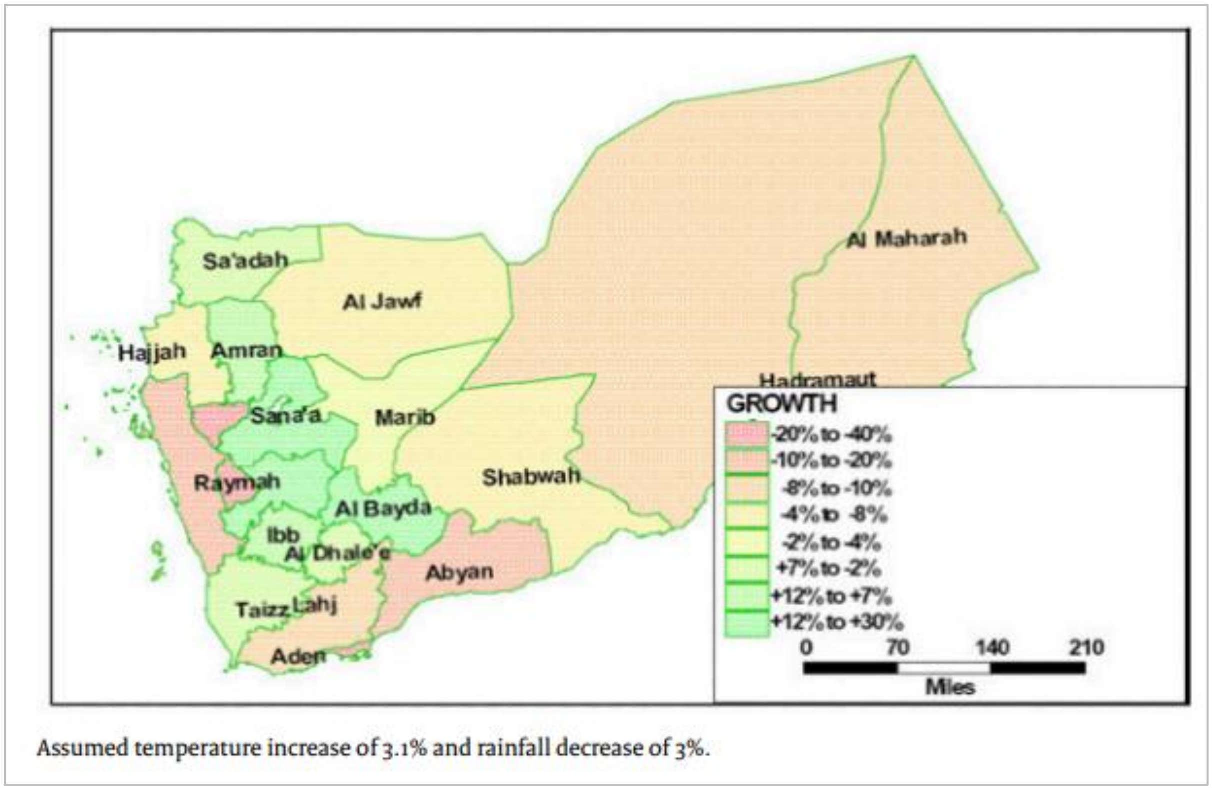


Figure 10: Decrease of cropland in Yemen during 2010-2020; (Hectare).
Source: Agricultural Statistical Yearbook, Different Issues.



Map 6: Changes in agricultural production by governorate ('mid' scenario 2080).

World Bank (2010): Yemen: Assessing the Impacts of Climate Change and Variability on the Water and Agricultural Sectors and the Policy Implications.

8.3- Food security sector

Yemen is one of the countries hit hard by the impacts of climate change effects because it relies heavily on food imports from other countries. Given the historically prominent levels of dependence on food imports, Yemen imports 90% of its food[28]. As such, the effects of global climate change pose a serious threat to Yemen's food security and threaten to further exacerbate food insecurity, undernutrition, and dependence on external assistance. The global impacts of climate change are likely to have a significant impact on Yemen's prospects. As of mid-2022, it is estimated that 19 million Yemenis (about 62% of the population) are food insecure with 161,000 people living in famine conditions (IPC 5).[29] In the 2022 Global Hunger Index, Yemen ranks 121st out of 121 countries. With a score of 45.1, Yemen has a level of hunger that is alarming.[30]

In the medium and long term, climate changes are likely to drive GDP further down. By 2050, Yemen's economy is projected to shrink by up to 24% due to climate change.[31] This is a significantly high percentage compared to sub-Saharan African countries whose GDP is projected to decline by up to 3% by 2050.[32] This puts enormous pressure on measures to confront and adapt to climate change in Yemen, given the poor financial conditions and a growing number of affected populations by the negative effects of climate change, mainly the poorest population. Low-income groups lack the necessary resources to withstand hot temperatures, rising sea levels, erratic rainfall, and other natural disasters. The poor in Yemen make up about 80% of the country's population.[33]

According to FAO estimates, the average Food Price Index of the FAO in Yemen increased from 95.1 percentage points in 2009 to 147.9 percentage points in 2022, about 55.6 percent up. Meanwhile, CPI - Food Consumption Indices in Yemen- spiked from 60 percentage points in 2009 to 161.4 percentage points in 2022, that is a 169.1% price increase, which is three times the increase in the FAO index, meaning global climate changes push food prices up, with poorer countries have experienced greater food inflation than higher income economies.[34] There is also a need to provide alternative food options to regions negatively affected by climate change, and to adopt domestic adaptation strategies that allow countries and regions to avoid excessive dependence on imports[35]. This indicates that Yemen is severely vulnerable in most dimensions of climate vulnerability and even more than countries with similar conditions, including food security issues.

8.4- Coastal zones sector

Yemen is particularly susceptible to coastal damage due to increased storm surges and sea level rise. More than 50% of Yemen’s coastal areas are at risk, affecting more than 55% of Yemen’s coastal population and 52% of areas contributing to GDP from coastal areas. Moreover, “Yemen is in the top 10 low-income countries most susceptible to coastal damage, threatening coastal infrastructure, ecosystems, and communities”[36].

Rising sea levels may cause accelerated coastal erosion, saltwater intrusion, increased frequency of floods, damage to ecosystems, and mass displacement and economic upheaval in coastal communities. It may also diminish the fisheries sector (2.4% contribution to GDP), increasing the vulnerability of up to 80,000 fishers who depend on this sector for work. (USAID,2016); approximately 3,441 species (millions of marine specimens) of the Yemeni coastal organisms could be endangered by sea level rise. Additionally, more than million farmers in Tehama will be affected as seawater rise and contaminates the freshwater used to irrigate their agricultural lands.[37]

8.5- Health sector

One of the most significant health impacts of climate change in Yemen is related to the spread of infectious diseases. Changes in temperature and rainfall patterns are creating conditions that are favorable for the spread of diseases such as dengue fever, malaria, and cholera. Flooding and water shortages are also increasing the risk of waterborne diseases. The country reports high numbers of serious illnesses related to vector-borne diseases, such as malaria, dengue fever, and cholera. As the global climate shifts, Yemen has seen an increase in cholera, the catastrophic outbreak that began in Yemen in October 2016 reaching its highest level in 2017 with over 2,000 reported deaths in that year alone, and in November 2021, there have been more than 2.5 million cases reported, and more than 4,000 people have died in the Yemen cholera outbreak, which the United Nations deemed the worst humanitarian crisis in the world at that time.[38] According to 2020, an estimated 18.8 million people in Yemen are living in areas at risk for malaria transmission, generating an estimated one million cases per year.[39]The ongoing conflict has exacerbated these issues, leaving nearly 2 million people, half of whom are children, malnourished (USAID 2016).

Many of the endemic and epidemic diseases in Yemen are affected by climate events. The spread of cholera, for example, is affected by heavy rain and drought events. "Increased storm surges and floods have led to displacement, injuries, and loss of life. For instance, in 2008, a major storm took the lives of 180 people and displaced an additional 20,000 people. The losses and damages amounted to 1.6 billion US dollars"[40]. Additionally, drought and flood are associated with an increased risk of malnutrition, vector-borne diseases, and waterborne diseases, with an expected increase in the variability of rainfall in the future, this is a key risk. Investments in ensuring that the population has access to water and sanitation as well as healthcare services can help reduce these impacts. Researchers also recommend disease surveillance systems to combat outbreaks in Yemen in an era of climate change (Bellizzi and Lane).

Extreme heat can increase morbidity and mortality of the most vulnerable such as older people, especially those above 65 years of age; people with pre-existing health conditions, such as heart disease, respiratory illness, and diabetes; young children; and people who are homeless or have inadequate housing, such as those living in camp settings (Singh et al. 2019).

As climate change exacerbates the ongoing food and water insecurity, Yemenis are at elevated risk of needing medical assistance. The incidence of heat-related illnesses is likely to rise along with the frequency of waterborne diseases. Vulnerable populations, such as children are at a higher risk of the adverse impacts of climate change on health. Extreme weather events will continue to displace many people and damage public infrastructure, healthcare facilities, and agriculture[41]

Yemen's public health system has been devastated by conflict for more than seven years. As a result, only 51 percent of health facilities are still functioning. Yemen Humanitarian Overview 2022 estimates that 21.9 million people, more than half of them children, need support to access critical health services. Additionally, more than eight million Yemenis need lifesaving nutrition assistance.[42]

Figure 11: Contamination sources that contribute to disease outbreaks such as cholera.

A. Wastewater Bani Al-Harith Sana'a. **B**. Turning dug well into a dump fill for household waste.

8.6- Vulnerable communities

Climate change has specific impacts on vulnerable communities, including women, IDPs and refugees, children, and older people.

8.6.1- Women and girls

Many studies have investigated the impacts of climate change on gender, particularly for access to water.[43]"Women are particularly impacted by water scarcity, it is usually their job to fetch water, even where it is kilometers away," explained Dr. Saleh.[44]That women are usually responsible for collecting water for their families is well known in the context of Yemen,[45]and as water sources decrease, women have to go further and further away to reach it. This puts women at risk of violence and harassment, as they often have to travel alone and through unsafe areas. Young girls are sometimes prevented from attending school because of the need to fetch water and the significant time that this may take due to its inaccessibility.[46]This can be particularly devastating in areas that have been mined, as women then face far greater risks of stepping on landmines along their journeys.[47] In some areas, women and girls jeopardize their lives to reach water sources. In one devastating incident, a woman in Sabir Al-Mawadim District of Taiz Governorate died two days before her wedding because she stepped on a landmine while walking to fetch water.[48]

A study launched by Muna Luqman and Dr. Nadia Al-Sakkaf described the many protection risks women and girls face in Yemen, as well as how these protection risks are predicted to be exacerbated by the current conflict and by climate change. In addition to the challenges women face stemming from their responsibility to fetch water, the study states that "early marriage has increased since the conflict began since families resort to marrying off their daughters as a means to make income from dowries."[49]Oxfam has also reported an increase in early marriage, including for girls as young as three years old, as a means of being able to buy food and shelter to save the rest of the family."[50]As climate change continues to slowly degrade rural communities' abilities to produce, Yemeni women bear the burden of food insecurity and caring for malnourished children while facing increasing malnutrition themselves. An estimated five million women and girls have limited or no access to reproductive health services. Child marriage, while it represents an issue that predates the conflict, is escalating with two-thirds of girls in Yemen married before the age of 18 and many before 15.

Around 36 percent of girls do not attend school a situation driven by gender norms that prioritize the education of boys over girls and give girls the burden of household chores and caring for younger siblings, in addition to increased numbers of female-headed households and gender-based violence will likely increase.[51] Approximately 30 percent of displaced households are now headed by women compared to 9 percent in 2015.[52] An estimated 73 percent of the over 4 million internally displaced people (IDPs) in Yemen are women and children. With limited shelter options, displaced women and girls tend to suffer most from lack of privacy, threats to safety, and limited access to basic services, making them even more vulnerable to violence and abuse. Agriculture is the most important employment sector for women in low- and lower-middle-income countries, during periods of drought and erratic rainfall, women, as agricultural workers and primary procurers, work harder to secure income and resources for their families. This puts added pressure on girls, who often have to leave school to help their mothers manage the increased burden. The fact is environmentalism has always been a women's issue[53].

Figure 13:Examples of climate change impacts on Yemeni women.

