Adaa Foundation
مؤسسة أداء للدراسات والابحاث

State of the Environment Report

Yemen

Evidence for Resilience,
Insights for Action

June 2026

An evidence-based assessment of climate, water, land, and marine systems in Yemen

Adaa Foundation
مؤسسة أداء للدراسات والابحاث

ADAA FOUNDATION FOR STUDIES AND RESEARCH

STATE OF ENVIRONMENT REPORT
Yemen

Evidence for Resilience
Insights for Action.

Final Report

Date: 26 July 2026

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STATE OF THE ENVIRONMENT REPORT / ADAA FOUNDATION

Yemen's Changing Climate:
A Decade in Data

From a fragmented monitoring network to an independent data baseline, 2014-2024.

3 SATELLITE DATASETS | 21 GOVERNORATES | 57 SOURCED FINDINGS | ZERO-BUDGET DESK ANALYSIS

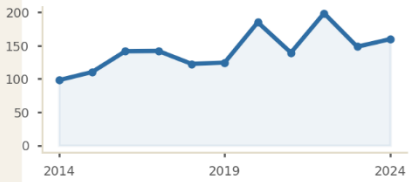
+6.3 mm/yr	65 m³	1/10	0.05 %
National rainfall trend 2014-2024, p=0.018	Water availability vs. 500 m³ scarcity line	Climate governance functions in place	Yemen's share of global GHG emissions

Three Datasets, One Pattern

Independent satellite evidence, cross-validated rather than assumed

Rainfall Trend

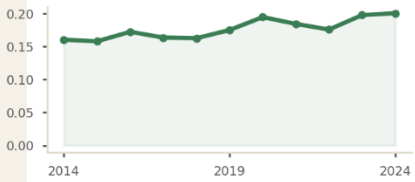
CHIRPS national mean, 2014-2024



+6.3mm/yr — significant (p=0.018)

Vegetation Trend

MODIS NDVI national mean



20 of 21 governorates significant

Strongest Trends

Top governorates, rainfall mm/yr

All 5 significant at p<0.05

KEY FINDING — WHY STATISTICAL TESTING MATTERED

Yemen's rainfall increase is real, but the intuitive story and the defensible one are not the same. The four governorates that looked strongest by raw trend size alone — Amanat Al Asimah, Sana'a, Amran, Al Mahwit — proved statistically indistinguishable from noise once tested. This was caught and corrected before publication, not after.

Beyond the Headline Numbers

Context that changes how the top-line figures should be read

WATER SCARCITY

65 m³

Per-capita freshwater availability vs. a 500m³ scarcity threshold — one of only 4 countries globally both low-income and water-scarce.

GOVERNANCE GAP

1 of 10

Climate governance functions rated fully in place (World Bank, 2022). The rest span law, strategy, budgeting and procurement.

EMISSIONS CONTEXT

0.05%

Yemen's share of global GHG emissions — among the lowest contributors, despite very high documented climate risk.

Reported Honestly, Not Smoothed Over

1 History vs. Recent Trend

World Bank's 50-year record (1971-2020) shows a declining, non-significant trend. Adaa's 11-year record shows a significant increase. Both reported together.

2 Terrain & Station Sparsity

CHIRPS accuracy degrades in mountainous, gauge-sparse terrain — exactly where 70% of Yemen's monitoring stations are non-operational.

3 Multiple-Comparisons Risk

21 separate governorate regressions were run per indicator; a methodological note on false-discovery risk is included, not omitted.

ROADMAP: COMPLETE — State of Environment baseline → NEXT — Institutional Governance Gap Assessment → THEN — Climate Finance Readiness Mapping

Methodology: CHIRPS v2.0, MODIS NDVI/land cover, JRC surface water, and Climate TRACE data via Google Earth Engine, cross-validated against World Bank, UNDP and UNFCCC sources. Every original trend tested for significance (p<0.05); cross-source discrepancies disclosed, not omitted.

Adaa Foundation
Working Draft, July 2026

Executive Summary

Yemen faces a compounding set of environmental and climate pressures layered onto more than a decade of armed conflict: rising temperatures, an increasingly erratic and locally intensifying rainfall pattern, severe and worsening water scarcity, extensive agricultural land degradation, and a coastline highly exposed to sea-level rise and storm surge. Half of all Yemenis are already exposed to at least one climate hazard, and without intervention, climate change could reduce Yemen's annual GDP by an average of 3.9% by 2040.

This report combines a systematic review of existing international and Yemeni literature with original data analysis conducted by Adaa Foundation, using open satellite and global climate datasets. A central original finding is a three-way cross-validation across independent NASA/satellite-derived datasets: rainfall (CHIRPS), vegetation greenness (MODIS NDVI), and land cover change (MODIS land cover) all independently show the same geographic pattern — Yemen's northern highland and central governorates (notably Sana'a, Hajjah, Dhamar, and Al Hudaydah) getting simultaneously wetter, greener, and gaining cropland at the expense of barren land over 2014-2024, while the arid eastern governorates remain comparatively static. Every trend reported from original analysis has been tested for statistical significance rather than presented on the basis of raw magnitude alone; this process identified and corrected an early error in which the largest-looking rainfall trends were mistaken for the most reliable ones. A separate original analysis of surface water and sector-level greenhouse gas emissions is also presented.

Yemen's policy and institutional response — spanning its 2009 National Adaptation Programme of Action through to its current National Adaptation Plan process and 2025 NDC 3.0 Vision — is substantial on paper but persistently constrained by fragmented governance: the World Bank's own 2022 assessment found only 1 of 10 core climate governance functions actually in place. This report is intended, in part, as a direct contribution toward closing the documented climate data gap underlying this constraint.

