Frederick S. Pardee Institute for International Futures
UNIVERSITY OF DENVER

Land Degradation and Human Development in Yemen

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A melon crop in Yemen.

PREFACE

This study, “Land Degradation and Human Development in Yemen,” was commissioned by UNDP in 2024 as part of a collaboration with the Frederick S. Pardee Institute for International Futures, Josef Korbel School of International Studies, University of Denver and climate researchers. Yemen is frequently said to be experiencing one of the worst development and humanitarian crises in the world after more than ten years of ongoing conflict. At the same time, it is among the countries most vulnerable to climate change and for decades has faced a worsening water crisis as well as land degradation (including deterioration of historical terracing systems), desertification and soil erosion. This report seeks to better understand how the above-mentioned phenomena could affect economic and human development in Yemen on immediate, medium and long-term timescales.

The report explores the links between climate change, land degradation and desertification, conflict, and human development outcomes in Yemen. This report begins with a review of the literature of the drivers, context, and intervening factors around land degradation and desertification in Yemen so far. This is followed by an analysis of historical subregional data on land degradation and climatic variables within the country. Turning toward the socioeconomic effects, the report first reviews literature on the pathways through which desertification can alter agricultural production and otherwise affect economic and human development. Finally, the report uses integrated modelling techniques and scenario analysis using the International Futures (IFs) model to explore the effect of degradation and restoration pathways on future development in Yemen. The IFs model has previously been applied to assess the effect of ongoing conflict in Yemen on human development and to examine possible recovery pathways in the Impact of War trilogy of reports and the Impact of Climate Change on Human Development produced by UNDP and the Frederick S. Pardee Institute for International Futures.

A farmer tends to his crops in Dhamar Governorate.

EXECUTIVE SUMMARY

Yemen, one of the world's most water-scarce countries, faces rising temperatures, shifting rainfall patterns, and more frequent extreme weather and climate-related disasters that exacerbate land degradation and strain natural and human resources. While warnings about potential environmental and water crises in the country are not new, they have been overshadowed by devastating conflict that has displaced millions and led to one of the worlds worst humanitarian and development crises. Yet these are interwoven challenges. Environmental degradation worsens the damage caused by conflict by affecting the food supply and agriculture. At the same time, it can increase risk of future security challenges, forced migration and clashes over scarce resources.

Understanding and addressing both the conflict and environmental crises are key to shaping a stronger future for Yemen. This report examines land degradation and desertification, focusing on historical causes and the interplay between climate factors and local agricultural policies. It analyses temperature and precipitation trends and their relationship to land degradation to project future patterns. Finally, using integrated modelling and scenario analysis, the report assesses the long-term socioeconomic impacts of land degradation and desertification on Yemen's development.

This report finds that, at a national level, links between land degradation and seasonal or annual precipitation patterns are limited. In western Yemen, particularly in non-agricultural areas, notable relationships between rainfall and vegetation health emerge. These connections weaken in irrigated areas however, indicating a disconnect between climate conditions and land degradation. Rising annual precipitation has been observed since 1981, with records set in 2020 and 2022 when intense, sudden rainfall events led to significant flooding.

The evolution of precipitation patterns in Yemen will play a pivotal role in shaping land degradation risks and opportunities. If episodic rainfall events continue to increase, as seen in recent years, precipitation trends may pose severe degradation risks that need to be mitigated. Conversely, if precipitation increases gradually, the next several decades may present a critical opportunity to strengthen ecosystem resilience by improving integrated water management. Proactive strategies could leverage these favourable trends to bolster agricultural productivity and mitigate long-term land degradation, creating a foundation for more sustainable land use practices across the country. It will be important to assess the benefits and potential negative impacts of these practices, which will not be homogenous, a process that itself will require integration and understanding of available data.

While high-quality historical data on disaster occurrence and impact may not exist across Yemen, any available data should be reviewed for potential co-occurrences. It may not be accurate to say that a locust outbreak, flash flood and heat wave and their respective indirect socioeconomic effects have not co-occurred. The lack of data on both the occurrence of individual hazards and overlapping indirect impacts, however, must be better assessed and understood. When the intention is to 'manage' extreme events, we must keep in mind that particularly devastating events, especially the most complex climatic, environmental and socioeconomic events (and their interactions) are still likely to take place occasionally, regardless of which future precipitation regimes are realized. Fortunately, advances in early warning system and anticipatory action programming design have incorporated a more dynamic thresholding approach, with multivariate triggers comprising various thresholds. Some include mechanisms that allow for abandoning actions when a 'band of appropriateness' for moderate extreme events is bypassed by a forecast or other risk data.

Land degradation and desertification in Yemen are expected to lead to lower agricultural production than in a *Baseline* scenario by reducing both arable land area and productivity. We use the International Futures (IFs) tool to forecast the impacts of a *Land Degradation* scenario on long-term socioeconomic development. By 2050, this scenario could lead to a relative reduction in gross domestic product (GDP) of 5.6 percent compared with the *Baseline*. Five million more people would be in extreme poverty and 4 million more would suffer from hunger.

This future is not inevitable. A range of policy measures can help to curb further deterioration. A *Land Restoration* scenario, focused on halting further degradation, restoring agricultural potential, and implementing environmental improvements, simulates how Yemen could make up for some of this damage and produce broad improvements. This scenario results in an increase in economic output of 15 percent by 2050 relative to the *Land Degradation* scenario, and halts the increase in hunger, resulting in 9 million fewer undernourished people by 2050. Poverty proves sticky, however, and GDP per capita by mid-century is still just two thirds of its pre-conflict value.

Transformative change will require combining restoration measures with broad-based development improvements. An *Integrated Restoration* scenario builds on the *Land Restoration* scenario by ending the current conflict, improving governance and inclusion, and addressing key human development deficits. This scenario is the only one in which Yemen can make up lost ground in human development in just 10 years, based on the Human Development Index, and regain pre-conflict levels of GDP per capita by 2055. By 2050, an *Integrated Restoration* scenario results in 22 million fewer Yemenis in poverty and 13 million fewer undernourished.

A coffee farm in Taiz Governorate, Yemen.

The following broad recommendations are based on this analysis:

- Prioritize efforts to reach a peaceful end to the current conflict.
- Continue to develop quality data and increase the understanding of quality of currently-available data; conduct research to improve the understanding of land degradation and desertification in Yemen.
- Enhance water resource management through regulation, efficient agricultural water use, optimal utilization of surface water, and water harvesting.
- Implement agricultural practices to prevent soil erosion and improve soil fertility, including the restoration of terraces where viable.
- Invest in infrastructure to anticipate, prepare for and recover from climate and weather related extreme events, including through early warning systems.
- Support broad improvements in human and socioeconomic development with a focus on vulnerable populations, including a disaggregation between levels of vulnerability to identify and support the most vulnerable.

The causes of desertification in Yemen are complex and varied, yet Yemen's future will depend on addressing its environmental challenges. This report highlights that climate change will certainly have significant effects in the country and is an important component of land degradation in Yemen. However, integrated water resource management, agricultural practices, and conflict resolution will have the greatest impact on land degradation outcomes in the future. Continued deterioration could further impede the economy, poverty reduction and efforts to improve food security. By contrast, targeted restoration and integrated development efforts could yield significant benefits. Realizing these will require committed, multisectoral action, but with the right investments and a sustained focus on peace and resilience, Yemen can build a more sustainable and prosperous future.

A farmer with his cabbage crop in Dhamar Governorate, Yemen.

CONTENTS

INTRODUCTION

For the past 10 years, civil war has devastated Yemen's economy, fractured its Government, destroyed its infrastructure, displaced millions and pushed much of the population into poverty and hunger. But the country has been experiencing severe environmental degradation for decades. Yemen is one of the most water-scarce countries in the world, a problem made worse by water-intensive agriculture and the deterioration of historical terracing systems. Rising temperatures, changing precipitation patterns, and more frequent and severe extreme weather and climate-related disasters will further exacerbate land degradation. The ongoing war fuels degradation through damage to land and infrastructure and prevents restorative measures. At the same time, deteriorating physical conditions can spur local conflicts over dwindling resources.

Paths to transformative change exist even in the face of these challenges. Unlike global climate change, to which Yemen is highly vulnerable but can do little to mitigate, continued land degradation and desertification are in large part driven by local human activity, including unsustainable practices and poor governance. Moreover, changes to water use, agricultural practices, and infrastructure and energy access can reverse these trends, leading to restoration and sustainable land use.

To halt further deterioration and pursue a future of land restoration, it is critical to better recognize and understand the causes, trends and consequences of degradation. This report explores these issues and the future of land degradation and desertification in Yemen based on an extensive review of existing research, historical subregional climatic and land trends, and scenario analysis. It estimates the long-term effects of degradation, presents a potential land restoration scenario, and considers how to combine restoration with an integrated development push to transform Yemen's future.

This work comes with several limitations. First, data on land and climatic indicators within Yemen are limited and vary in quality. The data are not sufficient to support a fully detailed model of land degradation and environmental effects. There is also a high degree of uncertainty in modelling the effects of land degradation on economic and human development. Some of this is inherent to any effort to forecast outcomes over medium and long time horizons. And the uncertainty is heightened as the effects of land degradation on human development are not fully understood. Even when it is not possible to exactly predict the future of desertification and its effects, integrated forecasting and scenario analysis can help improve our understanding of complex systems and problems where current knowledge is incomplete. The scenarios in this report are meant to explore potential futures but both the severity of desertification and its precise effects on socioeconomic indicators are uncertain. This exercise is therefore not intended to produce specific future predictions but to explore different pathways to help policymakers and practitioners understand how land degradation could interact with human development. It also helps to identify key interventions to mitigate damage and support recovery and restoration.

The report begins with a review of the literature on the drivers, context and intervening factors in land degradation and desertification in Yemen. This is followed by an analysis of historical subregional data on land degradation and climatic variables within the country. Turning towards the socioeconomic effects, the report first reviews literature on how desertification can alter agricultural production and otherwise affect economic and human development. It then uses integrated modelling techniques and scenario analysis to explore the effects of land degradation and restoration pathways on future development in Yemen.

TRENDS IN LAND DEGRADATION AND DESERTIFICATION IN YEMEN

Background

Land degradation refers broadly to the loss in the productivity of land due to human activity and environmental and climatic changes. Global estimates suggest that from 20 to 40 percent of land area is degraded or degrading (Shukla et al., 2019; UNCCD, 2022). The Middle East and North Africa (MENA) region is especially susceptible to land degradation and desertification, characterized by high aridity and water scarcity alongside population growth. Studies estimate that 40 to 70 percent of land in the region is degraded, including a quarter of arable land (Faour, 2014; World Bank, 2019). While rising temperatures and changing precipitation patterns related to climate change exacerbate land degradation, it is often heavily driven by human activities, including unsustainable land and agricultural management (Shukla et al., 2019).

The story of land degradation in Yemen is complex. It encompasses a history of unsustainable agricultural practices, the uncertain implications of climate change, the consequences of water scarcity and reliance on rain-fed agriculture, cycles of drought and flooding and subsequent soil erosion, and interlinkages between conflict and migration. Desertification threatens almost 97 percent of the country's agricultural land (Thamer et al., 2023). The most prevalent pathways to land degradation are aridity, which affects 90 percent of the country, and soil erosion, which affects 10 to 20 percent but is concentrated in agricultural regions (Prăvălie, 2021). The following sections review the literature and current understanding of pathways and factors influencing land degradation.

Water crisis and agriculture

Fresh water in Yemen is increasingly scarce, a shift driven by climate change and interannual and decadal variability (Wilby, 2008). The amount of water per capita is among the lowest in the region and globally, at 86 cubic meters a year, far below the international standard of 500 cubic meters a year (Gadain, 2023). Despite receiving more rain than anywhere else on the Arabian peninsula, Yemen retains just 5 percent of rainfall, much is lost due to evapotranspiration in a highly arid climate and discharge to the sea (Ward, 2014; World Bank, 2010).