8.6.2- IDPs and refugees

There are more than four million IDPs in Yemen with 172,000 people newly displaced in 2020 and almost 160,000 newly displaced in 2021, particularly in Marib, Hodeida, Hajjah, and Taizz Governorates. As for refugees, asylum seekers, and migrants. As of November 2021, Yemen hosted approximately 138,000 migrants and 142,000 refugees and asylum seekers, predominantly in urban and semi-urban areas. [54]

Climate change produces more IDPs and refugees, as the degradation of land and water sources displaces people in search of vital resources. After displacement, IDPs and refugees continue to face more challenges than their local counterparts when it comes to accessing the same resources, and they are at greater risk of being displaced again, particularly by extreme climate events.

Many IDPs and refugees have lost their livelihoods and thus do not have adequate income sources, which makes this situation even more challenging. Circumstances are particularly acute for the many families who have been displaced from rural areas. They often relied on farming and agriculture for their livelihood and thus may not have other skills or opportunities to find new jobs in the areas where they have been displaced.[55]Furthermore, IDPs and refugees not living in camps are also often in vulnerable positions to the host community, which may blame them for straining local resources and driving up rent prices.[56]

Displaced people are also more vulnerable to climate change and resulting extreme weather events, including “flood events that can quickly destroy the limited infrastructure in the camps, as well as heat waves that leave people with few options for cooling and shelter.”[57]In many of the recent extreme weather events that have wracked the country, IDPs were the most impacted. Camp housing often cannot withstand flooding and other weather effects, and IDPs are often already living in “abject poverty.”[58]Based on a recent assessment, UNHCR predicted that 70 percent of IDP sites in Taiz alone will be affected by rain in 2022.[59]This predication has already been born out in Marib, where 2500 IDP families were displaced due to flooding on July 13 and 14, 2022.[60]The flooding has since continued to displace many more.[61]

8.6.3- People with disabilities

According to WHO estimates that 4.5 million Yemenis (15 percent of the population) have at least one disability, and it is estimated that 70 percent of the total number of Yemenis with disabilities are male.

Extreme weather events such as droughts, floods, and other extreme weather events, can be especially difficult for persons with disabilities to navigate. For example, floods can make it difficult or impossible for persons with mobility impairments to move around, while droughts can exacerbate health conditions for those with respiratory issues.

Additionally, climate change can increase the spread of waterborne diseases, especially waterborne diseases, which can be particularly dangerous for persons with disabilities who may have compromised immune systems or other health conditions. Climate change can also lead to displacement, which can create additional hurdles for persons with disabilities to access necessary services and support in new locations.

Policymakers and humanitarian organizations need to acknowledge the specific challenges faced by persons with disabilities in Yemen and address them in their response to climate change.

8.6.4- Children

Children are particularly vulnerable groups to climate change and environmental degradation. Currently, children in Yemen have incredibly high rates of malnutrition, a total of 2.2 million children under five years suffer from acute malnutrition due to these events. Where families have been displaced, many children have had to drop out of school and find work to support their families.[62]According to Luqman and Al-Sakkaf's study on gender, conflict, and climate, poverty and hunger both exacerbated by climate change have also been a powerful contributor to the increase in child recruitment.[63]And, as described above, early marriage has also increased, putting female children at risk.

Diseases and a poor health environment are key drivers of childhood malnutrition," said WHO Director-General Dr Tedros Adhanom Ghebreyesus. At the same time, malnourished children are more vulnerable to waterborne and vector diseases including diarrhea, respiratory infections, and malaria, dengue fever, which are of great concern in Yemen, among others. It is a vicious and often deadly cycle, but with relatively cheap and simple interventions, many lives can be saved." After the flooding period, waterborne diseases including diarrheal diseases and dengue fever affects many children[64]. Furthermore, the conflict in Yemen and climate change coupled with poor access to healthcare are factors that increase the risk of diarrheal disease and acute malnutrition[65]. This is particularly true for IDP children at camps (1.65 million[66] in total) who are more at risk of frequent and severe storms and foods, which increase the risk of diarrheal disease and acute malnutrition, with few if any sanitation and hygiene services, limited access to healthcare for such camps.

Today, Yemen is one of the most dangerous places in the world for children to grow up. The country has high rates of communicable diseases, limited access to routine immunization and health services for children and families, poor infant and young child feeding practices, and inadequate sanitation and hygiene systems.[67]

8.6.5- Older people

People who are aged 65 and older are particularly vulnerable to the effects of climate change. Advancing age and the prevalence of special needs increase the vulnerability of these individuals to climate stressors and risks. Older persons, including particularly older persons with disabilities and older women, are among those most affected by climate-related harms such as the increasing spread of vector-borne diseases, heat stress, and the increasing frequency and intensity of sudden-and slow-onset disasters which can impact their physical and mental health and wellbeing.

Older adults are more vulnerable to extreme weather events due to aging immune systems and the propensity for dehydration because of their decreased sense of thirst and lower body fluid content. Older adults with chronic health conditions such as cardiovascular disease, hypertension, obesity, diabetes, and chronic kidney disease are especially at risk for disease exacerbations during times of temperature extremes, high stress, and limited resources. Elders with dementia (i.e., Alzheimer’s disease, vascular dementias) are at substantial risk during elevated temperatures for exacerbation of cognitive decline and hospitalization.

The outbreak of cholera in Yemen killed more people over the age of 60 than any other age group[68]. According to WHO figures from 2017 showed that 31% of cholera deaths in Yemen were older people. As well as cholera, older people are particularly vulnerable to malnutrition. Right now, malnutrition levels among older people in Yemen are alarmingly high.[69]

9. Conflict and climate change.

As climate change impacts natural resources, such as water and land, it can create competition and conflicts over access to these resources. For example, droughts and water scarcity can lead to disputes over water rights, while the degradation of land can cause conflicts over land use and ownership. Climate change can also exacerbate the existing social and political tensions, particularly in regions prone to instability, by increasing the frequency and intensity of extreme weather events, such as floods and hurricanes. These events can cause displacement, increase food insecurity, and fuel economic instability, which can lead to social and political unrest.

In Yemen, conflicts over resources are not a new phenomenon. Historically, local disputes over land and water distribution have been a major source of conflict. Before the conflict, some sources cited statistics from the Yemeni Ministry of Interior to report that around 4000 people die each year due to violent disputes over land and water.[70] Today conflicts over resources have continued across the country. For example, an activist from Marib stated that fights have often broken out within IDP camps between different families or groups over food and water.[71] Water scarcity in particular has led to significant outbreaks of violence. According to new research conducted by the Center for Civilians in Conflict (CIVIC), local conflicts are breaking out over water and other resources across Yemen. “Water scarcity is the biggest problem Yemen faces. It will tear at community resources and lead to further conflicts.”[72] For instance, two tribes living in Al-Muwadim District of Taiz Governorate have conflicted fresh water for over two decades, resulting in people from both tribes being killed and wounded. Another example is in Tarim District of Hadhramaut Governorate, after floods destroyed one of the canals emanating from Wadi Altahab, the farmers connected to it put a block on the entire canal system to keep their land from being flooded by heavy rainfall. However, this left all of the farmers who previously relied on the channels for irrigation without any water for their land. The situation led to fighting between the farmers and, ultimately, displacement, as families eventually moved after years of not being able to irrigate their land.[73]

Food access and allocation have also been a source of conflict, particularly in IDP camps. For example, in Marib, an IDP and community leader living in Al-Summaia camp stated that many of the community members who had been displaced from Sirwah and Al-Juba districts had not been receiving monthly food baskets since their displacement in October 2021. This sparked conflicts with other IDPs who had been receiving the food baskets, as well as conflicts with the NGOs and camp management that were handling the basket distribution.[74]Additionally, displacement in Yemen is one of the main links between climate change and conflict.[75] Climate change has the potential to displace millions of people in Yemen in the next few decades. Already, extreme weather events in the last few years have impacted hundreds of thousands of Yemenis and displaced tens of thousands. This displacement, in turn, has the potential to exacerbate a wide swath of conflict drivers: loss of livelihoods, particularly when people are displaced from rural areas; strains on critical resources in areas of relocation; and opportunities for armed groups to recruit more individuals. The loss of livelihood caused by displacement, particularly for the many farmers who have been displaced from their land, is likely to worsen factors already contributing to conflict. A government official who works in the executive unit for IDPs in Al-Jawf, for example, described how the IDPs displaced to Al-Rayan camp all used to be farmers. "They left their farms, their water resources, and their livelihoods, and their land is no longer usable. After they were displaced, they tried to find other jobs, such as in the army. Some families started to get income from drug dealing."[76] The areas to which these IDPs have been displaced then face greater resource constraints and, therefore, an increased possibility of conflict. Further, individuals, and children in particular, are more vulnerable to recruitment from armed groups when they have been displaced and lack economic opportunity.[77]Disputes between IDPs and host communities are frequent where IDPs have received resources from humanitarian aid organizations that host communities have not. Disputes are also frequent where the influx of IDPs has driven up rental costs and other living costs. "The host community is very angered that they are not getting resources that the IDPs are getting. The problems between these groups are also about rental prices and real estate. IDPs have driven up rental prices and sometimes landlords double the price if they'll kick out the former tenant."[78] Another official who works in the executive unit for IDPs in Marib stated that "Every day there are conflicts between host communities and IDPs over these resources as well as over the distribution of humanitarian assistance."[79]The same is true in many other areas of the country.

10.Climate change adaptation and mitigation

The following adaptation measures are expected to support Yemen to address climate change and raise resilience to its impacts in key vulnerable sectors:

10.1 Adaptation measures in the water sector

- **Desalination of water by using renewable energy sources**: Desalination can provide a reliable and sustainable source of drinking water. By using renewable energy sources, such as solar thermal, solar photovoltaics, wind, and geothermal energy, desalination can also reduce the country's dependence on fossil fuels, which are both expensive and environmentally damaging.
- **Rainwater harvesting in all sectors:** there are some common methods of rainwater harvesting such as the following:
  1- **Rooftop harvesting:** This involves collecting rainwater from rooftops and storing it in tanks or other containers. The water can be used for non-potable purposes such as irrigation, washing clothes, and flushing toilets.
  2- **Surface runoff harvesting:** This involves collecting rainwater from the surface of the ground and storing it in ponds or other storage structures. The water can be used for irrigation, groundwater recharge, and other purposes.
  3- **Infiltration trenches:** This involves digging trenches in the ground and filling them with gravel or other porous material. The trenches collect rainwater and allow it to infiltrate into the soil, recharging the groundwater.
  4- **Permeable pavements:** This involves using permeable materials for pavements, such as porous concrete or gravel, which allow rainwater to infiltrate into the soil and recharge groundwater. The water can then be collected and stored for later use.
  5- **Rain barrels:** This involves collecting rainwater in barrels or other containers and using it for non-potable purposes such as watering plants and washing cars.
  6- **Green roofs:** This involves planting vegetation on rooftops, which absorbs rainwater and reduces runoff. The water can be collected and stored for later use.

- **Applying water conservation techniques in agriculture sectors**: water conservation in agriculture is essential for sustainable food production and the protection of freshwater resources. By implementing water-saving practices and technologies, farmers can reduce water use and improve the efficiency and productivity of their crops. This could be done by using drip Irrigation, planting drought-tolerant crops, using hydroponics techniques, optimizing watering times, launching training programs for farmers on water use, laser field leveling, subsurface irrigation, mulch or black plastic, gravity drip buckets, sprinkler irrigation, and gated pipe irrigation. For more information about these techniques see appendix 1.

- **Restore or preserve mountain terraces and forests:** By restoring or preserving mountain terraces, farmers can increase the water-holding capacity of the soil and reduce soil erosion. Mountain terraces can also help to reduce the risk of landslides and other natural disasters, which can be exacerbated by water scarcity. appendix 2. Mountain forests, meanwhile, are important for preserving water resources. Forests help to regulate water flows by intercepting rainfall, reducing runoff, and increasing infiltration. They also help to maintain soil moisture levels and reduce the risk of water scarcity and drought. In addition, mountain forests can provide other benefits, such as reducing the risk of floods and landslides, providing habitat for wildlife, and supporting ecotourism.

- **Promote awareness of climatic variability and the potential risk of climate change at all levels of the community** (public and decision-makers), arrange local, regional, and national awareness-raising campaigns to disseminate information on water resources, their vulnerability, and adaptation measures on all levels including school and university curricula.