This version of the report reflects a full review of the two central primary sources (the World Bank's Yemen Country Climate and Development Report and its Water Security Diagnostic), read in complete form rather than via secondary summaries. This full review surfaced an important nuance handled explicitly in Chapter 1: the World Bank's own longer-term historical analysis (1971-2020) finds Yemen's national rainfall trend was slightly declining and not statistically significant, in contrast to Adaa's own statistically significant recent-decade (2014-2024) finding of increasing rainfall. Both findings are presented together, since they cover different periods and this is not read as a contradiction to be resolved by omission.

This report is intended not merely as a synthesis of existing literature, but as the first independently produced, satellite-based national environmental monitoring baseline for Yemen — demonstrating that credible, transparent environmental evidence can be generated using open data even where in-country monitoring infrastructure has collapsed.

How to read this report

This is a synthesis and analysis document. Original Adaa Foundation analysis is clearly labelled throughout; all other findings are attributed to their original source. Figures drawn from different sources may use different methodologies, time periods, or definitions, and are not always directly comparable — this is noted where relevant rather than smoothed over.

Chapter 1: Climate and Atmosphere

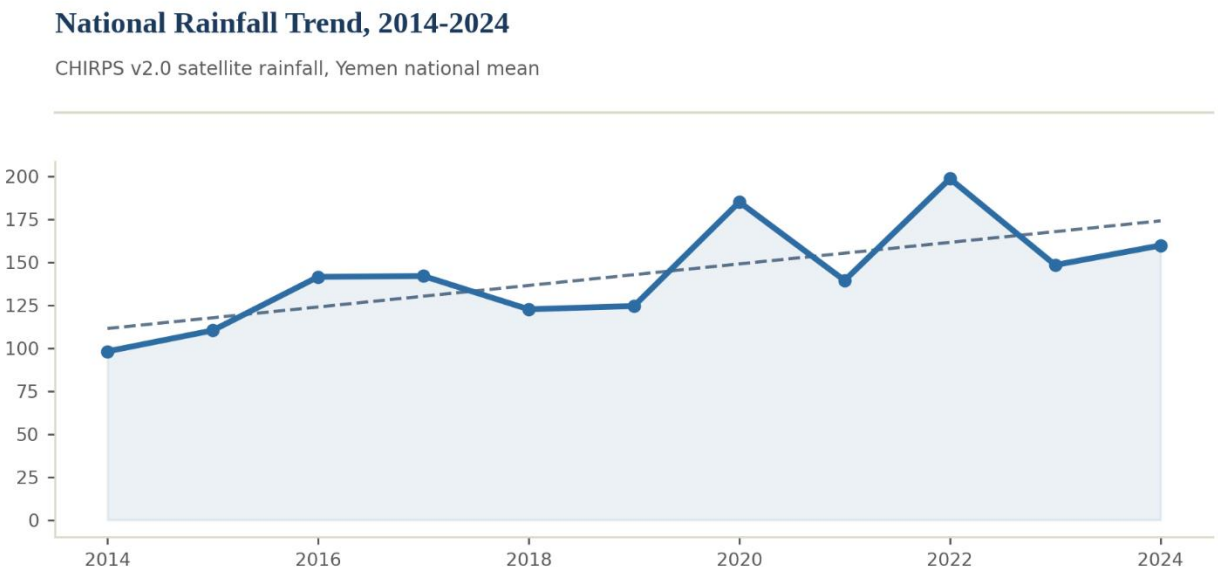
1.1 Driving Forces and Pressures

Yemen's climate is shaped by its position at the southern end of the Arabian Peninsula, spanning arid coastal plains, a semi-arid western highland zone, and a desert interior. Layered onto this naturally water-scarce geography is more than a decade of armed conflict. Yemen's National Water Resources Authority operated 354 hydro-meteorological monitoring stations in 2010; approximately 70% are now not operational, destroyed, or stolen, severely constraining the country's own capacity to observe and report on its changing climate.

1.2 State: Observed and Projected Climate Trends

Yemen's mean annual temperature increased by 0.42 degrees Celsius per decade between 1971 and 2020, with strong regional variation: Al Jawf recorded the highest increase (0.58 degrees Celsius per decade), while Aden recorded the lowest. Over the same 1971-2020 period, national annual precipitation showed a slight decreasing trend (-6.25mm per decade), though the World Bank's own analysis notes this trend lacks statistical significance at the national level given high year-to-year variability; regionally, the western and southwestern coastal governorates showed the most pronounced historical decreases, with Al Hudaydah recording the largest (-38.25mm per decade). This national trend, and its statistical significance, are shown in Figure 1.1 below:

Figure 1.1. National rainfall trend, 2014-2024 (CHIRPS v2.0)



Adaa Foundation's own original analysis, covering the more recent period of 2014-2024 using CHIRPS v2.0 satellite rainfall data masked precisely to Yemen's national and governorate boundaries, finds a different picture for this shorter, more recent window: a statistically significant national increase of approximately +6.3mm per year (p=0.018, R-squared=0.48). This is not necessarily a contradiction of the longer-term

1971-2020 finding above — a recent-decade uptick following a longer period of decline (or no significant trend) is plausible, and is broadly consistent with the World Bank's own future projections of increasing precipitation under most climate scenarios. However, the two findings should never be presented as if they measure the same thing: one reflects five decades of history to 2020, the other reflects the most recent eleven years only, using a different underlying dataset. Both are presented here explicitly, rather than selecting the version that tells a cleaner story.

At governorate level, Adaa applied statistical significance testing (linear regression) to every trend in its own recent-decade analysis rather than relying on the raw slope alone. Of Yemen's 21 governorates, 15 show a statistically significant rainfall increase ($p<0.05$) over 2014-2024 — a substantially stronger overall pattern than any single governorate figure conveys on its own. Table 1.1 presents the eight governorates with the strongest trends among these fifteen. Figure 1.2 maps this same governorate-level data, showing the spatial concentration of the strongest trends in the northern highlands and central governorates.