With an estimated 90 percent of available freshwater consumed by agriculture (FAO, 2008), Yemen's challenges with water scarcity are inextricably linked to the evolution of its agricultural practices over the past half century. As recently as 1970, agricultural production was focused on staple crops. Yemen imported less than 20 percent of its cereal (Ajl, 2018). But as cheap food imports became more available and urbanization and rising incomes drove market demand, Yemen began to import more of its food, reaching a share of roughly 80 percent today (ACAPS et al., 2023). Domestic production shifted towards water-intensive cash crops, including fruits, vegetables, and most notably qat. A plant with a mild stimulant effect, qat is chewed daily by the majority of men and a third of women in the country (Kasinof, 2023). The size of the area devoted to qat planting increased by an estimated 40 percent from 2016 to 2021 (Abu-Lohom et al., 2022). Qat is estimated to consume more than 40 percent of Yemen's renewable water resources and nearly one third of groundwater withdrawals (van den Berg et al., 2021).

Historically, large water management systems, terracing structures and water harvesting enabled agricultural production despite Yemen's arid climate and challenging terrain. The terracing systems, some of which date back 5,000 years, make up 20 to 25 percent of arable land (Al-Hebshi, 2019; Ghanem et al., 2011). Terracing systems retain runoff water and reduce the degradation of slopes from water erosion (Al-Hebshi, 2019). They allow more agricultural production in an arid climate, harvesting rainfall for local use. Regular maintenance is required, however. For the past 50 years, terrace systems have been gradually abandoned as people migrated from rural to urban areas and from Yemen to Saudi Arabia and other Gulf Cooperation Council countries in search of work (Ghanem et al., 2011).

Population growth in Yemen continues to increase the demand for both food and water. Groundwater abstraction is a major water source today but the depletion of water resources is occurring at twice the rate of its replenishment (al-Mowafak, 2020). The biggest groundwater reserves today are not economically viable, being either very deep or very far from population bases (Ward, 2014).

Climate change, droughts, and flooding

Water crisis and land degradation in Yemen are exacerbated by climate change, although the relationships among climate change, climate variability and water availability are complex. Yemen, along with the MENA region more broadly, is a hotspot of mean surface temperature increase globally (Dogar & Sato, 2018) with the greatest changes occurring in minimum temperatures (Al-Sakkaf et al., 2024). Both the Yemen and the Arab region are also subject to decadal variability in precipitation patterns, with significant swings from one extreme to another. On inter-annual timescales, Yemen is highly sensitive to external climate drivers and modes of variability, such as the El Nino Southern Oscillation and the Indian Ocean Dipole (Dasari et al., 2021).

This increasing variability could both worsen the water crisis and lead to cycles of flooding and drought. Between 1985 and 2015, the area under severe drought increased 26 percent while the area under moderate drought grew by 65 percent. Sand dune cover rose from 11 to 19 percent (Ahmed Ali Dhaifallah et al., 2018).

Droughts affect land and agriculture immediately and deplete land of the ability to absorb water, making it more vulnerable to flooding in the future. A recent study shows that while Yemen as a whole experienced decreased precipitation over the past three decades, future projections show high variability across the country (Al-Sakkaf et al., 2024). Heavier rainfall is expected in the highlands than in other agricultural regions (Gadain & Libanda, 2024).

With projected increased variability and extremes in precipitation patterns, Yemen could experience more frequent and severe floods. Flood risk can be complicated to forecast and depends on flood types and many other factors (Kruczkiewicz et al., 2022) In Yemen, flash floods occur with growing frequency, determined by rainfall characteristics (such as duration and intensity) and soil characteristics and can be analysed using the topographic wetness index, drainage density, and stream power index (Al-Aizari et al., 2022). Multiple highly damaging flood events in recent years include unprecedented flooding in 2024, affecting more than half a million people (IOM, 2024).

Soil erosion

Degradation weakens the ability of land to support vegetation and retain moisture. This, in turn, heightens susceptibility to erosion and reduces fertility, paving the way for desertification as the land transitions towards more arid conditions (Bowyer et al., 2008). Nearly 90 percent of soil degradation in Yemen is due to water erosion, with the remaining share mostly due to wind (Al-Mashreki et al., 2010). Mountainous, hilly and coastal plain areas are especially vulnerable to water erosion due to their steep, long slopes and exposure to storms and excess rainfall. In the highlands region, 40 percent of terraced soil is at high risk of erosion (Pietsch & Mabit, 2012). Terrace degradation contributes to more destructive flooding, lower water absorption and loss of farmland (Al-Hebshi, 2019; Lackner & Al-Eryani, 2020).

Land becomes more susceptible to soil erosion through overgrazing, the unsustainable cultivation of water-intensive crops, excessive groundwater extraction, and deforestation and depletion of tree cover. Soils in Yemen already have low levels of organic carbon (Ziadat et al., 2021), and these have fallen 15 percent further over the last 20 years (Pietsch & Mabit, 2012). Continued soil erosion can lead to losses in soil fertility, productivity and crop yields, and even the abandonment of land (Gomiero, 2016). Sea level rise can also lead to increased salinity in coastal aquifers, further reducing the water supply for major cities and also leading to soil salinization (World Bank, 2010).

Governance

Governance is an important underlying and interrelated component in all causes of land degradation. Yemen has a rich history of managing land and water-related issues. Various types of governance of groundwater management have been in place for as long as these resources have been used. From more traditional practices of community-based governance and decision-making to more recent versions of national government-influenced processes, governance of local groundwater management has been driven by several primary factors: local and traditional knowledge, the management of risks of conflict over water and managing depletion (Taher et al., 2012).

While governance has been designed and can be considered operational in Yemen, outstanding questions relate to policy implementation and a lack of structured and sustainable financial mechanisms (UNDP, 2022). There are significant gaps in appropriate actions to reduce irresponsible and inappropriate groundwater usage, for example, and ultimately, to limit risks of land degradation.

Considering the importance of water and agriculture to the lives and livelihoods of Yemenis, there is an increased responsibility to ensure that governance structures are developed and operate effectively, reflect regional standards and prioritize the most vulnerable and at-risk populations.

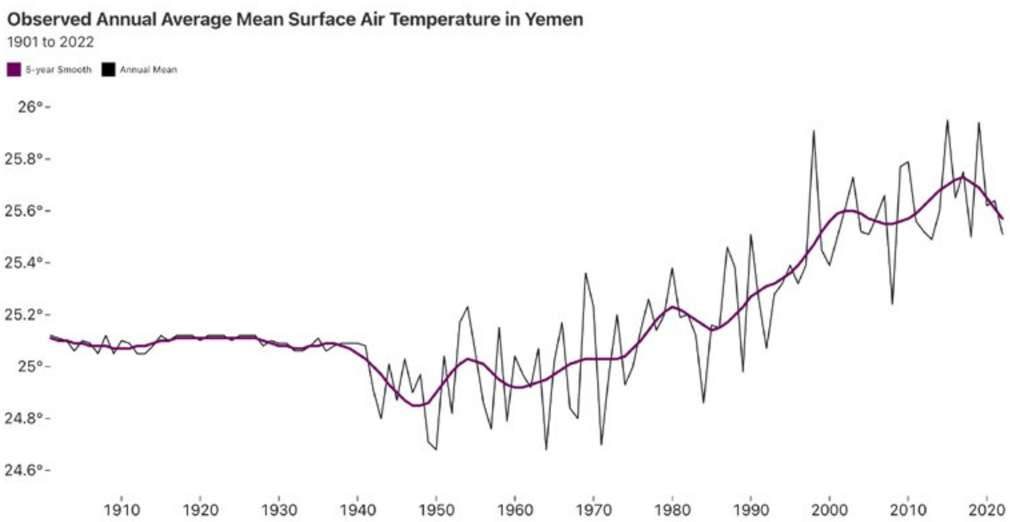
A farm in Dhamar Governorate, Yemen.

LINKS BETWEEN CLIMATE AND LAND DEGRADATION

Background

Since the twentieth century, Yemen's climate has shown distinct trends in temperature and precipitation. Warming has been relatively consistent and homogenous since 1960, affecting all five agroecological zones (Figure 1). Precipitation patterns have exhibited much greater variability, in part due to diverse and complex topography, and Yemen's position along the north-western Arabian Sea with associated risks of tropical cyclones. Its landscape includes mountainous highlands in the west, coastal plains along the Red Sea and Gulf of Aden, eastern plateaus, arid stretches of the Rub al Khali Desert and the unique biodiversity of the Socotra archipelago. Each of these agroecological zones exhibits different rainfall and temperature profiles. This current assessment addresses monthly averages and may not be indicative of shorter-term trends in periods of extreme heat and/or heat waves, which are likely to have implications for land degradation and desertification risks (Ilyas et al., 2023).[1]

Figure 1: Observed annual average surface air temperature, spatially averaged across Yemen, 1901–2022



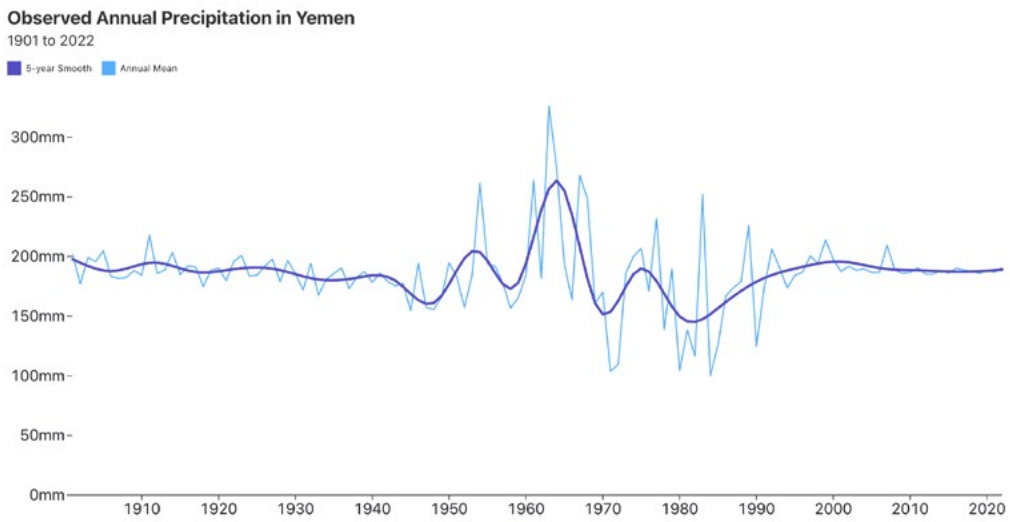
Source: Climatic Research Unit, University of East Anglia; gridded temperature data at 0.5° resolution, version 4.07.

As potential primary drivers of land degradation, precipitation and more specifically changes in precipitation – both excess and deficit, and on a variety of timescales, particularly in the arid and semi-arid regions – have implications for soil health, vegetation cover and agricultural viability (Mehmood et al., 2024). Long-term shifts in precipitation patterns can lead to reduced natural productivity, increased soil erosion and subsequent declines in biomass, all key indicators of land degradation (Herrera Calvo, 2024). Historical and future assessments, however, are limited by the lack of sufficiently granular station distribution, longstanding gaps in data quality, limited downscaled climate research specific to Yemen and sparse historical

1 For a detailed review of the climatology of each agroecological zone, see Hanna et al., (2023).

in situ impact data (Al-Sakkaf et al., 2024). Coarse-resolution climate models, such as the Intergovernmental Panel on Climate Change Coupled Model Intercomparison Project (CMIP6), have limited predictive capacity and present additional challenges to creating a cohesive, future model of impacts from land degradation driven by climate change. Given these data limitations, the approach here is to represent the historical data in an appropriate way while allowing the tailoring of outcomes specifically to understanding land degradation and desertification risks, with the objective to develop both preparedness and risk reduction strategies.