- **Wastewater recycling**: Wastewater recycling is a critical measure to increase the availability of water resources and reduce the pressure on freshwater sources. However, it is also essential to ensure that the treatment and recycling of wastewater are done safely and effectively to prevent the spread of water-borne diseases. The use of renewable energy sources for the treatment and recycling of wastewater can also reduce the environmental impact and help mitigate the effects of climate change. This is because the use of renewable energy sources, such as solar and wind energy, can reduce greenhouse gas emissions and contribute to a more sustainable energy system.

- **Improving the sanitation systems in the country:** To reduce the contamination of both surface water sources and shallow groundwater aquifers. This can be done by constructing wastewater recycling plants and improving the sewerage system in the country.
- **Artificial groundwater recharge:** By using different techniques such as constructing dams, check dykes, percolation ponds, groundwater dams or sub-surface dykes, injection wells, and recharge trenches. Appendix 3.
- **Rehabilitating the current infrastructure**: By improving the existing water infrastructure, such as reservoirs, pipelines, and treatment plants, they can become more efficient in managing the available water resources. This can include activities such as repairing leaks, upgrading water treatment technologies, and expanding water storage capacity.

10.2 Adaptation measures in the agriculture sector

- **Control and prevent land degradation and desertification**. This could be done by establishing programs to support and encourage farmers to cultivate their arable lands such as providing them with solar energy pumps, irrigation networks, providing them with needed seeds, pesticides, fertilizers, and greenhouse agriculture.
- **Design and implement terrace rehabilitation programs**. As they are particularly important for soil and water harvesting and recharging groundwater and providing a source of income for many Yemenis.
- **Diversification of crops:** Farmers can diversify their crop production to include more drought-resistant and heat-tolerant crops, such as millet, sorghum, and legumes. This can help to ensure food security even during periods of drought or extreme heat.
- **Use of improved crop varieties:** Improved crop varieties can help to increase crop yields and improve their resilience to climate change. These varieties are developed through breeding and genetic modification to have traits such as drought tolerance, heat tolerance, and disease resistance.
- **Preserving and restoring wetlands:** they serve as vital habitats for diverse species of plants and animals, and help to buffer pollution, absorb floods, and recharge aquifers. Unfortunately, wetlands in Yemen are increasingly degraded due to numerous factors such as climate change, limited water resources, and human activities including population growth and industry.

- **Compensate water losses in agriculture by using treated wastewater and mosques water for irrigation**: These sources of water can be used to supplement traditional water resources, reducing the demand for freshwater sources and conserving water.
- **Prepare agriculture manuals for the different zones of Yemen including sowing dates**: Sowing dates refer to the time during which seeds are planted in the soil for a particular crop. The timing of sowing is important because it affects the growth, development, and yield of the crop.
- **Utilization of flowing water in the wadies**: This can be implemented by building check dams, constructing diversion channels, planting more lands, and installing water harvesting structures such as gabions and stone bunds.
- **Encourage and promote awareness campaigns about the impact of climatic variability and the potential risks of climate change on agriculture across all levels of the community:** By doing so, we can help to promote the adoption of climate-resilient farming practices, reduce the risk of crop failure and food insecurity, and ensure the sustainable use of natural resources.
- **Establish flexible mechanisms for intervention, especially for dealing with Qat and other water-depleting crops** through providing new alternative cropping.
- **Support alternatives for fuel wood to control woodcutting and preserve plant cover**: Through the promotion of LPG use for cooking and solar energy applications for drying, heating, lighting, … etc.
- **Disseminate flowage/flood guidance stations at main wadies:** So that communities will be warned during flooding and the level of damages and loss of life will decrease.
- **Support using renewable energy sources in the agriculture sector:** Such as using solar and wind energies to reduce the total GHG emissions from the agriculture sector.
- **Livestock management:** Livestock production is an important source of income for many farmers. To adapt to climate change, farmers can adopt improved livestock management practices, such as breeding for heat tolerance, disease control, vaccination programs, better animal husbandry practices, and providing shade and water for animals during periods of extreme heat.

10.3 Adaptation measures in the coastal zones

- **Construct coastal defense walls for coastal areas subjected to sea level rise**: Coastal defenses, such as seawalls, breakwaters, levees, and dikes, can be built to protect against storm surges and sea level rise. These structures can also help to reduce coastal erosion and protect coastal communities and infrastructure.
- **Implementing studies to evaluate the affected areas by sea level rise in all coastal areas of the country.**
- **Establish an integrated coastal management network for all coasts of Yemen**: An integrated coastal management network involves the coordination and collaboration of various stakeholders, including government agencies, NGOs, local communities, and businesses, to manage and protect coastal resources sustainably.
- **Expand green belt for coastal areas** through protection and re-planting of mangroves and palms along the coastal zones.
- **Increase the level of awareness among fishers, sailors, island inhabitants, and other individuals associated with the marine environment:** Through the provision of guidance and information services about climate change and how to mitigate and adapt to its impacts on coastal zones and islands.
- **Reducing the contamination of seawater and shorelines of the country:** By improving the sanitation system which is contaminating a large area of the coastal zones.
- **Encourage sustainable fishing practices:** Promoting sustainable fishing practices, such as using eco-friendly gear and techniques, can help to reduce the impact of fishing on the marine environment and prevent overfishing.

10.4 Adaptation measures in the health sector

Adapting to and mitigating the impacts of climate change in Yemen's health sector requires a multi-faceted approach.

- **Climate-resilient health infrastructure:** This could be implemented by, assessing, and upgrading health facilities to withstand climate impacts, such as flooding, heatwaves, and storms, and ensuring the availability of backup power, water, and communication systems for uninterrupted services during extreme weather events.
- **Strengthening disease surveillance and early warning systems:** by expanding the monitoring and reporting of climate-sensitive diseases, such as malaria, dengue, and cholera. Enhancing the capacity of health professionals to analyze data and identify trends in disease patterns related to climate change. Establishing early warning systems to predict and respond to potential disease outbreaks.
- **Enhancing public health preparedness and response:** by developing and implementing climate-sensitive health policies and plans, including heatwave action plans and vector control programs. Providing training to health professionals on climate change impacts, adaptation, and mitigation strategies. Strengthening community engagement and awareness campaigns to promote health-protective behaviors, such as hygiene practices and the use of insecticide-treated bed nets.
- **Promoting access to clean water and sanitation:** This could be done by expanding access to safe and clean water sources in both urban and rural settings. Implementing water conservation and management practices to mitigate the effects of water scarcity. Strengthening sanitation infrastructure and promoting hygiene practices to reduce the risk of waterborne diseases.
- **Supporting climate-smart agriculture and food security:** by promoting climate-resilient agricultural practices to ensure food security, such as drought-tolerant crops and efficient irrigation systems. Enhancing the capacity of the agriculture sector to adapt to climate change and reduce its greenhouse gas emissions. Strengthening food distribution systems and providing support to vulnerable populations to improve nutrition and health.

- **Strengthening partnerships and international cooperation:** by collaborating with international organizations, such as the World Health Organization, United Nations Development Programme, and World Bank, to access technical assistance, funding, and knowledge sharing. Engaging with regional partners to share experiences and best practices in adapting to and mitigating the effects of climate change in the health sector.
- **Waste management:** By implementing waste management practices within the health sector, we can mitigate health risks, minimize pollution, reduce the environmental impact of healthcare facilities, and build more resilient healthcare infrastructure. Additionally, sustainable waste management practices contribute to overall efforts to reduce greenhouse gas emissions and promote a healthier, sustainable future. More information in appendix 4

11.Recommendations

1- Climate change adaptation and mitigation must be prioritized in all sectors.
2- The international community should provide resources, including funding, legitimacy, and support to NGOs and civil society organizations working on issues related to climate change and resource management.
3- The Yemeni government and all security actors should facilitate the passage of NGOs through checkpoints and give them approvals, particularly where they are working to mitigate harm from climate change.
4- Conducting more studies throughout the country to evaluate the impacts of climate change and prioritize the climate-related issues that must be addressed firstly.

12. Conclusion

In conclusion, climate change has already had severe impacts on Yemen, affecting all sectors and resources as well as communities across the country. Yemen's situation serves as a warning to the rest of the world of what could happen if climate change is not effectively and rapidly addressed. Government entities, civil society, community leaders, and the international community must work together to tackle climate change and environmental issues in Yemen before it is too late. The future of Yemen and its people depend on these collective efforts to mitigate and adapt to the impacts of climate change and protect the environment.

References

(n.d.). Retrieved from https://www.neoakruthi.com/blog

Al-Eryani, H. L. (2020, 12 14). *Yemen's Environmental Crisis Is the Biggest Risk for Its Future*.

CEOBS. (2020). *Yemen's agriculture in distress.* Conflict and Environment Observatory.

CIVIC. (2022). *Climate change, environmental destruction, and conflict in Yemen.* CIVIC.

Dr. A. M. AL-Sharjabi et al. (2014). *Drought conditions and management strategies in Yemen.* Dhamar: Ministry of Agriculture & Irrigation.

EPA. (2009). *National Adaptation Programme of Action.* Environmental Protection Authority.

EPA et all. (2017). *National Biodiversity Strategy and Action Plan II achieving a resilient, productive, and sustainable socio-ecosystem by 2050.* GEF, UNDP, EPA.

EPA et all,. (2017). *National Biodiversity Strategy and Action Plan II - (EPA).*

FAO. (2018). *Yemen Plan of Action 2018-2020.*

GFDRR. (2011). *Climate risk and adaptation country profile.*

ICRC. (2021). *Climate fact sheet of Yemen.* climate center (ICRC).

ICRC. (2022, June 5). *The water situation in Yemen/International Committee of the Red Cross*. Retrieved from https://www.icrc.org/en/document/water-situation-yemen#:~:text=The%20rate%20of%20groundwater%20overdraft,services%20in%20Yemen%20(OCHA).

ICRC. (2022). *Yemen's ancient honey industry at risk from combination of conflict and climate change*. Retrieved from https://www.climatecentre.org/8646/icrc-yemens-ancient-honey-industry-at-risk-from-combined-impact-of-conflict-and-climate-change/

IPCC. (2022). *IPCC Climate report 2022 summary*. IPCC.

IPCC. (2022). *IPCC summary for policymakers*. Retrieved from https://www.ipcc.ch/srccl/chapter/summary-for-policymakers/

King-Okumu, C. (2021). *A rapid review of drought risk mitigation measures.* Rome, Italy: FAO. Retrieved from https://www.fao.org/publications/card/en/c/CB7085EN/

M.Al Safaani, et al. (2015). *IMPACT OF SEA LEVEL RISE AND CLIMATE CHANGE ON THE COASTAL ZONE OF ADEN GOVERNORATE, REPUBLIC OF YEMEN.* Sana'a: Faculty of Science Bulletin, 27 (2015) 15-32 © 2015 Sana'a University ISSN 1684-100X .

Mr. Ammar Al-Aulaqi. (2021). *yemen-un-habitat-2021*. Grean Climate Fund.

NTG. (2018, June 6). *Northern Territory Government*. Retrieved from Flood mitigation measures: https://dipl.nt.gov.au/lands-and-planning/flood-mitigation/flood-mitigation-measures

NWRA. (2022, May 27). Groundwater depletion and possible solutions. (H. Akhdar, Interviewer)

OCHA. (2014). *Desertification a threat to millions of Yemenis.*

OCHA. (2022). *Severe and widespread floods across Yemen bring more hardship to tens of thousands of displaced families.*

Our world in data. (2019). *Yemen: CO2 Country Profile*. Retrieved from Our world in data: file:///D:/Climate%20change/Yemen_%20CO2%20Country%20Profile%20-%20Our%20World%20in%20Data.html?country=

PIRE. (2019, June 16). *8 innovative drought solutions that we can count 0n*. Retrieved from https://ripe.illinois.edu/news/8-innovative-drought-solutions-we-can-count-0n

Sana'a Center for Stratigic Studies. (2020, July). *Yemen Environmental Bulletin*. Retrieved from https://sanaacenter.org/programs/yeb#:~:text=Temperatures%20are%20rising%20in%20Yemen,the%20world's%20most%20fragile%20state.

UNCCD. (2022). *Global Land Outlook second edition.*

UNCCD et all,. (2000). *National Action Plan to Combat Desertification.* Republic of Yemen, Ministry of Agriculture and Irrigation.

UNDP. (2018). *Integrated Water Harvesting Technologies to Adapt to Climate-Induced Water.* Sana'a: UNDP.