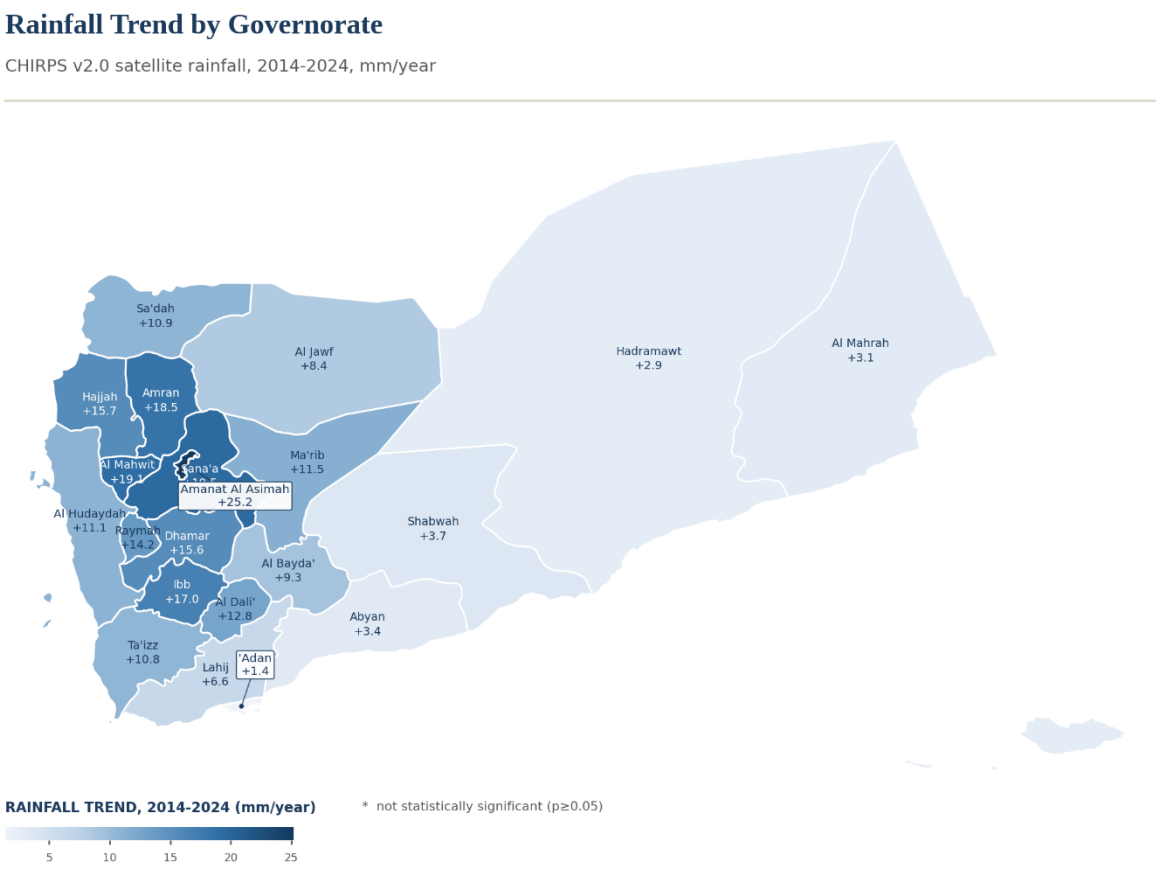
Table 1.1. Governorates with the strongest statistically significant rainfall trends, 2014-2024 (8 of 15 significant governorates shown; full 21-governorate results available in the underlying data workbook)[1]

Governorate	Mean annual rainfall 2014-2024 (mm)	Trend (mm/year)	P-value
Ibb	346.4	+16.99	0.004
Hajjah	297.9	+15.65	0.046
Dhamar	286.8	+15.55	0.019
Raymah	346.2	+14.16	0.047
Al Dali'	247.7	+12.80	0.003
Al Hudaydah	248.8	+11.08	0.039
Sa'dah	200.9	+10.86	0.032
Ta'izz	286.0	+10.84	0.009

Looking forward, the World Bank's climate modeling projects Yemen's national mean temperature could rise by as much as 1.69 degrees Celsius by 2050 under a pessimistic scenario (SSP3-7.0), while national precipitation is projected to increase by a median of 2.76% under the same pessimistic scenario, and by as much as 43% under a more optimistic scenario (SSP2-4.5). Aden is projected to see the largest median increase nationally (+9.70%), consistent with Yemen's own 2025 NDC 3.0 Vision submission to the UNFCCC, while Hajjah is projected to see the largest seasonal increase, at a median of 26.30% during summer months by mid-century.

[1] *Source: Adaa Foundation original analysis, CHIRPS v2.0, masked to Yemen's national/governorate boundaries (Natural Earth 10m); significance testing via ordinary least squares linear regression. Historical (1971-2020) and projected figures: World Bank Yemen Country Climate and Development Report (2024).*

Figure 1.2. Rainfall trend by governorate, 2014-2024



A correction made during quality review

An earlier working version of this analysis highlighted Amanat Al Asimah, Sana'a, Amran, and Al Mahwit as having the 'strongest' rainfall increases, based on their raw trend size alone. Applying formal statistical significance testing found that all four of these trends are NOT statistically distinguishable from noise (p=0.06-0.10), despite being numerically the largest. They have been removed from the headline table above and replaced with governorates whose trends are both sizeable and statistically significant. This correction is documented here deliberately, as part of Adaa Foundation's quality assurance process for this report.