Figure 2: Observed annual average precipitation spatially averaged across Yemen, 1901–2022



Source: Climatic Research Unit, University of East Anglia; gridded precipitation data at 0.5° resolution, version 4.07.

This analysis will first investigate historical trends in precipitation, land degradation and related factors (e.g., groundwater), and then project potential future outcomes and uncertainties across Yemen's varied geographies. Due to the conflict, the availability of in situ data has declined from an already limited base, compounded by uneven spatial distribution. Therefore, this study will primarily use satellite-derived data to build a historical record of climate and weather impacts on land degradation.

To establish a foundation for a baseline assessment of land degradation risk, the analysis will begin with an examination of historical trends in climate and their correlations with subnational proxies for land degradation over time. While various proxies exist, net primary productivity (NPP), has been identified as an important metric in not only understanding the evolution of desertification and land degradation over space and time but also across the spectrum of ecosystem services (Vallecillo et al., 2019). NPP is one of the primary measurements to assess biomass and carbon production per unit area and time period. Some of the main drivers of NPP changes include soil erosion from wind and water, depletion of nutrients, soil compaction and water depletion, amongst others.[2] The importance of these and other factors, however,

2 In arid regions like Yemen, water availability—including precipitation and groundwater—is a primary determinant of net primary productivity (NPP). While precipitation generally enhances NPP, the timing, intensity, and distribution of rainfall events significantly influence its effectiveness; for instance, episodic rainfall may lead to increased runoff, reducing water infiltration and availability for plants. The depth and accessibility of groundwater affect plant root development and, consequently, NPP. Overextraction of groundwater can lower water tables, further diminishing NPP. Other factors, such as temperature and soil nutrients, directly impact metabolic rates and nutrient uptake, respectively. In areas with high evapotranspiration, human interventions (e.g., terracing, water storage) are crucial for enhancing water retention and mitigating the adverse effects of groundwater overextraction on NPP (Wang & Collins, 2024).

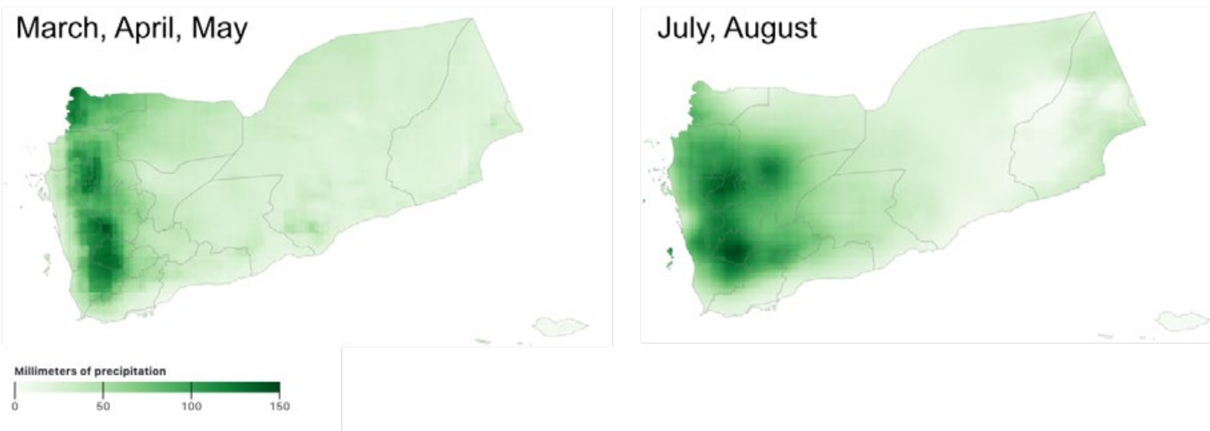
varies significantly by context, including geographic location (Alsafadi et al., 2022). While NPP is an important indicator, particularly of cross-timescale trends in extreme events, it is important not to 'overfit' when exploring the relationship to land degradation and/or desertification. For example, a decline in NPP does not necessarily indicate land degradation as biomass depends on multiple climate and socioeconomic factors (Bai et al., 2008; Hasan et al., 2024; Rousta et al., 2023).

Back-testing historical relationships allows the exploration and validation of connections between climate variables and land degradation indicators—or the recognition of their absence. Where these relationships prove robust, the analysis will be extended forward to construct limited scenarios to explore potential future impacts on Yemen's landscape. As land degradation is inherently multicausal, this analysis will present one pathway for climate impacts; future research should continue to explore more complex landscape-level interactions that may drive additional changes.

Trends in precipitation and net primary productivity

Rainfall data from the Climate Hazards Center of the University of California Santa Barbara (CHIRPS v2) have shown a high level of historical accuracy across Yemen's varied landscapes, and typical heavy and short rainfall events (Al-Falahi et al., 2020). The two primary rainy seasons in Yemen, March through May and July through August, are exhibited below using the CHIRPS pentad product. Rainfall is concentrated in the western highlands and along the Red Sea coastal plain.

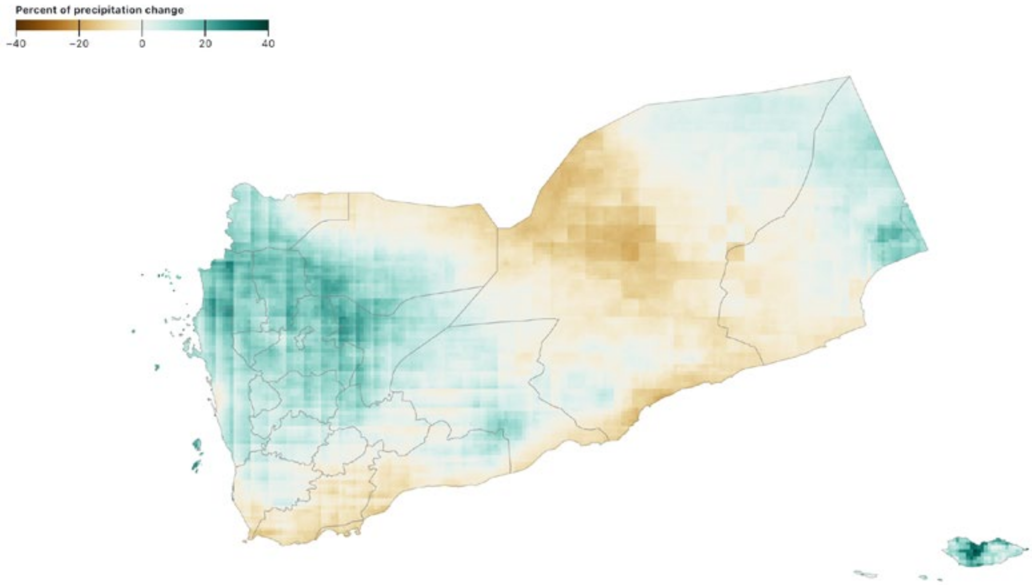
Figure 3: Seasonal annual average precipitation, 1981–2023



Source: CHIRPS gridded rainfall data at 0.05° resolution.

While Climatic Research Unit (CRU) Reanalysis Precipitation data highlight some decadal variability in precipitation (Figure 2), Yemen presents a relatively stable national trend. The pattern varies significantly at the subnational level, however (Figure 3). The north-western portions of the country (across both the western highlands and coastal plain) have experienced increases in precipitation while the southern coast along the Arabian Sea and central dry zone down through the Hadramout southern plateau have experienced similar declines in the magnitude of precipitation.

Figure 4: Observed annual precipitation trends, 1981–2001 compared to 2002–2023



Source: CHIRPS gridded rainfall data at 0.05° resolution.

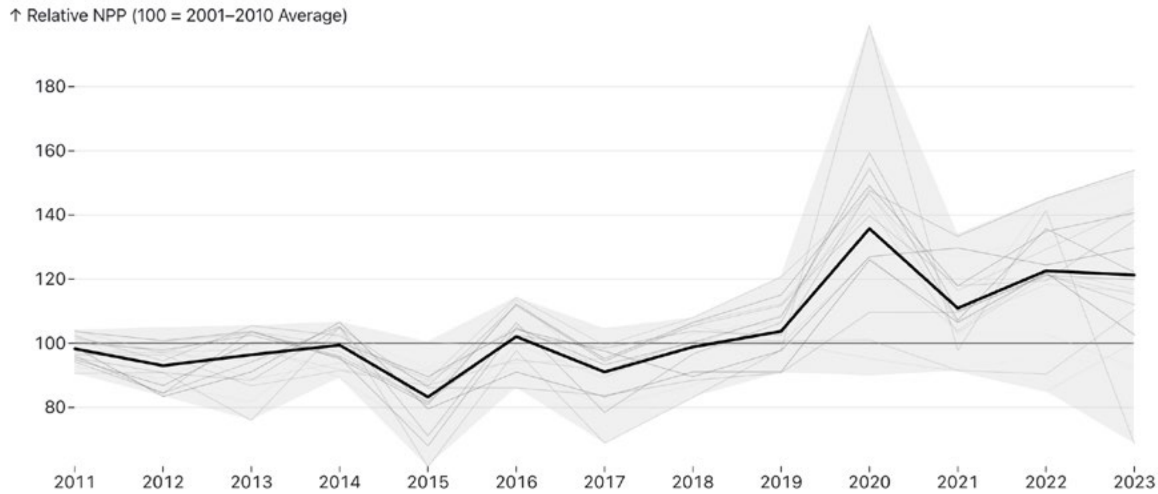
Over the past decade, advances in remote sensing have significantly enhanced the ability to measure and monitor vegetation health across both natural and human-influenced landscapes. In particular, the Food and Agriculture Organization's water productivity through open access of remotely sensed derived data (WaPOR) portal and, in the United States, the National Aeronautics and Space Administration's (NASA) LP DAAC have provided long-running datasets that support detailed assessments of ecosystem and landscape health.[3]

From 2001 to 2023, Yemen exhibited notable fluctuations in NPP. Figure 4 shows relative stability from 2011 to 2018, compared to the first decade of available data (2001–2010). This period of stability was followed by average increases of 20 to 40 percent across various governorates. While a longer time series is needed to establish a clear trend, recent years show increasing divergence in NPP across regions. Data limitations restrict conclusive insights into whether these patterns are driven by single causes or identifiable sources.

Governorates where data show rising precipitation values, such as Ma'rib, also have some of the highest NPP increases. In contrast, Hajjah Governorate—where precipitation has declined along the western coast (Figure 4)—experienced a net decline in NPP in 2023 relative to the baseline period. Similar to the decadal variability observed in the CRU precipitation data, these short-term fluctuations are not guaranteed as a phase shift, but rather underscore the uncertainty surrounding future NPP patterns. Long-term trends should be interpreted with caution as a range of climate, geophysical, and socioeconomic factors—each operating on different timescales—will influence NPP outcomes to varying degrees.

3 Annex 1 provides a small multiple time series of WaPOR NPP data.

Figure 5: Relative change in NPP by governorate, 2001–2023



Source: WAPOR Dekadal NPP 2.0, FAO; gridded NPP data at 250m resolution, relative change in mean daily carbon biomass production per dekad.