UNDP. (2021). *Water availability in Yemen.* ACACIA WATER.

UNDP et al. (2013). *Yemen's Second National Communication under the United Nations Framework Convention on Climate Change.* May.

UNF. (2022, May 16). Retrieved from https://unfoundation.org/blog/post/five-facts-about-gender-equality-and-climate-change/?gclid=Cj0KCQiA37KbBhDgARIsAIzce15LPcZlSoYg2XkpXdVVekapF4dSf-ChWqm0Xerr6BFuBqWWPu-5ZGkaArI-EALw_wcB

USAID. (2016). *Climate change risk profile.*

WHO. (2021). *Acute malnutrition threatens half of children under five in Yemen in 2021: UN*. Retrieved from https://www.who.int/news/item/12-02-2021-acute-malnutrition-threatens-half-of-children-under-five-in-yemen-in-2021-un

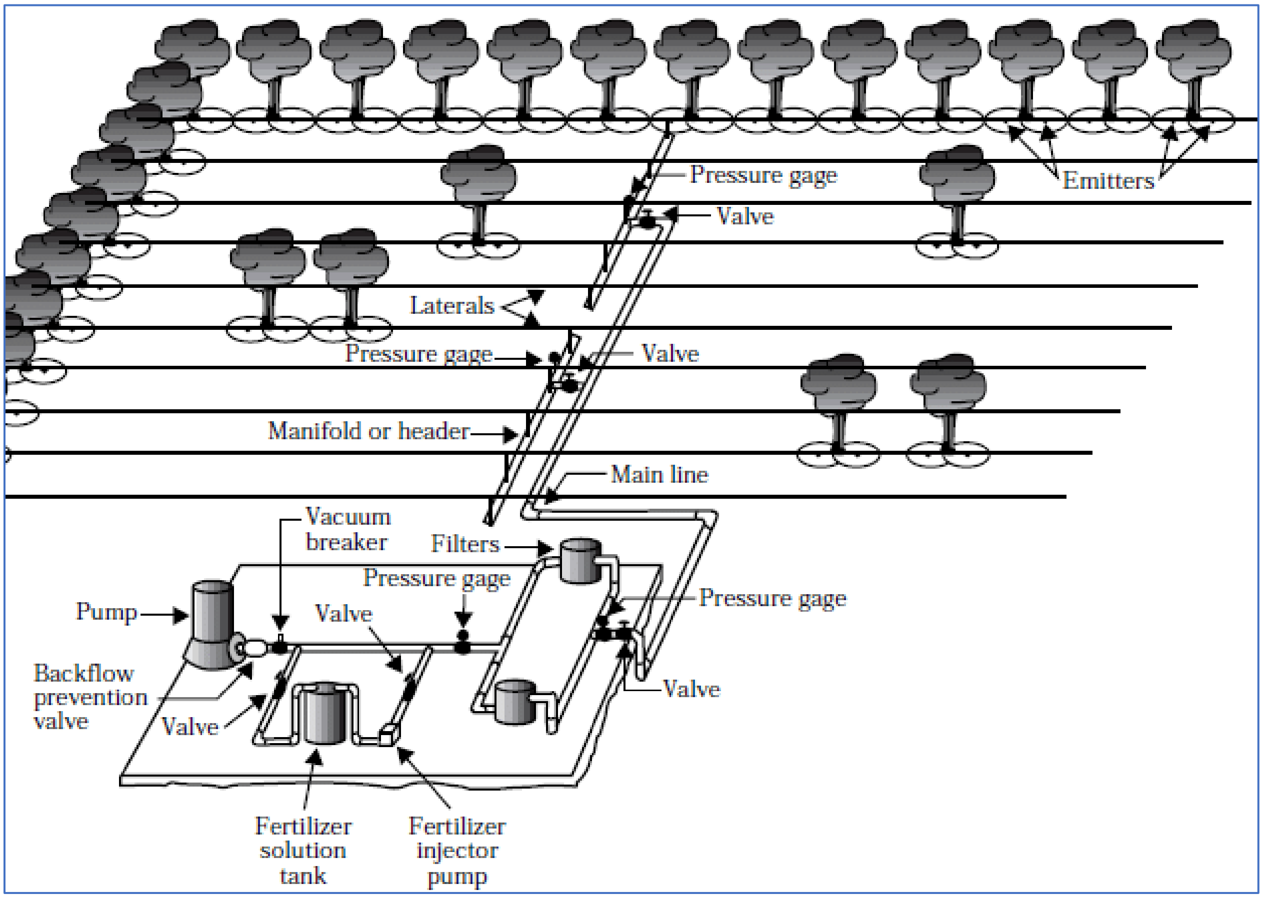
Women, U. (n.d.). *How gender inequality and climate change are interconnected*. Retrieved from https://www.unwomen.org/en/news-stories/explainer/2022/02/explainer-how-gender-inequality-and-climate-change-are-interconnected?gclid=Cj0KCQjwqoibBhDUARIsAH2OpWiBe_WAD6FtprQa50cZ7e_DMRLNAqRqlbubB9yyphjWXnE50lAl4FIaAlfcEALw_wcB

YEPA et al. (2009). *Yemen National Adaptation Programme of Action*. Retrieved from https://www.adaptation-undp.org/projects/yemen-national-adaptation-programme-action-napa#:~:text=Yemen%20is%20promoting%20sustainable%20use,and%20developing%20sustainable%20agricultural%20programs.

Appendices

<u>Appendix 1:</u> Water Conservation in the agriculture sector

1.1- Drip irrigation or trickle irrigation is a type of micro-irrigation system that has the potential to save water and nutrients by allowing water to drip slowly to the roots of plants, either from above the soil surface or buried below the surface. The goal is to place water directly into the root zone and minimize evaporation. Drip irrigation systems distribute water through a network of valves, pipes, tubing, and emitters. Depending on how well designed, installed, maintained, and operated it is, a drip irrigation system can be more efficient than other types of irrigation systems, such as surface irrigation or sprinkler irrigation.



Source: https://www.researchgate.net, 2018

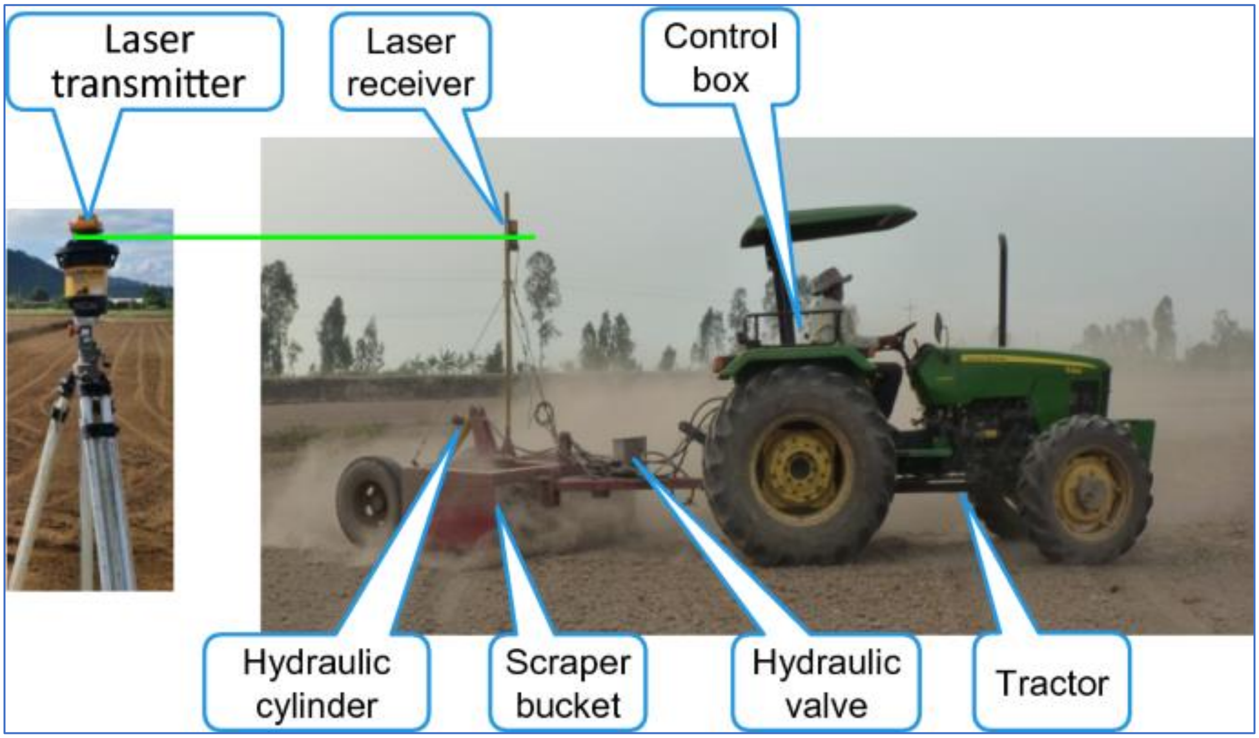
1.2- Optimize watering times:

It is generally accepted that watering during the heat of the day is only going to waste your water, but when is the best time to water? The best time to water plants is in the morning or evening.

Morning watering is preferable to evening watering as the plant has time to dry before the sun goes down. At night, water tends to rest in the soil, around the roots, and on the foliage, which encourages rot, fungal growth, and insects.

1.3- laser field leveling:

One of the biggest sources of water waste is runoff because the fields or gardens where you are planting are not perfectly leveled, so any water that does not soak into the soil immediately flows away. Laser land leveling reduces or even eliminates the problem of runoff by using lasers and other tools to make the field perfectly level before crops are planted, reducing runoff and, by proxy, preventing waste and promoting conservation.



Source: https://www.researchgate.net/figure/Components-of-laser-land-leveling-

1.4- Subsurface irrigation:

This takes drip irrigation to the next level. Instead of using lesser amounts of water on the surface, and letting it drip down into the soil, subsurface irrigation requires burying the irrigation pipes below the ground before planting the crops. They evenly distribute the water among the plant roots. There is almost no waste, and they free up the surface area around the plant for other activities.

Source: https://civconws.com.au/info/subsurface-drip-irrigation.

1.5- Mulch or black plastic:

Laying black plastic or using black plastic mulch is useful for more than just preventing weed growth. It also helps to keep soil warmer in cool climates. This prevents water from evaporating, keeping the soil moist and reducing the amount of water required to irrigate crops. The only downside of this type of water conservation is that it prevents rain from reaching the roots.

Source: https://www.amazon.com/Agricultural-Mulching-Biodegradable

1.6- Gravity drip buckets: This might not be a useful tool for large fields. But for someone who is planting a backyard garden and wants to conserve water, it is a fun afternoon project. All you need is a clean five-gallon bucket with a lid, a drill, and some vinyl or polyethylene tubing. Elevate the bucket and stick the end of your tube in the ground near your plants. Gravity will do the work for you. You will never have to worry about overwatering because the soil will simply stop absorbing the water once it is saturated.

Source: https://geohydrosupply.com/bucket-drip-irrigation

1.7- Train farmers on water use:

Provide training courses on the water cycle, including the relationship between rainfall, runoff, and soil water infiltration, as well as on the measurement of water volumes and irrigation timing.

1.8- Gated pipe irrigation:

In the 1940s, gated pipe irrigation was popular, this process spread water into unlined ditches and allowed it to saturate the soil, while preventing waste by limiting its flow into those ditches. It is a quite simple technique that can easily be upgraded by incorporating IoT sensors in the soil and remote or autonomous gates in each of the pipes.

Source: http://aridagriculture.com/2017/09/18

1.9- Sprinkler irrigation:

A sprinkler irrigation system allows the application of water under high pressure with the help of a pump. It releases water similar to rainfall through a small diameter nozzle placed in the pipes. Water is distributed through a system of pipes, sprayed into the air, and irrigates in most of the soil types due to the wide range of discharge capacity.

Source: https://blog.apnikheti.com/

Source: https://www.usgs.gov.

1.10- Hydroponics:

Is a type of agriculture and a subset of hydroculture that involves growing plants usually crops or medicinal plants without soil by using water-based mineral nutrient solutions in aqueous solvents. The advantages of this method represent by consuming less water up to 90% less than traditional field crop watering methods, higher yield, has a controlled level of nutrition, plants are healthier and mature faster, and susceptibility to pests and diseases is negligible. This method has been practiced in Yemen and it succeeded but it is not used throughout the country yet.