Methodological caveats

An 11-year record is short for establishing a definitive climate change signal; even statistically significant trends within this window should be read as a recent-decade observation, not as standalone proof of permanent change — particularly given that this recent trend runs in the opposite direction to the longer (though not statistically significant) 1971-2020 national trend reported above.

CHIRPS blends satellite estimates with ground-station input, and its accuracy is documented in the literature to degrade in mountainous terrain and where the underlying gauge network has collapsed — a condition this report itself documents (approximately 70% of Yemen's hydro-meteorological stations are non-operational). This matters directly for the finding above, since the western highlands are both the area of weakest station coverage and the area of the strongest reported wetting trend. This does not invalidate the finding, but it is a genuine data-quality caveat standard in the satellite-precipitation literature for data-sparse, conflict-affected settings, and is disclosed here rather than left unstated.

Twenty-one separate governorate-level regressions were run for both rainfall and vegetation trends. At a 95% confidence threshold, testing this many independent hypotheses carries a non-trivial statistical probability of at least one false positive arising by chance alone. The overall pattern found here — 15 of 21 governorates significant for rainfall, 20 of 21 for vegetation — is robust to this concern given its scale and consistency across two independent datasets, but a single false-positive result at the individual-governorate level cannot be fully excluded, and this finding should be read at the level of the overall pattern rather than any single governorate result in isolation.

Findings throughout this report represent a governorate-mean signal (approximately 250m resolution for MODIS-derived indicators, approximately 5km for CHIRPS), not a claim of spatial uniformity within any governorate.

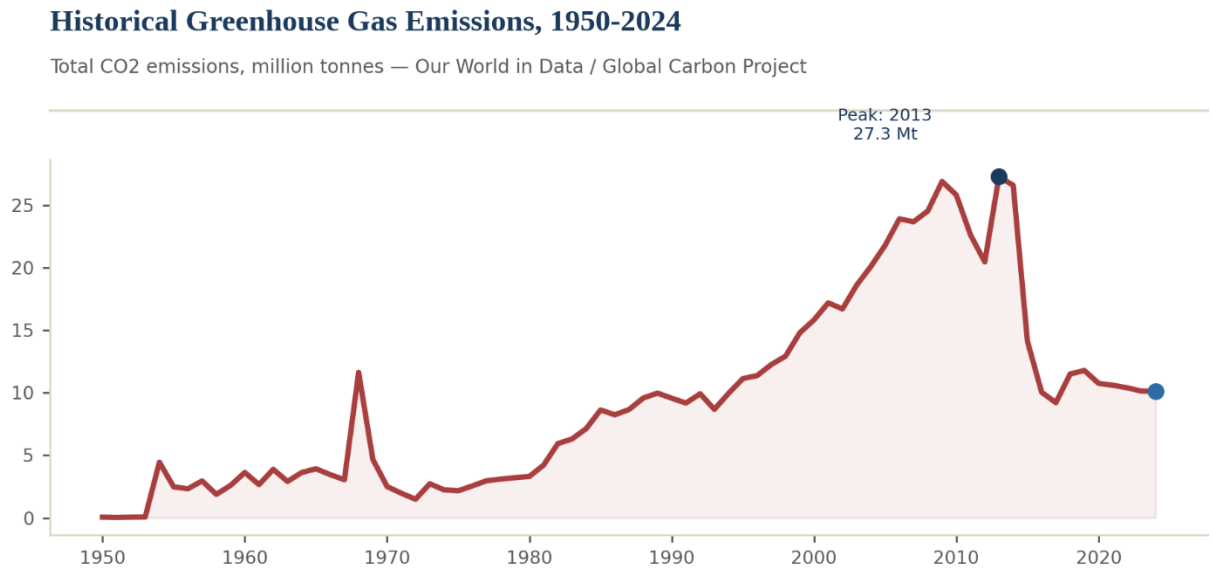
1.3 Impact: Extreme Events and Consequences

Severe flooding between April and August 2024 affected 19-20 of Yemen's 22 governorates and more than 400,000 people across roughly 63,000 households, destroying over 17,000 shelters and contributing to a cholera outbreak exceeding 186,000 suspected cases. The governorates most severely affected include Al Hudaydah, Hajjah, Marib, Ta'izz, Sa'dah, Al Jawf, and Dhamar — several of which (Dhamar, Hajjah, Al Hudaydah, Sa'dah, and Ta'izz) also show statistically significant rainfall increases in Adaa's own analysis above, providing a degree of independent cross-validation between satellite-derived trends and ground-reported impact.

1.4 Response and Emissions Context

Yemen's institutional response is addressed fully in Chapter 5. For emissions context: Yemen's total greenhouse gas emissions were approximately 26.7 million tonnes CO2-equivalent in 2024 (0.25 tonnes per capita), with road transportation, oil and gas production, cement manufacturing, and residential fuel use as the largest current sectoral sources. Yemen's emissions trajectory over this longer period is shown in Figure 1.3.