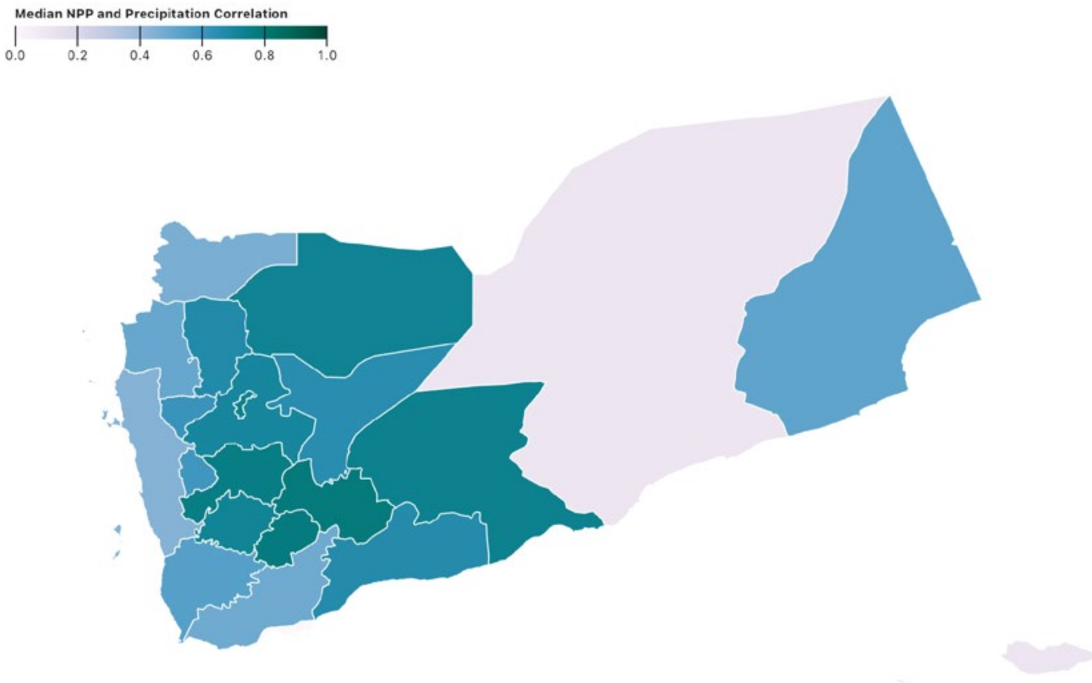
Building on observed trends of increasing and divergent NPP across governorates in Yemen, the following analysis will explore the underlying relationship between precipitation patterns and vegetation health. This approach aims to provide a clearer understanding of how precipitation variability shapes ecosystem productivity, considering both immediate and delayed environmental effects.

At a governorate level, there is a moderate correlation between median annual precipitation and NPP, with an R^2 of 0.37 for the western governorates from 2001 to 2023 (Figure 6). This indicates a general alignment between precipitation variability and vegetation productivity on a year-to-year basis across Yemen. Several governorates show weak or non-significant correlations, however; in some instances, the relationship is inverse, diverging from expected patterns.[4]

Introducing a lag of one year to account for delayed precipitation impacts—such as groundwater recharge and soil moisture retention—maintains the relationship, though with a slight reduction in strength. When extending this to a two-to-five–year moving average, the relationship is somewhat strengthened, hinting at multi-year cycles. Given the limited data set, these multi-year averages should be interpreted cautiously to avoid potential overfitting and overinterpretation. This suggests that while precipitation influences NPP changes, other factors such as soil properties, land use and water management also play significant roles.

4 Governorates with high correlations (>0.7) include Al Bayda, Al Dhale'e, Dhamar, Amanat Al Asimah, Shabwah, Al Jawf, Ibb, Sana'a, indicating a positive relationship. In contrast, governorates such as Hadramaut and Aden show low or inverse correlations (<0.1), suggesting no relationship.

Figure 6: Relationship between NPP and precipitation by governorate, 2001–2023

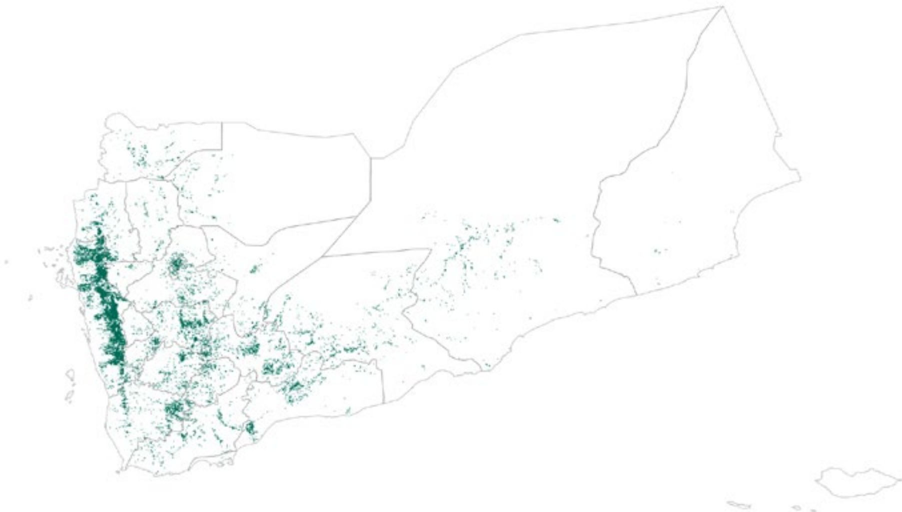


Water management and irrigation practices in areas such as terraced fields and croplands in western Yemen often reduce dependence on annual precipitation. Therefore, in order to appropriately assess the spatial consistency of precipitation relationships, the following analyses must be conducted across both natural and anthropogenically modified landscapes.

The European Space Agency's (ESA) WorldCereal 10m 2021 product provides critical data on crop areas, including confidence levels for annual and seasonal coverage (Van Tricht et al., 2023). Figure 7 highlights high-confidence crop areas in Yemen, particularly in western regions with high NPP in the Red Sea coast and central highlands agroecological zones. These high-confidence areas provide a focused subset within each governorate for more detailed analysis. Results from this analysis indicate that these irrigated zones display a significantly weaker correlation between precipitation and NPP from 2001 to 2023, pointing to irrigation, groundwater extraction and water management practices as possible buffers against precipitation variability. As WorldCereal data identify nearly all cropland in Yemen as irrigated, this limited relationship further provides evidence of the indirect role of precipitation in sustaining productivity in crop areas.

A seasonal lemon crop growing in Yemen.

Figure 7: WorldCereal high-confidence crop areas in western Yemen, 2021

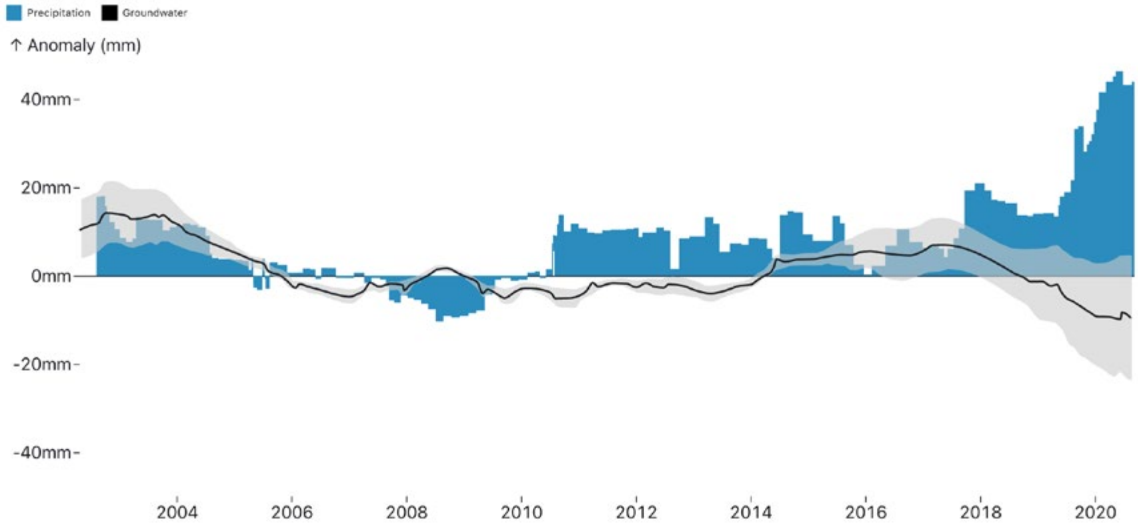


Note: High-confidence crop areas are defined as any crop area product type (temporary crops, winter cereals, spring cereals, maize and irrigated) with a confidence of 50 or higher. Source: ESA WorldCereal 10 m v100, 2021; global crop and irrigation mapping derived from Sentinel-1 and Sentinel-2 data, 10 m resolution.

Given the weak observed relationship between precipitation and NPP in crop areas, further investigation is needed into groundwater and precipitation dynamics across Yemen. Aquifer recharge may still reflect the long-term or delayed impacts of precipitation shifts, making it crucial to understand standard practices for aquifer management, including recharge protocols, and to identify critical thresholds and agreed tolerance levels for uncertainty (Arnous et al., 2020; Taher, 2016). As shown in Figure 8, in recent years, groundwater levels have declined despite record precipitation. While creating a fully integrated model to capture the interactions between groundwater, precipitation and NPP lies beyond the scope of this analysis, existing trends suggest that localized anthropogenic factors likely drive both land degradation and restoration processes within Yemen's agricultural zones.

A cabbage farm in Yemen.

Figure 8: Anomalies in western Yemen groundwater and precipitation, 2002–2020



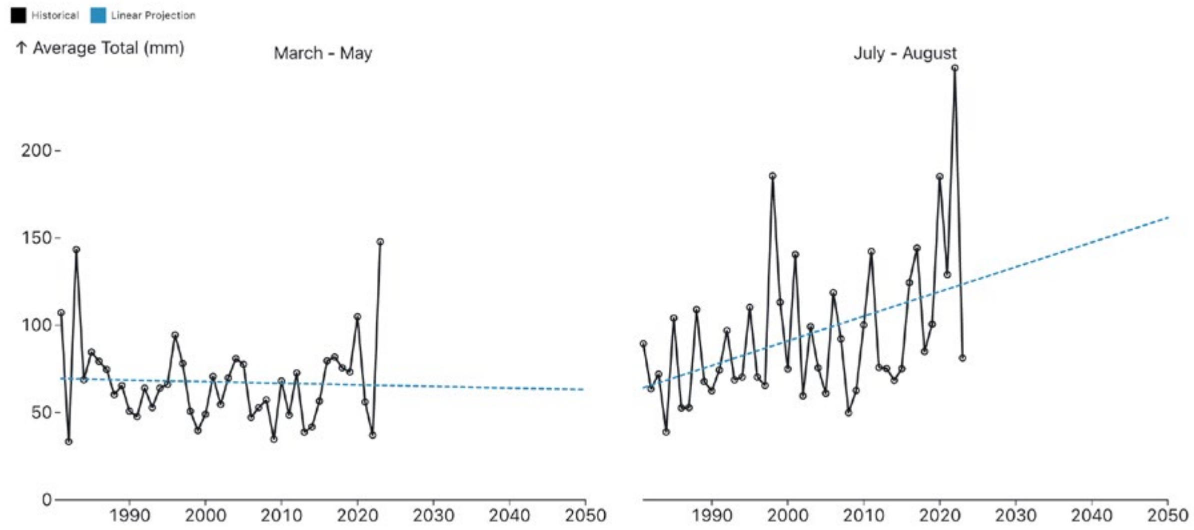
Note: This Replication of western Yemen groundwater and precipitation changes is from CEOBS 2021, based on a 24-month moving mean of anomaly (baseline 2004–2009). Groundwater is calculated from the NASA GRACE gravimetry and Copernicus C3s soil moisture products.

This analysis finds limited links between land degradation and seasonal or annual precipitation patterns on a national scale. Certain areas of western Yemen, however, notably the central highlands, exhibit significant relationships in landscapes not directly impacted by anthropogenic interventions.

In the central highlands, a clear positive trend in annual precipitation has been observed since 1981, with 2020 and 2022 reaching record rainfall levels of nearly 250 millimeters due to intense, sudden-onset rainfall events that triggered persistent flooding. Linear and non-linear analyses reveal increasing July to August rainfall in the central highlands, suggesting a significant seasonal shift in precipitation.[5] Based on these linear projections, July to August rainfall in the central highlands could rise from 65 millimeters in 1981 to 134 millimeters by 2030 and 161 millimeters by 2050.

5 These trends require further investigation, as broader Yemen inland and coastal rainfall patterns may diverge, with some research indicating a potential decrease in inland precipitation compared to the south-west coastal areas (Haleakala et al., 2022).

