Republic of Yemen

Third National Communication to the Conference of the Parties of United Nations Framework Convention on Climate Change

June 2018

Foreword

Responding to the challenge of climate change remains a strong focus of policy development in Yemen. Despite recent years of crippling and destructive conflict, which have overwhelmed government attention, the evidence of the adverse impacts of climate change are becoming all too familiar. Recurrent drought, larger number of extreme heat days, and increasingly variable rainfall are exacerbating already precarious survival stakes, particularly in rural areas where the majority of Yemen's predominantly poor population depend of natural resources for their daily livelihoods. This 3rd National Communication under the United Nations Framework Convention on Climate Change is evidence that Yemen will continue to take proactive steps in preparing for and adapting to the future impacts of climate change on its vulnerable populations, economic sectors, and natural systems. Together with the support of the international community, the nation will increase its capacity to quantify and respond to the range of risks posed by climate change.

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List of Acronyms

°C	degrees Centigrade
CH4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CSI	costal sensitivity index
CSO	Central Statistical Organization
DNA	Designated National Authority
DSAS	Digital Shoreline Analysis System
EPA	Environment Protection Authority (Yemen)
FAO	Food and Agriculture Organization of the United Nations
FGD	Focus Group Discussions
GDP	gross domestic product
Gg	Gigagrams (i.e., one billion grams)
GHG	Greenhouse gas
GJ	Gigajoule (10^9 joules)
GWP	Global warming potential
IEA	International Energy Agency
INC	Initial National Communication
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
KII	Key Informant Interviews
kJ	kilojoule (10^3 joules)
Km	kilometers
Km^2	square kilometers
kW	thousand watts
kWh	thousand watt-hours
LPG	Liquefied petroleum gas
LDC	Least Developed Country
LULUCF	Land Use and Land Use Change and Forestry
MJ	million joules
mm	millimeters
MoPIC	Ministry of Planning and International Cooperation
MRV	Measurement, Reporting and Verification
N_2O	nitrous oxide
NAMA	Nationally Appropriate Mitigation Action
NDC	Nationally Determined Contribution

NMVOC	non-methane volatile organic compounds
NO_x	nitrogen oxides
PEC	Public Electricity Corporation (Yemen)
PFCs	perfluorocarbons
PV	photovoltaic (solar)
REEE	Renewable Energy and Energy Efficiency
SLR	Sea level rise
SNC	Second National Communication
SO_2	sulfur dioxide
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change

Executive Summary

Yemen is an arid Middle Eastern country, occupying an area of 527,970 square km at the southern end of the Arabian Peninsula. It is bordered to the north by Saudi Arabia, to the East by Oman, and to the South and West by a 2,200 km coastline along the Gulf of Aden, Arabian Sea and the Red Sea.

National Circumstances

Yemen is characterized by a semi- to arid tropical climate that is typical of the region in which it is located. In 2014, its population reached 25.96 million, making Yemen the second most populous country in the Arabian Peninsula, just behind Saudi Arabia. Its population is largely rural-based (71%) and is one of the poorest in the Arab region with approximately 40% of the population living on less than $2/day. Compared to other countries in the Middle East & North Africa region, Yemen has poor healthcare indicators, with life expectancy at birth currently standing at 64 years. Over 50% of the country is classified as desert land, with only 3% considered suitable for agricultural activities. Yemen is one of the most water-scarce countries in the world with water scarcity exacerbated by groundwater withdrawal rates far in excess of recharge rates. Agriculture is the backbone of Yemen's labor economy though representing a small share on GDP. In contrast, oil and mineral exports represent a significant and growing source of revenue for the Yemeni government.

Greenhouse Gas Emission Inventory

Yemen compiled an update to its inventory of greenhouse gas emissions for the year 2010 (see Table ES.1). Total GHG emissions in 2010 were 34,136 Gg CO_2-equivalent, which includes 22,038 Gg from energy; 1,798 Gg from industrial processes; 8,247 Gg from agriculture and 2,053 Gg from waste. CO_2 sequestration by the forestry and land use sector in 2010 amounted to 1,885 Gg. Net GHG emissions are estimated at 32,249 Gg CO_2-equivalent. Emissions from perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulfur hexafluoride (SF6) in Yemen are negligible as the products containing these gases are not produced in the country.

Table ES.1: Total GHG emissions in the Republic of Yemen, 2010 (Gg)

GHG Sources & Sinks	CO_2-equiv	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
1 Energy	22,038	20,543	67	0	102	514	102	4
2 Industrial Processes	1,798	1,798	0	0	0	0	183	1
3 Solvent & Other Product Use	0	0	0	1	0	0	0	0
4 Agriculture	8,247	0	184	14	1	18	0	0
5 Land-Use Change & Forestry	-1,887	-1,887	0	0	0	0	0	0
6 Waste	2,053	0	83	1	0	0	0	0
Total National Emissions	34,136	22,341	334	16	103	532	285	5
Net National Emissions	**32,249**	**20,454**	**334**	**16**	**103**	**532**	**285**	**5**

Vulnerability and Adaptation

All areas of Yemen will get warmer, with the greatest change projected to occur during the winter months. Across the entire country, annual mean temperatures show the greatest rise under the A1B scenario, between 1.7 °C and 2.4°C by the 2050s, with an average annual increase of 2.0°C. Seasonal mean temperatures are also projected to increase by 2050. The largest seasonal temperature increases occur during the winter months and the smallest seasonal temperature increases occur during the summer months.

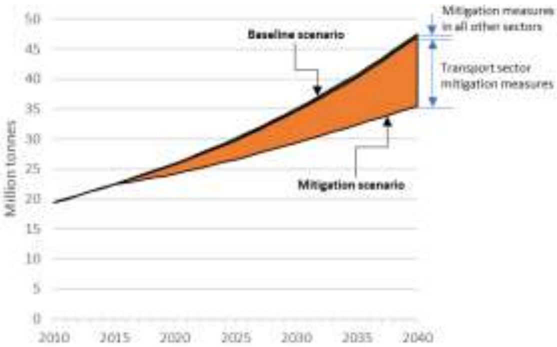
Many sectors are vulnerable to these climatic changes, with potentially grave environmental and social effects, compounded by the country's poverty alleviation challenges. A summary of key findings of the vulnerability assessments summarized in the bullets below. International support for adaptation measures is urgently required.

- *Water resources:* Climate change is among the priority water resource management threats in Yemen. A case study assessment of the Wadi Zabid drainage basin under a range of climate change scenarios showed that the region's aquifer will steadily deplete in the coming decades in the absence of effective adaptation initiatives.
- *Coastal zones:* Due to its long coastline and dependence on the marine environment, climate change is viewed in Yemen as a serious threat to urban livelihoods and infrastructure. A case study assessment of the Al Mukalla Coastal Zone showed that, among other impacts, sea level rise will exacerbate shoreline erosion rates and lead to corresponding land loss of about 440 hectares under an assumed rise of 0.5 meters of the waters of the Arabian Sea.
- *Agriculture:* Climate change will endanger agricultural systems and the livelihoods of those that depend on them in Yemen. A case study assessment of the Wadi Bana drainage basin under a range of climate change scenarios showed that wheat yields would be adversely impacted by climate change, with significant reductions in yield across all emission scenarios for both rainfed and irrigated areas.
- *Public health:* The public health status of Yemen's population is poor as evidence by high rates of infant mortality, maternal morbidity and under-five mortality. A national assessment showed that, fundamentally, a large part of Yemen's public health challenge is rooted in poverty, which is prevalent and has shown a steady increase in recent decades. Climate change will exacerbate health problems such as vector borne and waterborne diseases which may extend their range into areas that are presently unaffected, as well as chronic diseases such as cardiac, respiratory and renal disease.
- *Ecotourism:* Climate change will endanger Yemen's precious biodiversity and could limit the future potential of ecotourism. A case study assessment of Socotra, an island and an archipelago of four islands in the Arabian Sea, as well as of Jabal Bura'a protected area in the main land, showed that the unique biodiversity of both areas is highly sensitive to temperature change and could experience severe impacts. This is particularly true of visits to Socotra's limestone caves diving/snorkeling around its coral reefs, and touristic activities.

Greenhouse Gas Mitigation

An increase in the use of renewable energy and energy efficient equipment was examined across all energy-consuming sectors. Transport sector GHG mitigation measures focused on improving fuel economy of all vehicle classes; household sector mitigation measures focused on the introduction of efficient lighting and refrigeration; commercial/industrial sector mitigation measures focused on the introduction of efficient lighting and other efficient electrical devices, as well as fuel switching; and power generation mitigation measures focused on the complete phased replacement of existing diesel generation and planned coal-fired generation by a renewable power generation mix. The results of the assessment showed that these GHG mitigation measures will lead to substantial reductions in GHG emissions by 2040, as shown in Figure ES.2. Overall, GHG emissions decline from 48 million tonnes in 2040 in the Baseline scenario to 36 million tonnes in the Mitigation scenario, with cumulative savings of 133 million tonnes.

Figure ES.1: GHG emission trajectories, with and without GHG mitigation



Supplementary activities

A set of supplementary activities were undertaken that focused on rooftop PV diffusion, mapping shoreline change, nationally appropriate mitigation actions, mangrove forest resilience, and sea level rise awareness-raising. The results provide a set of insights into potential priorities for future funding and data development.

Constraints, gaps, and needs

The effectiveness of Yemen's efforts to actively engage in climate change negotiations abroad and promote climate-resilient socioeconomic growth at home will in large part depend on overcoming serious institutional, financial and technical constraints and gaps that currently impede concerted action. Several recommendations are offered regarding how to develop an enabling environment for effective action with a focus on key constraints, gaps, and needs to facilitate compliance with UNFCCC obligations and aspirational adaptation goals.

Chapter 1:

National Circumstances

This chapter provides a description of Yemen’s national circumstances, together with an overview of its development priorities and objectives on the basis of which it will address climate change and its adverse impacts. This chapter also includes information on features of Yemen’s geography, demography, climate and economy to describe the overall national context in which climate change challenges are being addressed.

1.1. Geography & Topography

Yemen is an arid Middle Eastern country, occupying an area of 527,970 square km at the southern end of the Arabian Peninsula. It is bordered to the north by Saudi Arabia, to the East by Oman, and to the South and West by a 2,200 km coastline along the Gulf of Aden, Arabian Sea and the Red Sea (Figure 1.1). Yemen controls Bab el Mandeb, the strait between the Red Sea and the Gulf of Aden, a heavily used shipping lane.

Figure 1.1: **Yemen’s Regional Context**

The country is characterized by five major land systems: 1) a hot and humid coastal Tihama plain, 30-60 km wide, along the Red Sea and the Gulf of Aden; 2) the Yemen Highlands, a volcanic region with elevations between 1,000 and 3,600 m parallel to the Red Sea coast, and with temperate climate and monsoon rains; 3) the dissected region of the Yemen High Plateaus and the Hadramawt - Mahra Uplands, with altitudes up to 1,000 meters; 4) the Al-Rub Al-Khali desert interior, with a hot and dry climate; and 5) the islands, including Socotra in the Arabian Sea and more than 112 islands in the Red Sea. Yemen's coastal and marine ecosystems which include extensive mangroves, coral reefs, and sea grass areas are of major economic importance for fisheries and tourism.

Some of Yemen’s ecological zones are confined to small areas (e.g., islands), with human communities, flora and fauna highly adapted to subsist within them. Other zones are much larger (e.g., Temperate Highlands) and support most of the country’s agricultural production. In both cases, climate change poses a major threat.

1.2. Climate

Long-term systematic observations of precipitation and temperature data are very scarce in Yemen. There are well-recognized data quality concerns associated with the daily and monthly meteorological record. Meteorological data are not held by a central authority but are collected by several authorities which include the Civil Aviation and Meteorological Authority (CAMA), Ministry of Agriculture and Irrigation (MAI), National Water Resource Authority (NWRA), Agriculture Research and Extension Authority (AREA) and the Tehama Development Authority (TDA). This lack of centralization hampers efforts in quantifying long-term changes in climate. Without reliable rainfall and temperature records, it will be hard to benchmark future climate variability and change, or associated impacts. (Wilby, 2009).

Rainfall occurs primarily in the spring and summer seasons and is determined by two main mechanisms: the Red Sea Convergence and the Inter Tropical Convergence Zone.

Temperature depends primarily on elevation, and in the coastal areas, increases the further inland from the sea. Yemen lies within the northern stretches of the tropical climatic zone and its border with the sub-tropical climatic zone. The extreme differences in elevation are largely responsible for the great variations in temperature and climate over the country. Mean annual temperatures range from less than 15°C in the highlands to 30°C in the coastal plains.

The occurrence of frequent prolonged hotter droughts during the last three decades has increased. These hotter droughts have been interrupted by occasional intense flooding events. Yemen's past climate can be characterized as dry with low rainfall and high temperatures. Regarding Yemen's future climate, some studies indicate that there is a large range in future temperature and precipitation. For example, according to a World Bank's study (World Ban, 2010), the three climate change scenarios described below bracket the range of possibilities in Yemen up through 2080.

- A "hot and dry" scenario of higher warming of 2 to 4.5 °C, with aridity dramatically increased due to the combined effects of low rainfall and high ET.
- A "mid" scenario, with considerable warming of between 1.6 and 3.1 °C but no significant change in average annual rainfall.
- A "warm and wet" scenario with lower warming of between 1 and 1.6 °C and an increase in average annual rainfall.

1.3. Population

Yemen's population is distributed across its 21 governorates and was estimated at about 25.96 million in 2014, 3.5% higher than 2013. Most people, about 71%, live in rural areas and the rest are urban-based (CSO, 2013). Yemen's population is growing at about 3.0% per year, a greater rate than its economy which has been growing at only about 2.7 % per year prior to the recent socioeconomic upheaval. With an average life expectancy at birth of 63.1 years (UNDP, 2015), the country has an overwhelmingly young population, with around 46 % under the age of 15, and a median age of 18.1 years. Overall population is expected to continue to grow at historical rates - even though fertility rates are markedly decreasing – and is expected to reach nearly 31 million by 2020.

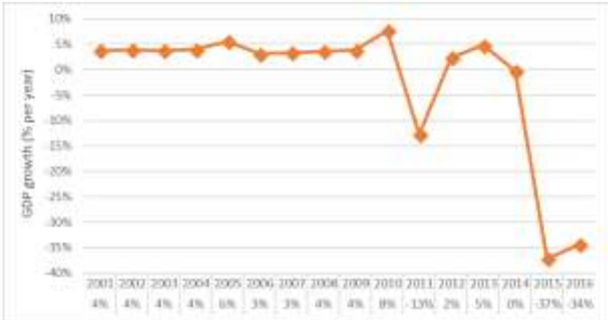
Although the country's population is currently predominantly rural in nature, urban populations are increasing rapidly. Between 2000 and 2016, the percentage of urban population increased from 26% to 29%. The continuing urbanization trend is attributable to increased immigration to urban cities along with a proliferation of unplanned settlements. High urbanization rates have led to environmental degradation in cities. Currently, Yemen's municipalities are incapable of providing the necessary land, services, and amenities which in turn caused significant threats to human health, biological resources, and ecosystem productivity.

1.4. Economy

Yemen's economy depends in large part on foreign aid and remittances from workers in neighboring Gulf States. The economy is dominated by the oil sector, which accounts for 27 % of the gross domestic product (GDP) and 70% of export revenues. Agriculture forms also a very important sector as it employs over 50% of the population. Before 2010, the government had engaged in efforts to diversify the economy from dependency on oil, and as a result, there was a surge of investment in the development of infrastructure for natural gas extraction. Yet, the political instability in 2011 has undermined development efforts, resulting in damage of infrastructure, rising unemployment, high inflation, depletion of oil reserves and ongoing disruptions at oil production facilities. This has led to a decline in exports of oil and gas, which stopped completely in 2015, leading to a loss of revenues and severe fiscal difficulties.

During the last two decades, GDP per capita (in constant 2010 US$) increased from US$ 973 in 1990 to US$ 1,101 in 2014. (World Bank, 2018). Although GDP Annual Growth Rate in Yemen averaged 2.9% from 2001 through 2013, reaching an all-time high of 7.7% in 2010, it recorded negative growth of 37.1%, and 34.3% in 2015 and 2016, respectively, due to the 2011 domestic political crisis and war since 2014 (see Figure 1.2).

Figure 1.2: GDP Trends Between 2001 – 2016 (Source: Central Statistics Office)



1.5. Poverty

Yemen is the poorest country in the Arab region. It is now the world's eighth most food-insecure country (IFPRI, 2014). It continues to experience a range of complex socioeconomic problems. It is still struggling to recover from the impacts of significantly raised international food and fuel prices in 2007/08; the 2011 domestic political crisis; and diminishing natural resources, mainly water and oil. Poverty is deeply entrenched and pronounced in rural areas, where 84% of residents live below the poverty line. Due to their reliance on natural resources for food, fuel and fodder to meet household needs, this group is particularly affected by the ongoing conflict.

Table 1.1 illustrates Yemen's progress in key Human Development Index (HDI) indicators. Between 1990 and 2012, a period prior to the current conflict, Yemen's life expectancy at birth increased by 7.9 years, mean years of schooling increased by 2.5 years and expected years of schooling increased by 1.5 years. Moreover, gross national income (GNI) was fairly stable while the aggregate human development index (HDI) increased by 60%, from 0.286 to 0.458. Overall literacy rates have shown steady improvement, from 37% in 1990 to 64% in 2010. Female literacy rates, through still significantly lower, are increasing even more rapidly, from only 17% in 1990 to 47% in 2010. Since 2012, some of these positive trends have been reversed, with, for example, a 31% decline in GNI over the 2012-2015 period.

Table 1.1: Yemen's socioeconomic development trends, 1990-2012 (source: UNDP, 2013, UNESCO, 2012)

Year	Life expectancy at birth	GNI per capita (2011 PPP$)	HDI value	Expected years of schooling	Education: Mean years of schooling	Education: Female literacy	Education: Male literacy	Education: Total literacy
1990	57.9	3,149	0.405	7.5	0.3	17%	57%	37%
2000	60.4	3,705	0.444	7.9	1.2	36%	74%	55%
2010	62.8	4.061	0.493	8.6	2.6	47%	81%	64%
2011	63.1	3,357	0.494	9.0	2.8	NA	NA	NA
2012	63.3	3,350	0.498	9.0	2.3	NA	NA	NA

As a Least Developed Country (LDC), Yemen experiences numerous development challenges which include high population growth and entrenched poverty, inadequate access to basic social services, limited infrastructure, low literacy rate, low per capita income, slow economic growth, and environmental degradation, all of which are aggravated by the ongoing conflict situation. There are also large gender disparities, with significant gaps in women's access to economic, social and political opportunities. Yemen also has the lowest level of official development assistance (ODA) per capita at $12.70, or just 2.2% of GDP, compared to $33.40 per capita (18.7% of GDP) for the other least developed countries in the World.

Sadly, the country's political instability, civil insecurity, intensified war, and localized conflicts have plunged the country into a humanitarian crisis and jeopardized an already precarious food security and rural poverty situation. According to the Yemen Humanitarian Response Plan, 14.7 million people - more than half of the Yemeni population - required humanitarian assistance in 2014. This number exceeded 21.2 million in 2015 (82% of the total population) and the severity of needs among vulnerable people has been intensified across all developmental sectors. Nearly 19.3 million people in 2015 – and this figure has been increasing - were lacking adequate access to clean water or sanitation and three out of four Yemeni are unable to meet their basic hygiene needs because of ongoing war and long-standing vulnerabilities. Moreover, the war has caused 1.8 million children to be out of school since mid-2015.

Currently, 14.1 million people are lacking sufficient access to basic healthcare and 3 million children and pregnant or lactating women require malnutrition treatment or preventive services. Medical equipment and supplies for mass casualty management and medicine for most chronic diseases are increasingly in short supply. The difficult and chronic economic conditions superimposed by war have also forced authorities to cut all discretionary spending for medical expenses for drugs and medications for chronic diseases.

1.6. Land use

The distribution of land use is summarized in Table 1.2. The largest portion of Yemen land is classified as desert (79.3% of total land area) with limited use potential. Rangelands, together with forest and woodlands, comprise about 16.7% of land area, with the remaining being agricultural lands located in low-lying areas and capable of supporting rich crop diversity (4%) and urban areas (0.04%). Additional details of natural areas are provided in the bullets below.

Table 1.2: Ecosystem cover in Yemen, 2012 (source: FAOSTAT)

Categories	Area (1,000 ha)	Share of total land area (%)
Rangelands	6,199	11.7%
Forest & woodland	2,652	5.0%
Desert	41,842	79.3%
Arable land	2,081	3.9%
Urban	23	0.04%
Total Land Mass	**52,797**	**100.0%**

- *Rangelands:* Rangelands provide an important environmental service, namely the provision of forage for herds and flocks and a cheap source of livestock feed. Yemen's rangelands also provide fuel wood, a source of energy for the rural poor, as well as a variety of medicinal plants. More importantly, rangelands support economic production processes through wildlife habitats, pollinators, soil erosion prevention, soil maintenance, carbon sequestration and numerous watershed properties. In monetary terms, the total value of goods and services produced by Yemen rangelands has been estimated at US$ 12.2 billion per year (Source: Economic Valuation of Key Ecosystem, Republic of Yemen 2014.). The bulk of this value (80.3%) is associated with fodder production for livestock, while the remaining share corresponds to other benefits such as honey production, medicinal plants, pollination of agricultural products and soil erosion prevention. Yemen's 22 million hectares of rangelands produces 2.2 million tons of fodder per year and supports about 9.1 million sheep, 8.9 million goats, 0.4 million camels and 1.6 million cattle.

- *Forests and woodlands:* Forest area and woodlands are being progressively depleted, primarily to meet household energy needs in rural areas. Annual wood removal for to meet household cooking needs in rural areas has increased from 302,000 m^3 in 2000 to 435,000 m^3 in 2010 leading to land degradation, desertification, and increased loss of carbon stocks. Yemen's forest and woodland resources deliver a wide range of direct & indirect benefits to Yemeni peoples & environment that have been valued at US$ 260.8 billion per year. Direct forest benefits include fuel wood, fodder, medicinal plants and honey production; indirect forest benefits include a range of ecosystem functions such as carbon sequestration, soil erosion prevention, biodiversity conservation, and watershed protection.
- *Arable land:* Of Yemen's 1.6 million hectares of arable land, nearly all of it (1.5 million hectares) are currently under cultivation for the production of cereals, vegetables, fodder, cash crops, fruits and qat. Cereals rank first among domestic agricultural products, accounting for about 57% of total area cultivated. Fruits, vegetables, and cash crops accounted for only 6% each (18% total), while qat and animal fodder accounted for 11% each. Arable land plays a fundamental role in achieving food security, increasing the GDP, diversifying the economic platform, creating job opportunities and reducing poverty, particularly in rural areas. Roughly 33% of the work force depends on it for its livelihood while 11.4% of GDP is directly attributed to it.

1.7. Agriculture

The production of major crops for 2010, the most recent year for which reliable data is available, is summarized in Table 1.3. Cash crops consist of cotton, sesame, tobacco, coffee and qat, accounting for about 3.6% of national GDP. Other cultivation includes subsistence crops and fruits/vegetables.

Table 1.3: Crop Production, 2010 (Source: Ministry of Agriculture and Irrigation, 2013)

Type		Quantity (million tonnes)
Cash crops		0.27
Fruits & Vegetables		2.20
Other crops		1.01
	Subtotal	3.48
Fodder		2.18
Total		**5.66**

Livestock and poultry-raising are included within agricultural activities. In Yemen, these activities produce wastes that are subsequently used as fertilizer and soil conditioner, thereby optimizing the efficiency of waste management. However, there are adverse aspects of current husbandry practices such as the manure pile being fertile ground for breeding rodents and pests that pose health risks. This is particularly important as most smallholder farmers keep their livestock and poultry inside the house for security reasons, thus increasing the possibility of the transfer of disease from animals to humans.