Figure 1.3. Historical greenhouse gas emissions, 1950-2024

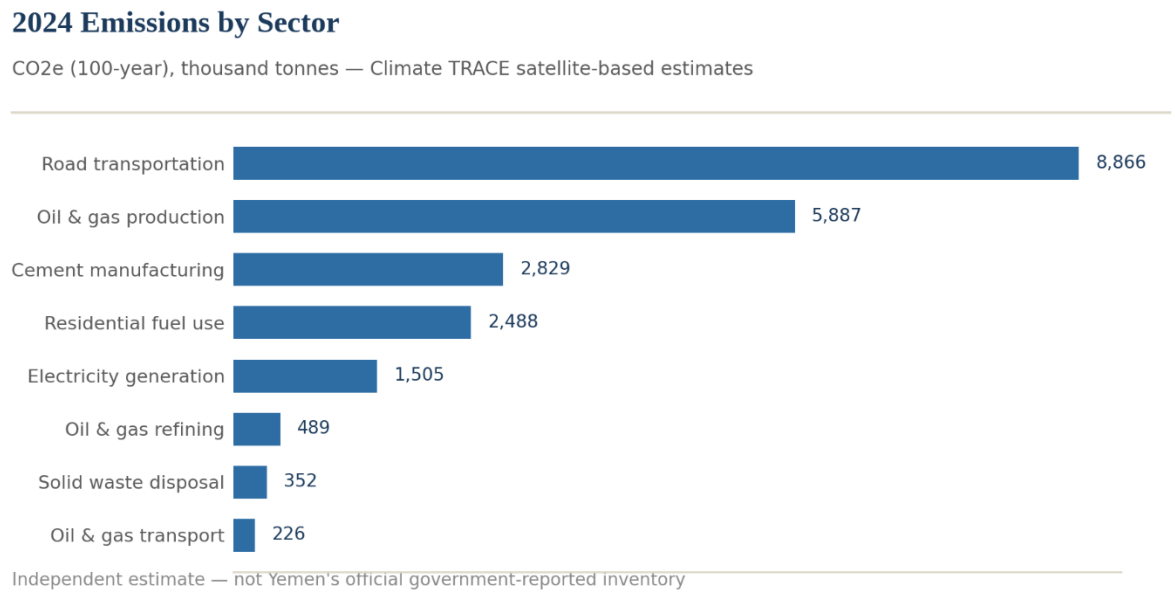


Labelling note

Emissions figures above are independent third-party estimates (Climate TRACE, Our World in Data), not Yemen's official government-reported inventory, which is under separate preparation via the Fourth National Communication process.

The sectoral composition of this estimate is shown in Figure 1.4.

Figure 1.4. Yemen's 2024 emissions by sector (Climate TRACE)



Chapter 2: Water Resources

2.1 Driving Forces and Pressures

Yemen is one of only four countries in the world classified as both low-income and experiencing absolute water scarcity, a condition long predating the current conflict but substantially worsened by it. Population growth, unregulated groundwater abstraction, weak water governance, and the cultivation of qat — a water-intensive cash crop — combine to place unsustainable pressure on a naturally limited resource base.

2.2 State: Current Water Resource Conditions

Yemen's per-capita renewable freshwater availability stood at 65 cubic meters in 2020, projected to fall further to 54 cubic meters by 2050 — far below the internationally recognized absolute water scarcity threshold of 500 cubic meters per capita. At the national scale, total water demand exceeds an estimated 5.1 billion cubic meters (BCM) annually, against roughly 2.5 BCM of total run-off, producing an estimated national deficit of approximately 2.6 BCM per year, met largely through unsustainable groundwater over-abstraction.

The World Bank's 2024 Water Security Diagnostic for Yemen ('Charting the Course') finds that qat cultivation alone consumed more than 36% of Yemen's total renewable water resources and 32% of all groundwater withdrawals prior to the conflict, and that the area under qat cultivation has since expanded by more than 40% in some regions between 2016 and 2021, driven by economic incentives — including solar-powered irrigation pumps enabling unregulated withdrawal — that outweigh regulatory enforcement. Rural communities facing water scarcity have, in documented cases, resorted to selling assets, abandoning agriculture, or migrating.

2.3 Impact

Water scarcity in Yemen is not a future risk but a present, lived reality shaping livelihoods, migration, and food security. Water tanker prices illustrate the human cost directly: an estimated USD 1.64 per cubic meter in Sana'a, rising to as much as USD 16 per cubic meter in Aden. The collapse of water and sanitation infrastructure was a direct contributor to the 2016-2017 cholera outbreak, the largest in modern recorded history, with the World Health Organization recording more than 2.5 million suspected cases and 3,997 deaths between April 2017 and April 2021.

The World Bank frames Yemen's water future through three scenarios: a 'Peace and Prosperity' pathway enabling integrated water management and major infrastructure investment; a 'Status Quo' pathway of continued fragmentation; and an 'Escalation and Intensification' pathway in which water insecurity deepens alongside continued conflict.

2.3.1 Original Analysis: Surface Water Trends, 2014-2021

As an original contribution, Adaa Foundation processed eight years (2014-2021) of the JRC Global Surface Water dataset via Google Earth Engine, the longest period currently available in this product. Focusing on Yemen's landlocked and inland governorates — where the signal reflects genuine inland freshwater bodies rather than coastal or open-sea pixels — surface water extent shows small but consistently positive trends

across the northern highlands. All twelve inland/landlocked governorates in the underlying data are shown in Table 2.1, not a selected subset; 9 of the 12 reach statistical significance (p<0.05).This pattern is mapped in Figure 2.1, with coastal governorates shown separately given the data-quality caveat below.