Figure 9: Trends in seasonal precipitation for the central highlands agroecological zone



Source: CHIRPS gridded rainfall data at 0.05° resolution.

If non-linear changes in rainfall occur—particularly through more extreme and episodic events—existing relationships between precipitation and NPP may be disrupted. Due to spatial and temporal limitations in the satellite-based products used for this analysis, modelling these impacts directly is highly constrained. The literature suggests that increasingly extreme precipitation events may not positively impact land productivity and could instead pose risks to soil integrity and other foundational elements of ecosystem health.

Further research is needed to develop more integrated, ground-truthed models that better address potential shifts in land degradation and examine how water management practices and other localized factors affect landscape health over time. Despite the current uncertainty surrounding these relationships and future forecasts, there is a clear opportunity in the near and medium term for improvements in localized water and land management to play a critical role in enhancing the sustainability of Yemen's landscapes.

If increases in precipitation are driven by extreme, episodic rainfall, risks in terms of land degradation may outweigh potential benefits.

With adequate research, policy and international funding, however, above-average precipitation—excluding the most severe events—could present opportunities to mitigate land degradation and support ecosystem health. While extreme precipitation events often exacerbate degradation, they can be acknowledged and managed proactively. Integrating dynamic, risk-informed forecasting within climate services and early warning systems will be essential to establishing procedures that prioritize vulnerable landscapes and communities at risk of degradation (Akbari et al., 2016; Boali et al., 2024; Kruczkiewicz et al., 2021).

An initial step to holistically address these risks involves distinguishing between types of precipitation changes. This approach guides a more comprehensive framework for managing degradation risks across timescales, and informs tailored policies, financing and actions (Hamed et al., 2024; Wiebelt et al., 2011). Ideally, scenarios for future precipitation patterns affecting land degradation should be co-developed with stakeholders and local communities across Yemen's agroclimatic zones.

Based on historical increasing trends, key precipitation regime distinctions could include:

- Increases in both annual average precipitation and extreme events;
- Increases in annual average precipitation, with stable extreme events; or
- Increases in annual average precipitation, with fewer extremes.

These simplified scenarios highlight the importance of distinguishing between meteorologically extreme events and those with significant impacts on land degradation. For instance, an increase in both annual precipitation and extreme events does not mean that all extremes will worsen degradation. Identifying these distinctions supports the setting of impact-based thresholds. It helps to build resilience to moderate extremes and understand the limits of mitigation strategies.

Even with measures to manage moderate extremes, severe events will still pose risks. Advances in early warning systems and anticipatory action now include dynamic thresholding and multivariate triggers, which adapt or abandon responses if forecasted impacts exceed certain "appropriateness" thresholds for land stability.

Defining flexible 'bands' of resilience to precipitation, particularly in relation to extreme events, is essential for land degradation management. These bands may shift with evolving climate and socioeconomic factors, but provide a foundation for setting actionable targets and managing degradation risks in the decades ahead.

A farmer and his okra yield in Yemen.

SOCIOECONOMIC IMPACTS OF LAND DEGRADATION

Background

Land degradation affects populations directly by determining the land available for agriculture along with its productivity. Globally, agricultural yields are expected to fall on average between 6 and 10 percent relative to projected increases in vulnerable regions, including in MENA (van der Esch et al., 2022). Areas already suffering from water scarcity, such as Yemen, will be especially affected. Desertification affects 3 to 5 percent of arable land in the country each year (CIF, 2012; YFCA, 2023) and an estimated 35 percent of arable land has been lost over the last two decades as a result of soil erosion and water scarcity (Breisinger et al., 2020). Droughts in Yemen have historically led to reductions in agricultural yields of up to 50 percent while also diminishing livestock numbers (Allah et al., 2017; Al-Sharjabi & Alsaghir, 2014).

Land degradation affects economies through the production of agriculture and other natural resources, environmental impacts such as decreases in soil fertility, and reductions in biodiversity and tourism potential. Less directly, its economic effects include those resulting from hazards such as dust storms, the health consequences of lower water quality, and migration away from degraded and desertified areas. Estimates of the global economic losses from land degradation, including the loss of ecosystem services, range from $6.3 trillion to $10.6 trillion annually. This comprises effects on ecosystem services with market value (such as crops and minerals) and those without (such as clean air and water filtration) (ELD Initiative, 2015). With a highly-agricultural economy, Yemen is especially vulnerable to the economic effects of land degradation and climate change (Hanna et al., 2023; YFCA, 2023). One study estimates that land degradation in Marib could lead to the loss of $200 million annually (Al-Akad et al., 2018).

The costs of land degradation are not borne equally. The most affected people are those most dependent on agriculture, natural resources, and ecosystem health, including farmers, rural populations, and the poor. The literature shows associations between high poverty levels and high levels of degradation (FAO, 2013), and that land degradation lessens the poverty-reducing effect of economic growth, widening inequalities (Barbier & Hochard, 2016). While data are limited, there is evidence of degradation leading to poverty at a local level in Yemen. In the highlands region, the loss of agricultural lands resulted in a 25 percent drop in household income for farming families (Pietsch & Mabit, 2012). Droughts in Tihama pushed rural families deeper into poverty (Allah et al., 2017).

By reducing agricultural production and rural incomes, land degradation is a serious threat to food security (Gomiero, 2016; Lal, 2004; Utuk & Daniel, 2015). Droughts and agricultural losses of land in Yemen have already been linked to heightened food insecurity, especially for vulnerable and rural populations (Allah et al., 2017; Pietsch & Mabit, 2012). This effect is amplified as global price shocks due to environmental and geopolitical factors lead to higher prices for food imports.

Rural to urban migration is a regular consequence of land degradation and climate change as farmers lose productive land and the ability to sustain their livelihoods (Allah et al., 2017; World Bank, 2023). In Marib, land degradation pushed 15 percent of the population to relocate in search of better opportunities (Al-Akad et al., 2018). This migration can further exacerbate environmental damage, overtax land and water resources in host communities, and lead to localized disputes and tensions as more people are forced to live off fewer resources (IOM, 2023). Scarce land, food and water resources can also lead to heightened conflict risk. Droughts and rising food prices have led to instability and arrests in many different contexts (Hendrix & Brinkman, 2013). Yemen has a history of disputes over water resources resulting in local and community-based conflicts (Barbier & Hochard, 2016; Ward, 2014).

Estimating the effect of land degradation

This analysis uses the International Futures (IFs) model to explore land degradation and pathways to restoration. Annex 2 offers more information about the model, scenario methodology and specific scenario interventions. Several scenarios were analysed to simulate pathways for land degradation or restoration most relevant to human development in Yemen (Table 1).

Table 1: Descriptions of scenarios used for socioeconomic analysis.

Scenario name	Description
Baseline	**The Baseline scenario simulates a world without future effects of land degradation on economic and human development by turning off relevant linkages in the model.**
Land Degradation	**The Land Degradation scenario models expected global and local effects of land degradation using pathways available in the IFs model, including increasing water scarcity, reductions in agricultural land and yields, and deforestation.**
Land Restoration	**This scenario simulates a set of interventions designed to prevent further deterioration and support restoration directly through improvements to water, agriculture and nutrition, and environmental and energy-related policies. This scenario is best compared to the Land Degradation scenario.**
Integrated Restoration	**The Integrated Restoration scenario builds on the direct land interventions included in the Land Restoration scenario. In addition, it includes broad measures to enhance economic and human development and support recovery from conflict. These measures include improvements to security, governance, gender equality, income inequality and access to education.**

Table 2 provides results for select outcome indicators across scenarios out to 2050. The following sections review results for each scenario.

Table 2: Results for key outcome indicators for all scenarios, 2024, 2030, 2040 and 2050.

	Scenario	2024	2030	2040	2050
GDP at MER (billions of dollars)	Baseline	24.6	28.9	40.4	63.3
	Land Degradation	24.6	28.3	38.1	59.8
	Land Restoration	24.6	30.8	44.8	68.4
	Integrated Restoration	24.6	31.6	50.0	81.8
GDP per capita at PPP (thousands of dollars)	Baseline	1.5	1.5	1.7	2.1
	Land Degradation	1.5	1.5	1.6	2.0
	Land Restoration	1.5	1.6	1.8	2.2
	Integrated Restoration	1.5	1.6	2.0	2.7
Extreme poverty rate (percentage, at $2.15 per day threshold)	Baseline	71	71	66	54
	Land Degradation	71	71	68	61
	Land Restoration	71	71	67	60
	Integrated Restoration	71	65	49	35
Extreme poverty headcount (millions, at $2.15 per day threshold)	Baseline	29	34	40	40
	Land Degradation	29	34	42	46
	Land Restoration	29	34	41	45
	Integrated Restoration	29	31	28	23
Undernourished population (percentage)	Baseline	40	36	32	27
	Land Degradation	40	38	35	33
	Land Restoration	40	31	25	21
	Integrated Restoration	40	29	22	17
Undernourished population (millions)	Baseline	16	18	19	20
	Land Degradation	16	18	22	24
	Land Restoration	16	16	15	15
	Integrated Restoration	16	15	13	11

Source: IFs 8.33.

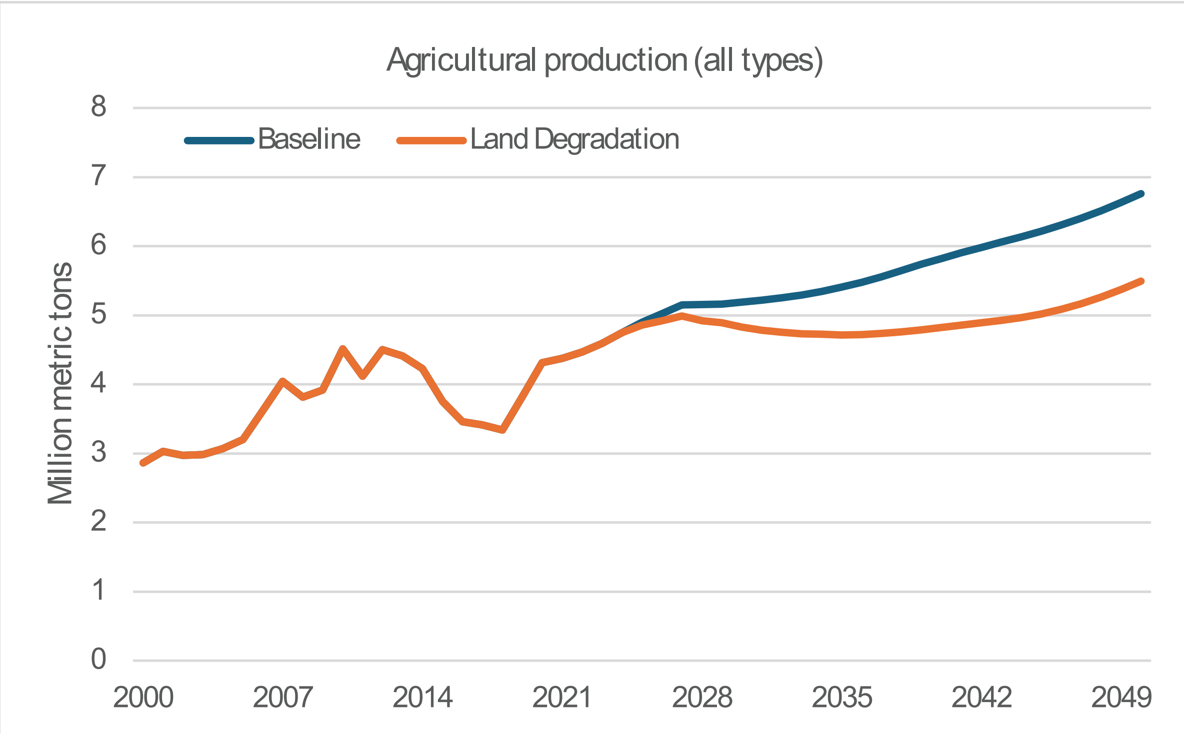
Land Degradation

The Land Degradation scenario models a likely future if land degradation and desertification continue unchecked. It highlights the agricultural and socioeconomic implications of continued environmental crisis. In this scenario, water scarcity worsens as groundwater is rapidly depleted by use in urban areas and by water-intensive farming. Yemen's ability to grow food for consumption is diminished, increasing its reliance on imports for food supply and thus its vulnerability to global shocks and increased food prices. Traditional irrigation systems such as terracing are abandoned beyond repair. Yemen enters more frequent and intense cycles of drought and flooding, which destroy infrastructure and crops directly, and over time reduce the total land available for agriculture.