1.8. Fisheries

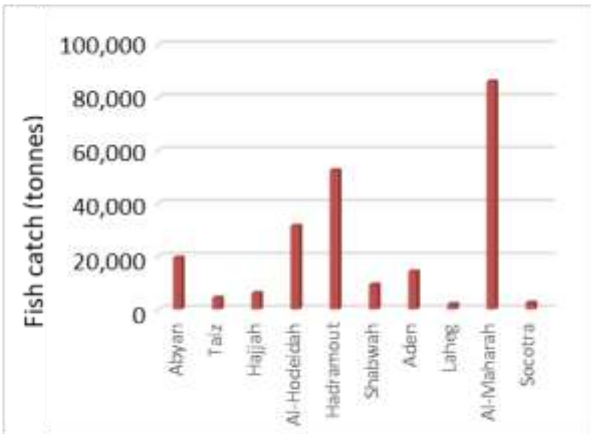
According to Yemen's Ministry of Fish Wealth available statistics for 2012, fishing is the main occupation of about 83,157 active artisanal fishermen directly supporting about 475,000 members of their families. While limited statistics are available, it is widely understood that relatively high numbers of people are engaged in different aspects of fish processing and marketing. In particular, fish processing plants, spread along the Yemen Red Sea and Gulf of Aden coastal zones, employ a large number of people, including women, in canning and other activities. Table 1.4. summarizes some aspects of the artisanal fishing sector for 2012.

Table 1.4: Selected artisanal fishing statistics for coastal governorates, 2012 (Source: Ministry of Fish Wealth statistics)

Governorate	Number of societies	Number of fishermen	Number of boats
Abyan	**7**	5,489	**1,420**
Taiz	**12**	3,928	**1,146**
Hajjah	**5**	1,950	**430**
Al Hudaidah	**34**	35,318	**7,112**
Hadramout	**20**	17,959	**5,700**
Shabwah	**12**	1,551	**818**
Aden	**8**	4,048	**2,132**
Lahjjj	**4**	2,272	**522**
Al-Maharah	**16**	6,568	**2,902**
Socotra island	**11**	4,074	**1,400**
Total	**129**	**83,157**	**23,582**

Total fish catch (artisanal and industrial) in 2012 was about 231 thousand tonnes. The overwhelming majority of this quantity, over 99%, was associated with artisanal fishing. Figure 1.4 illustrates the distribution of artisanal fish catch across the ten coastal governorates.

Figure 1.3: Spatial distribution of artisanal fish catch, 2012 (Source: Ministry of Fish Wealth)



1.9. Freshwater

Freshwater from wadis and groundwater are the main sources of water relied upon for socioeconomic development. As per 2010 data from Central Statistical Authority (CSO), water demand in agriculture accounts about 90% of available surface and ground water consumption, while the remainder is consumed by the household and industry sectors at 7% and 1% respectively.

Wadis and groundwater aquifers annually provide the country's poor population with about 62.1 billion liters of potable water plus an additional 805 million m^3 for agricultural purposes. The economic value of irrigation and domestic water is estimated to be approximately US$ 13.9 billion per year (UNDP, 2014). Of this amount, the largest share (92.8%) is associated with the value of irrigated agriculture and the remaining 7.2% is associated with the value of potable water for households.

Groundwater is being steadily withdrawn at rates that greatly exceed recharge rates. Specifically, total annual renewable water resources are estimated at 2.1 billion m^3 (1.1 billion m^3 of groundwater and 1 billion m^3 surface water) while water consumption is about 3.6 billion m^3, reflecting a groundwater depletion rate of 1.5 billion m^3 (170%) per year (CSO, 2010). This has led to a situation in which water resources are being vastly depleted, reaching critical levels. Driving reasons include high population growth rates, inefficient water distribution systems, cultivation of water-hungry crops such as qat, and erratic rainfall. Per capita water availability has dropped from 196 m^3 per year in 1990 to only 87 m^3 per year in 2010, positioning Yemen as having one of the lowest rates of per capita water availability in the world, roughly 2 % of the world average. The most disruptive impact of the continuing depletion of Yemen's groundwater resources is illustrated by the disparity in water supply among urban and rural populations. Rural populations that have access to safe and affordable drinking water have fluctuated between 57% and 59% over the period 2000 to 2008 compared with 72% to 82% for urban populations over the same period.

1.10. Wastewater

Only 29% of the total population had access to wastewater treatment services in 2012. There are currently 23 wastewater treatment plants in Yemen distributed across its many urban and rural centers. Of this total, about 14 treatments plants, having a total capacity of 246,126 m^3/d are operated utilizing stabilization pond technology, a low-cost technology particularly suitable for Yemen's hot climate. Another 8 plants, having a total capacity of 72,401 m^3/d are operated using Imhoff tanks. The remaining plant uses activated sludge procedure commonly used in many developed countries. While data on the quality of treated effluent are limited, those data that are available show that the effluent of at least two plants complies with the relatively lenient national standard of 150 mg/l of biological oxygen demand, a measure of organic pollution. However, none of the analyzed plants comply with the standard for fecal coliform, a measure of biological contamination.

Reuse of treated and untreated wastewater in agriculture is common in Yemen, but data on actual quantities used are unavailable. Wastewater from hospitals and medical laboratories is discharged into the sewer system, but cannot be adequately treated in the existing municipal wastewater treatment plants. This lack of a proper sanitation system negatively impact the quality of the environment and harms human health. Industrial wastewater is a major source of non-biodegradable organic and inorganic compounds that are directly to nearby water ways, a particularly problematic situation given food chain implications.

1.11. Municipal solid waste

About 3.8 million tonnes of municipal solid waste are typically sent to 21 dump sites in major cities of Yemen (CSO, 2013). Of these official sites, 15 were operated as open dumpsites, with the remaining 6 working as controlled dumps (SWEEP-Net, 2014). Inadequate municipal solid waste management is a serious problem in Yemeni cities as well as in small towns and villages. As waste collection facilities are poorly managed, most municipal solid waste is dumped into wadis, streets, and open dumps. Open burning and underground fires are common at 75% of the sites to reduce waste volumes or for the recovery of metals within the waste. Open burning results in serious hygienic and environmental impacts and reduced air quality in many rural and urban areas.

1.12. Industrial Minerals

In 2016, Yemen's gross domestic product (GDP) was valued at $27.3 billion compared with $43.2 billion in 2014, a decline attributed to the ongoing conflict throughout the country. In 2010, the contribution of the mineral industry to the country's GDP was 13.9%, indicating slight increase of 0.35% as compared with 2009. This increase was associated with production and exports of several hydrocarbon products such as crude oil and natural gas, along with other non-fuel products. Hydrocarbon exports accounted for 82% of Yemen's total merchandise exports in 2010, while non-fuel products, mainly, from agriculture, fisheries, gypsum and salts contributed the remaining 18% of national exports. Crude oil exports totaled 7.7 million barrels (Mbbl) in 2010, with another 6.9 billion cubic meters of LNG exported in that year. Other major exports in 2010 included 68,000 tonnes of gypsum and 5,369 of salt (World Bank, 2013).

Six cement plants were operational as of the end of 2013. Of these, the plants at Amran, Bajil, and Mafraq (Al Barh) are managed by state-owned Yemen Corporation for Cement Industry and Marketing (YCC), while the other three are privately owned. In 2012, the latest year for which statistics were available, total cement production from all plants was 2.8 million tonnes together with 3,000 tonnes of limestone.

1.13. Energy

Yemen is highly reliant on petroleum products with limited consumption of solid fuels such as biomass and coal. As shown in Table 1.5, liquid fuel consumption accounted about 97% of total fuel use in 2012, with biomass in the form of wood, dung and agricultural residues accounting for about 1.7% and coal and bitumen for cement production accounting for the remaining 1.7% of fuel consumption.

Table 1.5: Fuel consumption by sector, 2012 (sources: Ministry of Oil and wealth, UN Statistics Division, IEA)

Sector	Biomass (TJ)	Solid Fuel (TJ)	Liquid Fuel (TJ)	Total (TJ)
Electricity production	0	0	57,601	57,601
Industry	0	5,110	41,370	46,480
Transport	0	0	82,328	82,328
Residential	4,959	0	75,892	80,851
Commercial and public services	0	0	16,297	16,297
Agriculture/forestry and fishing	0	0	16,297	16,297
Final consumption from all sectors	**4,959**	**5,110**	**289,784**	**299,854**
Share of overall total (%)	1.7%	1.7%	96.6%	100.0%

Diesel and gasoline are most important fuel sources in Yemen. In 2012, diesel and gasoline consumption totaled 215,125 TJ, or about 74% of total energy consumption. Residual fuel oil and LPG were also important fuels, accounting for about 13.2% and 10.7%, respectively. The contributions of other fossil fuel products such as jet kerosene, other kerosene and natural gas were minor, accounting for less 1% each. On sectoral basis, the transport sector is the largest consumer of petroleum products (28%), followed by households (26%), electricity (20%), industry (14%), and agriculture and commercial with 6% each, as summarized in Table 1.6.

The consumption of petroleum products has significantly increased since 1995. Specifically, total fuel consumption increased from 139,344 TJ in 1995 to 289,784 in 2012, an average annual growth rate of 4.4% per year. This growth is attributed to an increasing number of vehicles utilizing mainly gasoline and diesel, together with increasing oil-fired electric generation. Diesel fuel accounted for the largest increase of energy consumption, growing at 8.7% per year over the 1995 to 2012 period.

Table 1.6: Liquid fuel consumption by sector and type, 2012 (sources: Ministry of Oil and Wealth, UN Statistics Division, IEA)

Sector	Natural gas liquids (TJ)	LPG (TJ)	Gasoline (TJ)	Kerosene (TJ) Jet	Kerosene (TJ) Other	Diesel (TJ)	Residual fuel oil (TJ)	Total (TJ)	Share (%)
Electricity	2,700	0	0	0	0	24,682	30,219	57,601	20%
Industry	0	0	0	0	0	33,411	7,959	41,370	14%
Transport	0	4,257	61,529	1,019	0	15,523	0	82,328	28%
Residential	0	26,866	0	0	1,639	47,386	0	75,892	26%
Commercial/public services	0	0	0	0	0	16,297	0	16,297	6%
Agriculture/forestry/fishing	0	0	0	0	0	16,297	0	16,297	6%
Total	**2,700**	**31,123**	**61,529**	**1,019**	**1,639**	**153,596**	**38,178**	**289,784**	**100%**
Share of overall total (%)	0.9%	10.7%	21.2%	0.4%	0.6%	53.0%	13.2%		100%

Despite a rapid increase in total electricity consumption over the past decade, per capita electricity consumption is still quite low - 191 kWh/capita/year in 2012 compared with the world average of about 2,800 kWh/capita/year. Yemenis have the lowest access to electricity in the Middle East and North Africa region with only 48.4% of the population having access, compared to a regional average of 90%. Although rural dwellers account for over 70% of the population, only about 33.5% have access to electricity compared with about 78.9% of the urban population. Notably, only about half of the population that has access to electricity are connected to the electric grid, with the other half having private access through diesel generators that typically operate only a few hours per day for lighting and certain electric appliances.

1.14. Implementation arrangements and report outline

As an LDC lacking adequate financial resources to implement its reporting commitments under the UNFCCC, Yemen requested and received financial support from the GEF for the preparation of its Third National Communication (TNC) and First Biennial Update Report (BUR). The UNDP served as the implementing partner, with staff from Yemen's Environment Protection Authority managing day-to-day activities and tasks. Local experts were instrumental in undertaking the various assessments in GHG inventory development vulnerability assessments, and mitigation analyses.

Findings of all project studies are reflected in this TNC. An update of the GHG inventory for 2010 is presented in chapter 2, findings of five V&A assessments (agriculture, water resources, coastal zones, public health, and ecotourism) as well as climate scenarios are presented in chapter 3, and an update of the GHG mitigation assessment is described in chapter 4. Chapter 5 provides an overview of supplementary activities undertaken during the project and chapter 6 discusses ongoing constraints, gaps and needs for future efforts to address climate change in Yemen.

The process has been a great opportunity for awareness-raising and building technical capacity about climate change, providing a source of climate change-related knowledge for stakeholder groups, and serving as a useful organizing framework for climate change policy development. All activities specified in the TNC-BUR project document and workplan were successfully completed on schedule as originally planned for June 2017.

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Chapter 2:

National Greenhouse Gas Inventory

This chapter presents estimates of national anthropogenic greenhouse gas emissions and sinks for the year 2010. The inventory includes five categories: energy; industrial processes; agriculture; land use, land use change and forestry (LULUCF) and waste.

2.1. Methodology

The methodology used to develop the inventory is based on the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* and the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (Good Practice Guidance) prepared by the Intergovernmental Panel on Climate Change (IPCC). As recommended by the IPCC Guidelines, country specific methods have been used as appropriate for certain GHG emitting sectors. In the subsections that follow, GHG emissions are reported both in absolute units of carbon dioxide, methane and nitrogen oxide emissions, as well as in units of CO_2-equivalent by applying 100-year GWPs of 1 for CO_2, 21 for CH_4, and 310 for nitrogen oxide, as recommended by the IPCC in its Second Assessment Report. Unless, as noted, generic emission factors from the IPCC guidelines have been used.

2.2. Total GHG Emissions

Table 2.1 presents total GHG emissions and sinks for the year 2010. Total GHG emissions in 2010 were 34,136 Gg CO_2-equivalent, which includes 22,038 Gg from energy; 1,798 Gg from industrial processes; 8,247 Gg from agriculture and 2,053 Gg from waste. CO_2 sequestration by the forestry and land use sector in 2010 amounted to 1,887 Gg. Net GHG emissions are estimated at 32,249 Gg CO_2-equivalent. Emissions from perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulfur hexafluoride (SF_6) in Yemen are negligible as the products containing these gases are not produced in the country.

Table 2.1: Total GHG emissions in Yemen, 2010 (Gg)

GHG Sources & Sinks	CO_2-equiv	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
1 Energy	22,038	20,543	66.75	0.30	102	514	102	4
2 Industrial Processes	1,798	1,798	0.00	0.00	0	0	183	1
3 Solvent & Other Product Use	0	0	0.00	0.00	0	0	0	0
4 Agriculture	8,247	0	184.00	14.14	1	18	0	0
5 Land-Use Change & Forestry	-1,887	-1,887	0.00	0.00	0	0	0	0
6 Waste	2, 053	0	83.00	1.00	0	0	0	0
Total National Emissions	34,136	22,341	333.75	15.44	103	532	285	5
Net National Emissions	**32,249**	**20,454**	333.75	15.44	**103**	**532**	**285**	**5**

Energy-related activities accounted for the dominant portion of GHG emissions in Yemen in 2010. Approximately 65% of all GHG emissions are associated with the combustion of fossil fuels for electricity production and the release of fugitive emissions from oil and gas operations. Emissions from agriculture accounted for 24% of all GHG emissions, followed by the waste and industrial sectors which accounted for about 6% and 5% of total emissions, respectively.

2.3. GHG Emission Trends

Figure 2.1 presents the trend in total GHG emissions for previous 1995 and 2000 inventories, and 2010, the year of the current GHG inventory. Emissions have increased by about 91%;

from 17,866 Gg CO_2equivalent in 1995 to about 34,136 Gg CO_2equivalent in 2010, or roughly 4%/year.

Figure 2.1: Total GHG emission trend, 1995, 2000, and 2010

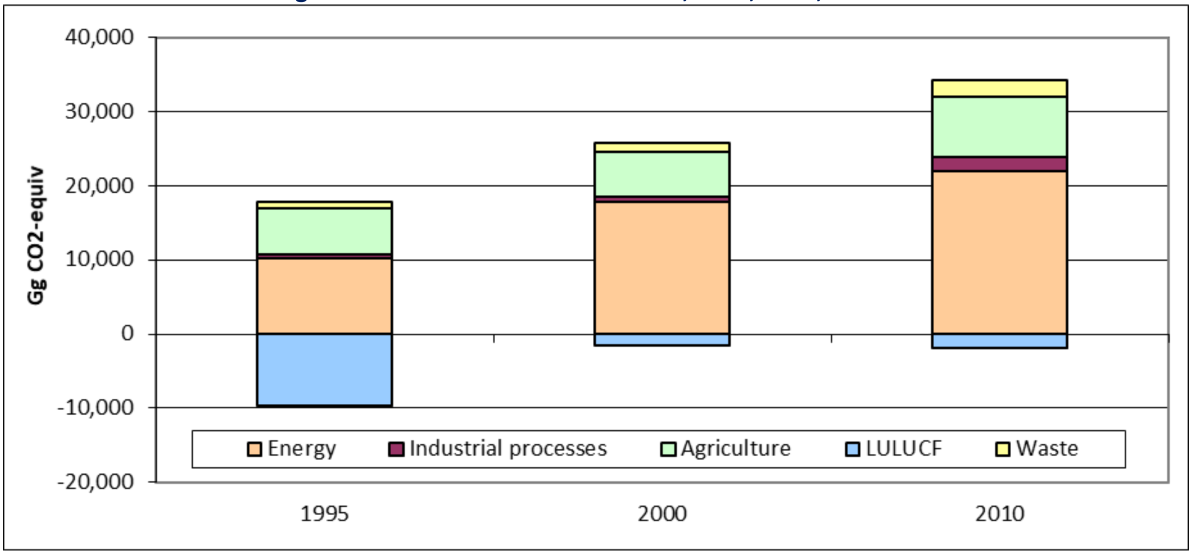
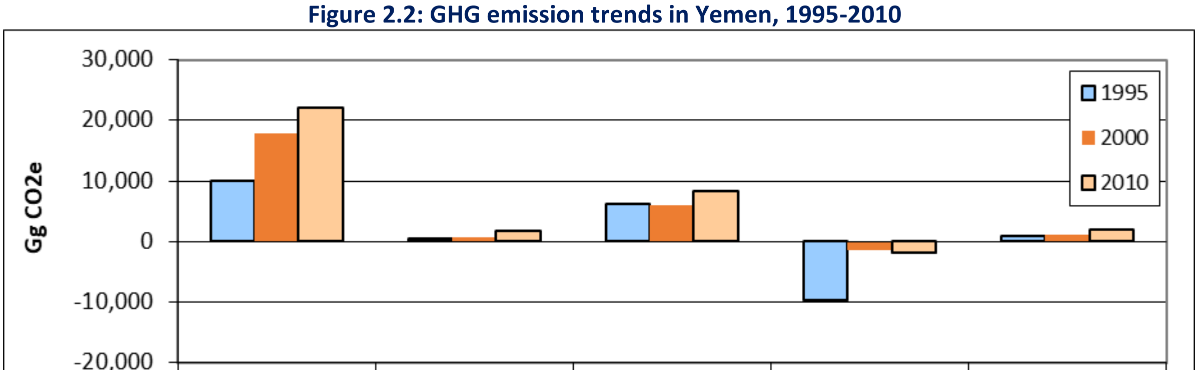


Figure 2.2 compares GHG emissions for each sector for the years 1995, 2000, and 2010 and highlights the fact that energy and agriculture are the main components responsible for the overall increasing trend in GHG emission levels in Yemen. Over the period, CO_2-equivalent emissions from energy use have increased by 132%, or about 5% per year. This is due primarily to increases in energy use for power generation and process heat in manufacturing industries. Also over this period, CO_2-equivalent emissions from agriculture have increased by 71%, or about 3% per year.

Figure 2.2: GHG emission trends in Yemen, 1995-2010



	Energy	Industrial processes	Agriculture	LULUCF	Waste
1995	10,132	547	6,294	-9,655	893
2000	17,797	734	5,948	-1,501	1,214
2010	22,038	1,798	8,247	-1,887	2,053

2.4. Energy

Table 2.2 summarizes GHG emissions associated with energy activity in 2010. Relative to overall anthropogenic GHG emissions, the 22,038 Gg CO_2-equivalent represents about 65% of total national emissions. Activity data have been obtained from published statistics by relevant agencies in Yemen. Energy data obtained from oil, gas and mineral statistics, published by the statistics technical committee in the Ministry of Oil and Minerals. Other local sources that were relied upon include annual statistics published by Central Statistics and surveys and reports developed the Yemen Geological Survey and Mineral Resources Board (GSMRB). Where data was either unavailable or of low quality, data from international sources were used after being validated. These international data sources included the U.S. Energy Information Administration, the United Nations Statistics Division, and the International Energy Agency (IEA).

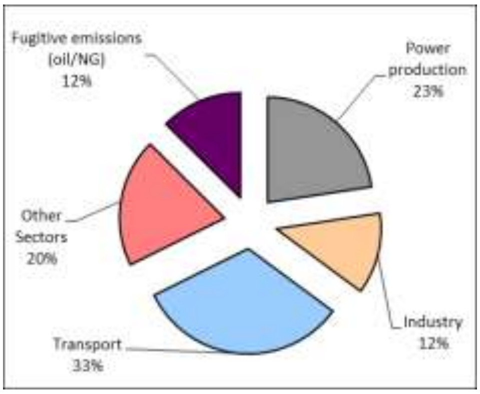
Table 2.2: GHG emissions from energy use, 2010 (Gg)

GHG Source Categories	CO_2-equiv	CO_2	CH_4	N_2O	NO_x	CO	NM VOC	SO_2
All energy emissions	**22,038**	**20,543**	**66.75**	**0.30**	**101**	**514**	**102**	**514**
A Fuel Combustion Activities	*19,269*	*19,173*	*2.19*	*0.16*	*101*	*514*	*97*	*514*
1 Energy Industries	4,987	4,970	0.20	0.04	13	1	0	1
2 Manufacturing Industries & Construction	2,753	2,745	0.07	0.02	7	0	0	0
3 Transport	7,181	7,134	1.34	0.06	63	501	94	501
4 Other Sectors	4,349	4,324	0.58	0.04	18	12	2	12
B Fugitive Emissions from Fuels	*2,769*	*1,370*	*64.56*	*0.14*	*0*	*0*	*5*	*0*
1 Solid Fuels	0	0	0	0	0	0	0	0
2 Oil and Natural Gas	2,769	1,370	64.56	0.14	0	0	5	0
Memo Items	*337*	*337*	*0.00*	*0.00*	*0*	*0*	*0*	*0*
International Bunkers	337	337	0.00	0.00	0	0	0	0
CO2 Emissions from Biomass	0	0	0.00	0.00	0	0	0	0

GHG emissions from energy production and consumption activities are due to fossil fuel combustion and fugitive emissions from oil and gas exploration activities. Fuel combustion emissions are associated with the use of a variety of petroleum products such as diesel, residual oil, and LPG. For the 2010 inventory year, natural gas was not consumed for either power or heat production. All of the diesel and gasoline quantities are consumed in road transport, with relatively negligible small quantities used for industrial processes. LPG is used in the residential and commercial/institutional sectors for cooking.

Figure 2.3 illustrates the breakdown in energy-related GHG emissions in 2010 by consuming activity. Emissions from transport showed the highest share of GHG emissions from gasoline and diesel consumption in 2010, about 33%. Power production is based overwhelmingly on the use of residual oil and diesel oil and accounted for about 23% of total emissions from energy-consuming activities in Yemen. Other sectors (mainly LPG, Kerosene and Diesel) accounted for 20%. The industrial sector (mostly food/dairy and cement) is relatively small in Yemen and accounted for about 12% of all energy-related emissions in 2010. Notably, fugitive emissions of methane, a gas that has a high global warming potential, accounted for about 12% of all GHG emissions in the energy industries sector.

Figure 2.3: Breakdown of GHG emissions associated with energy activities, 2010



2.5. Industrial Processes and Other Product Use

Table 2.3 summarizes GHG emissions associated with industrial processes and product use in 2010. Industrial processes are the fourth largest emitter of anthropogenic GHG emissions in Yemen, accounting for 1,798 Gg of CO_2–equivalent, or about 5% of national CO_2–equivalent emissions in 2010. Activity data for the industrial sector were based on Trade Statistics and surveys of key industries.