Figure 2.1. Surface water trend by governorate, 2014-2021

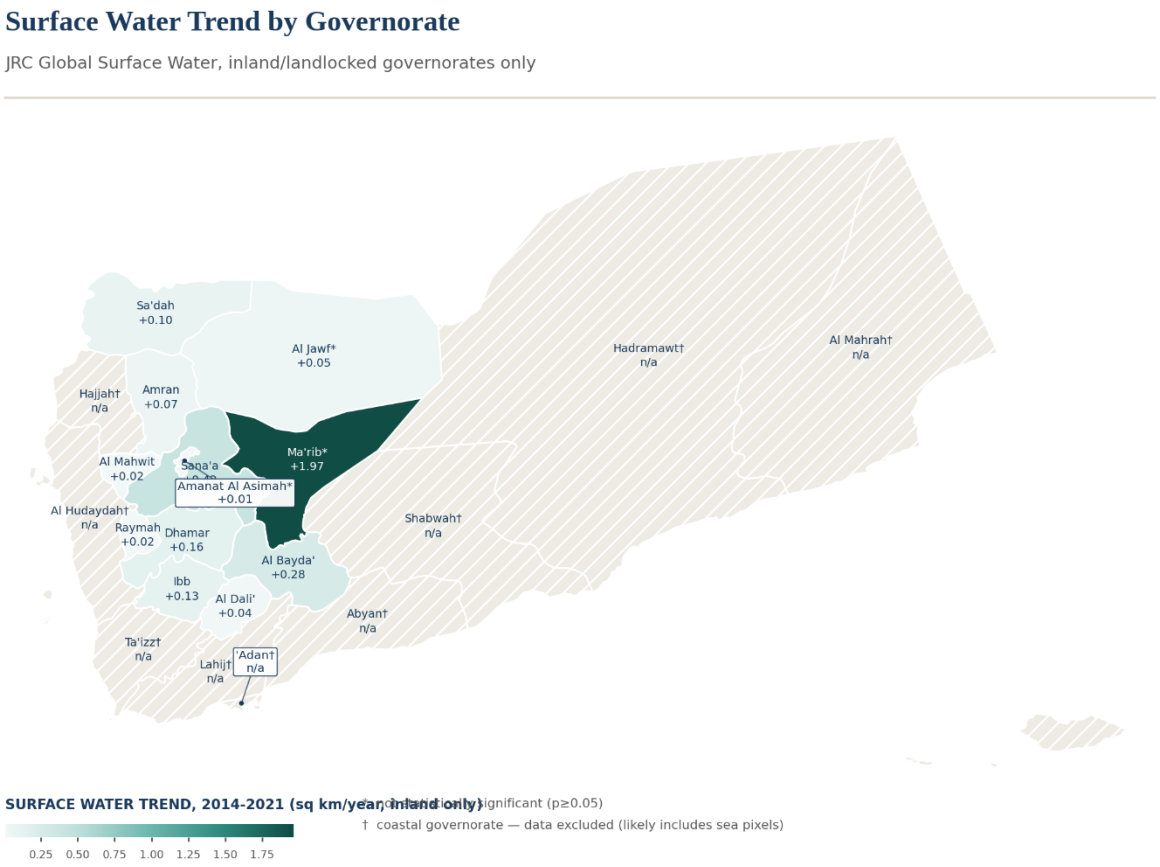


Table 2.1. Surface water extent trends for all 12 inland/landlocked governorates, 2014-2021

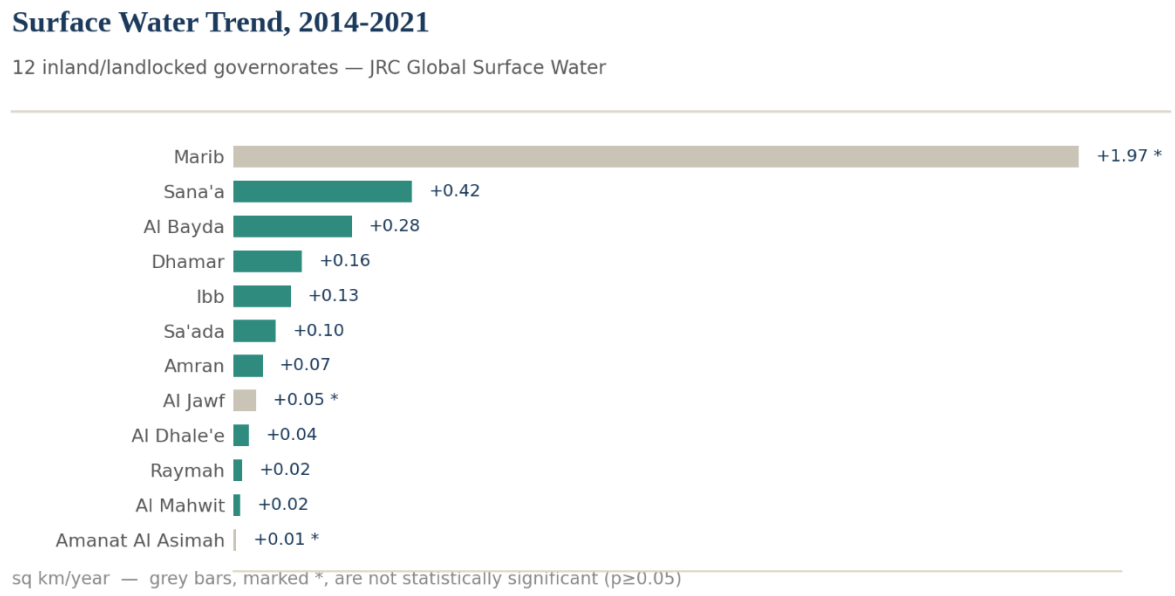
Governorate (inland/landlocked)	Mean water extent 2014-2021 (sq km)	Trend (sq km/year)	Significant (p<0.05)?
Marib	16.71	+1.97	No (p=0.130)
Al Bayda	1.46	+0.28	Yes (p=0.003)
Sana'a	1.44	+0.42	Yes (p=0.003)
Sa'ada	0.64	+0.10	Yes (p=0.012)
Dhamar	0.62	+0.16	Yes (p=0.013)
Amran	0.56	+0.07	Yes (p=0.008)
Ibb	0.52	+0.13	Yes (p=0.006)
Al Jawf	0.46	+0.05	No (p=0.057)
Al Dhale'e	0.21	+0.04	Yes (p=0.005)
Amanat Al Asimah	0.07	+0.01	No (p=0.222)
Raymah	0.05	+0.02	Yes (p=0.036)

Governorate (inland/landlocked)	Mean water extent 2014-2021 (sq km)	Trend (sq km/year)	Significant (p<0.05)?
Al Mahwit	0.05	+0.02	Yes (p=0.006)

Source: Adaa Foundation original analysis, JRC Global Surface Water Yearly History, processed via Google Earth Engine; significance testing via ordinary least squares linear regression.