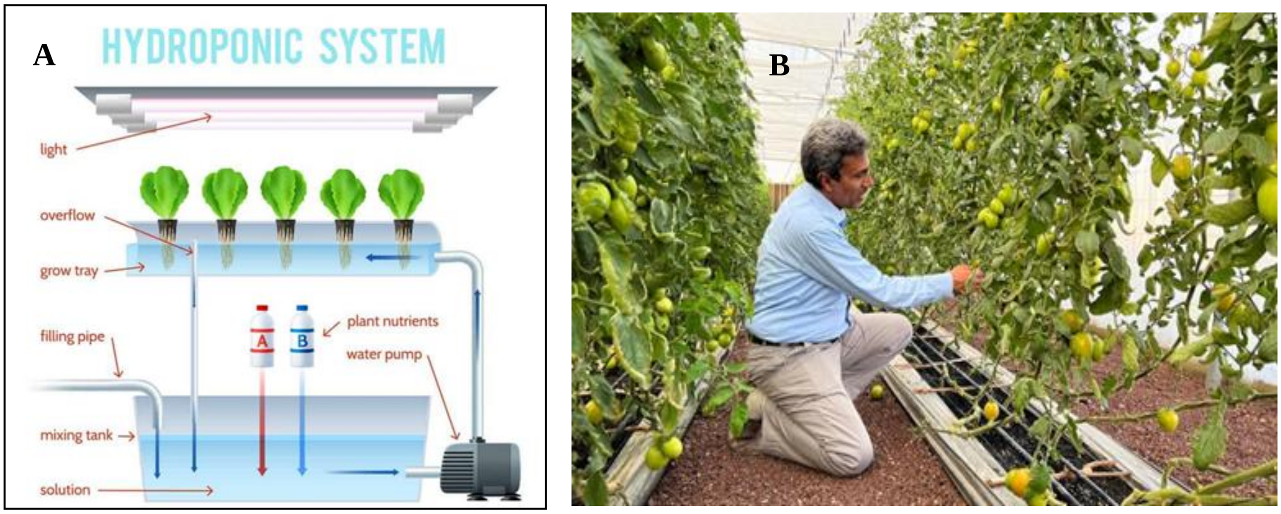


Figure 15:Hydroponics A. Hydroponics scheme. B. Hydroponics practice in Yemen.

Appendix 2: Mountain terraces

Yemen is characterized by terrace cultivation, which is considered an important national heritage. From a technical point of view terrace cultivation is an advanced farming system for soil and water harvesting and utilization of mountainous lands. For centuries Yemeni farmers have succeeded in creating sustainable farming systems based on the understanding of the basic processes of controlling and preventing the degradation of the resource base. The fertile highland terraces of Yemen demonstrate the importance of the careful resource management carried out over the centuries. However, the rapid social and economic developments in the last three decades have resulted in considerable changes in the pattern of resource management. As a consequence of these changes, traditionally maintained terraces fell into disrepair or are abandoned, and runoff was increased-which not only eroded the slopes but leads to destructive floods in the wadi (ephemeral streams) beds. The mountain terraces land is estimated to be 20%-25% of the arable land. It is worth noting that the absence of regular maintenance is one of the most key factors of terraces abandonment. Negligence of land for several seasons or years made farmlands, forests, and rangelands prone to excessive felling, overcutting, overgrazing and consequently losing their fertility and becoming prone to erosion.

Appendix 3: Methods and Techniques for groundwater recharge

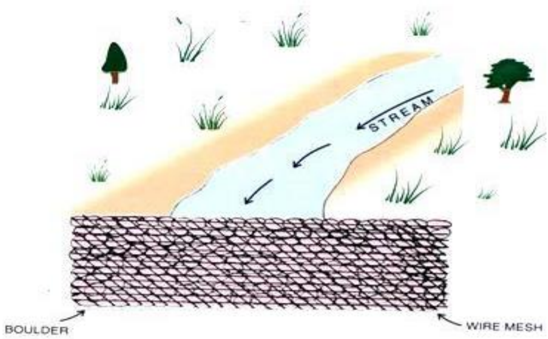
Urban Areas	Rural Areas
Roof Top Rainwater/runoff harvesting through. • Recharge Pit • Recharge Trench • Tube well • Recharge Well	Rainwater Harvesting through • Gully Plug • Gabion Structure • Percolation tank • Check Dam/ Cement Plug/ Nala Bund • Recharge shaft • Ground Water Dams/Subsurface Dike

4.1 Groundwater recharge in Rural areas

a. Gully plugs: Gully plugs, also called check dams, are mainly built to prevent erosion and settle sediments and pollutants. Furthermore, it is possible to keep soil moisture due to infiltration. Depending on the topography, amount of precipitation, material, and financial resources available, there are several methods to construct a gully plug. They have to be inspected regularly and any damages must be repaired.

b. Gabion structure

- This is a kind of check dam commonly constructed across small streams to conserve stream flows with practically no submergence beyond the stream course.
- A small bund across the stream is made by putting locally available boulders in a mesh of steel wires and anchored to the stream banks.
- The height of such structures is around 0.5 m and is normally used in streams with width of less than 10 m.
- The excess water overflows this structure storing some water to serve as a source of recharge. The silt content of stream water at the right time is deposited in the interstices of the boulders. With the growth of vegetation, the bund becomes quite impermeable and helps in retaining surface water runoff for a sufficient time after rains to recharge the groundwater body.



c. Percolation ponds:

Percolation ponds are generally constructed in a low-level wasteland or a small drain. It has a well-defined catchment and the water spilling over is diverted to a nearby natural drain. It consists of an earthen embankment and an overflow-type masonry waste weir. Permeable formation in the reservoir bed is an essential requirement of a percolation tank. The tank acts as storage of intercepted runoff, which percolates down to a phreatic aquifer creating a recharge mound.

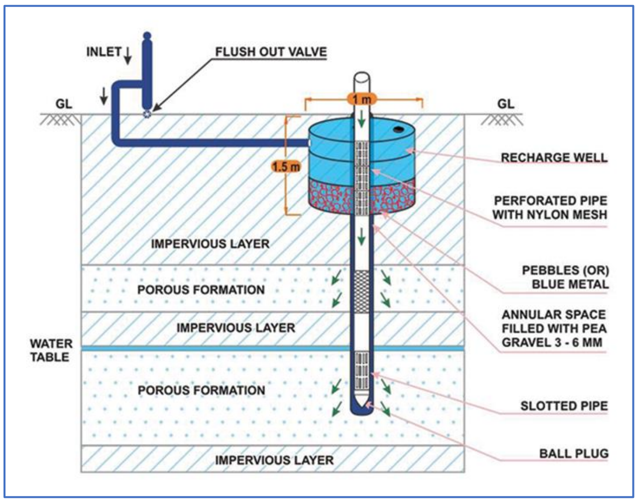
- The size of the percolation pond should be governed by the percolation capacity of the strata in the tank bed. Normally percolation tanks are designed for a storage capacity of 0.1 to 0.5 MCM. It is necessary to design the tank to provide a ponded water column generally between 3 & 4.5 m.

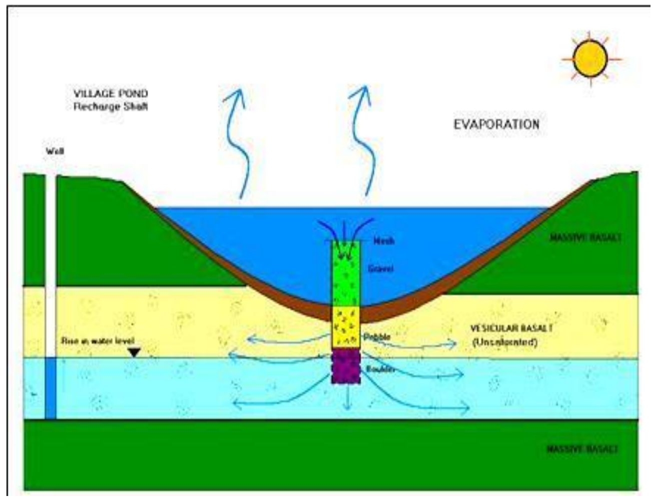
- The percolation tanks are mostly earthen dams with masonry structures only for spillways. The purpose of the percolation tanks is to recharge the groundwater storage and hence seepage below the seat of the bed is permissible. For dams up to 4.5 m in height, cut-off trenches are not necessary and keying and benching between the dam seat and the natural ground is sufficient.


d. Check dams/cement plugs.

- Check dams are constructed across small streams having gentle slopes. The site selected should have a sufficient thickness of permeable bed or weathered formation to facilitate the recharge of stored water within a fleeting time.
- The water stored in these structures is mostly confined to the stream course and the height is normally less than 2 m and excess water is allowed to flow over the wall. To avoid scouring from excess runoff, water cushions are provided on the downstream side.
- To harness the maximum runoff in the stream, a series of such check dams can be constructed to have recharge on a regional scale.
- Clay-filled cement bags arranged as a wall are also being successfully used as a barrier across small nalas. At places, the shallow trench is excavated across the nala, and asbestos sheets are put on two sides. The space between the rows of asbestos sheets across the nala is backfilled with clay. Thus, a low-cost check dam is created. On the upstream side clay filled cement bags can be stacked on a slope to provide stability to the structure.

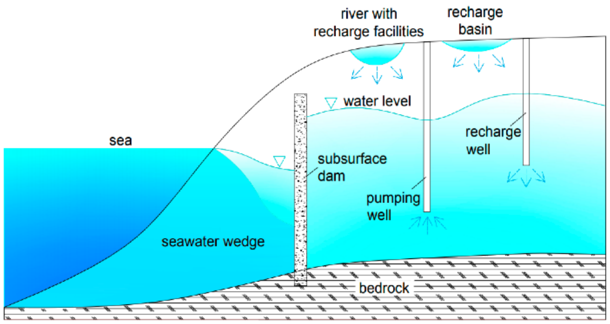

e. Recharge shaft: A shaft of diameter 0.5 meters and a depth varying from 10 to 15 meters, is constructed where the shallow aquifer is located below the clay surface or where the upper layer of soil is alluvial or less permeable. The constructed bore is lined with slotted or perforated PVC/MS pipe to prevent the collapse of the vertical side and is filled with boulders, gravel, and coarse sand. It should be constructed 10 to 15 meters away from the building. This is the most efficient and cost-effective technique to recharge unconfined aquifer overlain by poorly permeable strata.





f. Groundwater dams or sub-surface dykes

- A subsurface dike or underground dam is a subsurface barrier across the stream that retards the base flow and stores water upstream below the ground surface. By doing so, the water levels in the upstream part of the groundwater dam rise saturating the otherwise dry part of the aquifer.
- The site where the sub-surface embankment is proposed should have a shallow impervious layer with a wide valley and narrow outlet.
- After the selection of a suitable site, a trench of 1-2 m wide is dug across the breadth of the stream down to an impermeable bed. The trench may be filled with clay or brick/ concrete wall up to 0.5m. below the ground level.
- For ensuring total imperviousness, PVC sheets of 3000 PSI tearing strength at 400 to 600 gauge or low-density polythene film of 200 gauges can also be used to cover the cutout dyke faces.
- Since the water is stored within the aquifer, submergence of land can be avoided and land above the reservoir can be utilized even after the construction of the dam. No evaporation loss from the reservoir and no siltation in the reservoir takes place. Potential disasters like the collapse of the dams can also be avoided.



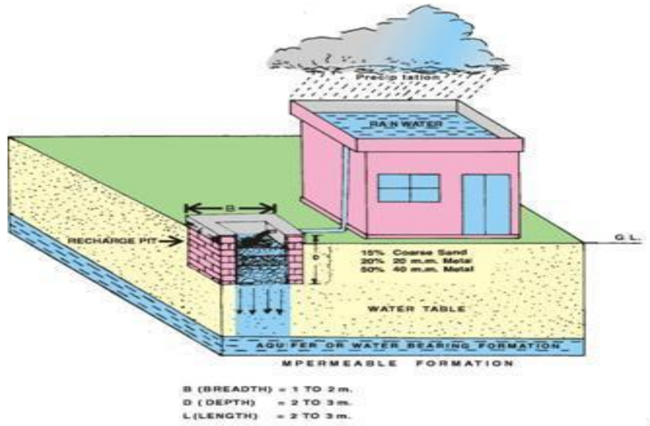
4.2 Groundwater recharge in urban areas

In rural areas, rainwater harvesting is taken up considering watersheds as a unit. Surface spreading techniques are common since space for such systems is available in plenty and the quantity of recharged water is also large. The following techniques may be adopted to save water going to waste through slopes, rivers, and rivulets. In urban areas, rainwater available from rooftops of buildings in paved and unpaved areas goes to waste. This water can be recharged to the aquifer and can be utilized gainfully at the time of need. The rainwater harvesting system needs to be designed in a way that it does not occupy a large space for a collection and recharge system. A few techniques of rooftop rainwater harvesting in urban areas are described below.