Table 2.3: GHG emissions from industrial activity, 2010 (Gg)

GHG Source Categories		CO_2-equiv	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
All industry emissions		1,798	1,798	0	0	0	0	183	1
Industrial Processes		1,798	1,798	0	0	0	0	183	1
A	Mineral Products	1,798	1,798	0	0	0	0	180	1
B	Chemical Industry	0	0	0	0	0	0	0	0
C	Metal Production	0	0	0	0	0	0	0	0
D	Other Production	0	0	0	0	0	0	2	0
E	Production of Halocarbons and Sulphur Hexafluoride	0	0	0	0	0	0	0	0
F	Consumption of Halocarbons and Sulphur Hexafluoride	0	0	0	0	0	0	0	0
Total Solvent and Other Product Use		*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
A	Paint Application	0	0	0	0	0	0	0	0
B	Degreasing and Dry Cleaning	0	0	0	0	0	0	0	0
C	Chemical Products, Manufacture and Processing	0	0	0	0	0	0	0	0
D	Other	0	0	0	0	0	0	0	0

Other than for mineral products, there is negligible industrial activity in Yemen that produces process-related emissions. Cement production is the dominant source of industrial GHG emissions, accounting for the entirety of emissions from the sector.

2.6. Agriculture

Table 2.4 summarizes GHG emissions associated with agriculture in 2010. Agricultural practices are the second largest emitter of anthropogenic GHG emissions in Yemen, accounting for 8,247 Gg of CO_2–equivalent, or about 24% of national CO_2–equivalent emissions in 2010. Activity data for the agriculture sector was based on the Agricultural Statistics Yearbook published by the Ministry of Agriculture and Irrigation.

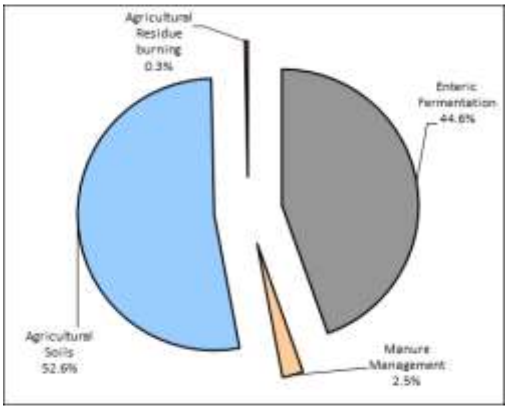
Figure 2.4 illustrates the breakdown in agriculture-related GHG emissions in 2010 by activity. Emissions associated with agricultural soils showed the highest share of GHG emissions in 2010, about 53%. These emissions are associated with nitrogen applications to cultivatable soils through the use of synthetic fertilizers, animal excreta, and crop residues. Emissions from enteric fermentation accounted for the second highest share, about 45%. Collectively, cattle, goats, and sheep account for the overwhelming majority of such emissions, nearly 90%, with the balance from camels, horses, mules, and donkeys.

Table 2.4: GHG emissions from agricultural activity, 2010 (Gg)

GHG Source Categories	CO_2-equiv	CO_2	CH_4	N_2O	NO_x	CO	NMVOC
All agriculture emissions	**8,247**		**184.00**	**14.14**	**1**	**18**	**0**
A Enteric Fermentation	3,675		175.00	0.00	0	0	0
B Manure Management	204		8.00	0.12	0	0	0
C Rice Cultivation	0		0.00	0.00	0	0	0
D Agricultural Soils	4,340		0.00	14.00	0	0	0
E Prescribed Burning of Savannas	0		0.00	0.00	0	0	0
F Field Burning of Agricultural Residues	29		1.00	0.03	1	18	0

The remaining sources of GHG in the agricultural sector (i.e., manure management and field burning of crop residues) accounted for the balance of about 3%. Emissions from manure management are mostly from dairy farms, poultry farms, and beef feedlots where animals are managed in confined spaces. GHG emissions from field burning of crop residues are negligible (i.e., just over 0.3%) and are associated with the burning of sorghum, wheat and millet crop wastes after each harvest cycle.

Figure 2.4: Breakdown of GHG emissions associated with agricultural activities, 2010



2.7. Land Use, Land Use Change and Forestry

Table 2.5 summarizes GHG emissions associated with land use, land use change and forestry in 2010. The 1,887 Gg CO_2-equivalent sequestered through changes in forested lands is roughly 6% of Yemen's overall anthropogenic GHG emissions.

Annual activity data was obtained from both national and international statistics and were considered adequate to establish emission estimates inventories for only a few of the IPCC categories, namely changes in forest and biomass stock as well as CO_2 uptake associated with land use change and management. Annual activity for other categories such as land conversion and abandoned lands was either unavailable or outdated for purposes of the GHG inventory update. As noted later in this chapter, the availability of better national documentation on forested areas, afforested areas, and tree plantation/removals would reduce the uncertainty of the current inventory significantly.

Table 2.5: GHG emissions from LULUCF activity, 2010 (Gg)

GHG Source Categories	CO_2-equiv	CO_2	CH_4	N_2O	NO_x	CO
All LULUCF emissions	-1,887	-1,887	0	0	0	0
A Changes in Forest & Other Woody Biomass Stocks	-11,743	-11,743	0	0	0	0
B Forest and Grassland Conversion	0	0	0	0	0	0
C Abandonment of Managed Lands	0	0	0	0	0	0
D CO2 Emissions and Removals from Soil	9,856	9,856	0	0	0	0
E Other	0	0	0	0	0	0

Changes in forest stocks accounted for a net 11,743 Gg CO_2-equivalent sequestered in Yemen. This amount is associated with roughly an additional 2,342 thousand hectares planted with various acacia species as well as a small amount of managed non-forested areas. Sequestered amounts are offset by roughly 134.4 thousand hectares that have been converted to cropland, leading to emissions of 9,856 Gg CO_2-equivalent. Combining these sources and sinks, there is a net sequestered amount of 1,887 Gg CO_2-equivalent.

4.1. Waste

Table 2.6 summarizes GHG emissions associated with waste management activity in 2010. Relative to overall anthropogenic GHG emissions, the 2,053 Gg CO_2-equivalent represented about 6% of total national emissions. Sources for waste management data included the Statistical Yearbook, as well as data contained in feasibility and other reports from the Environment Protection Authority and the Ministry of Water and Irrigation.

Table 2.6: GHG emissions from waste management activity, 2010 (Gg)

GHG Source Categories	CO_2-equiv	CO_2	CH_4	N_2O	NO_x	CO	NMVOC
All waste emissions	2,053	0	83.00	1.00	0	0	0
A Solid Waste Disposal on Land	1,218	0	58.00	0.00	0	0	0
B Wastewater Handling	835	0	25.00	1.00	0	0	0
C Waste Incineration	0	0	0.00	0.00	0	0	0
D Other (please specify)	0	0	0.00	0.00	0	0	0

In Yemen, there is no waste incineration of any kind. Hazardous wastes are collected and transferred outside the country for incineration, while all types of other solid waste (domestic, medical and industrial) are collected and transferred to municipal landfills distributed around the country, where they are burned in the open air. A small fraction of biogenic wastes is disposed of at landfills, where in some governorates they are scavenged and sold to companies which transfer it outside the country for recycling. Combustion of wastes occurs in the open air by the informal sector in their search for metals and other materials of commercial value. There are 36 landfills in Yemen; of these only 23 sites receive significant amounts of waste.

The main source of greenhouse gases within Yemen's waste sector is solid waste disposal which accounted for about 59% of waste-related emissions. Domestic and commercial wastewater handling in a total of nine wastewater treatment facilities accounted for the balance of waste-related emissions.

2.8. Emissions of PFCs, HFCs, and SF_6

According to the Revised IPCC Guidelines, the major emission sources of PFCs, HFCs, and SF_6 these gases are the following activities: replacement of ozone-depleting substances; HCFC-22 production; electric power transmission; production of primary aluminum; production of semiconductors; and production and processing of magnesium. Only the third activity occurs in Yemen (power transmission). PFCs and HFCs were not produced or imported/consumed as substitutes for ozone depleting substances in refrigeration and fire extinguishers because ozone-depleting substances were not banned in Yemen in 2010. The estimation of SF_6 emissions associated with electric power transmission proved to be a significant challenge due to data constraints and was assumed to be negligible.

2.9. Uncertainty Assessment

An uncertainty assessment was an essential element of the GHG emission inventory update to help prioritize efforts to improve the accuracy of future inventories. In Yemen, uncertainties are associated with data access/constraints, potential unsuitability of generic emission factors, and an incomplete understanding of the processes associated with emissions. Some of the current estimates, such as those for CO_2 emissions from energy-related activities and cement processing are considered to have minimal uncertainty associated with them. For some other categories of emissions such as afforested areas, however, a lack of information increases the uncertainty surrounding the estimates presented.

Table 2.7 summarizes the uncertainty assessment for Yemen GHG inventory. Based on expert judgment of specialists participating in the development of the inventory, the confidence in the results for each source/sink category was evaluated relative to the uncertainty associated with data quality and emission factor suitability. Less than 10% uncertainty was considered to be low; uncertainty between 10% and 50% was considered medium; and uncertainty greater than 50% was considered high. Grey-shaded cells indicate non-applicability.

Table 2.7: Uncertainty assessment associated with Yemen GHG inventory, 2010

Activity	Activity Data Uncertainty			Emission Factor Uncertainty			Combined Uncertainty		
	CO_2	CH_4	N_20	CO_2	CH_4	N_20	CO_2	CH_4	N_20
Energy Industries	Low	Low	Low	Low	Low	Low	Low	Low	Low
Manufacturing Industries and Construction	Low	Low	Low	Low	Low	Low	Low	Low	Low
Road Transportation	Low	Low	Low	Low	Low	Low	Low	Low	Low
Commercial/Institutional - Liquid Fuels	Low	Low	Low	Low	Low	Low	Low	Low	Low
Residential - Liquid Fuels	Low	Low	Low	Low	Low	Low	Low	Low	Low
Cement production	Medium			0			Medium		
Lime production	Medium			0			Medium		
Enteric fermentation		High			Poor			High	
Manure management		High	High		Poor	Poor		High	High
Changes in Forest and Other Woody Biomass Stocks	High			Poor			High		
CH_4 emissions from solid waste disposal sites		Medium			Poor			High	
CH_4 emission from Domestic and Commercial Waste water management		Medium			Poor			High	
N_2O emissions from human waste			Medium			poor			High

As shown in Table 2.7, estimates of CO_2, CH_4 and N_2O emissions from energy-related activities are considered to have minimal uncertainty associated with their calculation. Cement and limestone production are considered of medium uncertainty, while estimates of CO_2 emissions from afforested areas is estimated be highly uncertain. Additionally, estimates of CH_4 emissions from enteric fermentation, manure management, solid waste disposal and domestic and commercial waste water management were highly uncertain.

2.10. List of References

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Chapter 3:

Vulnerability and Adaptation

This chapter presents an overview of key sectors that are highly vulnerable to climate change in Yemen, namely water resources, coastal zones, and agriculture. Coupled with the assessment of vulnerability in each of these sectors are a set of recommended adaptation strategies for which international support will be critical.

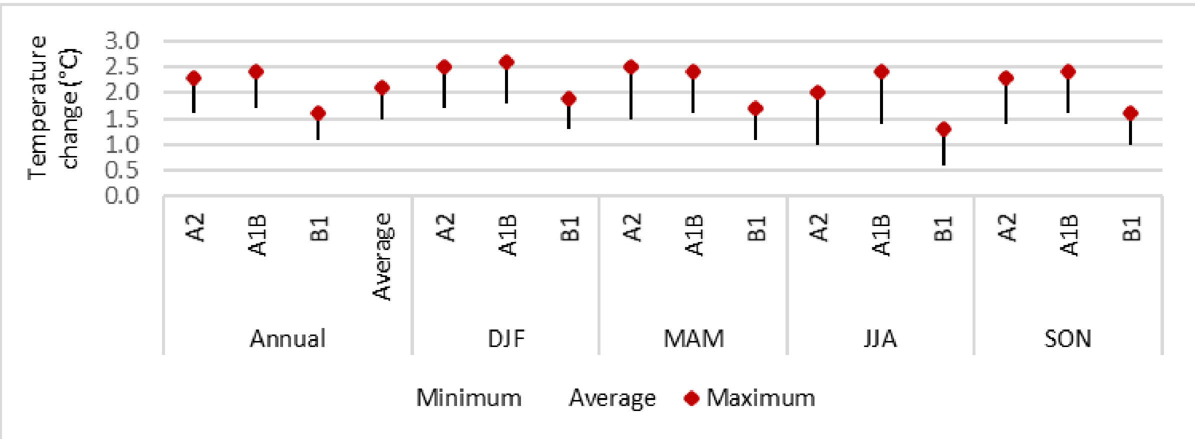
3.1. Future climate

Climate projections were developed to improve an understanding of the complexity of the climate, particularly for a future in which GHG concentrations are increasing (Al-Jibly, 2016). A scenario approach was adopted to bracket uncertainty. The Community Climate System Model (CCSM3) model, developed by the US National Center for Atmospheric Research (NCAR), was used with to project the regional climate under three scenarios developed by the IPCC's Special Report on Emission Scenarios (SRES); namely, the A2 (high-emission scenario), the A1B (medium-emission scenario) and the B1 (low-emission scenario). Climatic projections were made for the Mid-21st Century period (i.e., 2040 to 2059) and compared to the baseline climate, as defined by climatic conditions during 1980-1999 period.

Climate simulations were made at a global scale, with results extracted for the region surrounding Yemen. The focus of the simulations was on the projected increase in seasonal and annual mean temperature and projected changes in seasonal and annual total precipitation. Seasonal variations were defined for the winter season (December, January, and February, or DJF); spring season (March, April, May, or MAM); summer season (June, July, August, or JJA); and autumn season (September, October, November, or SON).

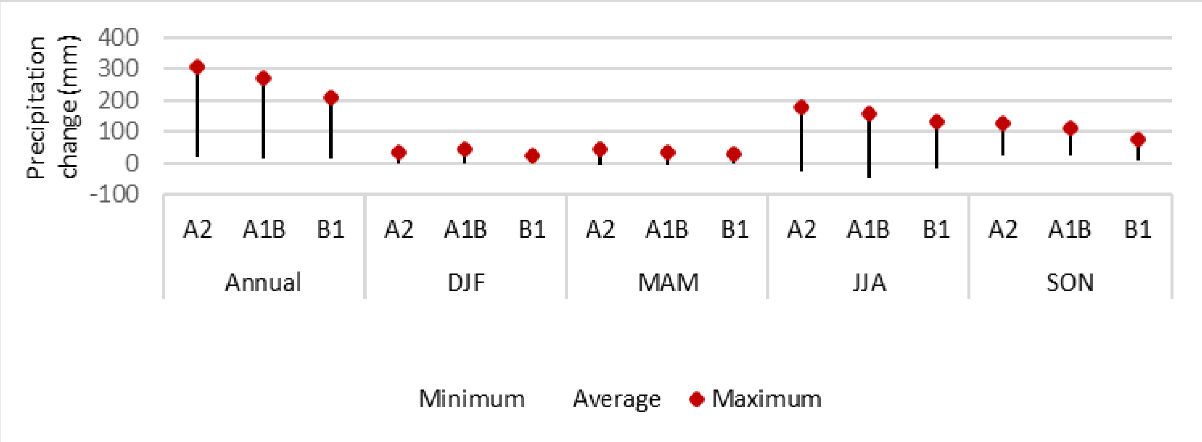
The results of the temperature simulations are illustrated in Figure 3.1. All areas of Yemen will get warmer, with the greatest change projected to occur during the winter months. Across the entire country, annual mean temperatures show the greatest rise under the A1B scenario, between 1.7 °C and 2.4°C by the 2050s, with an average annual increase of 2.0°C. Seasonal mean temperatures are also projected to increase by 2050. For each of the emission scenarios, the largest seasonal temperature increases occur during the winter months and the smallest seasonal temperature increases occur during the summer months.

Figure 3.1: Projected change in temperature for Yemen, 2050



The results of the precipitation simulations are illustrated in Figure 3.2. There is greater uncertainty with annual rainfall change projections as some season-scenario combinations show a future increase in rainfall and others show a decline in rainfall. Across the entire country, annual mean precipitation change shows the greatest rise under the A2 scenario, between 21 mm/year and 306 mm/year by the 2050s, with an average annual increase of 129 mm/year. Seasonal mean rainfall shows both increases and decreases by 2050. For each of the emission scenarios, the largest seasonal rainfall change occurs during the summer months, ranging between a decline of 14 to 47 mm/season and an increase of 131 to 179 mm/season across all emission scenarios. The smallest seasonal rainfall change occurs during the winter months, ranging between a decline of 1 mm/year and an increase of 27 to 45 mm/season across all emission scenarios.

Figure 3.2: Projected change in precipitation for Yemen, 2050



Going forward, there is a need for regular updates of the above climate change scenarios for Yemen to keep pace with unfolding developments in the tools, emissions scenarios and climate models. In particular, the immediate next step should focus on developing the capacity to undertake regional climatic modeling that can better account for Yemen's local conditions - such as its mountainous topography and extended coastlines - as well as increase the spatial resolution of the climatic simulations. In addition, greater coordination should be pursued between the Environmental Protection Authority and the Meteorological Authority to facilitate creation of climatic data bank that could be used to ground truth future regional climatic modeling efforts.

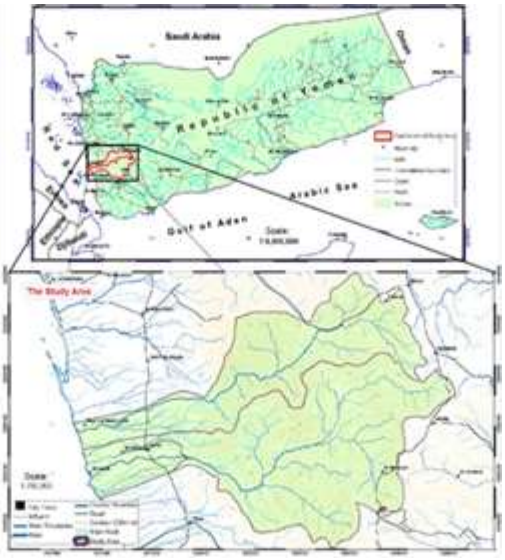
3.2. Water Resources

Climate change is among the priority water resource management threats in Yemen. To explore the magnitude of potential impacts and the viability of some adaptation strategies, an illustrative case study assessment of the Wadi Zabid drainage basin was udnertaken (Noman, 2016). The intense use of groundwater for irrigated agriculture in this region – and its clear impact on lowering of the groundwater table - was the underlying motivation for exploring the potential impacts of climate change.

3.2.1. Main features of study area

The Wadi Zabid watershed is located on the Western Escarpment of the highlands along the western part of Yemen, as shown in Figure 3.3. The catchment extends as far east as the green Yemen region around the city of Ibb in the Al-Odien province. Comprising about about 4,630 km^2, it considered one of the seven main agricultural regions in Yemen, draining surface waters from the semi-arid western mountain slopes of Yemen into the Red Sea. The region is socially and economically important because of its major agricultural activities that support livelihoods in many neighboring cities. A brief overview of that watershed is provided in the bullets below.

Figure 3.3: Location of the Wadi Zabid drainage basin



- About 2,533 km^2 (55%) of the watershed is uncultivated, rugged mountainous terrain with sparse vegetative cover. In this upper area, elevations can reach upward of 3,000 meters above sea level and annual rainfall averages around 800 mm.
- About 1,945 km^2 (42%) of the watershed is mountainous terrain with shallow soil depths varying from 1.5 to 3 meters. In this middle area, terraced farming is heavily practiced and annual rainfall averages around 300 mm.
- The remaining 152 km^2 (3%) of the watershed is located in coastal regions where spate-irrigated cultivation of cereals, legumes, qat, vegetables, tree crops, and a number of other commerical crops is practiced. In this lower area near the Red Sea, the wadi discharges into a flat area known as the Tihama Zone where annual rainfall averages around 100 mm.

Figure 3.4 summarizes historical surface water discharge levels through the wadi and its tributaries for the period 1970 to 2010. There is significant variation in flow quantities across the months of the year, as well as from year to year. The monthly average of surface water runoff is in the range of about 9.9 MCM per month, with maximum discharge levels occurring between May and August (see Figure 3.4a). The average annual flow level is about 118.1 MCM, an amount which includes both surface runoff and base-flow in the wadi and its tributaries (see Figure 3.4b).

Figure 3.4: Wadi Zabid water discharge levels, 1970-2010 (Source: Noman, 2016)

a) Average monthly runoff **b) Annual flow**

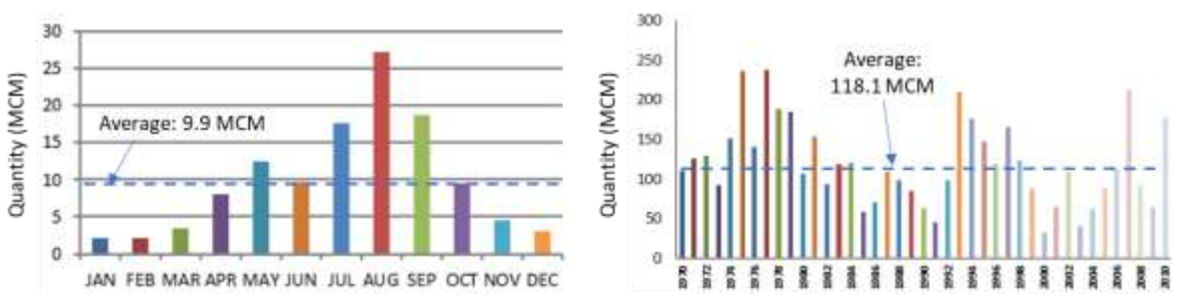


Table 3.1 summarizes current cropping patterns and water use in the coastal plain portion of the watershed for the year 2002. Since ancient times, agricultural production in the coastal region has depended primarily on groundwater abstraction and spate irrigation. In the 1970s,

however, significant investments were made to enhance agricultural production and public services. The construction of many diversion structures and canals in the many tributaries led to a change in cropping patterns, with farmers switching from grain cultivation to more commercial crops such as bananas and mangoes which are more water-intensive.

Table 3.1: Crop patterns in coastal region of Wadi Zabid watershed, 2002 (Source: adapted from General statistical organization)

Type of crop	Crop variety	Share (%)	Area (km²)	Irrigation type (%): Ground water	Spate irrigation	Total
Cereal grains	Sorghum grains, Sorghum fodder, maize	53%	80.6	20%	80%	100%
Fruits	Papaya, melon, banana, mango	23%	36.5	90%	10%	100%
Vegetables	Tomatoes, onion, cucumber, peppers, etc	3%	4.6	70%	30%	100%
Other cash crops	Cotton, tobacco, sesame	20%	30.4	90%	10%	100%
	Total	**100%**	**152.2**	**52%**	**48%**	**100%**

Greater access to water has led to the expansion of cultivated areas, particularly in upstream areas of the coastal plain. In these areas, farmers have been diverting increasing amounts of spate water to meet their increasing crop cultivation needs, adversely impacting water availability for downstream farmers and disrupting the application of age-old water distribution rights.

Figure 3.5 provides an overview of the change in water well installations in the coastal plain over the past 50 years. Investments to enhance water availability for agricultural production have led to a sharp increase in the number of drilled wells - from 460 wells at the end of 1950s to about 2,950 in 2000s – an average annual growth rate of 3.8% that exceeds population growth over the same period. This growth is particularly evident throughout the 1980s and 1990s.