Figure 2.2 presents the same twelve governorates ranked by trend magnitude, with non-significant results marked.

Figure 2.2. Surface water trend, all 12 inland governorates, ranked



Important methodological caveats

Coastal governorates (e.g. Al Hudaydah, Hadramaut, Aden) show surface water totals an order of magnitude larger than any inland governorate. This is judged to reflect sea and coastal water pixels captured within the governorate boundary polygon, not genuine inland freshwater resources, and these coastal totals are therefore excluded from Table 2.1 to avoid creating a misleading impression of water abundance in a country facing acute freshwater scarcity. This distinction should be preserved in any future use of this data.

Marib's trend, despite being the largest numerically among inland governorates, is not statistically significant (p=0.130), nor are Al Jawf's or Amanat Al Asimah's, and these three should not be presented as confirmed findings without this caveat.

2.4 Response

Multiple donor-funded programs currently target water resource management directly, including the World Bank-funded IWISE project (building a national Climate and Water Information Management System), and smaller integrated water resource management projects funded by KfW/Germany and implemented by UNDP in the Tuban, Al Musaimeir, Al Mawaset, and Al Selw districts. The World Bank's

Water Security Diagnostic itself sets out ten specific 'no regrets' measures for immediate implementation, including institutional diagnostics, hydro-meteorological data system investment, infrastructure needs assessments, and remote-sensing-supported enforcement of groundwater withdrawal limits — an agenda these donor programs' recurring emphasis on integrated, cross-sectoral water governance closely tracks.

Chapter 3: Land, Vegetation and Agriculture

3.1 Driving Forces and Pressures

Only around 3% of Yemen's total land area is arable, and agriculture nonetheless supports the livelihoods of the majority of Yemen's population — over 75% of whom are rural-based. This structural scarcity of productive land is compounded by desertification, soil erosion on Yemen's historic highland terrace systems, and the water-intensive cultivation of qat, now estimated to consume more than 40% of Yemen's renewable water resources and nearly one-third of groundwater withdrawals — up from earlier pre-conflict estimates of 36% and 32% respectively, consistent with qat cultivation area having expanded by roughly 40% between 2016 and 2021.

3.2 State: Land Condition

Multiple distinct, properly sourced figures describe Yemen's land degradation, and should not be conflated with one another. An estimated 35% of Yemen's arable land has been lost over the last two decades due to soil erosion and water scarcity. Desertification actively affects 3-5% of arable land each year. In its broadest sense — land at risk, not land already lost — desertification is estimated to threaten almost 97% of Yemen's agricultural land. Aridity affects an estimated 90% of the country's total land area, while soil erosion affects 10-20% of land, concentrated in agricultural regions; nearly 90% of this soil degradation is attributed to water erosion, with the remainder mostly wind erosion.

Yemen's highland terracing systems, some dating back 5,000 years, cover an estimated 20-25% of the country's arable land and have historically been central to managing agriculture in an arid climate. In highland regions, however, 40% of terraced soil is now at high risk of erosion, and soil organic carbon has fallen a further 15% over the last 20 years. Between 1985 and 2015, the area of Yemen under severe drought increased by 26% and under moderate drought by 65%, while sand dune cover expanded from 11% to 19% of the relevant assessed area.

> **A note on sourcing**
>
> The figures above are drawn from a December 2024 UNDP report specifically commissioned for the UNCCD's COP16, which itself draws on peer-reviewed and satellite-derived sources. This replaces an earlier version of this section, which relied on a poorly-dated, loosely sourced figure; the correction is noted here as part of Adaa Foundation's quality assurance process.

3.3 Original Analysis: Vegetation Trends, 2014-2024

As an original contribution to this report, Adaa Foundation processed eleven years (2014-2024) of MODIS satellite vegetation index data (NDVI), averaged annually at the governorate level, via Google Earth Engine. All 21 of Yemen's governorates show a positive vegetation trend over this period, summarized in Table 3.1. This pattern is mapped in Figure 3.1.