This scenario is compared with a Baseline scenario, which follows Yemen's business-as-usual economic and socioeconomic development trajectory but does not include the direct effects of land degradation and desertification. A more detailed explanation of scenario interventions is available in Annex 2.

Through reducing arable land and productivity, land degradation lowers crop production and decreases overall agricultural production by more than 1.2 million metric tons or nearly 20 percent less than projected along the Baseline by 2050 (Figure 10). As a result of reduced output, land degradation and desertification are expected to stunt economic growth. GDP is projected to be nearly 5.6 percent lower than the Baseline by 2050, with cumulative GDP losses totalling nearly $50 billion.

Figure 10: total agricultural production (all types) in Yemen



Source: IFs 8.33.

These effects are not distributed equally, and poorer and more vulnerable populations are likely to suffer more from deteriorating environmental conditions. While conventional survey methods to estimate poverty are not possible, nearly a decade of conflict has clearly led to immense suffering in the country (World Bank, 2024). UNDP (2023) estimates that more than 80 percent of Yemenis live in multidimensional poverty; IFs estimates suggest that at least 7 out of 10 Yemenis live below the international extreme poverty line ($2.15 per day in 2017 dollars PPP). In a Baseline scenario, an absence of significant conflict escalation could lead to gradual improvements, although the poverty rate is still projected to be greater than 50 percent by 2050. A Land Degradation scenario slows this alleviation, especially in the long term, resulting in an additional 7 percent of the population (roughly 5 million Yemenis) suffering from extreme poverty.

Yemen's conflict has led to staggering hunger levels. Undernutrition affects an estimated 40 percent of the total population. Even with a Baseline scenario suggesting slow relief over the coming decades, undernutrition does not return to a pre-conflict level for nearly 20 years. Land degradation slows that relief by another decade and by 2050 is responsible for nearly 5 million undernourished Yemenis above the Baseline projection.

Land Restoration

While Yemen stands to suffer from land degradation and desertification, much can still be done to not only address the problem directly but also to mitigate its damage. The Land Restoration scenario models a future in which water management and conservation slows the depletion of groundwater and begins to increase the renewable water supply through improvements to infrastructure and irrigation systems. Additional agricultural efficiency and productivity measures include moving away from some highly water-intensive crops, such as qat, and growing more drought-resistant strains. Where viable, terracing structures are revived and restored. The expansion and improvement of renewable energy production increases access to electricity while lowering demand for firewood and slowing deforestation.

The Land Restoration scenario halts the degradation of cropland while improving the productivity and efficiency of that in use, increasing total agricultural production to just over 8.5 million metric tons by 2050 (50 percent higher than in the Land Degradation scenario). While this reflects significant growth, agricultural production per capita, an indicator falling steadily for the past decades, is expected to remain at relatively the same level in the Land Restoration scenario, whereas it continues to fall in the Land Degradation scenario. As a result, Yemen will continue to rely heavily on imports to feed its population.

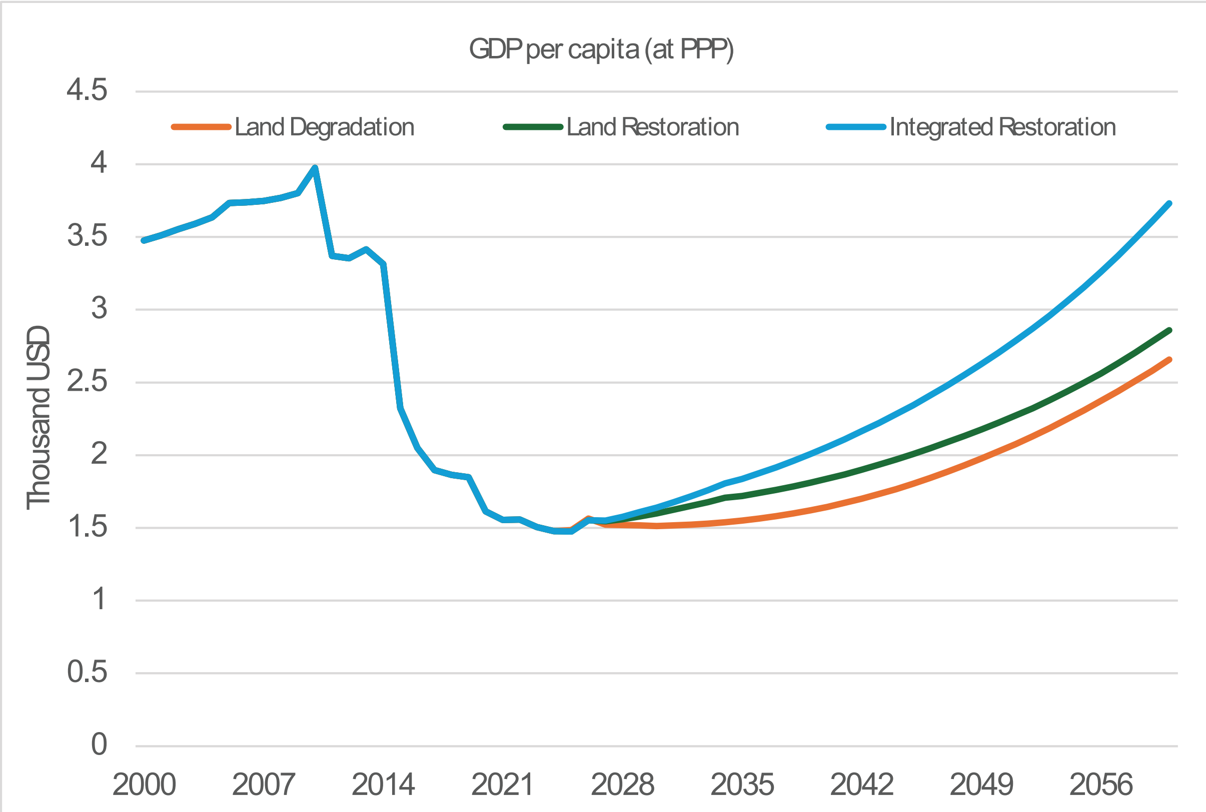
The Land Restoration scenario does help to alleviate poverty levels relative to the Land Degradation scenario, but only slowly. The poverty rate does not meaningfully diverge from the degradation scenario until 2050. By 2060 it falls 8 percentage points below the Land Degradation scenario but is still higher than the Baseline projection. But by including measures that address the distribution of calories directly through maintaining existing access levels, the Land Restoration scenario does lead to 9 million fewer Yemenis being undernourished by 2050.

An Integrated Restoration

It is important to address the direct causes and effects of land degradation to slow desertification and mitigate human suffering. Yemen's development trajectory is already highly precarious, however, with years of devastating conflict setting development back by decades (Hanna et al., 2023). A final scenario, Integrated Restoration, adds measures to the Land Restoration scenario that include improving security, access to education, gender empowerment, and lowering inequalities in access to income and food. This scenario simulates an achievable but ambitious future in which a lasting peace, improvements in governance and inclusion alongside expanded service delivery promote overall human development.

The Integrated Restoration scenario grows GDP overall while improving human development broadly. It allows greater economic output, reaching pre-conflict (2014) levels by 2037, seven years ahead of the Land Degradation scenario. By 2050, GDP in the integrated restoration scenario is more than one third higher than in the Land Degradation scenario, leading to a cumulative $260 billion in GDP gains. At the same time, GDP per capita grows from its current low point of $1,500 to $2,700 by 2050. By 2060, GDP per capita ($3,700) exceeds Yemen's 2014 level and nearly catches back up to the country's historic high ($4,000 in 2010).

Figure 11: GDP per capita under different scenarios

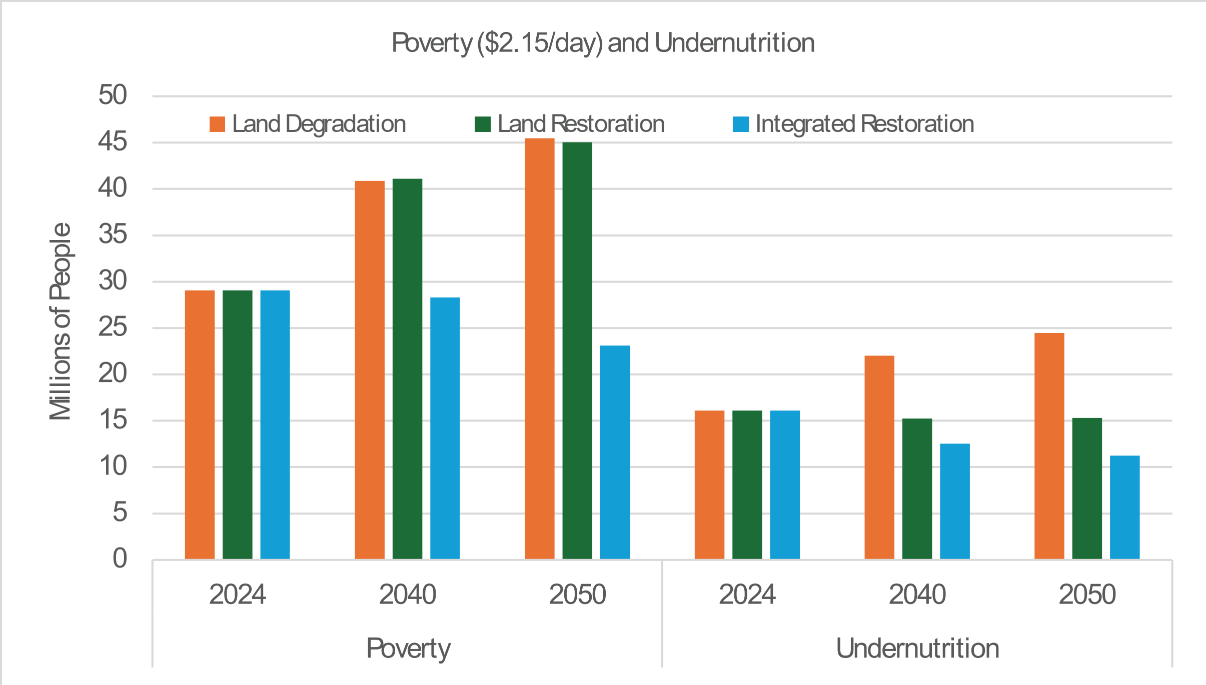


Source: IFs 8.33 in 2017 dollars PPP.

Crucially, an Integrated Restoration scenario must ensure that growth and other improvements target those who are the worst off and improve equality in income and access to nutrition and services. This scenario combines measures to grow the economy and food production with steps to improve the distribution of income and calories, targeting poverty and undernutrition directly. Under a Land Degradation scenario, a weak economy and growing population lead to the number of people in poverty growing from nearly 30 million today to 45 million by 2050. An Integrated Restoration scenario halts and eventually reverses that trend, leading to a difference in poverty with the Land Degradation scenario of more than 20 million by mid-century.

Similar improvements are seen in undernutrition, which is projected to climb from an estimated 15 million today to nearly 25 million by mid-century in the Land Degradation scenario. An Integrated Restoration scenario improves caloric distribution and reduces the number of undernourished people to 11 million by 2050.

Figure 12: Differences in poverty and undernutrition headcounts across scenarios



Source: IFs 8.33. Based on a $2.15 per day poverty line in 2017 dollars PPP.