Figure 3.5: Wells drilled in Wadi Zabid watershed over time (Tihama Development Authority)

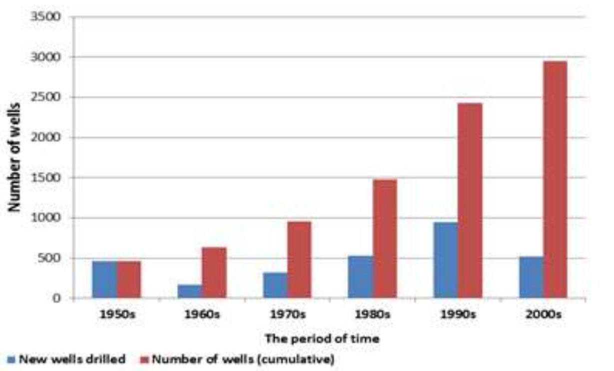


Table 3.2 summarizes groundwater supply and demand patterns throughout the watershed. At present, annual withdrawals from the underlying quaternary aquifer (i.e., essentially fossil groundwater from the Cenozoic Era) exceed annual recharge levels

Table 3.2: Groundwater supply and demand patterns in Wadi Zabid watershed (source: Noman, 2016)

SUPPLY	Source					Total
	Rainfall (MCM/yr)					30
	Wadi infiltration (MCM/yr)					118
	Total (MCM/yr)					148
DEMAND		Agriculture		Residential & industrial	Evapo-transpiration	
	Parameter	banana	other			Total
	Abstraction (MCM/yr)	222	68	10	45	345
	Return infiltration (MCM/yr)	66.6	20.4			87
	Net abstraction (MCM/yr)	155.4	47.6	10	45	258
	Share (%/yr)	60%	18%	4%	17%	100%
NET	Over-withdrawal (MCM/yr)					110

from surface runoff and storage. While annual groundwater recharge consists of 148 million cubic meters (MCM) - 80% from surface water infiltration and 20% from rainfall - net annual groundwater withdrawal is much greater, about 258 MCM, placing enormous stress on the aquifer. Banana cultivation alone accounts for about 60% of net groundwater demand, with all other crops (i.e., fodder, vegetables, cereals) accounting for only 18% of net groundwater demand. Remaining shares of water consumption are from evapotranspiration (17%) and residential/industrial uses (4%). As a result, the groundwater table has been dropping steadily over the years. Currently, the annual average drop in the groundwater table is about 0.3 meters per year, a trend that is expected to intensify in the future in the absence of any strategic interventions.

3.2.2. Vulnerability assessment framework

The goal of the vulnerability assessment for the Wadi Zabid watershed was to establish the future rate of groundwater depletion under a range of socioeconomic and climatic conditions. A planning horizon for the period 2008 through 2033 was assumed. Over this period, groundwater abstraction levels were modeled to reflect total water demands consistent with modest growth in agricultural production.

The first step in the assessment was to obtain the perspectives of local stakeholders. A comprehensive consultation process was undertaken with relevant stakeholders including women, during which several constraints, challenges, and concerns contributing collectively to the deterioration of water resources in the study area were identified, as summarized below:

- Lack of financial resources to enable authorities to improve the performance of agricultural extension services;
- No priority is given to consider sustainability of groundwater resources by decision-makers at all levels;
- Absence of effective coordination and cooperation among relevant authorities and stakeholders for water resource management;
- Lack of effective implementation of water-related laws, regulations, policies, and water distribution rights;
- Absence of an effective planning framework (e.g., integrated water resources management) to help address and balance competing water demands;
- Inadequate awareness on responsibilities and roles among relevant bodies including Water Users Associations (WUAs); and
- Poverty, desertification sand dune movement, drought, rainfall shortages were also among problems mentioned.

Analytical activities sought to address stakeholder observations and involved the use of a scenario-driven water balance modelling platform - the Water Evaluation and Planning (WEAP) software (Yates et al., 2005). Three climatic scenarios were considered; a Reference Scenario which assumed the historical climate and two different climate change scenarios, one representing an ‘optimistic case’ wetter future climate and the other representing a ‘worst case’ drier future climate. Hydrologic modeling within WEAP relied on the Rainfall Runoff Soil moisture method, a one-dimensional two-soil-layer algorithm for calculating evapotranspiration, surface runoff, sub-surface runoff and deep percolation.

Table 3.3: Impact of adaptation on future groundwater storage in Wadi Zabid region (Noman, 2016)

Climate Scenario	Fossil groundwater storage (BCM) 2008	2033	Rate of groundwater depletion (MCM/year)	Full depletion (years)
Future baseline climate	27	17.9	364	49
Future wet climate	27	18.1	356	51
Future dry climate	27	16.7	412	41

Table 3.3 summarizes the results of the vulnerability assessment. Absent any interventions to reduce water demand levels, the aquifer will steadily deplete in the coming decades. The rate of groundwater depletion exceeds 350 million cubic meters per year across all climatic scenarios. In the worst case (i.e., future dry climate), the aquifer in the the Wadi Zabid region will be depleted within the next 41 years. Even under an optimistic future climate scenario in which average rainfall increases over the Arabian Peninsula, the aquifer is projected to be depleted within the next 51 years.

3.2.3. Adaptation assessment framework

Several adaptation strategies were evaluated within the WEAP modeling framework relative to the future dry climate scenario, as outlined in the bullets below:

- *Improved water irrigation efficiency:* This involved the transition to the use of high-efficiency drip irrigation;
- *Reduced evapotranspiration:* This involved the installation of enclosed conduits in place of open channels;
- *Reduced water losses:* This involved the rehabilitation of traditional irrigation channels to reduce water infiltration to the underlying soil; and
- *Alternative cropping schemes:* This involved changes to the type of crop cultivated through upstream and downstream areas.

Table 3.4 summarizes the results of the adaptation assessment. Each of these adaptation strategies is able to reduce the pressure on the aquifer from the rate of groundwater depletion of 412 million cubic meters per year in the future dry climate scenario. Of these, the most effective adaptation strategy is high-efficiency drip irrigation which redcues the rate of groundwater depletion from 412 to 280 million cubic meters per year, or about a 32%

Table 3.4: Impact of adaptation on future groundwater storage in Wadi Zabid region under the future dry climate scenario (Noman, 2016)

Adaptation Scenario	Fossil groundwater storage (BCM) 2008	2033	Rate of groundwater depletion (MCM/ year)	Full depletion (years)	Effectiveness (%)
High-efficiency drip irrigation	27	20.0	280	71	32%
Enclosed conduits	27	18.4	344	53	17%
Rehabilitation of traditional irrigation channels	27	17.9	364	49	12%
Crop cultivation changes	27	17.2	392	44	5%

improvement, while extending the life of the aquifer by 30 years. Enclosed conduits and rehabilitation of traditional irrigation channels also improve groundwater storage but at levels roughly half and a third of drip irrigation, respectively. Changing crop patterns shows a negible groundwater storage improvement percentage up to maximum of 5%. Future research on these adaptation strategies will focus on exploring the benefits of combining several strategies.

3.3. Coastal Zones

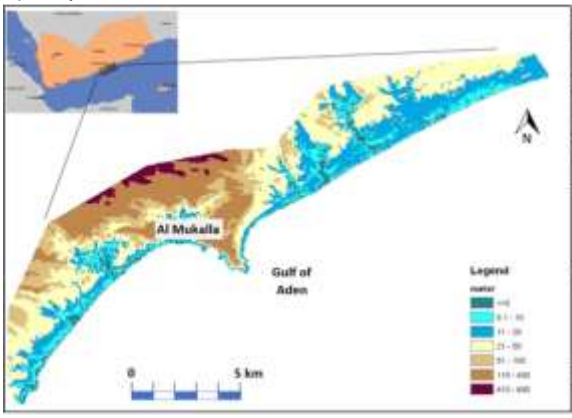
Due to its long coastline and dependence on the marine environment, climate change is viewed in Yemen as a serious threat to urban livelihoods and infrastructure. Rising sea levels combined with an increasing frequency of cyclonic events will pose threats of destructive storm surges, while changes to the physical properies of the Arabian Sea will pose threats to marine biodiversity and fishing activities. To explore the magnitude of potential impacts and the viability of adaptation strategies, an illustrative case study assessment of Al Mukalla Coastal Zone was undertaken (Ahmed, K, 2016).

3.3.1. Main Features of Study Area

The Al Mukalla Coastal Zone Study Area (MCZSA) is located in the Hadhramaut governorate along the Gulf of Aden (Latitude: 14°33'; Longitude: 49°02'). It is essentially a narrow 75-km long coastal plain with maximum width of about 5-7 km. Much of the elevation of the area is less than 20 meters above sea level (ASL), with mountain peaks reaching 650 ASL around the center (see Figure 3.6a). The Al Mukalla seaport is the second largest urban community in southern Yemen.

Figure 3.6: Location of the Al Mukalla coastal zone (Ahmed, 2016)

a) Map of the MCZSA



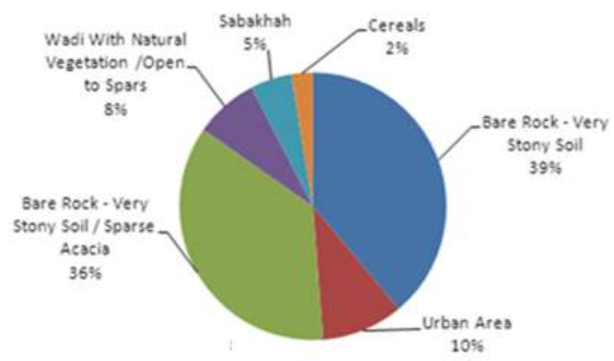
b) Characteristics of the MCZSA

Area	Urban Center	Number of Quarters	Area, 2007 (km²)	Population, 2004	Quarters surveyed
Central urban agglomeration	Old Mukalla	5	7	119,303	30-November, October, Al-Shaheed Khaled, other small quarters
	Al Sharg	6			
	Ad dies	5			
West urban agglomeration	Fuwah	5	10	35,010	Foah, Ebn Seena, Al-Sadeeq, other small quarters
	Embaikha	1			
	Hillah	3			
East urban agglomeration	JolMashaa	1	32	24,786	Rokab, Boaaesh, Gool Mashah, other small quarters
	Al Harshyat	2			
	Khalf	5			
	Rokab	2			
	Buwaish	2			
	Al Eass	1			
	Falak	6			
	Al Riyan	1			
Rural areas			251	170,901	
	Total	45	300	350,000	

Al Mukalla is an elongated city comprised of three urban agglomerations, numerous distinct urban centers, and quarters (see Figure 3.6b). The central urban agglomeration contains the Old Mukalla urban center and two other urban centers; the western suburbs consist of three urban centers; and the eastern suburbs consist of eight urban centers. Overall It has an area of nearly 300 km^2 and had a 2004 population of 350,000 most of whom live within an area equivalent to about 10% of the overall area of the MCZSA. The population is growing rapidly due to returning citizens from abroad and internal migration from different parts of the Hadhramaut governorate. By 2025, the population is projected to reach 530,000 people, a growth rate of about 4.2% per year. Additional features of the MCZSA are summarized in the bullets below:

- *Livelihoods:* The urban population in the MCZSA suffers from extreme poverty - roughly a third of the population have incomes below Yemen's poverty line. Income sources are mainly from all kinds of trade from small/informal retail business. Salaries and pensions are main source of income for public/private employees, with some of the population having access to remittances from family members abroad or from small touristic ventures.
- *Economy:* The local economy is built around the fishing industry, boatbuilding, and exports of tobacco and other products from the port of Mukalla. In addition, several large industries exist to east and west of old Mukalla city, namely iron, steel, cement, food processing, and construction. There are also numerous tourist hotels and beach parks.
- *Environment:* The natural environment of the coastal area is low-lying and incised by several wadi deltas, with extensive areas of sand dunes and gravelly beaches subject to coastal erosion where elevations are less than 5 meters. The region enjoys a rich marine fauna that includes mollusks, crustaceans, and benthic flora like algae and sea grasses. East of MCZSA is one of the most important turtle nesting areas in the world for green turtles. The rich mud flats in the valleys where wadi waters reach the sea are also important for migratory birds.
- *Land Cover:* There are six major land cover types as shown in Figure 3.7. About 75% of the MCZSA area is characterized as Bare Rock - Very Stony Soil. Roughly 36% of this area is sparsely covered with Acacia trees. About 15% consists of wadi beds, sabkhahs (i.e., mudflats) and agricultural cultivation (i.e., cereals). Urban areas take up the remaining 10% of the land area

Figure 3.7: MCZSA land cover (Ahmed, 2016)



- *Climate:* The MCZSA has an arid coastal climate characterized by low annual rainfall (around 70 mm/year), high temperatures (from 21.5°C to 32.4°C), and high relative humidity (i.e., reaching 93%). Two types of rainfall-related flooding events are common - wadi seil floods and urban flash flooding – and are associated with heavy rainfall from tropical depressions and cyclones. Daily average wind speeds vary from 0.2 m/s to 2.7 m/s (calm to light breeze), rarely exceeding 20 m/s (gale). Wind direction is highly variable and is not predominantly from any single direction. It is least often out of the north and NNE (0% of the time). South, SSE and SSW wind directions are prevailing (24%) over the course of year. Annual average sea-surface height (SSH) or topography relief is 0.5627 meters. Calculations of the Standard Precipitation Index (SPI) and Discomfort index (DI) for the recent historical period indicate a high degree of climate-related hardship for residents of the MCZSA.

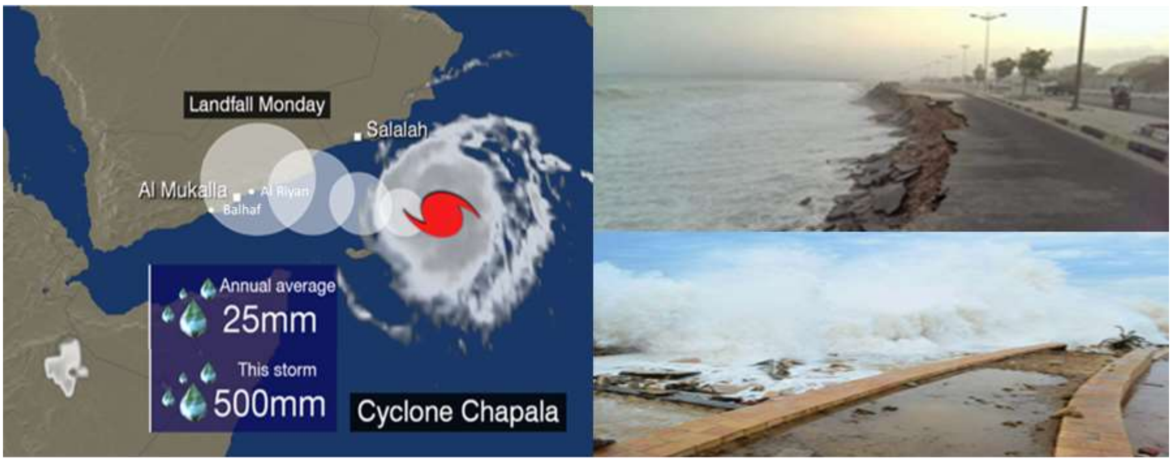
3.3.2. Vulnerability assessment framework

The overall goal of the vulnerability assessment was to develop a set of vulnerability indices that could help reveal the severity of climate change risks to the continued socio-economic development of the region and to the protection of the natural environment. Specifically, the assessment was structured around developing a better understanding of the potential impacts of the following threats:

- *Risk multiplier on livelihoods:* Given the poverty situation of the MCZSA, climate change hazards such as heat waves, heavy rainfall-induced flooding, land inundation, and vector borne diseases may act as a risk multiplier, rendering already vulnerable populations at even greater risk. Threats may include, among others, increased potential for climate-related migration, increased stress on local resources, reduced prospects of aid effectiveness, and increased challenges to governmental coordination of social safety networks and programmes.
- *Cyclonic activity:* The MCZSA is exposed to remnants of cyclonic storms in the Arabian Sea. There are typically at least two tropical cyclones each year, some of which are intense enough to be classified as very severe or super cyclonic storms. The most recent example of cyclonic activity was in November of 2015 when cyclone Chapala made initial landfall striking Al Riyan, a region just east of Al Mukalla (see Figure 3.8), with winds of 120 km/hr that generated 10-meter high storm surges that inundated about 12% of the coastal aea and caused extensive road damage. Subsequently, it moved offshore and made a second landfall west of Balhaf, travelling a total distance of 2,248 km. Cyclone Megh followed after only a few days, reaching wind speeds of 55 km/hr and travelling a total distance of 2,307 km.

Figure 3.8: Cyclone Chapala, 2015 (source: adapted from http://pbs.twimg.com/media/CSrasCGXIAAzGZN.png and public websites)

a) Cyclone pathway toward Yemeni coast **b) Images of cyclone damage to built environment**



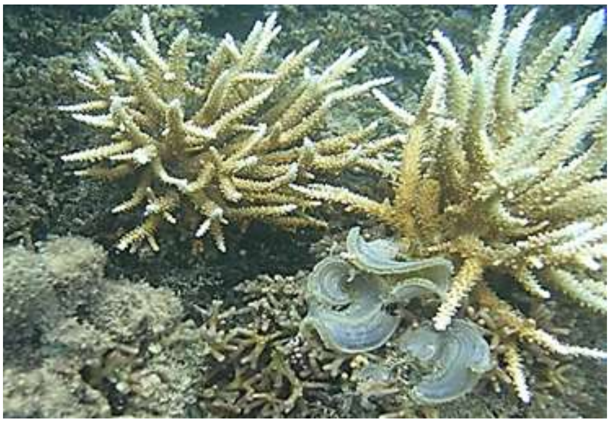
- *Sea level rise (SLR):* Sea level rise poses a threat to the MCZSA's built environment in the form of ocean waters reaching further inland, particularly under high tide conditions. It also increases the potential for adverse shoreline change (i.e., erosion, sediment transport), salt water intrusion, loss of wetlands for migrating waterfowl, loss of habitats for sea turtles (green, hawksbill, loggerhead), and infrastructure damage, especially when combined with storm surge associated with extreme storm events. Sea levels have been rising in the coastal waters off the MCZSA at a rate of about 1.77 mm per year over the past 20 years, or roughly the same as the global average of 1.80 mm per year (see Table 3.5). There is signifiant spatial distribution of SLR trends ranging from 1.57 mm/year in the eastern/landward portion of the marine area to about 2.23 mm/year in westward seaward areas.

Table 3.5: Sea level rise trends in MCZSA, 1992-2012 (source: AVISO, 2016)

Latitude	Longitude	SLR (mm/yr)
13.75	48.75	2.23
13.75	49.00	1.93
13.75	49.25	1.76
13.75	49.50	1.73
14.00	48.75	2.03
14.00	49.00	1.74
14.00	49.25	1.59
14.00	49.50	1.59
14.25	48.75	1.94
14.25	49.00	1.70
14.25	49.25	1.57
14.25	49.50	1.59
14.50	48.75	1.91
14.50	49.00	1.72
14.50	49.25	1.61
14.50	49.50	1.65
	Average	1.77

- *Marine ecosystem degradation:* Climate change is altering physical properties such as salinity, temperature, and pH levels in the marine environment which can lead to adverse impacts on marine biodiversity and commercial fisheries. For example, there is increasing evidence that coral reefs in the northern part of the Gulf of Aden are being damaged by unusual marine conditions, and coral bleaching and mortality events attributed to higher sea water temperatures have been more frequent in the Gulf of Aden (see Figure 3.9). Warmer water temperatures and acidifying oceans can also threaten the artisanal and commercial fisheries on which many coastal communities depend through a disruption of the migration patterns of pelagic fishes, as well as lead to adverse physiological impacts on marine algae growth and seagrass photosynthesis.

Figure 3.9: Coral bleaching in the Gulf of Aden during the last years (Photo: G. Bawazir)



A variety of methods and tools were applied to explore and/or quantify the magnitude of the above risks on the population and environment of the MCZSA. Climatic and hydrographic data were obtained from various publicly available sources. Social and economic data was obtained from the national 2004 census and national statistical data. In addition, a questionnaire was developed and administered to establish indicators of livelihood vulnerability. Technical details are reported in Ahmed (2016). A summary of the approach and results are provided in the bullets below.

- *Erosion:* The Bruun Rule was used to estimate coastal land loss due to sea level rise under a single scenario. Sea level rise will exacerbate shoreline erosion rates and lead to corresponding land loss of about 9% of the urban area, or 440 hectares, under an assumed rise of 0.5 meters of the waters of the Arabian Sea by the year 2035 (see Table 3.6). Most of eroded land, about 17%, is projected to be in the West urban agglomeration. These land losses are in the vicinity of current important habitats for migratory water birds and nesting grounds for a variety of sea turtles.

Table 3.6: Impacts of sea level rise on coastal erosion in the MCZSA (source: Ahmed, 2016)

Area	Urban Area (ha)	Land loss (ha)	Land loss (%)
Central urban agglomeration	663	57	9%
West urban agglomeration	1,033	171	17%
East urban agglomeration	3,211	210	7%
Total	4,907	438	9%

- *Coastal vulnerability:* A Coastal Vulnerability Index (CVI) was computed based on eight physical parameters: geology, geomorphology, elevation, shoreline slope, shoreline recession, sea level rise by 2035, significant wave height. The results show that the quarters in the West urban agglomeration (i.e., Ebn Seena, Fuwah and Al-Sadeeq) are most vulnerable. In addition, increasing storm frequency could lead to changing beach structure, loss of habitats, and perturbed interspecies competition, and the increased potential for monetary damages associated with the built environment.

- *Livelihoods vulnerability:* A questionnaire was developed and administered to a randomly-selected 1% of MCZSA's households across 9 urban centers to develop a Livelihood Vulnerability Index (LVI). The index was computed based on eight physical parameters: demography, social, economy, stability, health, accessibility, climatic hazards projected for 2035, and climatic risks. The results show that the Fuwah and Al-Sadeeq quarters are the most vulnerable (see livelihood vulnerability columns of Table 3.7). Additional explorations using similar analytical techniques were conducted across the 9 quarters that focused on sensitivity and adaptive capacity relative to climatic hazards. The results show that adaptive capacity is lowest for Al-Shaheed Khaled and highest for JolMashaa. Sensitivity to climatic hazards is highest for the 30-November quarter and lowest for the October quarter (see adaptive capacity and sensitivity columns of Table 3.7).

Table 3.7: Impacts of sea level rise on coastal erosion in the MCZSA (source: Ahmed, 2016)

		Livelihood vulnerability		Adaptive capacity		Sensitivity	
Area	Quarter	Index	Status	Index	Status	Index	Status
Central urban agglomeration	30-November	0.825	Mid	0.651	High	0.684	High
	October	0.875	Mid	0.494	Mid	0.260	Low
	Al-Shaheed Khaled	0.876	Mid	0.355	Low	0.410	Mid
West urban agglomeration	Fuwah	0.905	High	0.500	Mid	0.510	Mid
	Ebn Seena	0.875	Mid	0.444	Mid	0.505	Mid
	Al-Sadeeq	0.904	High	0.523	Mid	0.500	Mid
East urban agglomeration	JolMashaa	0.790	Low	0.678	High	0.420	Mid
	Rokab	0.810	Low	0.455	Mid	0.600	High
	Buwaish	0.825	Mid	0.634	High	0.600	High

3.3.3. Adaptation assessment framework

Several adaptation strategies were identified to confront the vulnerabilities described above. A multi-criteria assessment (MCA) framework was used among Yemeni stakeholders from government institutions and civil society to evaluate dozens of potential coastal adaptation strategies. A total of five (5) priority adaptation measures are identified through the process, the major highlights of which are briefly summarized in the bullets below.

- *Integrated coastal zone management (ICZM):* The impacts of sea level rise and increased cyclonic activity will result in erosion and flooding, causing damages and losses in the coastal system (infrastructure, housing, livelihoods, coastal resources, etc.) and leading to human migration. A shift away from business-as-usual practices in coastal management is needed urgently. A new planning paradigm is needed, one offered by the development of an ICZM plan based on risk-based assessments, systematic coastal databases, institutional coordination, and effective early warning.