1. Recharge pit

- In alluvial areas where permeable rocks are exposed on the land surface or are located at very shallow depths, rainwater harvesting can be done through recharge pits.
- The technique is suitable for buildings having a roof area of 100 m^2. These are constructed for recharging the shallow aquifers.
- Recharge Pits may be of any shape and size. They are generally constructed 1 to 2 m. wide and 2 to 3 m deep. The pits are filled with boulders (5-20 cm), gravel (5-10mm), and coarse sand (1.5- 2mm) in graded form. Boulders at the bottom, gravels in between, and coarse sand at the top so that the silt content that will come with runoff water will be deposited on the top of the coarse sand layer and can easily be removed. For smaller roof areas, the pit may be filled with broken bricks/ cobbles.

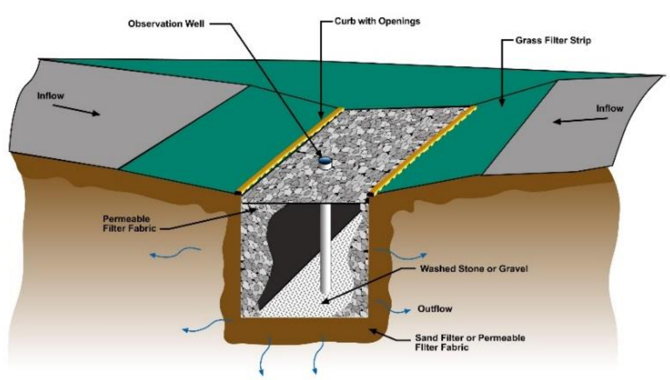
- A mesh should be provided at the roof so that leaves or any other solid waste/debris is prevented from entering the pit. A desilting /collection chamber may also be provided at the ground to arrest the flow of finer particles to the recharge pit.
- The top layer of sand should be cleaned periodically to maintain the recharge rate.



- The bypass arrangement is to be provided before the collection chamber rejects the first showers.

2. Recharge trench

- Recharge trenches are suitable for buildings having a roof area of 200-300 sq. m. and where permeable strata are available at shallow depths.
- The trench maybe 0.5 to 1 m wide, 1 to 1.5m. deep, and 10 to 20 m. long depending upon the availability of water to be recharged.
- These are backfilled with boulders (5-20cm), gravel (5-10 mm), and coarse sand (1.5-2 mm) in graded form boulders at the bottom, gravel in between, and coarse sand at the top so that the silt content that will come with runoff will be coarse sand at the top of the sand layer and can easily be removed.
- A mesh should be provided at the roof so that leaves or any other solid waste/debris is prevented from entering the trenches and a desilting/collection chamber may also be provided on the ground to arrest the flow of finer particles to the trench.
- The bypass arrangement is to be provided before the collection chamber rejects the first showers.

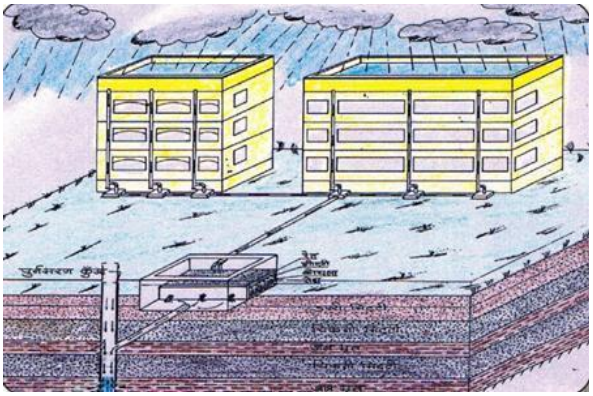
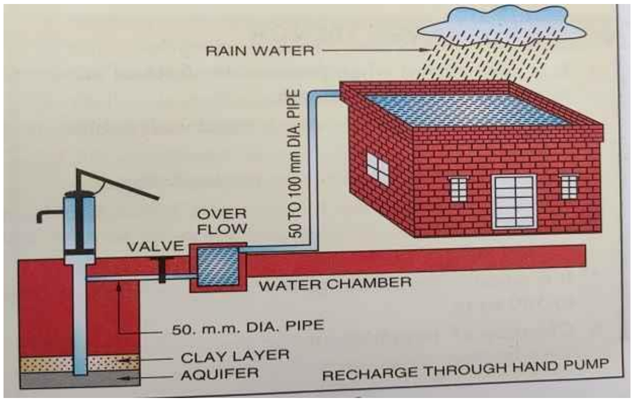


INFILTRATION TRENCH

- The top layer of sand should be cleaned periodically to maintain the recharge rate.

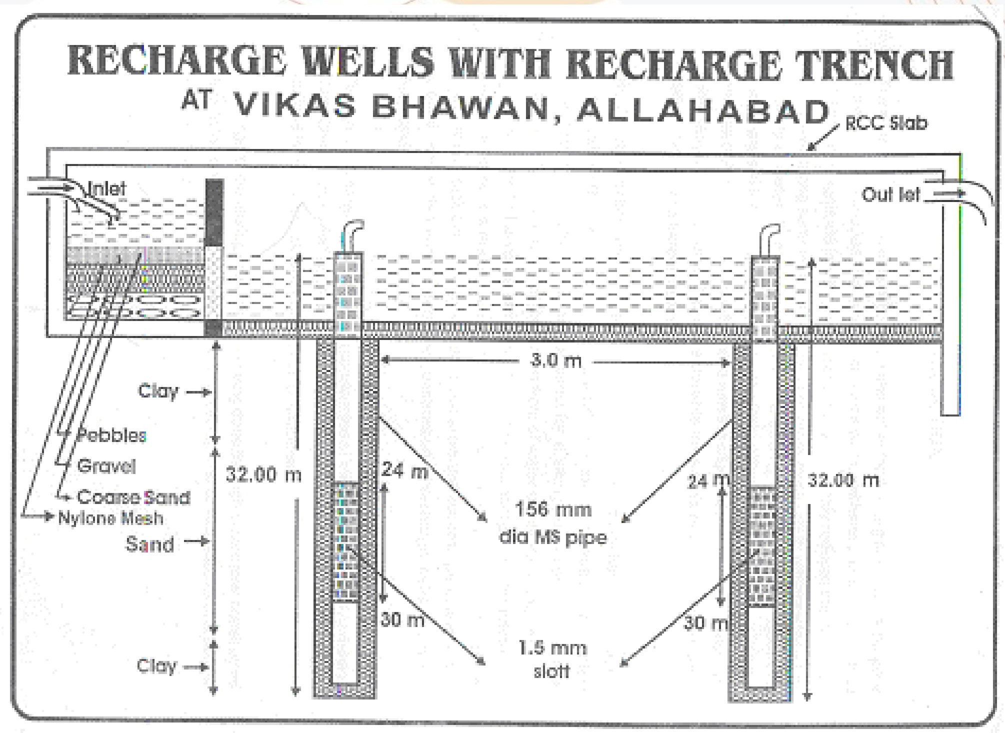
3. Tube wells

- In areas where the shallow aquifers have dried up and existing tube wells are tapping deeper aquifers, rainwater harvesting through existing tube wells can be adopted to recharge the deeper aquifers.
- PVC pipes of 10 cm diameter are connected to roof drains to collect rainwater. The first roof runoff is let off through the bottom of the drainpipe. After closing the bottom pipe, the rainwater of subsequent rain showers is taken through a T to an online PVC filter. The filter may be provided before the water enters the tube wells. The filter is 1 –1.2 m. in length and is made up of PVC pipe. Its diameter should vary depending on the area of the roof, 15 cm if the roof area is less than 150 sq m and 20 cm if the roof area is more. The filter is provided with a reducer of 6.25 cm on both sides. The filter is divided into three chambers by PVC screens so that filter material is not mixed up. The first chamber is filled up with gravel (6-10mm), the middle chamber with pebbles (12-20 mm), and the last chamber with bigger pebbles (20-40 mm).
- If the roof area is more, a filter pit may be provided. Rainwater from roofs is taken to collection/desilting chambers located on the ground. These collection chambers are interconnected as well as connected to the filter pit through pipes having a slope of 1:15. The filter pit may vary in shape and size depending upon available runoff and is back-filled with graded material, boulder at the bottom, gravel in the middle and sand at the top with varying thickness (0.30-0.50m) and may be separated by a screen. The pit is divided into two chambers, the filter material is in one chamber and the other chamber is kept empty to accommodate excess filtered water and to monitor the quality of filtered water. A connecting pipe with a recharge well is provided at the bottom of the pit for recharging filtered water through the well.

4. Trench with recharge well

- In areas where the surface soil is impervious and copious quantities of roof water or surface runoff is available within a fleeting period of heavy rainfall, the use of trench/ pits is made to store the water in a filter media and subsequently recharge to groundwater through specially constructed recharge wells.
- This technique is ideally suited for areas where the permeable horizon is within 3m below ground level.
- A recharge well of 100-300 diameter is constructed to a depth of at least 3 to 5 m below the water level. Based on the lithology of the area, well assembly is designed with slotted pipe against the shallow and deeper aquifer.
- A lateral trench of 1.5 to 3m width and 10 to 30 m length, depending upon the availability of water is constructed with the recharge well in the center.
- The number of recharge wells in the trench can be decided based on water availability and the local vertical permeability of the rocks.
- The trench is backfilled with boulders, gravel, and coarse sand to function as a filter media for the recharge wells.
- If the aquifer is available at greater depth say more than 20 m, a shallow shaft of 2 to 5 m diameter and 3-5 meters deep may be constructed depending upon the availability of runoff. Inside the shaft, a recharge well of 100-300 mm diameter is constructed for recharging the available water to the deeper aquifers. At the bottom of the shaft, a filter media is provided to avoid choking the recharge well.



Source: https://www.researchgate.net/

Appendix 4: Waste Management

Waste disposal leads to direct and in direct environmental impacts, such as land occupation, resource depletion, amplification of global warming due to methane and other greenhouse gas emissions, waters intoxication due landfilling, as well as acidification and toxic effects from emissions to air in the case of incineration.

Waste management is defined as: the different approaches and procedures designed and implemented to identify, control, and handle the different types of waste from generation and until disposal. Full implementation of waste management processes, including waste prevention and reuse, and recycling wherever possible, has and can further help avoid considerable environmental impacts when assessed from a life-cycle perspective – considering direct effects such as emissions and indirect effects such as resource depletion.

The benefits of effective waste management are substantial and wide-ranging, including the reduction of greenhouse gas emissions, the protection of natural resources, the promotion of circular economy models, the creation of green jobs, and the improvement of public health and well-being.

1. Types of waste

A waste is any solid, liquid, or contained gaseous material that is being discarded by disposal, recycling, burning or incineration. It can be a byproduct of a manufacturing process or an obsolete commercial product that can no longer be used for intended purpose and requires disposal.

Waste can be categorized on many different bases; we will focus on three of the most prominent approaches to categorizing wastes and are demonstrated in table 4 below.

Table 4: waste categorization approaches.

Characterization	Types of waste
Based on physical properties, effects etc.	• Solid wasters: Wastes in the form of solid i.e., local, commercial, and industrial waste. • Liquid wastes: Wastes in the form of liquid or watery. i.e., oils, chemicals, polluted water from ponds or rivers etc.
Based on the biological properties of wastes.	• Biodegradable wastes. • Non-biodegradable wastes.
Base on the effects of waste on human health and environment	• Hazardous wastes: Dangerous substances emitted from the commercial, industrial and agriculture or economical use, which are unsafe to use for further purpose. • Non-hazardous wastes: Safe wastes emitted from the commercial, industrial and agriculture or economical use, considered harmless to use for further purpose.

Wastes can also be classified as follows:

1- **Municipal solid waste (MSW):** This is the waste generated by households, businesses, and institutions, and typically includes food waste, paper, plastics, metals, glass, and other materials.