A Yemeni farmer surveys his farmland.

RECOMMENDATIONS

This section lists several recommendations to help address the risks and challenges of land degradation and desertification in Yemen. While there is a critical and urgent need to mitigate socioeconomic damage from land degradation, it is also important to build resilience and improve development more broadly.

These recommendations are not specific policy prescriptions or necessarily applicable to all regions of the country. Local experts, policymakers and practitioners must carefully consider which interventions are right for their environment and context, and how to tailor them accordingly, including based on factors such as the population profile, conflict exposure and governance capacity.

Continue to support efforts to build a lasting peace through a peaceful end to conflict and effective governance.

The greatest threat to Yemen's future is continued conflict. It has already set human development back by two decades (Hanna et al., 2023; Moyer et al., 2019) and poses a major barrier to acting on climate change, the water crisis, and desertification. Achieving a successful and lasting peace is a key component and important prerequisite to improvements modelled in the Integrated Restoration scenario.

Improve understanding of land degradation and its effects through enhanced data standards and research.

The development of data standards to improve the quality of data production, dissemination and integration, along with an associated call to prioritize both core natural and applied interdisciplinary research, are critical to addressing challenges now as well as evolving patterns of land degradation and environmental change in the future. As an example, sufficiently detailed landcover maps are needed to understand the spatiotemporal evolution of precipitation and evapotranspiration in the most vulnerable valleys and wadis (Al-Qubatee et al., 2023; Noaman, 2021). Closing such data gaps will require a more robust and sustainable network of reporting stations as well as support for data cleaning and analysis and integration into policy and practice (Al-Falahi et al., 2020; Kruczkiewicz et al., 2023; Mason et al., 2015). Improved data and monitoring of land use, soil health, water levels, and crop conditions could help support early warning systems, policy adjustments, and real-time decision-making (Al-Mashreki et al., 2010; Faour, 2014).

Beyond data production, maintenance and integration, further research can build a greater understanding of the drivers, intervening factors, and implications of land degradation and desertification. This includes a more granular understanding of patterns of human mobility and migration and their interaction with patterns of land degradation, and attribution to both climate and socioeconomic forces. It also calls for more research on the geospatial distribution as well as interannual and decadal variability of climate trends and fluctuations.

Move toward more sustainable use of scarce water resources by regulating groundwater extraction and optimizing water use in agriculture.

Groundwater fluctuations have occurred over time; however, evidence indicates that these fluctuations are becoming more extreme, more sudden and less predictable. Enforced extraction limits, including through community and local governance frameworks, could curb the overuse of aquifers and reduce conflicts over resources (IOM, 2023; Lackner & Al-Eryani, 2020). Policies related to water governance must account for the increasing variability in groundwater levels and risks of changes due to long-term stresses as well as shocks.

Agricultural practices that overtax the water supply should be addressed. This may include introducing more efficient irrigation technologies such as drip irrigation or promoting rainwater harvesting to maximize water availability in rain-fed areas (Almeshreki et al., 2012). It may also encompass encouraging a transition towards more drought-resistant crop varieties and away from highly water-intensive crops, such as qat.

Implement agricultural practices to support soil and land restoration, such as the rehabilitation of terraces and more sustainable farming practices.

Yemen's terrace system has historically played a significant role in managing agriculture in arid conditions. Its restoration could make an important contribution to combatting land degradation and restoring land quality and productivity (ICED, 2019). Terrace rehabilitation, especially in the highland areas, could reduce soil erosion, increase water retention, and improve agricultural productivity (Al-Hebshi, 2019). Financial and technical support for continued terrace maintenance could prevent further deterioration in regions with high rural-to-urban migration (Ghanem et al., 2011).

Additional farming practices, such as crop rotation and agroforestry practices, could improve soil fertility and support environmental resilience (Gomiero, 2016). Reducing reliance on chemical fertilizers would help to maintain soil quality and protect biodiversity (Al-Mashreki et al., 2010).

Establish infrastructure adapted to extreme events.

Climate change could lead to the increased frequency and severity of extreme events, such as flooding and heat waves, as well as interconnected compound events whereby individual hazards interact with each other (such as the impact from extreme heat interacting with the impact from tropical cyclone related hydrometeorological hazards). Addressing desertification challenges should include planning for these occurrences by improving and adapting infrastructure and services to support affected areas. Early warning systems should be designed to address specific risks related to land degradation and desertification (AL-Falahi et al., 2024; IFRC, 2024). Infrastructure as noted here refers to various necessary elements including physical, social and digital infrastructure to ensure the warnings can be rigorously co-developed with the most vulnerable communities, issued in an accessible and robust way, while leading to sufficient recognition to the increased level of risk identified and leads to subsequent action that decreases risk.

Develop broad and integrated development policies that support vulnerable populations and improve human development.

Land degradation will have increasingly more significant impacts on the more vulnerable and lower income populations, yet it can be said that all Yemenis and all sectors will experience direct or indirect impacts to some extent. While all populations, communities and sectors must be supported, the extent to which the most vulnerable and lowest income communities can be prioritized is a critical lens that must be applied for all next steps. Doing so should include prioritizing rural populations and smallholder farmers who depend heavily on the land for their livelihoods and Yemenis that have been involuntarily forced to move. Building resilience to the consequences of land degradation means not only addressing land, water, and agricultural systems, but also understanding social dynamics and tailoring policies that contribute directly to poverty alleviation, food affordability, access to healthcare and education services. An integrated approach to land restoration must identify opportunities to recover from and move beyond the damage to human development and infrastructure done by the war, and to directly support the lives and livelihoods of Yemenis.

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ANNEX 1: CLIMATE AND LAND DATA

Figure A.1.1: Evolution of net primary productivity, 2009–2023

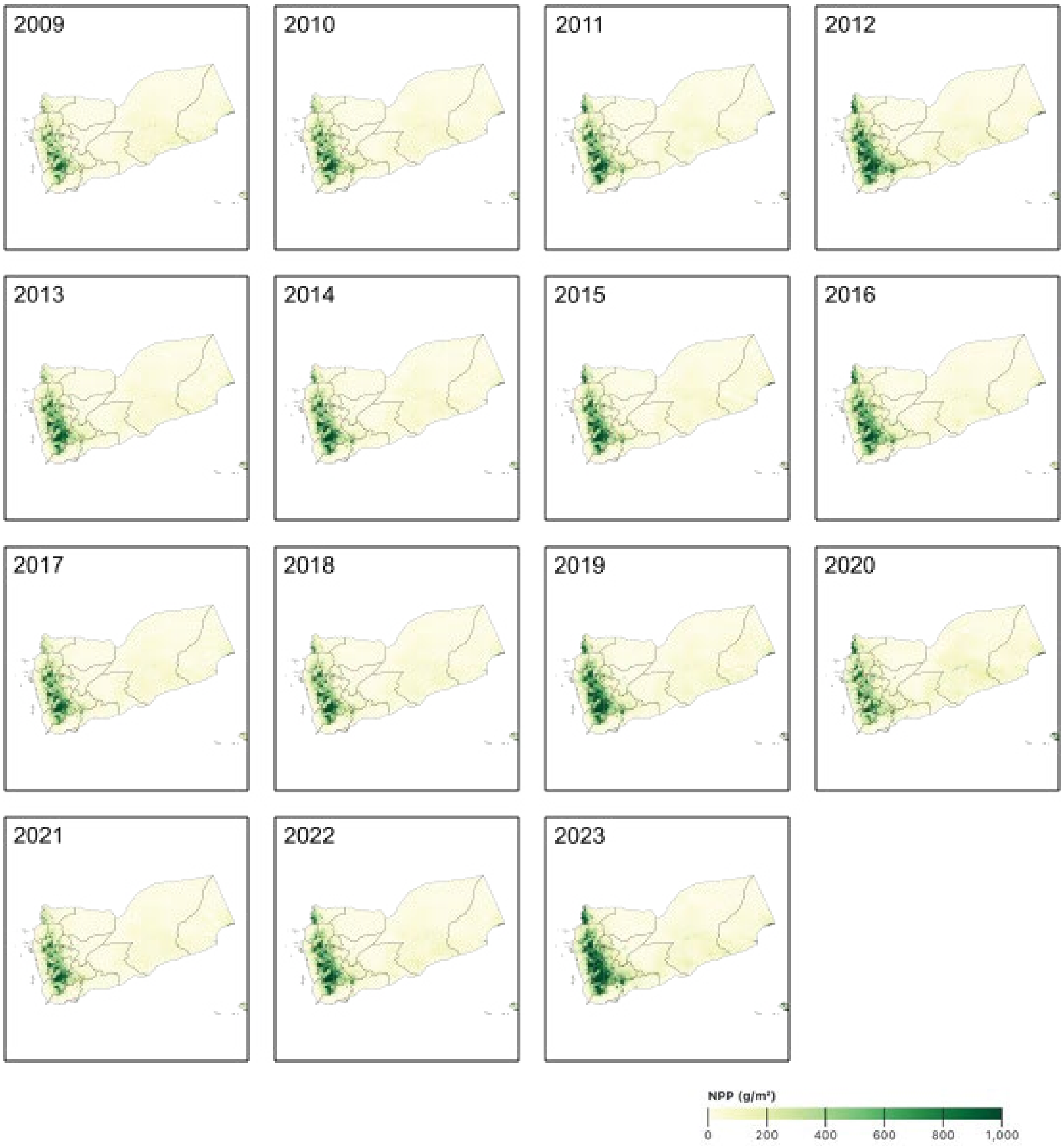
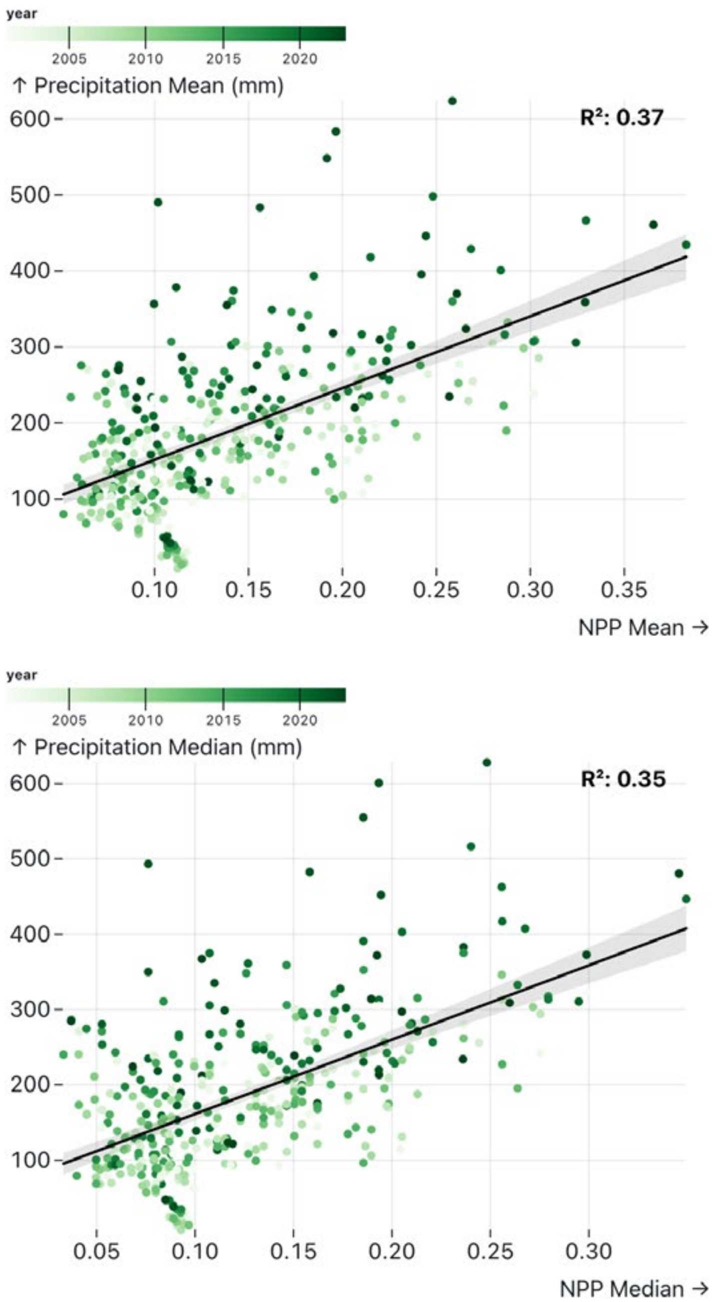
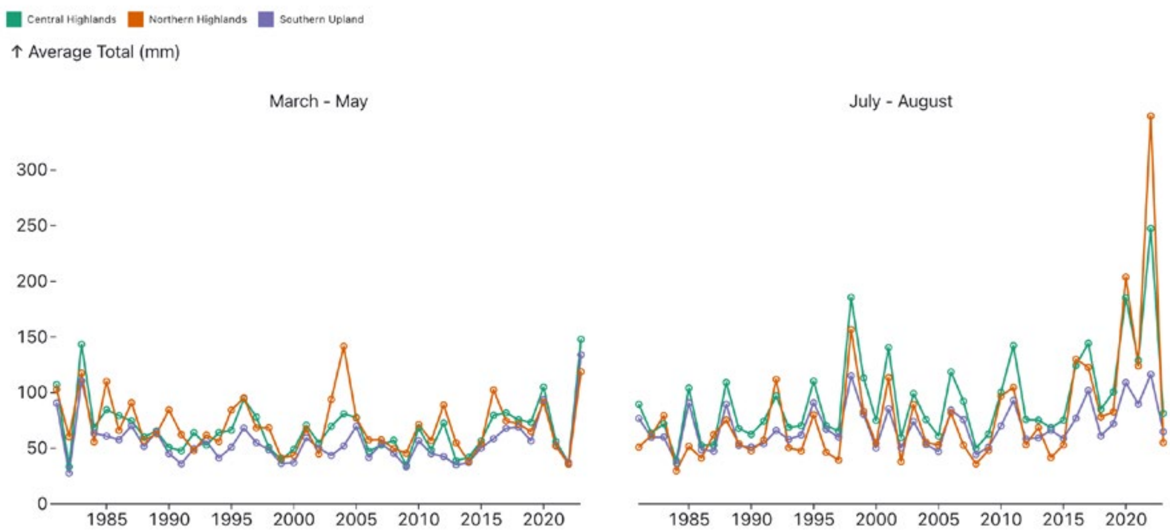