- *Beach Protection and Nourishment:* Al Mukalla's beaches are currently exposed to wind and wave erosion. Investments are needed urgently in defensive barriers to reduce wave energy using appropriate techniques, especially in the western part of the area. Beach nourishment and land use regulations are needed in the eastern and central areas to offset land loss and stabilize beach areas.
- *Urban flood drainage:* Al Mukalla's drainage system design is incompatible with coastal flooding risks associated with extreme storm events. The potential for widespread flooding from sea level rise enhanced storm surge associated with increased cyclonic activity is well beyond the capacity of the city's drainage system. The implementation of the urban flooding system should be based on risk mapping and other activities inherent in the ICZM planning process.
- *Cooling System for Extreme Hot Weather:* An increase in the number of extreme hot days is projected for the months May through September in the future. Because of Al Mukalla's heat island effect, this poses significant risks to children and the elderly. In addition to the introduction of new building and road design codes through the ICZM process, immediate actions should focus on measures such as painting outside walls white to minimize indoor temperatures, replacing asphalt roads with bricks, planting of shade trees, and providing poor households with electricity for space cooling.
- *Ecosystems protection:* Marine habitats are already experiencing adverse impacts from changes in the physical properties of the nearby marine environment. To reduce consequences of extreme weather events on various ecosystems, a network of marine protected and rehabilitated areas should be developed, together with the equipment and computer systems needed for ongoing monitoring. Existing regulations governing commercial fisheries and living marine resources should be duly enforced.

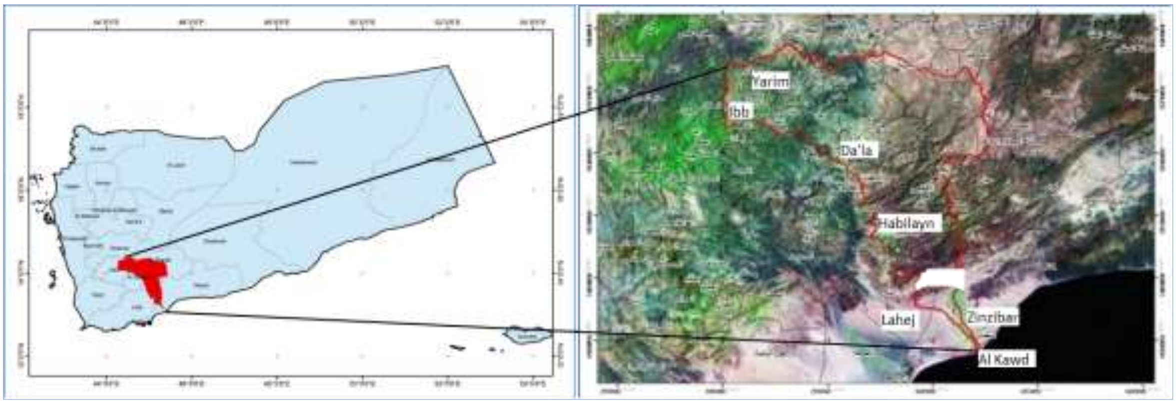
3.4. Agriculture

Climate change will endanger agricultural systems and the livelihoods of those that depend on them in Yemen. Farming communities in Yemen have already begun witnessing impacts such as more frequent drought, erratic rainfall patterns, and decreasing agricultural production for some types of subsistence crops. To explore the magnitude of potential climate change impacts and the range of potential adaptation strategies, an illustrative case study assessment of Wadi Bana drainage basin under a range of climate change scenarios was undertaken (Al-Nabhani, 2016).

3.4.1. Main Features of study area

Wadi Bana is considered one of the main agricultural areas in Yemen, draining surface waters from the semi-arid western mountain slopes of Yemen, into the Arabian Sea, as shown by the red-shaded area in Figure 3.10. Though facing serious development constraints, the region is

Figure 3.10: **Location of the Wadi Bana drainage basin (Al-Nabhani, 2016)**



socially and economically important because of its major agricultural activities supporting many neighboring cities. Wadi Bana is also region that has a rapidly growing population, raising the potential to greatly increase the demand for food, water and forage for livestock (cattle, donkeys, sheep) in the region. In addition, Greater Aden relies on its underlying aquifer for its water supply. Some of its key features are summarized in the bullets below:

- *Livelihoods:* In general, livelihoods in the Wadi Bana region are closely linked to the natural resource base. Wadi Bana is mainly dominated by rainfed crop production, including an increasing use of small- and large-scale irrigated farming, and livestock raising. There is deep poverty in the basin, with about 26% of the population classified as either destitute or in severe poverty (see Table 3.8). There are significant poverty disparities both between the regional populations and in comparison to national levels. Poverty negatively impacts public health, livestock maintenance, and the social order, leading to increasing levels of urban migration.

Table 3.8: Multi-dimension Poverty Index in Wadi Bana (source: Al-Nabhani, 2016)

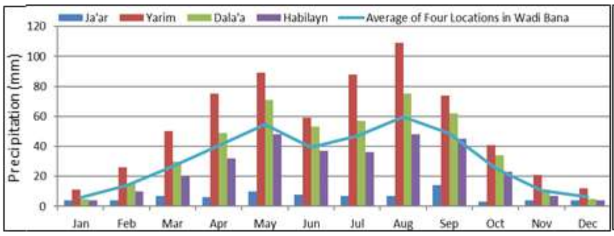
Region	Percent of region population: Vulnerable to Poverty	In Severe Poverty	Destitute	Other	Percent of national population
Ibb	23%	17%	13%	47%	11%
Da'la	29%	16%	9%	45%	3%
Lahej	23%	17%	14%	46%	3%
Habilayn	25%	10%	9%	56%	2%
Regional Average	25%	15%	11%	49%	5%
Yemen	**19%**	**23%**	**19%**	**39%**	**100%**

- *Environment:* Wadi Bana drainage basin has a catchment area of 7,600 km^2 which extends over five governorates and over three agro-climatic zones of Yemen (Upper highlands, Lower highlands, and Arabian Sea coast). The wadi originates in mountainous areas about 3,000 meters above mean sea level near the town of Yarim. These mountainous areas are the highest rainfall areas of the southern highlands and midlands of the country As it winds nears the Gulf of Aden, the wadi flows down to the coast between the towns of Al-Kawd (to the west) and the city of Zinjibar (to the east). While such altitudinal variation results in a great diversity in climates and landscapes, land resources are being degraded through soil erosion, salinization of irrigated areas, land degradation from overgrazing, over-extraction of ground water, growing susceptibility to disease and build-up of pest resistance favored by the spread of monocultures and the use of pesticides, and loss of biodiversity.

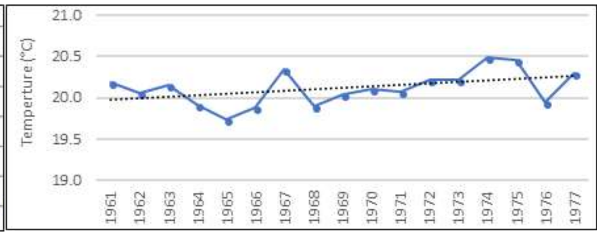
- *Climate:* Wadi Bani has an arid tropical climate and is characterized by high water stress and recurrent droughts. Most of the basin is prone to droughts and (e.g., Ibb experienced a severe drought during early 2013) and frequent flooding (e.g., flash floods hit some districts of Habilayn and Ibb in August of 2013). Annual average precipitation varies between 50 mm in the lower parts near Al-Kawd and 650 mm in the upper part of wadi near Yarim. Throughout the basin, rainfall average about nearly 380 mm/year. The rainy season occurs between April and September when 71% of the annual precipitation occurs, and the dry season extends from October through March (see Figure 3.11a). Average annual runoff of 153 million m^3 flows into the drainage basin, the highest in the entire country, which accounts for the intensive cultivation found at its lower elevations. Highest runoff levels occur from July through September, accounting for 90 Mm^3 or nearly 60% of annual runoff. Average annual temperatures are moderate throughout the basin though exhibit a warming trend since the 1960s, as shown by the dashed trendline in Figure 3.11b. The average annual temperature over the 1961-1990 period is about 20.4°C, with the highest monthly temperature of 23.7°C occuring in July.

Figure 3.11: **Average rainfall and temperature in Wadi Bani, 1961-1990 (Al-Nabhani, 2016)**

a) Monthly rainfall at various locations



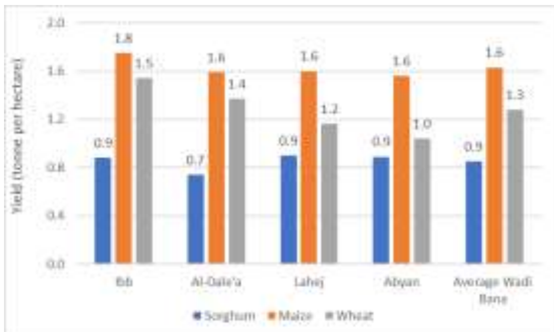
b) Annual temperature across entire drainage basin



- *Agricultural production:* Agricultural production in the Wadi Bana region is characterized by the rainfed cultivation of several main crops; namely cereals (sorghum, maize), fruits, vegetables, cotton, coffee and qat. The crops showing the largest harvested areas are wheat, maize, and sorghum, which are also the same crops that contribute most significantly to local food security. Agriculture is a major contributor to the region economy engaging more than 55% of the labor force. Crop yields vary significantly across the different governorates depending on a range of factors including access to irrigation. Average yields are illustrated in Figure 3.12 for various subregions in the basin. There is a strong relationship between increasing levels of local food insecurity and climate variability, higher input costs, and low crop yields.

- *Infrastructure and services:* Prior to 2011, the Wadi Bana basin was a focus of capital investment for infrastructure development, mainly in road networks and transportation, communication, and power supply with the aim of expanding the delivery of services. However, limited water harvesting

Figure 3.12: **Productivity of main cereals crops in the Wadi Bana region (Al-Nabhani, 2016)**



infrastructure exists, with poor and/or old flood control structures, resulting in chronic risks of flooding, soil erosion, and damage to physical and economic assets. In addition, the lack of well-functioning agricultural markets adversely impacts agriculture marketing and distribution. Agriculture extension services are almost entirely absent in Wadi Bana, with most relevant agencies suffering from poor capacity, old and poor technologies, and budget shortages. Credit and cooperation activities are limited to large farm owners, and the cooperatives of big farmers.

3.4.2. Vulnerability assessment framework

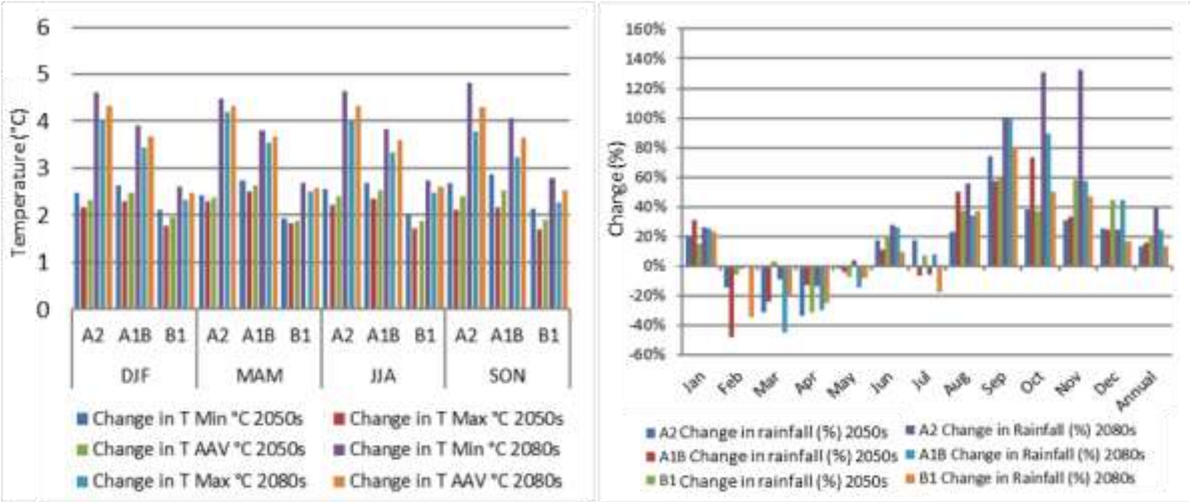
A scenario-driven water-crop modelling framework was used to conduct the agriculture vulnerability assessment. The goal of the assessment was to determine the change in crop yields in the Wadi Bana region under climate change for the periods 2046-2065 and 2081-2100, relative to average historical yields. The crops selected for the study were wheat, maize, and sorghum. Key elements underlying the assessment are described in the bullets below:

- *Data development:* Several qualitative and participatory assessment techniques were used to develop the range of non-climatic data required for the assessment. These included literature review, local informant interviews, focus group discussions, synthesis of available case studies, and structured observations. Baseline climatology was defined by accessing national meteorological agencies and archives, supranational and global data sets and weather generators. Observed historical climate data in the study area were collected from relevant meteorological stations. Gaps regarding climatic data were addressed by interpolation techniques and comparisons to publicly available global climate datasets. Gaps regarding other non-climatic parameters (e.g., soil structure, crop characteristics) were addressed through expert judgement.
- *Climatic forecasting methodology:* Forecasting relied on statistical downscaling of the IPCC's low resolution climatic projections produced by General Circulation Models (GCMs). Two tools (i.e., Statistical Downscaling Model (version 5.2) and the World Bank's ClimateWizard Engine) – were used to undertake the downscaling under three global emission scenarios: A2, A1B, B1. Temperatures are projected to rise substantially in the Wadi Bana basin under the three emission scenarios, with minimum temperatures increasing by nearly 5°C by 2080 in the A2 scenario. Although annual rainfall is projected to increase under the three scenarios, lower rainfall levels are projected for April and May, the early part of the rainy season (see Figure 3.13).
- *Crop modeling methodology:* The methodology for modeling crop production relied on the incorporation of local soil and crop parameters into three crop models, namely FAO AquaCrop, DSSAT, and FAO CropWat. Simulations were undertaken using these models for both rainfed and irrigated conditions.

Figure 3.14 summarizes the impact of climate change on the production of wheat, maize, and sorghum in 2050 and 2080. The projected change in future yields varies strongly across the three selected crops. Wheat yields are adversely impacts by climate change, showing significant reductions in yield across all emission scenarios and for both rainfed and irrigated areas in the Wadi Bana drainage basin. Maize and sorghum show the opposite trend, with climate change leading to a boost in productivity across all emission scenarios and both

Figure 3.13: **Projected temperature and changes in rainfall in Wadi Bana basin under different emission scenarios, 2046-2065 and 2081-2100 (Al-Nabhani, 2016)**

a) Seasonal temperature **b) Change in annual rainfall**

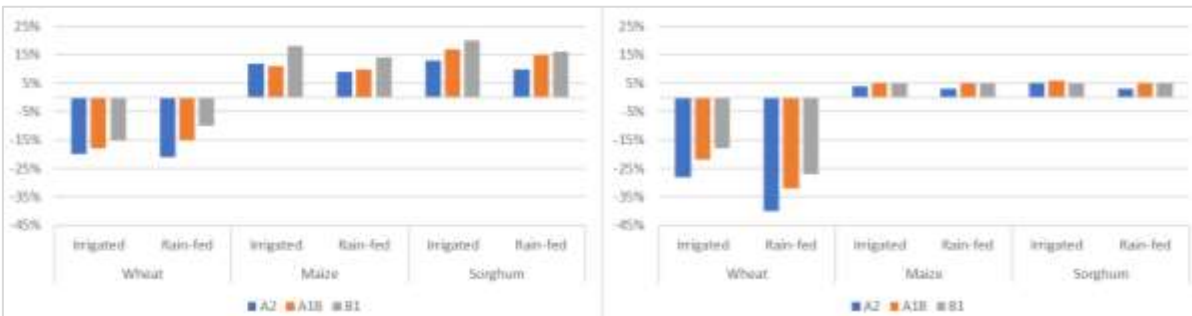


cultivation methods. The differences are driven by changing rainfall patterns, increased temperature and increased C02 concentrations. Some potential implications from the results of the assessment are summarized in the bullets below:

- *Drought risk:* An increase in projected temperatures and a decrease in seasonal precipitation during the March-April-May (MAM) season will lead to an increase in the number of projected hot days, fewer number of projected cold days and decreased number of projected days with precipitation. Together, these changes suggest that increased drought frequency may likely be experienced in the basin, aggravating an already serious situation.
- *Climatic variability:* At present, rainfall variability in terms of the timing and amount of rainfall, delays in onset and/or early end of rains, and length of dry spells pose the major risks for crop production. With climate change, the early stages of the rainy season (March through May) are likely to exhibit greater variability which could adversely impact rain-fed agricultural production, food security, and the basin's environmental service functions, while leading to water shortages and lower economic productivity.

Figure 3.14: Projected change in wheat, maize, and sorghum productivity under climate change conditions (Al-Nabhani, 2016)

a) Change in crop yield by 2050 **b) Change in crop yield by 2080**



- *Climatic thresholds:* Wheat, maize, and sorghum exhibit threshold responses to climate. Any increase in future climate variability in the basin may exceed threshold levels of climatic conditions (i.e., temperature, radiation, precipitation, water vapor pressure, wind speed) that the individual crop physiologies can tolerate. That is, the physical, chemical and biological processes that drive the productivity of wheat, maize, and sorghum may be adversely affected and limit their growth, development and yields. Even climatic thresholds that span only a few days can hamper the crop reproductive system.
- *Higher temperatures:* The chronic effects of warmer temperatures on wheat, maize, and sorghum productivity are potentially even more important than climatic thresholds. Yields reflect season-long effects, and these crops generally have a greater yield when temperatures are cooler during the primary growth cycles. Increased temperatures will decrease the duration between sowing and harvesting - for maize it could be between one and four weeks shorter. While this could contribute to a greater number of cropping cycles, such a decrease could adversely affect productivity. Moreover, a greater number of cropping cycles would require greater inputs, likely leading to a depletion of soil nutrients and moisture, greater exposure to pests, and greater pressure on already marginal lands.
- *Other considerations:* A decrease in wheat, maize and sorghum production due to climate change may introduce public health consequences in the region. In upstream areas, households are likely to face decreased water availability, with implications for food processing and consumption. In coastal areas, households exposed to combination of higher temperatures and periodic heavy downpours could be expose to a potential increase in vector-borne (e.g., malaria) and water-borne (e.g., cholera) diseases. Finally, lower seasonal rainfall levels during March through May could have negative impacts on vegetation and biodiversity, with the possible disappearance of some indigenous trees, shrubs, plants, and fodder grasses.

3.4.3. Adaptations assessment framework

A combination of biophysical, socio-economic and technological conditions will influence the capacity of farmers to adapt to these changing conditions. Some farmers may be able to adapt while others, particularly wheat farmers with modest means, may experience predominantly negative outcomes. Yemen is in the process of building upon past adaptation dialogues initiated during the National Adaptation Programme of Action (NAPA) to plan for future investments in Wadi Bana region to account for the above findings. This involves addressing the relevant socio-economic factors (e.g., literacy, gender equity, wages) and technological factors (e.g., irrigation efficiency, infrastructure, seed varieties) that underlie the adaptive capacity of the resource-dependent societies throughout the Wadi Bana region. Urgent adaptation measures to build resilience of agricultural production in the Wadi Bana basin are summarized in the bullets below:

- *Diversify livelihoods:* This refers to developing policies to overcome capital investment barriers to promote opportunities of off-farm income that is not dependent on rainfall such as small businesses and cottage industries. While off-farm income could compensate for shortfalls in crop production, it could also be invested back in agriculture to meet the increasing costs of some required inputs. Crop diversification is also recommended, specifically introducing cash crops such as fruits, vegetables as well as poultry farms.

- *Introduce alternative practices:* This refers to a suit of crop measures (i.e., drought resistant crops, early-maturing varieties, improved seeds for greater productivity), rangeland rehabilitation for greater livestock production, and adjustments in crop rotation patterns to account for shifts in the onset of the rainy season. With increasingly variable onset of rains, farmers often run out of conventional seed if a dry spell sets in after planting, causing the planted seed to die and requiring farmers to replant several times. These measures depend on improvements in agricultural extension services, an increase in farm subsidies, and the introduction of better short-term weather forecasts.
- *Increase water management:* Increasing water supply and improving irrigation efficiency improvement are essential for Wadi Bana households to cope with future rainfall patterns. Specific technologies for improving irrigation efficiency are widely available and should be urgently introduced (e.g., drip and bubbler systems) while water storage and conservation techniques (e.g., dams, water ponds, boreholes, rainwater harvesting, terrace rehabilitation, desalination) can increased available supply.
- *Exploit land management co-benefits:* This refers to measures that can stabilize slopes, conserve soils, and improve soil fertility, and which also provide co-benefits to build household resilience. For example, tree planting could help stabilize slopes and protect soils while also providing a cooking fuel source. Moreover, soil conservation measures (e.g., wadi bank protection; use of manure, compost and fertilizers) could not only increase soil fertility but reduce erosion and flooding risks.
- *Build local capacity:* This refers to providing farmers with access to training and technologies across the range of needs. For example, heavy equipment to build water storage structures will build water management capacity; treated mosquito nets and better sanitation/housing will build capacity to deal with health impacts of climate change; better education opportunities will build capacity to better understand climate risks; and improved food storage facilities will build capacity to prevent disease and improve food quality.

The above adaptation strategies will be integral to improving the resilience of households in the Wadi Bana region to cope with projected changes in climate. The actual implementation of such measures relies on overcoming the following barriers:

- *Capital and credit access limitations:* The lack of access to capital and credit severely hampers prospects for building resilience among households in the Wadi Bana region. Typically, the lack of seeds, fertilizers, irrigation equipment, veterinary services are unaffordable rather than unavailable. Most farmers do not have access to credit, except for those that are organized in groups or cooperatives and receive support from various project interventions. Credit institutions (and, sometimes, individual lenders) impose collateral requirements, interest rates, and repayment timeframes that smallholders can rarely meet.
- *Local market weaknesses*: There is a need for support from government and non-government organizations to help farmers secure better prices for their products. This

includes the introduction of (i) technical assistance to improve produce quality; (ii) storage infrastructure to improve preservation and to allow farmers to wait for market prices to increase; (iii) price support and market outlets to allow destocking at times of drought; (iv) training and assistance in organizing groups for processing and marketing purposes; (v) help in linking with export markets (vi) solutions for surplus of product during the peak production seasons.

- *Extension service constraints:* There is a need for increased quality, availability, and affordability of agricultural extension services. In particular, livestock-centered (i.e., veterinary) extension services can help in diversifying household incomes and improve soil fertility at a lower cost than what is needed to buy fertilizer. Extension services should also include a role for food aid to help families better adapt by freeing up scarce cash that is now being used to buy food to be allocated to more productive investments and diversification of income generation activities.

3.5. Public health

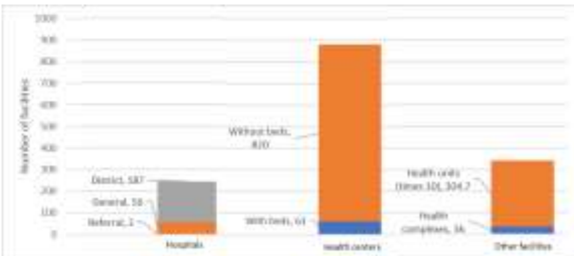
Climate change will endanger an already precarious public health situation in Yemen. Much of Yemen's public health challenge is rooted in poverty, which is prevalent and has shown a steady increase in recent decades. Roughly 85% of the population lives in extreme poverty, particularly households in rural, remote and less accessible areas who lack the resources to access the kinds of nutritious food that can promote healthy and productive lifestyles. Hunger and undernutrition are widespread in these areas, with one in three being acutely hungry; one in two children under 5 being stunted; and more than half of all children under 5 years being underweight. To explore the potential links of health situation with climate change, a qualitative assessment was undertaken at the national level (Al Akel, 2016),

3.5.1. Main features of the public health situation in Yemen

The public health status of Yemen's population is poor as evidenced by high rates of infant mortality, maternal morbidity and under-five mortality. Morbidity and mortality associated with communicable diseases comprise about 97% of the total burden of disease in Yemen, with acute diarrhea, upper respiratory tract infections, malaria, and lower respiratory tract infections accounting for the overwhelming majority. Non-communicable diseases, while currently account for only 3% of the burden of disease, consist of about 23 diseases which are on the increase. Some of the key features public health in Yemen are summarized in the bullets below:

- *Institutional infrastructure:* The public health sector consists of 4,209 health institutions and facilities with a total of 16,851 beds. Facilities include hospitals, health centers (with and without beds), primary health care units, and health complexes (see Figure 3.15). Despite the numbers, the facilities are poorly distributed throughout the country, inadequately staffed, and poorly financed.