2- **Hazardous waste:** This includes waste materials that are potentially harmful to human health and the environment, such as chemicals, batteries, electronic equipment, and medical waste. Hazardous waste requires special handling and disposal procedures to prevent harm to people and the environment.

3- **Industrial waste:** This includes waste materials generated by manufacturing, construction, mining, and other industries, such as scrap metal, chemicals, and construction debris.

4- **Electronic waste (e-waste):** This includes waste materials from electronic devices, such as computers, televisions, and cell phones. E-waste can contain hazardous substances, such as lead, mercury, and cadmium, and requires special handling and disposal procedures to prevent environmental contamination.

5- **Biomedical waste:** This includes waste materials generated by healthcare facilities, such as syringes, medical equipment, and human and animal tissue. Biomedical waste requires special handling and disposal procedures to prevent the spread of infectious diseases and protect public health.

The most known type of waste, which will be focused on during this text will be Municipal Solid Waste (MSW) as it accounts for most of the waste outputted to dumpsites and has a high potential to be managed. MSW is a biomass waste type consisting of glass, food wastes, metals, textiles, wood, plastics, and paper. The methods most commonly used for management of MSW are open dumping and landfilling. Both methods have side effects such as environmental contamination, methane gas generation which promote global warming and labor issues.

The presence of chemical bonding between C–H–O, MSW allows for energy generation whenever these bonds are broken, this characteristic presented the potential for extracting methane from the biodegradable components in MSW, and further use it for the purpose of generating electricity.

In 2016, urban population generated 2.01 billion tons solid waste with each person contributing approximately 0.74 kg/day. With increasing urbanization, the annual generation of wastes is expected to increase by 70% from 2016 to 2050. The waste generation is expected to increase from around two billion tons from 2016 to 3 billion tons by 2050 (World Bank, 2019). Annually, 1.9 billion tons of MSW is generated with each person contributing 218 kg MSW to this grand total. This shows the immense potential of putting MSW into use, rather than using traditional landfilling and dumping approaches.

2. Waste management principles and procedures

Effective waste management involves a range of principles and procedures that are designed to minimize the environmental and health impacts of waste and maximize its potential value. Some of the key principles and procedures include:

1. **Waste reduction:** This involves reducing the amount of waste generated in the first place, through strategies such as waste prevention, product redesign, and reuse.
2. **Source separation:** This involves separating diverse types of waste at the source, such as households or businesses, to facilitate recycling and recovery.
3. **Recycling and recovery:** This involve recovering materials from waste streams that can be reused or recycled, such as paper, plastics, metals, and glass.
4. **Treatment and disposal:** This involve treating and disposing of waste materials that cannot be recycled or recovered in a way that minimizes their environmental and health impacts, such as landfilling, incineration, or waste-to-energy facilities.
5. **Hazardous waste management:** This involves the safe handling, storage, and disposal of hazardous waste materials, such as chemicals, batteries, and electronic waste.
6. **Public education and participation:** This involve engaging the public in waste management practices and providing information on waste reduction, recycling, and proper disposal.
7. **Environmental monitoring:** This involves monitoring the environmental impacts of waste management practices, such as air and water pollution, to ensure that they meet regulatory standards and do not harm human health or the environment.

3. Waste- to-energy

Waste-to-energy (WTE) is the process of converting waste materials into energy, typically in the form of electricity, steam, or heat. This process can be used to reduce the volume of waste sent to landfills, recover resources from waste streams, and generate renewable energy.

There are several technologies used for waste-to-energy processes, including:

1. **Incineration:** This is the most common waste-to-energy technology, and involves burning waste to produce steam, which drives a turbine to generate electricity.
2. **Gasification:** This is a process that converts waste into a gas, which can then be burned to generate electricity or heat.
3. **Pyrolysis:** This is a process that involves heating waste in the absence of oxygen to produce a gas, liquid, and solid product. The gas and liquid can be used to generate energy, while the solid product can be used as a fuel or a soil amendment.
4. **Anaerobic digestion:** This is a biological process that involves breaking down organic waste materials in the absence of oxygen, producing biogas that can be used to generate electricity or heat.

However, the use of waste-to-energy technologies also has some drawbacks, including potential air emissions and the need for careful management of waste streams to prevent contamination. Effective waste-to-energy requires careful planning, design, and management to ensure that it is environmentally and socially responsible.

In the following papers, we will describe each type of waste-to-energy technologies.

1. **Incineration:** involves the combustion of waste materials at hot temperatures to produce heat and electricity. During the incineration process, waste is burned in a controlled environment, and the resulting heat is used to generate steam, which drives a turbine to produce electricity.

Positive impacts of incineration on environment	Negative impacts of incineration on environment
1. Reduction of waste volume: **2. Energy generation:** 3. **Reduction of methane emissions:** Incineration can help reduce methane emissions from decomposing waste in landfills, which is a potent greenhouse gas. 4. **Recovery of materials:** Incineration can also recover valuable materials from waste streams that can be recycled or reused, such as metals and plastics. 5. **Land preservation:** Incineration can reduce the need for new landfill sites, preserving land resources and reducing the environmental impact of waste disposal.	1. **Air pollution:** Incineration can produce air emissions, including particulate matter, nitrogen oxides, and sulfur dioxide, which can contribute to air pollution and respiratory problems. 2. **Greenhouse gas emissions:** While incineration can reduce methane emissions from landfills, it can produce carbon dioxide emissions, which contribute to climate change. 3. **Ash residues:** Incineration produces ash residues that may contain heavy metals and other pollutants, which require careful management to prevent environmental contamination. 4. **Toxic emissions:** Incineration can emit toxic pollutants such as dioxins and furans, which can have negative impacts on human health and the environment.

2. **Gasification:** In this process, waste materials are heated in a low-oxygen environment to produce a gas mixture called syngas, which is composed mainly of carbon monoxide, hydrogen, and methane.

Positive impacts of gasification on environment	Negative impacts of gasification on environment
1. **Energy generation:** Gasification can generate electricity and heat from waste materials, reducing the need for fossil fuels and promoting renewable energy sources. 2. **Waste reduction:** Gasification can reduce the volume of waste sent to landfills, which can help conserve land resources and reduce greenhouse gas emissions associated with landfilling. 3. **Material recovery:** Gasification can recover materials such as metals and glass from waste streams, increasing recycling rates and reducing the need for virgin materials. 4. **Environmental benefits:** It can reduce the environmental impacts of waste disposal, such as air and water pollution, greenhouse gas emissions, and leachate contamination.	1. **Air emissions:** Gasification can produce air emissions, including particulate matter, nitrogen oxides, and sulfur dioxide, which can contribute to air pollution and respiratory problems. 2. **Greenhouse gas emissions:** While gasification can reduce methane emissions from landfills, it can produce carbon dioxide emissions from the combustion of syngas, which contribute to climate change. 3. **Waste sorting:** It requires proper sorting and preparation of waste streams, and if not done properly, can lead to the gasification of hazardous waste materials. 4. **Complex technology:** It requires complex technology and high capital and operating costs, which can make it difficult to implement and manage effectively.

3. **Pyrolysis:** involves the thermal degradation of organic materials in the absence of oxygen to produce a liquid, solid, and gas product. In this process, waste materials are heated at hot temperatures (typically between 400-700°C) in a low-oxygen environment, which causes the organic matter to break down into its constituent parts.

Compared to incineration, which is another common waste-to-energy technology, pyrolysis generally has lower emissions of air pollutants and greenhouse gases and produces biochar as a valuable co-product. However, pyrolysis can be more expensive than incineration due to its higher capital and operating costs.

Positive impacts of pyrolysis on environment	Negative impacts of pyrolysis on environment
1. **Energy generation:** 2. **Waste reduction:** 3. **Material recovery:** 4. **Environmental benefits:** It can reduce the environmental impacts of waste disposal, such as air and water pollution, greenhouse gas emissions, and leachate contamination. 5. **Biochar:** It produces biochar, a soil amendment that can improve soil fertility, water retention, and carbon sequestration.	1. **Air emissions:** It can produce air emissions, including particulate matter, nitrogen oxides, and volatile organic compounds, which can contribute to air pollution and respiratory problems. 2. **Greenhouse gas emissions:** While pyrolysis can reduce methane emissions from landfills, it can produce carbon dioxide emissions from the combustion of syngas, which contribute to climate change. 3. **Waste sorting:** It requires proper sorting and preparation of waste streams, and if not done properly, can lead to the pyrolysis of hazardous waste materials. 4. **Complex technology:** It requires complex technology and high capital and operating costs, which can make it difficult to implement and manage effectively.

4. **Anaerobic digestion:** It involves the breakdown of organic materials in the absence of oxygen to produce biogas and digestate. In this process, organic waste materials are placed in an airtight container called a digester, where they are broken down by microorganisms in a series of biochemical reactions.

The biogas produced by anaerobic digestion is composed mainly of methane and carbon dioxide and can be used to generate electricity and heat or upgraded to natural gas quality and injected into the gas grid. The digestate is a nutrient-rich material that can be used as a fertilizer or soil amendment.

Positive impacts of anaerobic digestion on environment	Negative impacts of anaerobic digestion on environment
1. **Energy generation:** 2. **Waste reduction:** 3. **Material recovery:** It can recover materials such as nutrients and organic matter from waste streams, increasing recycling rates and reducing the need for virgin materials. 4. **Environmental benefits:** It can reduce the environmental impacts of waste disposal, such as air and water pollution, greenhouse gas emissions, and leachate contamination.	1. **Air emissions:** It can produce air emissions, including methane and odorous compounds, which can contribute to air pollution and odors. 2. **Water pollution:** Inadequate management of digestate can lead to water pollution from excess nutrients and pathogens. 3. **Waste sorting:** It requires proper sorting and preparation of waste streams, and if not done properly, can lead to the digestion of hazardous waste materials. 4. **Complex technology:** It requires complex technology and high capital and operating costs, which can make it difficult to implement and manage effectively

Overall, the choice of waste-to-energy technology depends on several factors, including the type of waste being processed, the intended end use of the energy or products produced, and the environmental and economic considerations. Effective waste-to-energy requires careful planning, design, and management to minimize its negative impacts on the environment and human health, and to ensure that it is economically feasible and socially responsible.

Endnote

[1] IPCC. Summary for Urban Policymakers: What the IPCC Special Report on Global Warming of 1.5 ◦C Means for Cities; Intergovernmental Panel on Climate Change: Geneva, Switzerland, 2018.

[2] DeNicola, E.; Aburizaiza, O.S.; Siddique, A.; Khwaja, H.; Carpenter, D.O. Climate change and water scarcity: The case of Saudi Arabia. Ann. Glob. Health **2015**, 81, 342–353. [CrossRef] [PubMed]

[3] Second National communication under the United Nations Framework Convention on Climate Change, May,2013.

[4] Worldometer elaboration UN data

[5] Ministry of Foreign Affairs (MFA) 2018).

[6] February, 2021, World Bank, " "Yemen Economic Monitoring Brief"

[7] https://ourworldindata.org/co2-emissions#per-capita-co2-emissions

[8] "Yemen's Environmental Crisis Is the Biggest Risk for Its Future," The Century Foundation, December 2020, https://tcf.org/content/report/yemens-environmental-crisis-biggest-risk-future/?session=1.

[9] "Locust Watch: Current upsurge (2019-2021)," UN Food and Agriculture Organization, accessed February 4, 2021, http://www.fao.org/ag/locusts/en/info/2094/index.html

[10] Yemen Red Crescent Society, 2006, information bulletin, Yemen, Landslide

[11] https://thinkhazard.org/en/report/269-republic-of-yemen/LS

12 Dr. A. M. AL-Sharjabi et al. (2014). Drought conditions and management strategies in Yemen. Dhamar: Ministry of Agriculture & Irrigation.

[13] https://reports.unocha.org/en/country/yemen/card/3xgDjvW1Ud/

[14] FAO,2022, QUARTERLY FOOD SECURITY REPORT .Global Events, Inflation and Erosion of Livelihoods Driving Food Insecurity in Yemen

[15]shttps://assafirarabi.com/en/48629/2022/11/09/yemen-instability-hits-the-climate-too/#:~:text=The%20rate%20of%20desertification%20in,residents%20try%20to%20access%20them.