Figure A.1.2: Relationship between NPP and precipitation in the western governorates, 2001–2023



Note: A subset of agroecological regions within the western governorates, the central highlands and southern uplands shows stronger relationships. This pattern is concentrated in the central highlands, covering the governorates of Taizz, Ibb, Al Dhale'e, Abyan and Lahj, with a mean R^2 of 0.63 and a median R^2 of 0.58.

Figure A.1.3: Precipitation by agroecological zone, 1981–2023



ANNEX 2: DETAILED ASSUMPTIONS FOR IFS SCENARIOS

This annex includes detailed information about the interventions used in the IFs model for each of the four socioeconomic scenarios assessed for this report: Baseline, Land Degradation, Land Restoration, and Integrated Restoration. All scenarios were run in IFs version 8.33, available for free download.6 More information about IFs is available at https://pardeewiki.du.edu/ and in Hughes (2019).

Baseline

The Baseline scenario includes several interventions meant to adjust the baseline in the model to reflect data and known information about Yemen's context as well as interventions meant to shut off forward linkages from climate and land-oriented variables.

Table A.2.1: Detailed interventions for the Baseline scenario.

Intervention	General description	Literature backing	IFs operationalization
Income inequality increase	The Gini coefficient is increased by 20 percent and maintained through 2100.	In the current version of IFs, this intervention yields a level of poverty similar to that modelled in previous work looking at the effect of conflict on Yemen (Moyer et al., 2019), which was supported by two microsimulation studies (Arezki, Mottaghi, Barone, Fan, Harb, et al., 2018; Arezki, Mottaghi, Barone, Fan, Kiendrebeogo, et al., 2018).	*ginidomm* initialized at 1.2 and held over the horizon.
Caloric coefficient of variation	The caloric coefficient of variation is increased by 20 percent and maintained through 2100.	The coefficient of variation parameter mirrors that of the Gini, reflecting inequality in access to food.	*clpccvm* initialized at 1.2 and held over the horizon.
Reductions across the education system	Educational variables, including intake, graduation and transmission rates across primary and secondary levels, are reduced.	Conflict in Yemen resulted in reduced access to education (Moyer et al., 2019; UNICEF, 2018). This intervention adjusts the current path to reflect this challenge early in the time horizon.	The following parameters are changed to 0.75 through the current conflict years before being slowly returned to 1 by the end of the horizon: *edpriintnm, edprisurm, edseclowrgram, edseclowrtranm, edsecupprgram, edsecupprtranm.*

6 See: https://ifs02.du.edu/IFs%20with%20Pardee%208_33%20October%2022%202024.zip

Reduction in electricity access	Electricity access is reduced to 43 percent of the population.	According to the latest data from the International Energy Agency (IEA, 2020), in 2019, just 43 percent of Yemenis had access to electricity.	*infraelecaccm* for the total is set at 0.55 and maintained throughout the horizon.
Climate change forward effects turned off	A number of parameters are used to mute the effect of climate change and land degradation on agriculture and the economy in the IFs model.	NA	*envco2fert* and *envylchgm are* set to 0 through the horizon, turning off effects on crop yields. *climeconimpsw* and *climeconimpperctrysw* are set to 1 through the horizon while *climeconimpsq* is set to 0.

Land Degradation

Interventions in the Land Degradation scenario are meant to simulate the pathways through which land degradation and desertification are likely to impact human development in Yemen according to data and literature. These interventions are made on top of the Baseline interventions listed in Table 4.

Table A.2.2: Detailed interventions for the Land Degradation scenario.

Intervention	General description	Literature backing	IFs operationalization
Climate change forward effects turned on	Climate change effects are enabled, allowing changes in temperature, water resources, and precipitation to affect crop yields.	NA	*envylchgm* parameter turned on and increased from 1 to 4 over 30 years.
Income distribution	Gini coefficient increased, reflecting worsening income inequality due to climate and degradation.	The literature suggests that climate change is likely to lead to an increase in income inequality. Paglialunga (2022) identifies a relationship in which a 1 percent increase in temperature is associated with a 0.5 percentage point increase in the Gini coefficient on a 100-point scale.	*ginidomm* increases from a baseline of 1.2 to 1.5 over 30 years. This results in a change to Gini reflecting the elasticity identified in Paglialunga 2022.
Increased inequality of calorie access	Growing food insecurity through a rise in calorie access inequality	Climate change is likely to result in increasing inequality in access to food as a result of changes to local agricultural production and global food prices (Havlík et al., 2015).	*clpccvm* increases from a baseline of 1.2 to 1.4 over 25 years.

Cropland area	Cropland is reduced, reflecting losses due to desertification.	Several sources report that desertification has led to a loss in arable land of 3 to 5 percent annually (CIF, 2012; YFCA, 2023), while Breisinger, et al. (2020) finds that 35 percent of arable land has been lost over the past 20 years.	*ldcropm* reduced from 1 to 0.75 over 35 years.
Agricultural yields	Agricultural productivity (average crop yield) falls due to land degradation and environmental stress.	The World Bank (2010) finds that depletion of water resources alone, not including the effects of climate change, could lead to a 40 percent of reduction in agricultural production.	*ylm* reduced from 1 to 0.6 over 35 years.
Water resources	Total exploitable renewable water resources falls, reflecting increasing water scarcity.	Yemen's water resources are dwindling (World Bank, 2010) with groundwater sources being depleted twice as fast as they are being recharged (al-Mowafak, 2020).	*watresexploitrenewm* for total is reduced from 1 to 0.6 over 10 years.
Deforestation	Deforestation increases slightly over time as the population increasingly depends on forest resources.	An increased reliance on firewood has led to deforestation with one interview suggesting that 213 kilometers of land around Sanaa was lost over three years (Abdullah, 2021).	*forest*m adjusted downward to 0.95 over 10 years before being returned to 1 over an additional decade**.**

Land Restoration

The Land Restoration scenario assumes the levels of land degradation in the Land Degradation scenario and includes all other adjustments from the Baseline scenario.

Table A.2.3: Detailed interventions for the Land Restoration scenario.

Intervention	General description	IFs operationalization
Maintenance of cropland	Total cropland area is maintained rather than falling as in the *Land Degradation* scenario.	*ldcropm* is held over the horizon.
Improved food access	Distribution of calories becomes more equal, reflecting increased access to food.	*clpccvm,* initialized at 1.2, reduces to 1 over 10 years.
Increased agricultural yields	Improvements in crop yields reflect measures to improve agricultural productivity and efficiency.	*ylm* is increased to 1.3 over 10 years.

Reduced agricultural losses	Agricultural production becomes more efficient as losses during both production and transportation are reduced.	*aglossprodm* and *aglosstransm* are reduced to 0.8 over 10 years.
Inequality maintained	The inequality-increasing effects of climate change modeled in the *Land Degradation* scenario are prevented.	*ginidomm* is maintained at 1.2 through the horizon.
Water resources	Water management allows for a sustained increase in the total exploitable water resources.	*watresexploitrenewm* is increased to 1.1 over 10 years.
Forest restoration	Small amounts of forested and wooded areas are restored.	*forestm* is increased to 1.1 over 10 years, maintained for 5, and decreased back to 1 over 10 years.
Improved irrigation efficiency	Techniques for irrigating land are improved and more efficient, proxied by increasing the land area equipped for irrigation.	*landirareaequipm* is increased to 1.1 over 10 years.
Expanded electricity access	Electricity access expands across the populations.	*infraelecaccm* is increased from an initialization of 0.55 to 1 over 10 years.
Increased solar energy production	Generation of renewable energy, especially from solar sources, is boosted.	*enpm* for Solar category is increased to 3 over 10 years.

Integrated Restoration

Finally, the Integrated Restoration scenario includes all interventions in the Land Restoration scenario including any remaining adjustments from the Land Degradation and Baseline scenarios.

Table 6: Detailed interventions for the Integrated Restoration scenario.

Intervention	General description	IFs operationalization
***Land Restoration* scenario fulfilled**	All interventions from the *Land Restoration* scenario are included in this scenario as well.	All in Table A.2.3.
Improved security situation	Conflict declines as measured by the likelihood and magnitude of conflict.	*sfintlwaradd*, a measure of the likelihood of internal war in a forecast year is reduced to –.4, while *sfintlwarmagm*, measuring the magnitude, is reduced to 0.8, both over 10 years.

Government effectiveness	Government effectiveness, as measured by The World Bank's World Governance Indicators, improves.	*goveffectm* is increased to 1.5 over 10 years.
Welfare support for poor households	Funds are transferred from the government and directed to increasing consumption in poor households.	*govhhtrnwelm* is increased to 1.4 over 20 years, directed toward unskilled households.
Gender empowerment	Gender empowerment and equality, as proxied by the Gender Empowerment Measure, improves, reflecting greater equity for women.	*gemm* is increased to 1.5 over 10 years.
Female labor force participation	Women's participation in the labour force grows.	*labparm* for females is increased to 1.5 over 10 years.
Improvements across the education system	The education system improves more rapidly from the damage experienced due to conflict.	The following parameters are initialized at 0.75 and returned to 1 over 10 years: *edpriintnm, edprisurm, edseclowrgram, edseclowrtranm, edsecupprgram, edsecupprtranm.*
Increased remittance receipts	Leveraging the diaspora, remittance receipts in Yemeni households increases.	*xworkremitinm* is increased to 2 over 10 years.

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