Figure 3.15: Type and number of public health facilities, 2014 (source: Annual Statistical Health Report, 2014)



Administration is characterized by poor logistics making coverage and quality of health services problematic. At present, 16.4 million people lack access to health services (WHO, 2017).

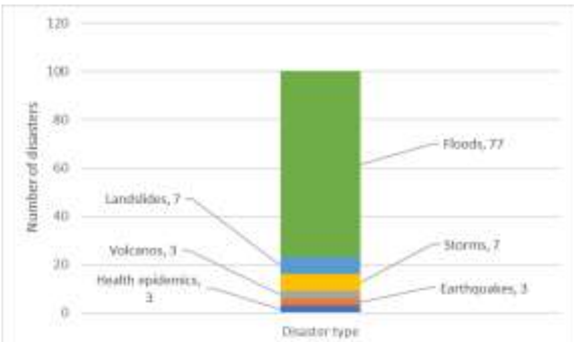
- *Medical resources:* Yemen suffers from critical shortages of medical personnel. As of 2006, there were only 0.86 doctors, nurses, and midwives per 1,000 people, compared to WHO minimum standards of 2.3 per 1,000 people. Medical equipment and supplies for mass casualty management and medicine for most chronic diseases are increasingly in short supply. The difficult and chronic economic conditions superimposed by the current conflict have also forced authorities to reduce operational expenses, even funding for drugs and medications. With medical services at nearly 600 health facilities severely curtailed due to the persistence of war, epidemics such as dengue fever has appeared in Al Hodeida, Aden and Taiz with high fatality rates (OCHA, Yemen. 2015).
- *Nutrition:* Hunger and malnutrition are widespread. The effects of poor nutrition on growth and development can be highly damaging to children due to their immature physiology and metabolism, their unique exposure pathways, their biological sensitivities and limits to their adaptive capacity. In 2016, more than 40% of the population were children below the age of 15, almost 15% were under the age of 5 and 3% were infants. Young girls, in particular, are generally at greater risk of adverse health outcomes from poor nutrition (DHS, Yemen, 2013). Key factors contributing to poor nutrition are high poverty levels and nearly five children per family (more in rural areas).

3.5.2. Vulnerability assessment framework

The overall goal of the vulnerability assessment was to identify vulnerable population groups and regions and explore the potential links between public health and climate change. The assessment was undertaken at a national scale, and given the fragmentation and limitations of health data, it was qualitative in nature (Al Akel, 2016). Structured interviews and questionnaires targeting leadership and decision makers in the Ministry of Public Health and Population (MoPHP) were developed and carried out, together with desk-based research. The assessment was structured to layer climate change onto the following underlying public health challenges:

- *Prevalence of current climatic risks to public health:* Yemen is already a disaster-prone country facing a number of natural hazards every year that take a toll on population morbidity and mortality (See Figure 3.16 and Box 3.1).
- *Rapid population growth:* Yemen's population has been growing rapidly, outpacing available the availability of medical practitioners, infrastructure, and related resources;
- *Communicable disease prevalence:* Limited resources renders the population

Figure 3.16: **Yemen natural disasters incidence by type, 1900 - 2011 (source: EM-DAT: The OFDA/CRED International Disaster Database, Université Catholique de Louvain, Brussels, Belgium Data version: v11.08)**



potentially more vulnerable to outbreaks of communicable diseases which pose a heavy burden layered upon chronic diseases;

- *Low public health budgets:* There is an inadequate allocation of financial resources to the public health sector resulting in low capacity, poor operational efficiency, and insufficient supplies of medicines and drugs;
- *Low industry incomes:* Doctors, nurses, midwives, and support medical staff command very low wages, with little to no incentives;
- *Medical staff flight:* There has been a serious and ongoing depletion of trained and qualified medical personnel to practice abroad, primarily in the Gulf States.

Box 3.1: Recent climate events in Yemen that have damaged human health

All governorates have been hit by extreme weather events that have led to injuries and fatalities. A review of some of the most destructive events are sumamrized below:

- *June 1996:* Flash floods hit the governorates of Shabwa, Mareb and Hadramout resulting in 338 drowning fatalities and 238,210 people suffering from hypothermia, diarrhoeal disease, and waterborne/vector-borne disease.
- *October 2008:* Heavy rains associated with tropical storm Deep Depression ARB 02 brought 90 mm of rainfall over the course of 30 hours, leading to severe flooding in Hadramout and Al-Mahara governorates, over 70 deaths, and the displacement of 25,000 people.
- *November 2015:* Cyclone Chapala was the first known hurricane-strength storm to make landfall in Yemen since modern records began in 1940s. Hadramout, Al-Mahara, Shabwa governorates and Socotra Island were hardest hit and witnessed the displacement of over 36,000 people and a subsequent outbreak of dengue fever that left 7 people dead.

- *Ineffective institutions:* Weak institutional planning of the health services coupled with poor sector coordination in and outside the health system, resulting in ineffective policymaking and poorly defined roles, responsibilities and mandates to supervise, measure, monitor and evaluate performance;
- *Lack of medical insurance:* There is an absence of any form of health insurance leading to high costs of health services to be borne by individuals and an exacerbation of a chronic poverty cycle;
- *Poor water and sanitation infrastructure:* There are multiple challenges regarding the supply of clean water resources, operation of piped water networks, and provision of effective solid/water waste management. Many communities are characterized by a lack of proper public infrastructure, contaminated water supplies and poor sanitation.

Climate change is expected to intensify hazards that threaten public health through the onset of higher temperatures, more frequent and longer heat waves, more frequent extreme storms and associated floods, increased potential for landslides, rising sea levels with accompanying higher storm surges, and recurrent drought. Exposure to these climate-related hazards will severely exacerbate health problems and may lead to vector borne and waterborne diseases which may extend their range into areas that are presently unaffected. Moreover, chronic diseases such as cardiac, respiratory and renal diseases may be aggravated by atmospheric conditions (i.e., temperature, humidity) that exceed historical variability.

Human health is sensitive to shifts in weather patterns and hence all populations are vulnerable climate change. The largest risks to public health will occur mainly in areas and communities where conditions of poor nutrition, food insecurity, and poverty prevail.

Specifically, the assessment found seven (7) specific groups within Yemen whose health status would be critically impacted under the combination of deteriorating socioeconomic situation and climate change, as outlined in Table 3.9. The elderly, poor, and internally displaced are among the most vulnerable in the country. Underlying these findings are the following core observations from the assessment:

Table 3.9: Overall impact of climate change on vulnerable population groups in Yemen (Al Akel, 2016)

Vulnerable group	***Key climatic factor***	***Key health effect***	***Overall impact***
Children	*Temperature increase*	*Under-5 malnutrition*	*Moderate to high*
Women	*Temperature increase*	*Heat stress related diseases*	*Moderate to high*
Pregnant Women	*Temperature increase*	*Heat stress related diseases*	*Moderate to high*
Elderly People	*Temperature increase*	*Heat related deaths & injuries*	*High*
Outdoor workers	*Temperature increase*	*Heat stroke*	*Neutral to moderate*
Population with low socioeconomic status	*Temperature increase, flood risks*	*Chronic diseases*	*High*
Internally displaced persons	*Increase in temperature*	*Vector borne diseases*	*High*

- *Increased vulnerability of key groups:* The impact of climate change is expected to be more severe in children, poor people, women (particularly pregnant women), elderly people, people with chronic medical conditions and disabilities, and internally displaced people (IDPs). The impact of climate change on health occurs directly as a result of the increased incidence of heat waves, floods, droughts, and fires, and indirectly through ecological disruptions brought on by climate change on crop failures, shifting patterns of disease vectors, or on social responses to climate change such as displacement of populations following prolonged drought.
- *Increased pathogen reproduction risks:* The seasonality, distribution, and prevalence of vector-borne diseases are influenced significantly by climate factors, primarily high and low temperature extremes and precipitation patterns. Climate may act directly by influencing growth, survival, persistence, transmission, or virulence of pathogens; indirect influences include climate-related perturbations in local ecosystems or the habitat of species that act as zoonotic reservoirs. An increase in extreme events can affect disease outbreaks by altering biological variables such as vector population size and density, vector survival rates, the relative abundance of disease-carrying animal (zoonotic) reservoir hosts, and pathogen reproduction rates. Collectively, these changes may contribute to an increase in the risk of harmful pathogen being transmitted to humans.
- *Increased waterborne disease potential:* A higher incidence of extreme weather events such as floods, droughts, heat waves, heavy storms, and changes in rain patterns affects the biological, physical and chemical components of water through different paths and thus enhancing the risk of waterborne diseases. Floods have a direct impact on human health and well-being by increasing event-related deaths and injuries, and indirectly by contributing to elevated disease burden from waterborne diseases, outbreaks of other infectious diseases, and stress-related disorders after a severe rainfall event. IDPs, a vulnerable group numbering about 3 million in July 2016, may be harder hit than the rest of the population as climate change unfolds in the near-term.

- *Increased occupational hazards:* About 60% of Yemen's population works outdoors in agriculture and construction activities. With climate change, more cases of heat-related illnesses such as heat stroke and heat exhaustion and fatigue among laborers is expected due to these physically demanding occupations. Heat stress and fatigue can also result in reduced vigilance, safety lapses, reduced work capacity, and increased risk of injury. People living in rural and remote areas, which are characterized by rugged topography, lack of essential social services and with no social safety net, are at increased risk of ill health. Furthermore, Yemen is an endemic country for malaria and dengue fever diseases, and people working out door in fields without effective protection may experience a higher incidence of these diseases when climatic conditions favor mosquito breeding and biting.

3.5.3. Adaptation:assessment framework

Several adaptation strategies were identified to build resilience among the vulnerable groups described above and address new climate-related threats to public health. To first order, building the resilience of health systems (i.e., infrastructure, policies, programs) to climate risks requires flexibility and adaptive management to respond adequately, quickly and cost-effectively to more frequent/intense climate-related hazards. Key adaptation-related factors include training and capacity building, introduction of effective surveillance, promotion of disaster preparedness, development of emergency response systems, and facilitation of sustainable prevention and control programs, as described in the bullets below:

- *Surveillance:* This involves the establishment of an epidemiological surveillance system for monitoring changes in vector population abundance in the main targeted high risk and expected transmission areas; establishing surveillance system for temperature-related mortality and morbidity and adverse health effects of air pollution exposure; and strengthening surveillance systems for vector borne, waterborne and foodborne diseases.
- *Preparedness:* This involves the development of effective and responsive preparedness system with full capabilities to deal with unexpectedly disasters. It also involves research on the field of climate change and its linkage to infectious disease and temperature related mortalities and morbidities.
- *Access:* This involves improving access and utilization of health care services for all vulnerable populations taking into accounts equity and gender disparities. It also involves ensuring that there is access to essential medical supplies for effective post-disaster distribution to increase the ability of communities to manage large-scale floods and storms, as well as improving access to clean water and sanitation services for underserved and vulnerable groups.
- *Services:* This involves strengthening and expanding routine vaccination programs, as well as expanding the supply of drugs against malaria and enteric infections for the prompt treatment of people. It also involves capacity building in the field of climate change impact which include training, surveillance and emergency response, and prevention and control programs.

Successfully integrating the above adaptation-related factors within the Yemen public health system will require attention to the general recommendations below and the specific activities described in Box 3.2.

Box 3.2: Specific activities to promote public health resilience in the context of emerging climate risks

The MoPHP should generalize concepts of precise, accurate and valid routine data collection through well established and monitored health information systems. Specific recommendations include:

- Develop systematic morbidity and mortality data collection formats;
- Record patient diagnoses clearly with date and time and adequately maintain records;
- Establish a system for keeping death records and certificates;
- Introduce a physician code of conduct that requires a declaration of direct and/or indirect cause of death;
- Adopt WHO indicators and standards at national level;
- Strengthen ongoing prevention and control programs such as malaria, diarrhea, nutrition and schistosomiasis.
- Establish an epidemiological surveillance system for monitoring changes in vector population abundance in high risk and expected transmission areas;
- Ensure an adequate supply of drugs against malaria and enteric infections;
- Improve access and utilization of health care services for all groups, accounting for gender differences;
- Strengthen and expand routine vaccination programs; and
- Coordinate with relevant authorities to improve access to clean water and sanitation services.

- *Account for development context:* Climate-related adaptation strategies should not be considered in isolation of broader public health concerns such as population growth and demographic change, poverty, public health infrastructure, sanitation, availability and accessibility of health care, nutrition, risky behaviors, misuse of antibiotics, pesticide resistance, and environmental degradation. These factors, and others, will influence the vulnerability of populations and health impacts they experience, as well as the effectiveness of specific adaptation responses.
- *Enhance policymaking framework:* Health impacts of climate change should be integrated and stated clearly and efficiently by the MoPHP in national health policies, plans and long-term vision documents. This should include policies to providing adequate budgets to monitor and evaluate diseases related to climate change, including training, surveillance and emergency response, prevention and control programs, and ensuring essential medical supplies for post-disaster distribution.
- *Strengthen health-related infrastructure:* Additional resources should be devoted to supporting health services; emergency response preparedness; training of health workers on how to deal with health impacts of climate change; surveilling vector borne, waterborne, foodborne, and air pollutant-rated diseases; and monitoring of potential health impacts of climate change.

3.6. Ecotourism

Climate change will endanger terrestrial and marine biodiversity in Yemen. Due to its geographical position at the conjunction of the African, and Asian ecological zones, Yemen enjoys the richest biodiversity of any country on the Arabian Peninsula, with a wide range of terrestrial, coastal, and marine natural habitats, species and genetic diversity, including many endemic species. These resources are of major economic importance because of their potential for ecotourism and other activities. To explore the magnitude of potential climate change impacts on ecotourism and the range of potential adaptation strategies, an illustrative case study assessment was undertaken of two areas: the island of Socotra and the Jabal Bura'a region (Rajeh, A. 2017).

3.6.1. Main Features of the study areas

Ecotourism is recognized as being capable of offering environmental, socio-economic benefits and cultural benefits at both local and national levels in Yemen. While the development of ecotourism has been adversely affected by the recent political conflict, there is widespread recognition throughout the public and private sectors that Yemen, given its rich biodiversity and unique civilization, could someday be an attractive venue for international and local ecotourism. The post-conflict sustainable development of this industry is expected to be an important source of foreign exchange capable of creating new employment opportunities for its citizens.

Socotra is an island and an archipelago of four islands that lies in the north-western corner of the Western Indian Ocean, at the junction between the Gulf of Aden and the Arabian Sea at 12°30'N; 54°00'E. The archipelago is approximately 110 km long and about 40 km wide. It has an area of about 3,900 km^2 and is located about 600 km south of the mainland, as shown in Figure 3.17. Its highest elevation is at Jabal Dryet (1,526 meters) in the central Hagghier Massif. Socotra lies within boundaries of the monsoonal precipitation regime (also called the Indian summer monsoon). Key productive activities for the island's approximately 44,000 inhabitants include pastoralism and fishing. Additional features of Socotra are summarized in the bullets below:

Figure 3.17: **Location of Socotra (Rajeh, A. 2017)**

- *Flora and fauna:* The long geological isolation of the Socotra archipelago and its fierce heat and drought has combined to create a unique and spectacular endemic flora. Surveys have revealed that more than a third of the 800 or so plant species of Socotra are found nowhere else. Botanists rank the flora of Socotra among the ten most endangered island flora in the world. It is well-known historically for its unique vegetation with spectacular plants such as dragon blood, bottle tree, and frankincense (see Figure 3.18). All of the terrestrial mollusks, 90 % of the reptiles (over 30 vertebrates) and 33% of the plants (307 species) are endemic making it one of the most important centers for biodiversity that are entirely arid and characterized by concentrations of high endemism. The island provides a striking example of how local people have responsibly managed their habitat and lived in harmony with their environment until through the present day.

Figure 3.18: **Dragon Blood tree and Socotra Desert Rose (Rajeh, A. 2017)**

- *Protected areas:* Within the Island, there are about 32 listed protected areas, 10 of which are marine, covering an area of about 2,830 Km² and 1,668 Km² of land and marine ecosystems respectively. Bird

Life International recognizes 22 important bird areas within the archipelago, and it forms one of the world's 221 globally important Endemic Bird Areas. The Worldwide Fund for Nature (WWF) lists it as one of their 200 Eco-regions and it is also included in the regional network of important Marine Protected Areas. It was designated by UNESCO Man and Biosphere Reserve Framework as Biosphere Reserve in 2003 and was also listed by UNESCO in the World Heritage Site in 2008. O

- *Ecotourism potential:* The unique landscape, botanical, marine, bird biodiversity features of the Island offer tremendously attractive destinations for ecotourism. Socotra is a major attraction for birdwatchers, having six endemic species as well as dozens of permanent and migrant birds. A variety of beautiful wild shrubs such as the Bottle trees are ubiquitous against mountainous landscapes that are suitable for trekking and white sandy beaches that are excellent for swimming and snorkeling. In addition, there are numerous sizable cave systems within the limestone plateau that stretches over much of the island, averaging between 300 -700 meters in elevation. A total of about 22 km of caves suitable for exploration has been mapped for the first time in recent years.

The Jabal Bura'a Protected Area is a forested mountainous region spread over 4,000 hectares located 60 km southwest of the capital of Sana'a, and reaches 2,000 meters in elevation (see Figure 3.19). It is situated on the slopes of the Tehama foothills and surrounded by Almarawa'h, Raymah, Alsokhnah, and Bajel districts. It consists of moderate to steep mountains facing the Red sea into which flows the Wadi Rijah. The locally well-known Bura'a forest is the last surviving forested area on the Tihama escarpment and is the largest remaining area on the Arabian Peninsula. Additional features of the Jabal Bura'a protected area are summarized in the bullets below:

Figure 3.19: **Location of Jabal Bura'a protected area (Rajeh, A. 2017)**

- *Tree species:* The forest area spans about 1,500 hectares and is the major habitat for 12 regionally threatened tree species in Arabian Peninsula. The valley of Wadi Rijaf contains the best preserved high-density remnants of indigenous Afro-tropical Sudanian forest in Yemen, roughly 300 hectares in size and growing between 300 and 800 meters in elevation. Lower density remnants, open woodland, and shrub lands occupy the remaining 1,200 hectares on adjacent slopes. Given the large difference in elevation from Wadi Rijaf bottom to the highest point in the catchment area, there are marked differences in climate across and a dramatic shift from humid tropical conditions at lower levels to temperate conditions at the highest elevations.
- *Flora:* The Jabal Bura'a Protected Area represents a unique combination of biophysical conditions that support a variety of ecosystems with high biodiversity values including several endemic and threatened species. The area is an important center of genetic diversity within the mountain zone, especially in view of the degraded nature of much of the surrounding area. It is dominated by a mixture of Sudanese and desert region plants as well as few Mediterranean plants. About 315 plant species are found, including 8

native, 63 rare and 35 facing extinction risk, which altogether account for about 10% of Yemen plants. In 2011, UNESCO added the Jabal Bura'a Protected Area to its list of World Network of Biosphere Reserves as the second Yemeni protectorate to be included in the World Heritage registration after Socotra.

- *Fauna:* Jabal Bura'a contains animal species common to the Africa, Arab and Asian geographic regions. It also has 93 species of birds and is one of 57 locations that are maximum importance to birds, as per the International Organization for Bird Protection. There are also 13 species of reptiles, 5 amphibians and 60 butterflies. Its forest is home to various wildlife such as Arabic leopard (*pantherapardusnimir*), Arabian wolf (*Canis lupus*), Caracal Lynx (*caracal caracal*), striped hyena (*hyaenahyaena*), lesser Indian civet cat (*Viverriculaindica*), wild Cat (*Felissylvestris*), Arabian Oryx (*Oryx leucoryx*) and many others.
- *Ecotourism potential:* The unique forested landscape of Jabal Bura'a offers an attractive destination for ecotourism. The region has averaged over 25,000 visitors over the 2005-2014 period, though this number fell to only 9,000 in 2015 on account of the social conflict besetting the country. Nevertheless, the area remains a unique attraction in Yemen known for its lush landscapes, birdwatching opportunities, and mountain trails suitable for trekking.

3.6.2. Vulnerability assessment framework

The overall goal of the vulnerability assessment was to develop a better understanding of how climate change could endanger Yemen's precious biodiversity and limit the future potential of ecotourism in Socotra and Jabal Bura'a. Specifically, the assessment the study aimed to assess the extent to which climate change could adversely impact local ecosystems and habitats, using qualitative and quantitative analysis tools, and to identify potential adaptation strategies. The assessment was structured to account for the following underlying conditions:

- *Ecotourism and climatic factors:* The relationship between ecotourism and climate is very complex and remains difficult to define. Climate affects a wide range of environmental resources that are central to successful ecotourism. Changes in climatic factors such as higher temperatures and less precipitation may adversely affect ecotourism activities by damaging biodiversity in natural areas and increasing the risks of altering the sensitive equilibriums associated with plant-wildlife-insect populations and their distribution.
- *Ecotourism and socioeconomic conditions:* There is a strong relationship between ecotourism and civil tranquility. That is, not only are worthy attractions required but there must be stable security conditions ensuring safe travel and sightseeing for a prosperous ecotourism sector. Today, ecotourism is at minimum levels due to widespread poverty, a conflict-ridden countryside, marine resource degradation, and declining access to water and other essential resources.
- *Future climate:* Based on the results of global climate modeling experiments, it was assumed that the future climate for Socotra and Jabal Bura'a would approximate a hotter and drier scenario. Climatic hazards considered were temperature increase well above

historical means, sharp fluctuations in rainfall, recurrent drought, and sea level rise with potential increase in the frequency of coastal storms and tropical cyclones.

For Socotra, a hotter and drier future climate would lead to several adverse impacts, as outlined in the bullets below:

- *Biodiversity loss:* Climate change will likely lead to a decrease in biodiversity and increased risks of invasive species. For example, Socotra's unique Dracaena cinnabari (dragon blood), and Frankincense trees are highly sensitive to drought and temperature changes and could experience a drastic reduction in their size and extent.

Figure 3.20: Underground cave in Socotra

- *Limestone cave deterioration:* Socotra's limestone caves are fragile systems that are sensitive to climatic changes. Socotra has many such caves because of the abundant presence of limestone (see Figure 3.20). These underground cave systems are composed of smaller overhangs and tunnels that are unique ecosystems with an extremely delicate balance of interaction between the physical elements of the inner environment, heat, and humidity. The crystals within the caves take hundreds of years to form. The delicate climate and environment of caves make them highly susceptible to even small changes in temperature and humidity.
- *Decline of marine-based touristic activities:* Activities such as diving and snorkeling could also be adversely affected by climate change. Any increase in the intensity and/or frequency of such climatic events increase the potential for damage to marine biodiversity such as coral reefs and sea grasses and hence undermine marine based ecotourism. Moreover, Dihamri, Homhil, Mahferhin, are extremely sensitive to coastal erosion, and more intense cyclones would increase the risks to land-based infrastructure needed to support ecotourism activities.

For Jabal Bara'a, a hotter and drier future climate would lead to several adverse impacts, as outlined in the bullets below:

- *Biodiversity loss:* Increased aridity is expected to inhibit forest growth and production, likely resulting in a loss of biodiversity. Preliminary estimates suggest that overall biodiversity in Jabal Bura'a is expected to decline by about 10% and 20% in 2050 and 2080, respectively, absent any strategic interventions. This could have a significant impact on the attractiveness of the region as a touristic destination.
- *Invasive species:* Climate change could exacerbate the existing challenge of invasive species in Jabal Bura'a protected area. Longer seasons could lead to invasive plants encroaching on mountain slope while extended springs could mean invasive species could more quickly push aside native species and transform ecosystems.
- *Wildlife migration:* Aridity would also increase the risk of wildlife migration, which could also disturb the ecological balance of the forest ecosystem. It's possible that certain animal species may be particularly vulnerable to a hotter and drier climate and will seek

out new habitats with more preferable climate conditions by the middle to the end of this century.