[16] https://reliefweb.int/report/yemen/drought-and-floods-yemen-affect-food-security

[17] https://reliefweb.int/report/yemen/yemen-ancestral-honey-production-yemen-risk-due-impact-conflict-and-climate-change-enar

[18] UNDP,2022, Water availability in Yemen. *https://www.undp.org/yemen/publications/water-availability-yemen?utm_source=EN&utm_medium=GSR&utm_content=US_UNDP_PaidSearch_Brand_English&utm_campai*

gn=CENTRAL&c_src=CENTRAL&c_src2=GSR&gclid=CjwKCAiAheacBhB8EiwAItVO28exNdmHnvMkTCQQHf5oMribXxVsqVU6upDW84vlIV7w-DaPEx2-RRoCo2sQAvD_BwE

19 "Humanitarian Update," UNICEF, June 2022, https://reliefweb.int/node/3866097; https://twitter.com/OCHAYemen/ status/1545090857048612864?s=20&t=lJrXWQCcG3JStaxX1ch6FQ

20 ICRC. (2022, June 5). The water situation in Yemen/International Committee of the Red Cross . Retrieved from https://www.icrc.org/en/document/water-situation yemen#:~:text=The%20rate%20of%20groundwater%20overdraft,services%20in%20Yemen%20(OCHA).

21 EPA et all,2017, National Biodiversity Strategy and Action Plan II achieving a resilient, productive and sustainable socio-ecosystem by 2050. *https://www.cbd.int/doc/world/ye/ye-nbsap-v2-en.pdf*

22 According to "Water availability in Yemen: Literature review of the current and future water resources and water demand in Yemen" by Acacia Water (2021).

23 Holm Akhdar interview with National Water Resources Authority, Yemen. 2022.

24 NWRA. (2022, May 27). Groundwater depletion and possible solutions. (H. Akhdar, Interviewer)

25 UNDP. (2018). Integrated Water Harvesting Technologies to Adapt to Climate Induced Water. Sana'a: UNDP.

26 The second national communication under the United Nations Framework Convention on Climate Change, Republic of Yemen, 2013.

27 YEPA et al. (2009). Yemen National Adaptation Programme of Action. Retrieved from https://www.adaptation-undp.org/projects/yemen-national-adaptation-programme-action napa#:~:text=Yemen%20is%20promoting%20sustainable%20use,and%20developing%20sustainable%20agricultural%20programs.

28 Unprecedented spike in food prices puts Yemenis at risk of extreme hunger. 28 Jul 2022. https://reliefweb.int/report/yemen/unprecedented-spike-foodprices-puts-yemenis-risk-extreme-hunger https://www.ifpri.org/publication/2022-global-food-policy-report-climate-change-and-food-systems.

29 World Bank, Yemen Emeregency Health and Nutrition Project ، , April 16, 2019, WB. https://documents1.worldbank.org/curated/ru/683071559295728398/Yemen-Emergency-Health-and-Nutrition-Project-Third-Additional-Financing.doc

30 https://www.globalhungerindex.org/pdf/en/2022/Yemen.pdf

31 World Bank, Yemen Emeregency Health and Nutrition Project ، , April 16, 2019, WB. https://documents1.worldbank.org/curated/ru/683071559295728398/Yemen-Emergency-Health-and-Nutrition-Project-Third-Additional-Financing.doc

32 Climate change triggers mounting food insecurity, poverty and displacement in Africa, Published 19 October 2021. © 2022 World Meteorological Organization (WMO). https://public.wmo.int/en/media/press-release/climate-change-triggers-mounting-food-insecurity-poverty-and-displacement-africa

[33] Yemen Humanitarian Needs Overview 2022 (April 2022). https://reliefweb.int/report/yemen/yemen-humanitarian-needs-overview-2022-april-2022.

[34] FAO, A body of evidence: What climate change implies for global food security and trade. 2015. https://www.fao.org/news/story/en/item/293954/icode/

[35] GIEWS - Global Information and Early Warning System on Food and Agriculture. Food Outlook. FAO, Release dates for 2022: 9 June, 10 November. https://www.fao.org/giews/reports/food-outlook/en/

[36]https://www.climatelinks.org/sites/default/files/asset/document/2016_USAID%20GCC%20Office_Climate%20Risk%20Profile_Yemen.pdf

[37] Alkharraz, Abdulqader. 2020. Expected environmental hazards of the ship Safer (floating bomb on the Yemeni coast in the Red Sea.

[38] Federspiel F, Ali M (December 2018). "The cholera outbreak in Yemen: lessons learned and way forward.

[39]Reliefweb,2022. Volunteering for the fight against malaria in Yemen

https://reliefweb.int/report/yemen/volunteering-fight-against-malaria-yemen#:~:text=According%20to%20the%202020%20World,one%20million%20cases%20per%20year.

40 USAID 2016

[41] ICRC. (2021). Climate fact sheet of Yemen. climate center (ICRC).

[42]https://www.worldbank.org/en/news/feature/2022/11/07/yemen-investing-in-human-capital-to-protect-the-future.print#:~:text=As%20a%20result%2C%20only%2051,Yemenis%20need%20lifesaving%20nutrition%20assistance.

[43] Luqman and Al–Sakkaf, "Gender, Climate and Security in Yemen - The Linkages and Ways Forward," Geneva Center for Security and Governance, May 18, 2022, https://www.dcaf.ch/sites/default/files/publications/documents/GenderClimateSecurityYemen_EN.pdf; "Explainer: How gender inequality and climate change are interconnected," UN Women, February 28, 2022, https://www.unwomen.org/en/news-stories/explainer/2022/02/explainer-how-gender-inequality-andclimate-change-are

[44] CIVIC interview with a UN official, #31, Aden, May 2022.

[45] Friedrich Ebert Stiftung, "Climate change in conflict areas: How extreme weather ravaged conflict-affected Palestine and Yemen," https://www.fes.de/en/iez/global-policy-and-development/international-social-and-gender-policies/article-ininternational-social-and-gender-policies/climate-change-in-conflict-areas-how-extreme-weather-ravaged-conflict-affectedpalestine-and-yemen; Luqman and Al–Sakkaf, "Gender, Climate and Security in Yemen - The Linkages and Ways Forward."

[46] Frederika Whitehead, "Water scarcity in Yemen: the country's forgotten conflict," The Guardian (April 2, 2015), https://www.the guardian.com/global-development-professionals-network/2015/apr/02/water-scarcity-Yemen-conflict.

[47] CIVIC interview with Colonel Aref Ali Al-Khatani, the Director of Yemen Executive Mine Action Centre in Taiz, conducted via video call from Aden to Taiz, June 2022.

[48] Ibid.

[49] Luqman and Al–Sakkaf, "Gender, Climate and Security in Yemen - The Linkages and Ways Forward."

[50] "Yemeni crisis forces families to take desperate measures to survive," Oxfam International, February 26, 2019, https://www.oxfam.org/en/press-releases/yemeni-crisis-forces-families-take-desperate-measures-survive.

[51] "Gender & Climate Change: 3 Things You Should Know," The World Bank, 2011, https://openknowledge.worldbank.org/bitstream/handle/10986/27356/658420REPLACEM00Box374367B00PUBLIC0.pdf?sequence=1&isAllowed=y.

[52] OCHA,2021, Women and girls' protection needs urgent, but resources are limited. https://reports.unocha.org/en/country/yemen/card/3X9vmoUQZh/

[53] UNF. (2022, May 16). Retrieved from https://unfoundation.org/blog/post/five-facts-about-gender-equality-and-climate-change/?gclid=Cj0KCQiA37KbBhDgARIsAIzce15LPcZlSoYg2XkpXdVVekapF4dSf-ChWqm0Xerr6BFuBqWWPu-5ZGkaArI-EALw_wcB

[54] UNY. (2022). UNITED NATIONS YEMEN SUSTAINABLE DEVELOPMENT COOPERATION FRAMEWORK 2022-2024. United Nations Yemen.

[55] Lyon, "Water crisis threatens Yemen's swelling population," Reuters, August 30, 2009, https://www.reuters.com/article/usyemen-water-idUSTRE57T0HK20090830.

[56] CIVIC interview with community leaders, Marib, May 2022.

[57] "Climate Fact Sheet – Yemen," Climate Centre, 2021, https://www.climatecentre.org/wp-content/uploads/RCCC-ICRC-Countryprofiles-Yemen.pdf.

[58] "300,000 people lose homes, incomes, food supplies and belongings due to catastrophic flooding in Yemen," United Nations High Commissioner for Refugees, August 21, 2020, https://www.unhcr.org/news/briefing/2020/8/5f3e7faf4/300000-peoplelose-homes-incomes-food-supplies-belongings-due-catastrophic.html.

[59] "Yemen: UNHCR Operational Update, covering the period from 21 to 30 June," UNHCR, June 30, 2022, https://reliefweb.int/report/yemen/yemen-unhcr-operational-update-covering-period-21-30-june .

[60] Fatma Ben Hamad, "Yemen: Torrential rains destroy camps for thousands of internally displaced people," The Observers: France 24, July 15, 2022, https://observers.france24.com/en/middle-east/20220718-yemen-torrential-rains-destroy-camps-forthousands-of-internally-displaced-people.

[61] "Floods in Yemen upend lives for tens of thousands already fleeing brutal conflict," United Nations Population Fund (September 6, 2022), https://reliefweb.int/report/yemen/floods-yemen-upend-lives-tens-thousands-already-fleeing-brutal-conflict; Sadam Al-Adwar, Security Forces Program Officer at CIVIC, via phone call from Beirut to Marib, August 2022.

[62] CIVIC interview with a government official, #18, Marib, May 2022.

[63] Luqman and Dr. Nadia Al–Sakkaf, "Gender, Climate and Security in Yemen - The Linkages and Ways Forward,"

[64] Acute malnutrition threatens half of children under five in Yemen in 2021: UN

https://www.who.int/news/item/12-02-2021-acute-malnutrition-threatens-half-of-children-under-five-in-yemen-in 2021-un

[65] ANNUAL COUNTRY INDEX WITH NEW FOOD DEPENDENCY DATA REFLECTS VULNERABILITY TO CLIMATE CHANGE. Published: September 24, 2020.

[66] https://gain.nd.edu/news/annual-country-index-with-new-food-dependency-data-reflects-vulnerability-to-climate-change /

[67] WHO. (2021). Acute malnutrition threatens half of children under five in Yemen in 2021: UN. Retrieved from https://www.who.int/news/item/12-02-2021-acute-malnutrition-threatens-half-of-children-under-five-in-yemen-in-2021-un

[68] https://www.ageinternational.org.uk/news-features/news/2018/cholera-outbreak-yemen-kills-more-older-people-than-children/

[69] https://www.ageinternational.org.uk/news-features/news/2018/cholera-outbreak-yemen-kills-more-older-people-than-children/

[70] "Under pressure: Social violence over land and water in Yemen," Yemen Armed Violence Assessment, October 2010, https:// www.files.ethz.ch/isn/123971/Yemen-Armed-Violence-IB2-Social-violence-over-land-and-water-in-Yemen.pdf; Iona Craig, "Yemen's deadly fight for land and water," Yemen Times, October 27, 2010, https://reliefweb.int/report/yemen/yemens-deadlyfight-land-and-water; Frederika Whitehead, "Water scarcity in Yemen: the country's forgotten conflict," The Guardian, April 2, 2015, https://www.theguardian.com/global-development-professionals-network/2015/apr/02/water-scarcity-yemen-conflict;
CIVIC interview Dr. Walid Saleh, Chief Technical Advisor at the UN Food and Agricultural Organization (UNFAO), Aden, May 2022.

[71] CIVIC interview with a government official, #19, Marib, May 2020.

[72] CIVIC interview with a UN official, #31, Aden, May 2022

[73] Ibid.

[74] CIVIC interview with a community leader, #12, Marib, May 2022.

[75] "Pathways of Climate Insecurity: Guidance for Policymakers," Stockholm International Peace Research Institute, November 2020, https://www.sipri.org/sites/default/files/2020-11/pb_2011_pathways_2.pdf

[76] CIVIC interview with a government official, #16, Marib, May 2022.

[77] "Children associated with armed forces or armed groups," Handbook for the Protection of Internally Displaced Persons (June 2010), 204, https://www.unhcr.org/4794b3782.pdf.

[78] CIVIC interview with a community leader, #13, Marib, May 2022.

[79] CIVIC interview with a community leader, #13, Marib, May 2022.