3.6.3. Adaptation assessment framework

Biodiversity in Socotra and Jabal Bura'a are extremely vulnerable to climate risks. The combined impact of temperature increase, rainfall fluctuation, and drought compounded with lack of adaptive capacity could lead to severe reduction of habitat abundance and richness of important plant and wildlife species in both areas. Sea level rise with potential increase in the frequency of coastal storms and tropical cyclones would be an additional threat in the case of Socotra. The results of the assessments have helped to clarify the complex links between ecotourism vulnerability and climate change.

The assessments also identified opportunities for climate-resilient ecotourism growth which could help vulnerable stakeholders to cope with and adapt to the adverse impact of climate change. Several adaptation strategies were identified to build resilience in key sectors supporting ecotourism in the two areas. Specifically, there are several priority adaptation areas that were identified on the basis of a consultative process, as outlined in the bullets below. Each of these measures can be categorized as incremental and transitional in nature.

- *Coastal areas and marine biodiversity:* Adaptation in coastal and marine areas would involve: 1) enforcement of enhanced design and planning guidelines for ecotourism establishments in order to increase their resilience to the impacts of climate change; 2) integration of climate change risks into regulatory frameworks for ecotourism development, such as environmental impact assessment and strategic environmental assessments; and 3) establishment of protected beaches and marine ecosystems against threats of uncoordinated resort development and urban sprawl.
- *Terrestrial biodiversity:* Adaptation actions include: 1) support of protected area management in order to enhance resilience of land-based ecosystems and ecological resources; 2) restoration of forest cover in deforested areas to improve the vegetation cover, reduce erosion and increase water infiltration; and 3) enforcement of laws and traditional knowledge to control cutting of trees and grazing in the forest area and rangelands.
- *Economic management:* Adaptation actions include: 1) creation of financial incentives to encourage investment in sustainable ecotourism activities; 2) build business sector awareness of economic benefits associated with sustainable ecotourism; 3) build public awareness of ecotourism activities; and 4) provision of climatic information to the tourism sector through cooperation with the national meteorological services.

3.1. List of References

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Chapter 4:

Greenhouse Gas Mitigation

Despite its very low GHG emission levels, the process for quantifying potential GHG reductions is viewed within Yemen as an opportunity to strengthen national capacity, promote sustainable resource management, facilitate technology transfer, and identify synergies between national economic objectives and sustainable development. This chapter provides a description of Yemen's efforts in understanding its options in reducing greenhouse gas emissions within the context of key sustainable development initiatives. It also provides an overview of the reductions that could be achieved in critical emitting sectors and a forward-looking set of recommendations for overcoming current challenges and barriers.

4.1. Scope, methodology, and data sources

The scope of the GHG mitigation study is on energy production and consumption. This is because energy used throughout the economy (i.e., in the transport, power generation, household, agricultural, industrial, and commercial sectors) accounts for the largest share of emissions in Yemen's GHG inventory. As indicated previously, the 22,034 Gg CO_2-equivalent emissions associated with energy use in 2010 represents about 65% of total national emissions.

While there are non-energy related GHG reduction opportunities in the next largest-emitting sector, agriculture, responsible for 24% of emissions in 2010, the focus of planning in the agricultural sector is primarily focused on climate change adaptation strategies. Hence, a tactical decision during initial mitigation planning was made to limit the scope of the GHG mitigation assessment solely to way that energy is produced and consumed in Yemen's economy.

A scenario-driven energy balance modelling platform - the well-known Long-range Energy Alternatives Planning (LEAP) system developed by the Stockholm Environment Institute – US Center - was used to conduct the assessment. The goal of the assessment was to establish annual and cumulative GHG emission reductions due to the introduction of several energy efficiency and renewable energy options. A planning horizon for the period between a Base Year of 2010 (i.e., the year of the current GHG inventory) through 2040 was assumed.

Two emission scenarios were considered; a Baseline Scenario which assumed the continuation of historical trends in energy supply and demand and a Mitigation Scenario which assumed that Yemen would implement a set of measures to use energy more efficiently and reduce its consumption of liquid fossil fuels. Due to resource and time constraints, the assessment was limited to GHG reductions only (i.e., costs were not considered).

Most of the data required to undertake the assessment was acquired from governmental sources. Additional data was obtained from experts who participated in the preparation of these reports as well as from household energy survey results in the different parts of the country. Physical properties of fuels (e.g., GHG emission factors, energy densities) are based on IPCC default factors used in the development of the GHG inventory.

Basic parameters and assumptions regarding future development in Yemen (e.g., population growth, electric capacity expansion, transport sector characteristics, etc) were sought from official sources and combined with expert judgment where such information was unavailable.

Performance characteristics of mitigation technologies (e.g., combustion efficiency) were obtained from a range of international sources.

4.2. Baseline scenario trajectories

The domestic consumption of refined oil products across various demand sectors accounted for 97% of all energy-related GHG emissions in Yemen in 2010 (see Chapter 1). Since 1995, the year of Yemen's initial GHG inventory, there has been steady growth in fossil fuel use in the country. This is particularly evident for transport (diesel, gasoline) and electricity generation (diesel, residual fuel oil). Major assumptions regarding the development of the Baseline emission scenario are outlined in the bullets below.

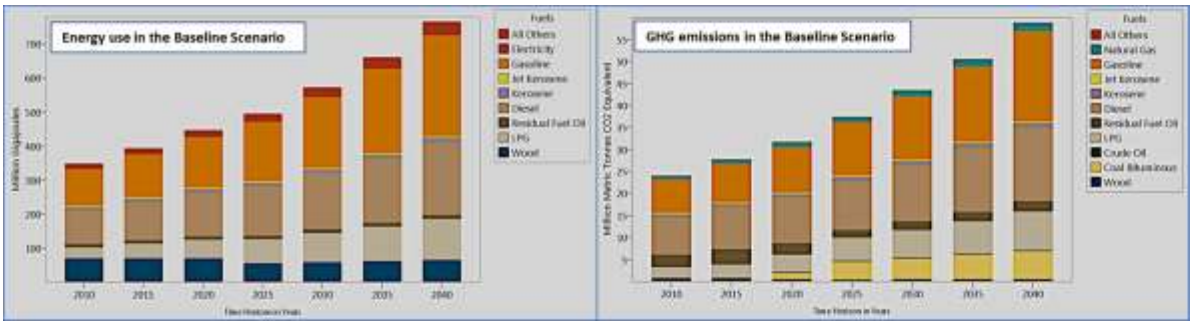
- *Transport sector:* Passenger and freight vehicle categories were considered. Passenger vehicles include private, governmental, and fleet vehicles (i.e., taxis). Freight vehicles include heavy duty long haul trucks. Estimates of the growth in registered vehicles, fuel economy of new vehicles, the future gasoline/diesel mix, and annual vehicle kilometers travelled were combined to develop annual estimates of energy consumption.
- *Household sector:* Households were classified in two ways, rural vs urban and as having access to the electric grid or not. Energy consuming characteristics were developed for each of the four ensuing groups. Electricity availability for rural households was assumed to increase significantly over the planning horizon - from 34% of rural households in 2010 to 55% in 2040. Non-electrified rural households rely on woodfuel and animal residues for cooking, as well as kerosene and LPG for lighting. All major end uses were considered (i.e., lighting, refrigeration, water heating, space cooling and other uses), appropriate to household location, whether rural or urban.
- *Commercial sector:* There are three major subsectors considered in the assessment. General services comprise public buildings (non-ministry), street lighting and water pumping where electricity is the sole energy type consumed. Government comprises ministries and government corporations where electricity is the sole energy type consumed. Other services comprise restaurant, bakeries and all other commercial enterprises where a total of six different types of fuels are consumed: electricity, LPG, diesel, kerosene, wood and charcoal.
- *Industrial sector:* Yemeni industries are small- to medium-sized industries in cement industries, food industries (food stuffs and non-alcoholic beverages), and other industries. Electricity and diesel fuel are the main types of energy consumed. Industrial sector growth is projected to be slow over the planning horizon, about 0.3% per year, with correspondingly slow growth in energy use.
- *Agricultural sector:* Agricultural sector energy use is associated with diesel fuels used to pump water for irrigation and for running farming equipment (e.g., tractors). Growth in fuel use is projected to be around 2.5% per year.
- *Power generation and transmission:* Electricity is produced by a thermal steam power plants using heavy fuel oil, natural gas-fired combustion turbines, and diesel-fired units. No bulk power transfers across international boundaries are in place or are projected during the planning period. Transmission losses are very high, estimated at 46% in 2013.

A total of 3.2 GW of new capacity is projected to come online, with 1.9 GW associated with new coal capacity.

The Baseline scenario trajectories of energy consumption and GHG emissions are illustrated in Figure 4.1. The left side of the figure shows that energy use is dominated by gasoline and diesel which together make up about 70% of energy use. Woodfuel use in 2040, though less than 2010 levels, still represents about 7% of total energy use in Yemen. Overall, energy use grows from 350 million GJ in 2010 to 764 million GJ in 2040, an average annual rate of 2.6% per year.

The right side of Figure 4.1 shows that total GHG emissions grow from 24 million tonnes of CO_2-equivalent in 2010 to about 59 million tonnes in 2040, an average annual rate of about 3.0% per year. While emissions from gasoline and diesel also represent the largest shares, emissions from coal become substantial from 2020 onward due to the introduction of new coal-fired electric generation capacity. The introduction of coal, with a carbon intensity nearly double that of liquid fuels is a major reason why the annual average growth rate of GHG emissions exceeds that of energy.

Figure 4.1: Baseline scenario energy and GHG emission trajectories (Sufian and Asaad, 2016)



4.3. GHG reduction strategies

Several mitigation measures across energy supply and demand were assessed relative to their capacity to achieve long-term GHG emission reductions in Yemen. Mitigation measures were evaluated in each of the five (5) emitting sectors that were selected on the basis of three main criteria; consistency with existing sustainable development objectives, implementation feasibility, and large emission reductions under Yemeni conditions. Each of these priority measures is briefly described below.

- *Transport sector mitigation measures:* These measures focus on improving fuel economy of all vehicle classes. It involves the development and implementation of an annual vehicle maintenance, inspection and tuning programme. Such a programme was assumed to become effective for all vehicle classes in 2018 and is projected to increase average fuel economy by 33%, 35%, and 38% for cars, heavy duty trucks, and motor bikes/buses, respectively, by 2040 relative to the baseline.
- *Household sector mitigation measures:* These measures focus on the introduction of efficient lighting and refrigeration. For lighting, it involves the phaseout of low-efficiency, incandescent lighting and gradual replacement by high-efficiency lighting that are 60%

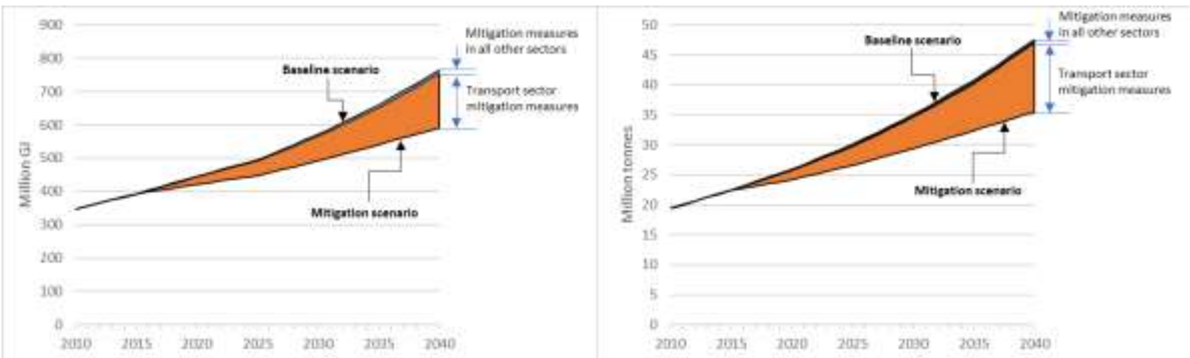
more efficient. For refrigeration, it involves the phaseout of low-efficiency, traditional refrigerators and gradual replacement by high-efficiency refrigerators that are 50% to 72% more efficient Such a programme was assumed to be phased in starting in 2018 and achieve complete turnover in the lighting and refrigerator stock by 2040.

- *Commercial sector mitigation measures:* These measures focus on the introduction in 2018 of efficient lighting and other efficient electrical devices, as well as fuel switching. For lighting and other electrical devices, it involves the gradual introduction of high-efficiency equipment such that average energy intensity improves by 25% of its 2010 value by 2040. For fuel switching, it involves the complete replacement by LPG by 2040 of diesel, kerosene, and woodfuel in bakeries and restaurants.
- *Industrial sector mitigation measures:* These measures focus on the introduction, starting in 2018, of efficient lighting and other efficient electrical devices, as well as fuel switching. For lighting and other electrical devices, it involves the gradual introduction of high-efficiency equipment such that average energy intensity improves by 25% of its 2010 value by 2040. For fuel switching, it involves the complete replacement by natural gas by 2040 of heavy fuel oil in the cement industry and of charcoal in all other industries.
- *Agricultural sector mitigation measures:* These measures focus on the complete replacement, starting in 2018, of diesel groundwater pumps in low-lying agricultural areas with solar pumps.
- *Power generation mitigation measures:* These measures focus on the complete phased replacement, starting in 2020, of existing diesel generation and planned coal-fired generation by a renewable power generation mix in 2040 that consists of 20% solar PV, 40% wind, and 40% geothermal.

4.4. Mitigation scenario trajectories

The Mitigation scenario trajectories of energy consumption and GHG emissions are illustrated in Figure 4.2. The left side of the figure shows that the integration of the GHG mitigation measures will lead to substantial energy savings by 2040, equal to about 23% lower than the Baseline scenario. Most of these savings, about 94%, are derived from transport sector mitigation measures. Overall, energy use declines from 764 million GJ in 2040 in the Baseline scenario to 591 million GJ in the Mitigation scenario, with cumulative savings of 1.9 billion GJ.

Figure 4.2: **Baseline scenario energy and GHG emission trajectories (Sufian and Asaad, 2015)**



The right side of Figure 4.2 shows that the integration of the GHG mitigation measures will lead to substantial reductions in GHG emissions by 2040, equal to about 26% lower than the Baseline scenario. Most of these reductions, about 96%, are derived from transport sector mitigation measures. Overall, GHG emissions decline from 48 million tonnes in 2040 in the Baseline scenario to 36 million tonnes in the Mitigation scenario, with cumulative savings of 133 million tonnes. Moreover, the carbon intensity of the Yemeni economy declines from 62 kg/GJ in 2040 in the Baseline scenario to 60 kg/GJ in the Mitigation scenario.

4.5. Next steps

The results of the GHG mitigation assessment shows that were such options to be taken up and implemented, significant GHG reductions can be achieved. The magnitudes of these reductions are reasonable and a valid basis for future policy dialogues in Yemen. Engaging stakeholders across public and private sector entities will be essential to develop a legislative and regulatory environment that effectively promote GHG mitigation in the Yemen economy. A working framework for such future stakeholder discussions is outlined below.

Transport sector

- Activate new regulations to improve fuel economy in all types of vehicles, including the introduction of standards and norms for all imported used vehicles.
- Reduce import tariffs on new high-efficient gasoline vehicles, while increasing taxation on new vehicles with low fuel economy, and extending the existing ban on importing vehicles of 5 years old and above.
- Introduce a mandatory annual vehicle inspection programme that includes emission testing in order to identify high-emitting cars, buses and lorries for subsequent scrappage.
- Make use of the media and launch awareness programs to educate vehicle users of the importance of keeping a pollutant efficient vehicle to our environment,

Power generation sector

- Continue implementing electrification programmes in urban and rural areas.
- Gradually replace existing inefficient diesel- and heavy fuel oil-fired electricity generation technologies with renewable energy technologies.
- Encourage local and external private investment in the generation of electrical power using renewable energies such as wind and solar energies in large quantities and sell to the national grid.

Commercial and industrial sectors

- Develop regulatory framework to increase access to natural gas in the industrial and commercial Sectors.

Household sector

- Introduce new regulations to gradually replace conventional lighting and refrigerators systems by more energy efficient alternatives.

- Reduce the cost of LPG cylinders so that those households who cannot presently afford them can switch to LPG stoves, while introducing awareness programs to educate the public of the benefit of using LPG stoves to the environment,
- Reduce or abolish taxation on LPG cooking equipment.

4.6. List of references

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Chapter 5:

Supplementary Activities

Findings from the assessments described in the previous chapters led to several interesting follow-up questions. With the availability of time and budget resources, these questions were explored within a set of supplementary activities that focused on rooftop PV diffusion, mapping shoreline change, nationally appropriate mitigation actions, mangrove forest resilience, and sea level rise awareness-raising. The results of these supplementary activities are briefly discussed in the sections that follow.

5.1. Diffusion of rooftop solar power systems

Even before the onset of civil strife in 2015, electricity access was very limited in Yemen, with only about 40% of households connected the national grid. But in the years since, daily blackouts have become increasingly common due to damage to generation facilities and transmission/distribution networks, as well as difficulties in effecting repairs. Moreover, alternatives such as electric self-generators have become similarly problematic due to unreliable retail diesel fuel supplies. In response, urban and rural Yemeni households have begun to autonomously adopt stand-alone rooftop solar photovoltaic (PV) systems to generate electricity to meet their energy needs.

To examine the rate of diffusion of such systems, a household energy survey was conducted in the Sana’a Governorate in 2017. A total of 400 households were randomly selected; 300 urban and 100 rural households. Urban households were distributed across 10 districts in the capital city itself, while rural households were distributed across 10 rural districts in the Sana'a Governorate within 60 km of the capital city. The survey posed questions regarding respondent access to grid electricity, performance of a rooftop PV system (if installed), levels of grid/PV electricity consumption, and consumption of other forms of energy. Survey results were used to calculate the diffusion rate of rooftop solar PV systems, as well as fossil fuel savings and carbon dioxide emissions avoided. Results are summarized in Table 5.1 and discussed in the bullets that follow.

Table 5.1: Overall impact of rooftop solar PV systems (Adimi, 2018)

		Number of installed household rooftop PV systems			Household fossil fuel savings (GJ/yr)			Household CO_2 reductions (thousand tonnes/yr)		
Unit	Period	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural	Total
Sample (400 households)	Pre-2015	0	0	0	0	0	0	0	0	0
	Post-2015	258	95	353	6.6	4.5	11.1	0.50	0.34	0.84
Extrapolation to Sana’a governorate	Pre-2015	0	0	0	0	0	0	0	0	0
	Post-2015	210,670	36,300	246,670	1,700	430	2,130	130	32	162

- *Diffusion of rooftop solar PV systems:* Prior to 2015, none of the households surveyed possessed a rooftop unit. At the time of the survey in 2017, a total of 258 and 95 of the sampled urban and rural households, respectively, had installed a rooftop solar PV system at high cost because of low supply and high demand. This corresponds to a diffusion rate of 86% among urban households and 95% among rural households. If this rate is representative of all households in the Sana’a governorate, it implies that 210,670 urban households and 36,300 rural households meet some portion of their energy needs through solar power.

- *Fuel savings:* Electricity generated from rooftop solar PV systems displaces electricity from that would otherwise have been consumed from the national grid (assuming uninterrupted service) as well as from diesel-power self-generators. Average annual electricity consumption levels are about 439 and 298 kWh per household per year, for urban and rural households, respectively, and currently entirely met by solar power. Electricity is used for lighting, refrigeration, space cooling, and certain appliances (e.g., mobile phone, computers); it is not used for cooking. Assuming an average of 15,000 kJ of fossil fuels are consumed at power stations and self-generators for each kWh consumed, solar PV generated electricity displaces about 6.6 GJ and 4.5 GJ of fossil fuels per household per year in the sampled urban and rural households, respectively. If this level is representative of all households in the Sana'a governorate, it implies fossil fuel savings of 1,700 GJ/year for urban households and 430 GJ/year for rural households, or 2,130 GJ/year in total.
- *Carbon dioxide reductions:* The fuel savings above translate directly into reductions of carbon dioxide emissions. Assuming an aggregate fuel mix at power stations and self-generators of 80% diesel and 20% natural gas, the use of solar PV generated electricity leads to a reduction of about 502 tonnes and 343 tonnes of carbon dioxide per household per year in the sampled urban and rural households, respectively. If this level is representative of all households in the Sana'a governorate, it implies carbon dioxide reductions of 130 thousand tonnes/year for urban households and 32 thousand tonnes/year for rural households, or 162 thousand tonnes/year in total.

Going forward, there are several observations and lessons that can be gleaned from the survey results, as outlined in the bullets below:

- *Autonomous adoption:* Although there are high capital costs associated with rooftop PV systems in Yemen, people found that to be the only option available. As a result, there was widespread acceptance of the technology, sufficient to overcome the general lack of awareness of such systems, and resulting in a high level of diffusion in urban and rural areas of Sana'a. On the one hand, rooftop PV systems have proven viable for meeting household energy needs, thereby increasing the resilience of households while also contributing to the expansion of clean energy alternatives. On the other hand, it is clear that the diffusion rate is sustainable and replicable to other areas apart from any generous subsidies.
- *Incentivize renewable energy:* In the coming post-conflict period, government resources and international assistance should expand the current National Strategy for Renewable Energy and Energy Efficiency (REEE) by seeking to systematically replicate the Sana'a experience to other governorates. Overcoming capital cost barriers should be addressed by offering incentives such as tax exemptions to encourage imports and local manufacturing, as well as concessionary loan terms to households for promoting retail sales. Information barriers should be addressed by facilitating the establishment of technical training and vocational training centers to build local capacity, as well as by introducing nationwide campaigns to promote public awareness of the benefits of rooftop PV systems.

- *Revisit renewable energy diffusion targets:* Current targets in the REEE call for the diffusion of rooftop PV systems to 100,000 households by 2025, or roughly 2% of all households by that year. However, given the high diffusion rates in the Sana'a governorate since 2015, it will be important to set more ambitious targets that account for the viability and desirability of such systems for meeting household electricity needs. Given the Sana'a experience, a realistic target would be diffusion of rooftop PV systems to 20% of all households by 2025, or roughly 1 million households by that year.

5.2. Data development for monitoring shoreline change

In order to develop the kinds of data to inform future assessments of coastal vulnerability to sea level rise and storm surge, shoreline changes between 1984 and 2017 were examined. This involved the use of remote sensing and GIS spatial analysis tools to assess shoreline topography and land use along nearshore areas of Yemen's entire 2,200 km coastline (see red-shaded area in Figure 5.1). Low-lying areas vulnerable to inundation by rising sea levels were identified, as were areas that are experiencing coastal erosion. As a result of the mapping exercise, a set of detailed topographic, shoreline change and sensitivity maps was produced, as well as a list of priority areas that require urgent adaptation actions.

Figure 5.1: Study area for mapping shoreline change (Ahmed, 2018)

Shoreline change between 1984 and 2017 – both accretion and erosion – was analyzed by measuring differences in past and present shoreline locations using remote sensing and GIS tools at a coarse level of spatial resolution (i.e., 50 km segments). The Digital Shoreline Analysis System (DSAS), a software extension for ArcGIS, was used to carry out automated shoreline change calculations along Yemen districts' shoreline. Finally, coastal sensitivities were identified and mapped using a modified costal sensitivity index (CSI) that accounted for eleven (11) structural, physical and socio-economic variables. The overall results of the assessment are summarized in the bullets below:

- *Erosion and accretion rates:* The entire shoreline of Yemen underwent either erosion and accretion over the 33-year period from 1984 to 2017. About 53% of all coastal segments experienced erosion and the remaining 47% experienced accretion. There were no coastal segments that remain unchanged over the period. The average rate of accretion across the entire Yemen shoreline is 1.9 meters per year, with the Al Munirah district of Al Hudaidah governorate showing the highest rate, about 7.6 meters per year, followed by similar levels for most districts in the cities of Aden and Al Mukalla. Regarding erosion, the average rate across the entire Yemen shoreline is about 0.8 meters per year, with the Ar Raydah Wa Qusayar district in the Hadhramut governorate showing the highest rate, about 2.8 meters per year.
- *Land expansion/loss rates:* Average shoreline movement from 1984 to 2017 was about 15.6 meters per year. In general, western shorelines along the Red Sea as well as the Aden

governorate show expansion of shoreline toward the sea, while the remaining shoreline experienced a loss of shoreline. Land expansion rates varied considerably, with high rates of 42.0, 36.5 28.5, and 20.0 hectares per year evident in the Al Salif, Al Luhaia, Al Munierah, and Alluheyah districts of the Al Hudaidah governorate, respectively. Other districts that experienced land expansion rates less than 20 hectares per year include Midi (Hajjah governorate), Kamaran (Al Hudaidah governorate), and Al Mansura and Khur Maksar in the Aden governorate. Land loss rates also varied considerably, with high rates of 14.7, 10.3, and 9.6 hectares per year evident for the Ad Duraihimi, Dhubab, and Ar Raydah Wa Qusayar districts of the Hadhramut governorate.

Table 5.2: Most sensitive coastal regions in Yemen to shoreline change, erosion, and inundation (Ahmed, 2018)

#	Region	Governorate	Area (km^2)
1	Midi - Al-Luhayyah	Hajjah	300
2	Al-Hudaydah	Al-Hudaydah	50
3	Bahr Ibn Abbas	Al-Hudaydah	350
4	Al-'Urj	Al-Hudaydah	15
5	Nukhaylah – Ghulayfiqah	Al-Hudaydah	18
6	Jaza'ir al-Zubayr	Al-Hudaydah	33
7	Jaza'ir al-Hanish	Al-Hudaydah	280
8	Al-Mukha - Al-Khawkhah	Taiz	70
9	Bab al-Mandab - Mawza	Taiz	50
10	Hiswat al-Hugayma	Lahij	250
11	Khor Umairah	Lahij	NA
12	Aden Coastal Wetlands	Aden	100
13	Balhaf Burum	Hadhramaut	NA
14	Karif Shoran	Shabwah	NA
15	Baraqa, Sikha Hallaniyah	Shabwah	3
16	Sharma and Jathmun	Hadhramaut	NA
17	Qishn Beach	Al Mahrah	1
18	Ra's Fartak	Al Mahrah	100
19	Abdullah Gharib Lagoons	Al Mahrah	1
20	The wooded Mahra	Al Mahrah	150
21	Qalansiya Lagoon	Socotra	5
		Total	1,776

- *Coastal sensitivity index:* A coastal sensitivity index was developed relative to shoreline change, erosion, and inundation potential. Regarding shoreline change, about 32.5 % of the Yemen shoreline, comprising 13 districts, is highly sensitive to shoreline change, with Al Mansurah and Khour Maksar in the Aden governorate as well as the Al Hali district in Al Hudaidah governorate showing the greatest sensitivity. Regarding erosion, about 45% of the Yemen shoreline, comprising 18 districts, is highly sensitive to erosion, with a wide distribution of districts across the Aden, Abyan, Hadhramaut, Al Maharah governorates. Regarding inundation, about 35% of the Yemen shoreline, comprising 14 districts, is highly sensitive to inundation, with Al Hali of the Al Hudaydah Governorate as well as Crater and Khour Maksar of Aden governorate and Socotra Island showing the greatest sensitivity. Each of these areas exhibits elevations of less than 5 meters above sea level extending inland for 5 km. Altogether, there are 21 coastal regions, totaling nearly 1,800 km^2, that display the highest sensitivity to shoreline change, erosion, and inundation potential, as shown in Table 5.2.

Going forward, building upon the above findings should focus on the following key recommendations:

- *Improve knowledge base in highly sensitive regions:* To promote sound adaptation planning, future efforts to characterize shoreline change should develop accurate and detailed elevation data via physical surveying to develop a high-resolution digital elevation model for the areas identified as most sensitive to shoreline change, erosion, and inundation potential. Such information should be augmented by satellite images, high resolution time series of climatic, socioeconomic, environmental and oceanographic data.

If possible, regional ocean modeling capable of representing air-ocean-ice dynamics should be undertaken to project sea level rise and ocean wave properties.

- *Improve spatial resolution:* To further refine an understanding of shoreline change and sensitivity, future efforts should divide the shoreline in highly sensitive regions into small segments of 20 Km long and up to 5 km wide. Within each segment, all shoreline changes should be examined, including hinterland geomorphology and landforms, land cover-land use, ecosystems and socio economic activities. In addition, a detailed inventory of public and private infrastructure assets should be assembled. The results of the effort should be incorporated into a segment-specific coastal sensitivity index.
- *Maintain an up-to-date knowledge base:* To obtain shoreline changes over time, an assessment should be conducted at least once every five years on the high-resolution coastal segments. This period of time will enable adequate chronological comparisons to be made in order to evaluate coastal sensitivities, changes, risks, and emerging trends regarding shoreline change.

5.3. Framework for the development of Nationally Appropriate Mitigation Actions

In anticipation of the Paris Climate Conference, Yemen submitted its Intended Nationally Determined Contribution (INDC) document on 21 November 2015. With this submission, Yemen signaled its intention to reduce future growth in GHG emissions. A 14% reduction target was adopted for 2030, consisting of domestic-only actions contributing 1% of the target and internationally-assisted actions contributing the remaining 13%. Altogether, 35 $MtCO_2$-eq of cumulative GHG reductions would be achieved under the overall target by measures mostly focused in the energy and waste management sectors.

Following the Paris Climate Conference, the Paris Agreement was signed by Yemen on 23 September 2016, although ratification is still pending. Since Yemen's INDC would automatically turn into its Nationally Determined Contribution (NDC) at the point of ratification unless action is taken (i.e., based on Article III, paragraph 22 of FCCC/CP/2015/10/Add.1), the intended GHG emission reduction target offers a useful point of departure to explore a range of specific Nationally Appropriate Mitigation Actions (NAMAs) and related institutional and other requirements for successful implementation that could be incorporated into an eventual NDC.

A detailed list of potential NAMAs has been assembled through extensive stakeholder consultations (Al-Sakaf, O., 2018). Over 50 proposed measures have been identified across the energy and waste management, sectors which account for over 70% of net national GHG emissions. The proposed measures would lead to significant future GHG emission reductions, while also promoting a low emission national development pathway and producing a host of valuable local co-benefits.

Most of the proposed measures are project-based (e.g., retrofitting open-cycle/single-cycle gas turbine plants into more efficient combined-cycle gas plants; capturing methane from wastewater treatment plants that use anaerobic digestion lagoons). However, the list also includes numerous programmatic measures (e.g., energy-efficient building codes and regulations; fuel economy standards for light and heavy-duty vehicles) and policies (e.g., feed-in tariffs to promote grid-connected renewable energy systems; tax incentives for electric or fuel-efficient light duty vehicle purchases).

While the individual and collective emission reduction potential of these measures has not yet been quantified through a formal GHG mitigation analysis process, it is clear from internal discussions among sectoral experts that emission reductions would be well in excess of the 14% reduction target even for a small subset of the projects, programmes, and policies. An indication of the GHG emission reduction potential of three of the most promising measures – totaling about 10% in emission reductions - are highlighted in the bullets below for illustrative purposes.

- *Windfarms:* Preliminary assessments indicate abundant untapped wind energy potential at certain locations, with a technical potential for large-scale grid-based power generation of about 34,286 MW. The harnessing of only 400 MW of this potential, a target consistent with the current National Strategy for Renewable Energy and Energy Efficiency (REEE), would displace about 1,020 thousand tonnes of CO_2 per year, roughly equivalent to about 5.0% of energy sector emissions.
- *Solar-powered electric vehicles:* The use of solar energy from rooftop PV systems or large centralized PV facilities for home-based recharging stations for lithium ion batteries in electric vehicles offers an opportunity for zero-carbon transport. While not yet formally incorporated into the REEE, electric vehicles have shown increasing penetration in global markets and represent an emerging opportunity to reduce emissions and introduce important co-benefits (i.e., air quality improvements urban noise reduction). A gradual introduction of electric vehicles, eventually reaching 25% of the light duty vehicle fleet, would displace about 840 thousand tonnes of CO_2 per year, roughly equivalent to about 4.1% of energy sector emissions.
- *Rooftop PV systems:* These systems would enable the electricity produced by rooftop systems to be either consumed on location or be sold into the electricity grid. The installation of 20,000 rooftop PV systems, an aspirational target consistent with government-approved renewable energy, energy efficiency and rural electrification strategies, would displace about 100 thousand tonnes of CO_2 per year, roughly equivalent to about 0.9% of energy sector emissions.

Several barriers hinder Yemen's ability to develop NAMAs that are measurable, reportable and verifiable. The most significant barriers are described in the bullets below. A summary of proposed measures to overcome these barriers is shown in Table 5.3.

- *Institutional, legal and policy barriers:* Yemen's Ministry of Planning and International Cooperation (MoPIC) possesses the mandate of socio-economic development planning and programming and is the direct partner for donors and supporting countries in development cooperation. At present, the MoPIC does not have the capacity in place to effectively identify and address legal and policy gaps associated with NAMA development and implementation.
- *Technical Capacity barriers:* There are significant technical capacity constraints associated with NAMA development, including the use of appropriate methods and tools to quantify achievable emission reduction and prioritize activities in the context of sustainable

Table 5.3: Approach to overcoming barriers to NAMA development (Alsakaf, O., 2018)

Type of barrier	Approach to overcoming barriers
Institutional, legal & policy	• Strengthen mandate of MoPIC and NAMA focal points at line ministries • Update legislation to promote/enforce sustainable development and attract green technology investment.
Technical capacity	• Strengthen Inter-Ministerial Committee on Climate Change (IMCCC) to provide guidance on access NAMAs/climate finance and attract multilateral donor support • Strengthen EPA and Designated National Authority (DNA) to assess project feasibility, develop GHG inventory management systems, construct/analyze green energy scenarios, and develop NAMA proposals. • Increase cooperation within other LDCs for joint development of strategies/activities, joint application for funding
Measurement, Reporting and Verification	• Develop MRV protocols for estimating, reporting, and verifying actual emissions over a defined period of time at national, organizational and facility levels. • Develop MRV protocols for assessing GHG emissions reductions and/or co-benefits of policies, projects, and actions, as well as monitoring implementation progress. • Develop MRV protocols to monitor the provision and receipt of financial flows, technical knowledge, and capacity building, and evaluating the results and impact of support.

development needs; design of inter-ministerial cooperation frameworks to ensure appropriation of strategies by relevant stakeholders; estimation of resources (financial and technical) required for the implementation of NAMAs; and understanding of climate financing assessment methods.

- *Measurement, Reporting and Verification (MRV) barriers:* Yemen lacks a MRV framework to quantify and track emissions reduction impacts of NAMAs. Moreover, there are no institutional arrangements in place for GHG mitigation assessment and the application of MRV protocols, including ongoing updates of the national GHG inventory and preparation of national communications and biennial update reports. Currently, the Climate Change Unit (CCU) of the Environmental Protection Authority (EPA) develops these reports on an ad-hoc basis

Implementing the above approach to barrier removal would produce an enabling environment to support the identification, assessment, and verification of NAMAs. The immediate next step is the launching of a nation-wide process for NAMA development, making use of available international support. Special emphasis should be given to establishing technical capacity building programs that prioritize training in methods and tools for quantifying GHG emission, conducting feasibility assessments, and developing MRV protocols for estimating, reporting, and verifying emission reductions.

5.4. Resilience building among mangrove forests and communities along the Red Sea

Mangroves are of prime importance to Yemeni communities. Along Red Sea shorelines, where 95% of all Yemeni mangroves are located, they provide numerous benefits to coastal communities such as shoreline stabilization, wave energy reduction, as well as carbon sequestration benefits and habitats for a range of terrestrial and marine species. To a significant extent, fisheries in coastal areas of the Red Sea owe their productivity to the continuing presence of mangrove forests.

At present, mangroves along the Red Sea coast face increasing anthropogenic threats. These include intensive camel grazing, firewood extraction, harvesting for local construction needs, pollution from oil tankers, and unregulated touristic development. As a result, many mangrove forests have already been badly damaged, with some being completely destroyed along with the habitats they provided and ecosystem services they offered to coastal communities. The extent to which these impacts adversely affect local communities is considered to be significant. At present, no mangrove plantation activities exist in Yemen, nor reforestation of existing degraded mangrove areas.

To explore the linkages between mangroves and community resilience, a case study was undertaken for communities in the Al-Luhaia district and Kamaran island in the Al Hudaydah governorate along the Red Sea (see Figure 5.2). Combined, the communities cover an area of about 1,406 km^2 with a population of over 108,000 with livelihoods largely dependent on fishing, pastoralism, and farming; living at or below the poverty line.

Figure 5.2: Mangroves and community resilience case study areas (Alnabhani, S., 2018)

The assessment was qualitative in nature and relied on consultations with communities and desk-based research. Primary data were collected using key Informant Interviews (KII), Focus Group Discussions (FGDs), participant observations, as well as field surveys. Secondary data were also obtained from available relevant documents and reports. Major characteristics of the mangroves in the areas are summarized in the bullets below:

- *Spatial extent:* Mangroves exist as dense, narrow (i.e., between 50 and 300 meters) forests along the shoreline, on near- and off-shore islands and fringe tidal inlets and channels area. Typically, the length of mangrove stands range from 20 to 100 km in length. A total of about 40.7 km of mangrove stands were considered; 33.7 km in Al-Luhaia and 7.0 km in Kamaran island, representing about 32% of total mangrove stands.
- *Ecosystem services:* The majority of mangroves in both case study sites remain highly productive and generate important ecosystem services that are well understood and valued by the communities (i.e., timber, fuel wood, erosion control, as well as breeding, spawning and nursery habitats for commercial fish).
- *Species:* The majority of the forests are mono-specific stands of *Avicenna marina* with a few exceptions where *Rhizophora mucronata* is also present. *Avicenna marina* trees typically do not exceed 3 to 6 meters in height, and can grow up to 11 meters at Al-Urj south of the case study sites, where the biggest and oldest *Avicenna marina* in Yemen are found. *Rhizophora mucronata* may grow up to 7 to 9 meters and is mostly found on Kamaran Island, where some of the most dense and pristine mangrove areas in the country are found. The distribution and density of mangroves decrease in extent and structure from North to South.

Currently, mangrove stands in the two areas are subject to several specific anthropogenic and climate change-related threats., as outlined in the bullets below:

- *Animal grazing:* The greenery of mangrove trees attracts pastoralists to bring their camels and goats to graze on mangrove leaves. There is little in the way of protection mechanism which has led to over-grazing and a significant loss of habitat in several areas.

- *Unsustainable harvesting:* Cutting and removal of mangroves is more destructive than animal grazing. Unplanned mangrove cutting leading to mature trees with broken limbs was apparent in several mangrove stands, leading to denuded patches, barren depressions with modified hydrological regimes, and compaction of the surface soil. Given their spatial distribution limits, these impacts are severe.
- *Pollution:* Domestic solid-waste in the form of polythene bags and bottles, rubber, plastic and metal cans are disposed of in large quantities near community centers. Several stands near Al-Luhaia currently suffer from large accumulations of such wastes which are often dumped directly into the mangrove stands and is then transferred by wind and tidal water becoming trapped among the trees and their aerial roots.
- *Land use change:* The major cause of the mangrove mortality in the case study areas appears to be localized modifications to the topography of the coastal area. This has led to diversion or blocking of tidal water flow and drying up of the mangrove stands.
- *Climate change:* Layered on top of the above threat is climate change which is projected to cause major changes in mangrove distribution and productivity and lower the capacity of mangroves to recover from stress or disturbance. This loss of resilience is linked to rising levels of the Red Sea, and in combination with impacting activities, threatens the continued existence of mangrove ecosystems in the region.

In the future, protecting mangrove resources in the study area will help preserve the important environmental services they produce, and in the process build the resilience of coastal communities to climate change. Several action are proposed, as outlined in the bullets below:

- *Increase ecological resilience:* Reducing anthropogenic stressors can help to foster ecological resilience of mangrove stands. Primarily, this should involve a ban destructive on destructive fishing practices and physical damage to mangroves from animal grazing and unsustainable harvesting. Such restrictions, including no-take areas, are essential to reduce some key non-climate stressors to the mangroves, reefs and related ecosystems. These restrictions should be established based on a participatory process with local communities in which the links between ecological resilience and community resilience are accounted for.
- *Promote livelihood diversification:* Key indicators of social resilience include the diversity of income sources, the level of education, participation in decision-making, ability to self-organize, and access to credit. Given that communities in Al-Luhaia district and Kamaran island display high social vulnerability to climate change, investments in social development programmes such as poverty alleviation and the creation of infrastructure are central to help build their adaptive capacity. Such initiatives will allow communities to prioritize conservation opportunities in daily decisions. During the field data collection phase, 13 viable income generation activities were identified.
- *Engage civil society groups:* There are several newly established community service organizations and non-governmental organizations that can contribute to increased socio-ecological resilience in the study areas through a range of activities, including involvement in development and implementation of sustainable management plans,

communication and awareness raising about climate change, and adopting good governance practices. Each is highly relevant to fostering adaptive capacity in mangrove forest communities.

- *Promote economic and educational opportunities:* The widespread poverty in the areas is an important determinant of vulnerability to climate change as well as an indicator of low adaptation capacity. Increasing individual, household, or community income opportunities will enable people to better prepare for climate disasters. Enabling adaptation in the longer term will depend in large part on identifying and exploiting wealth generation opportunities in the region. Fostering greater access to formal education will also help increase resilience to climate change disasters by increasing potential household income, increasing awareness and understanding of possible climate change risks, and increasing access to risk-related information.
- *Provide family planning guidance:* The study areas are characterized by large families, about 6.7 people per family. High population growth rates can magnify vulnerability to climate change by increasing the number of people living in potentially impacted areas. At the household level, large families make coping with food insecurity and insufficient resources much more difficult. Providing access to family counseling services will help to manage vulnerability at an inter-generational level.

5.5. Raising awareness of sea level rise in Aden city

Aden, a city of about 1 million people on the southwestern tip of Yemen, is surrounded by coastal and marine ecosystems representing a rich repository of resources supporting the local and national economy. Commercial fisheries, extensive wetlands, sea grass beds, coral reefs, beaches and sand dunes as well as natural and cultural heritage sites are highly valued resources. While the threats to these resources from anthropogenic factors (i.e., resource overexploitation, transformation/degradation of habitats, pollution) are well understood, threats from climate change – and specifically sea level rise – are much less well understood by the city's populace.

The impact of climate change on Aden's marine ecosystems include the likely submergence of the low-lying coastal areas. Indeed, the coastal zone of Aden governorate is considered as one of the country's most vulnerable areas to sea level rise. Potential impacts include land, beach and infrastructure damage and loss. Previous studies have documented the extent of potential inundation under a set of sea level rise scenarios. At present, much of the city's infrastructure, commercial properties, and businesses are located within zones that are projected to be vulnerable to inundation from sea level rise.

Raising local awareness to this potential eventuality is essential for ensuring community engagement in identifying appropriate adaptation strategies. To this end, activities were undertaken in Aden to discuss the state of knowledge and implications of sea level rise among policy makers, teachers, students, and other stakeholders. The effort included a set of awareness-raising workshops, consultative meetings with relevant government institutions and NGOs, training seminars for targeted groups, and the production/dissemination of informational materials. A local NGO, Sustainability For Nature Conservation (SFNC), was selected to carry out these activities over a 6-month period in 2017-2018.

Overall, the effort proved to be a valuable experience for exposing members of the community to a largely new topic, sea level rise. Some of the highlights of the exercise are outlined in the bullets below:

- *Media coverage:* Activities under this exercise received a wide media coverage from different media such as TV channels, radio, new papers, and news sites.
- *Community participation:* There were 1,352 participants from different relevant institutions including decision makers; 17,869 school students across 15 Schools visited.
- *Information packages:* Awareness and training materials produced within this exercise were well received. Storm surges associated with the two cyclones, *Sagar* and *Mekunu,* that hit Yemen in May 2018 were poignant reminders of the relevance of sea level rise.
- *Follow-up:* The exercise created a communication and coordination mechanism between relevant bodies in Aden to enable follow-up regarding proactive preparations for future sea level rise.

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Chapter 6:

Constraints, Gaps and Needs

While Yemen's contribution to global anthropogenic GHG emissions is very low, its vulnerability to climate change-related impacts on fragile sectors, systems, and populations is acute. Findings of the V&A assessments discussed previously bear out this fundamental condition and exacerbate current and future sustainable development challenges associated with limited resources, little technical capacity, and very low ODA per capita. Rural livelihoods, where the majority of the population lives, carry a daily burden of decreasing water access and agriculture productivity as a result of changes of rainfall patterns and more frequent droughts. For Yemen to respond effectively to the challenge of climate change, substantial investments and international support will be needed.

Yemen will continue to actively engage in climate change negotiations abroad and promote climate-resilient socioeconomic growth at home. The effectiveness of such efforts will in large part depend on overcoming serious institutional, financial and technical constraints and gaps that currently impede concerted action. It is unlikely that Yemen can build climate change resilience and ensure low-emission development trajectories unless adequate support is provided becomes available to develop an enabling environment for effective action. The subsection below outline the key constraints, gaps, and needs to facilitate compliance with UNFCCC obligations and aspirational adaptation goals.

6.1. Constraints

Several technical, institutional, legislative, and financial constraints across various levels have been identified hindering implementation of climate change adaptation and mitigation activities in Yemen. The following bullets are examples of such constraints:

- Numerous development challenges including high poverty prevalence, and lack of access to basic services such as safe drinking water, proper sanitations, health, education, and poor infrastructure like roads and electricity networks.
- Lack of data bases, and inadequate information and data collection, analysis and dissemination.
- Weak institutional structures with overlaps of roles and responsibilities.
- Lack of financial resources.
- Weak rule and enforcement of laws and regulations.
- Absence of partnership and private sector engagement.
- High illiteracy rate and low awareness.
- Very limited technical capacities.
- Low human development, with deep gender disparities.
- Lack of scientific research.
- Scattered rural settlements across varying topographical settings including hard mountainous region accessibility
- Weak political leadership.

6.2. Gaps

The following outlines the key capacity gaps with respect to implementation of climate change adaptation and mitigation as a requirement under the UNFCCC convention:

- Lack of access to climate information.
- Lack of accurate climate information and uncertainties about climate change projections on Yemen.
- Low quality GHG emission inventories.
- Limited reporting capacity to regularly update national communications, to meet all needs and covering all areas as stated by the UNFCCC conventions.
- Lack of awareness among community and policy-makers regarding climate change.
- Inadequate institutional, technical and financial capacity to plan and implement climate change adaptation, and mitigation actions.
- Lack of funding to implement climate change adaptation, and mitigation measures.
- Limited climate change related Research.

6.3. Needs

Several capacity development needs were identified in order to strengthen actions on climate change adaptation as well as mitigation, and hence facilitate compliance with UNFCCC requirements. The following are among the key needs:

- Mobilize financial resources to address vulnerable sector and systems;
- Build public, and policy-maker awareness on climate change;
- Promote information and knowledge management;
- Strengthen institutional and technical capacities;
- Enhance coordination among stakeholders at different levels;
- Enhance capacities on climate change and GHG data collection, analysis, monitoring, and reporting;
- Integrate climate change consideration into national and sectoral development planning and budgeting processes;
- Develop and strengthen dedicated observation networks to enhance the quality and accuracy of future GHG emission inventories;
- Strengthen research centers on climate change;
- Enhance collaboration between educational, training and research institutions to enable exchange of experiences and lessons learned among different institutions of the respective regions; and
- Promote Involvement of media in awareness raising of climate change impacts and risks

The above-mentioned constraints, gaps and needs are just a few examples to affirm that what has already been reported in several previous submissions remain current day challenges. Therefore, the contents of this section aim to offer a brief synthesis of the core challenges that Yemen continues to face as it struggles to cope with a changing climate.