Figure 3.1. Vegetation (NDVI) trend by governorate, 2014-2024

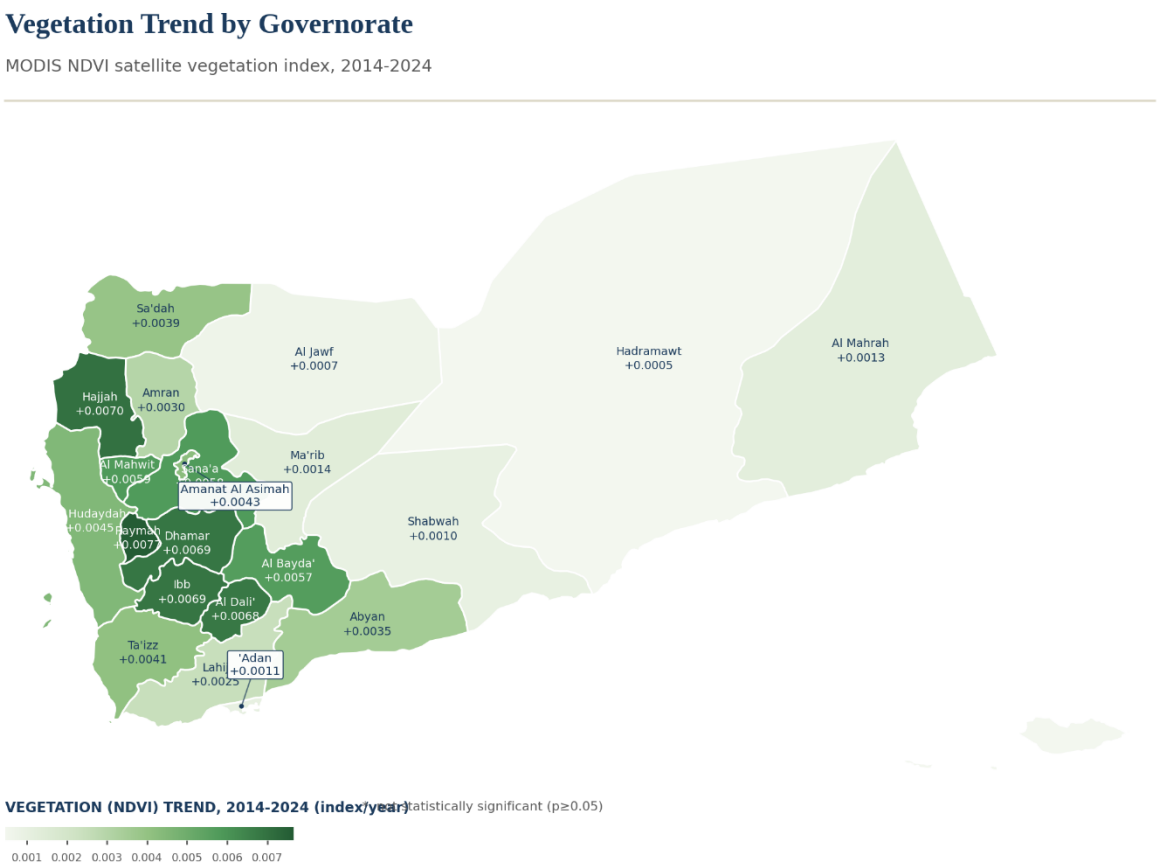


Table 3.1. Governorates with the strongest vegetation (NDVI) trends, 2014-2024

Governorate	Mean NDVI 2014-2024	Trend (NDVI/year)	Trend (% of mean/year)
Al Bayda	0.1582	+0.00572	+3.6%
Hajjah	0.2062	+0.00704	+3.4%
Sana'a	0.1787	+0.00581	+3.3%
Al Dhale'e	0.2152	+0.00682	+3.2%
Dhamar	0.2331	+0.00688	+3.0%
Ibb	0.3111	+0.00692	+2.2%
Marib	0.1020	+0.00137	+1.4%
Al Maharah	0.1315	+0.00127	+1.0%
Shabwah	0.1142	+0.00103	+0.9%
Al Jawf	0.1019	+0.00072	+0.7%
Hadramaut	0.1331	+0.00046	+0.3%

Source: Adaa Foundation original analysis, MODIS MOD13Q1 vegetation index (NDVI), processed via Google Earth Engine, governorate boundaries per FAO GAUL 2015.

A genuine cross-validation finding

The geographic pattern of vegetation increase closely tracks the geographic pattern of rainfall increase found independently in Chapter 1 (Section 1.2): both the MODIS vegetation data and the separately-sourced CHIRPS rainfall data show the northern highland and central governorates (Sana'a, Dhamar, Hajjah) increasing faster than the arid eastern governorates (Hadramaut, Al Jawf, Shabwah, Al Maharah), which show the weakest trends in both independent datasets. Two unrelated satellite data sources pointing to the same spatial pattern is a genuine, methodologically meaningful point of corroboration, not a coincidence to pass over quickly.

One disclosure against this pattern: a separate December 2024 UNDP analysis, using a different vegetation metric (net primary productivity, or NPP, rather than NDVI) and a different baseline period, found Hajjah specifically experienced a net vegetation decline in 2023, attributed to declining coastal precipitation. The two analyses differ in methodology, metric, and exact time window, so this is not read as a direct contradiction of Adaa's own 2014-2024 finding for Hajjah — but it is disclosed here rather than omitted, consistent with this report's approach to cross-source discrepancies.

Unlike the rainfall data, the vegetation trend is statistically significant ($p<0.05$) in 20 of Yemen's 21 governorates, including all governorates listed in Table 3.1 above (p-values ranging from 0.0001 to 0.023) — a substantially more consistent and statistically robust signal than the rainfall analysis alone.

3.3 Impact

Land degradation directly threatens food security in a country that already imports a large majority of its food. Using International Futures economic modeling, a December 2024 UNDP study projects that continued land degradation could reduce Yemen's GDP by 5.6% relative to a no-degradation baseline by 2050 (a cumulative loss of nearly USD 50 billion), push an additional 5 million Yemenis into extreme poverty, and leave 5 million more people undernourished than would otherwise be the case. The same study's more optimistic 'Land Restoration' scenario projects 9 million fewer undernourished Yemenis by 2050 relative to the degradation pathway, illustrating that the current trajectory is not inevitable. Separately, the World Bank's 2024 CCDR finds that, under optimistic climate scenarios with targeted investment in water storage, groundwater management, and adaptive agricultural techniques, Yemen could see crop production gains of up to 13.5% between 2041 and 2050.

3.4 Original Analysis: Land Cover Change, 2014-2022

Extending this analysis, Adaa Foundation processed MODIS land cover classification data (2014 vs. 2022) via Google Earth Engine, tracking the share of each governorate classified as barren land versus cropland. The results reinforce the same geographic pattern found independently in both the rainfall and vegetation analyses: the northern highland governorates show barren land shrinking and cropland expanding, while the arid eastern governorates show minimal change from an already near-total barren baseline. This is mapped in Figure 3.2

Figure 3.2. Land cover change by governorate: barren land shrinkage, 2014-2022

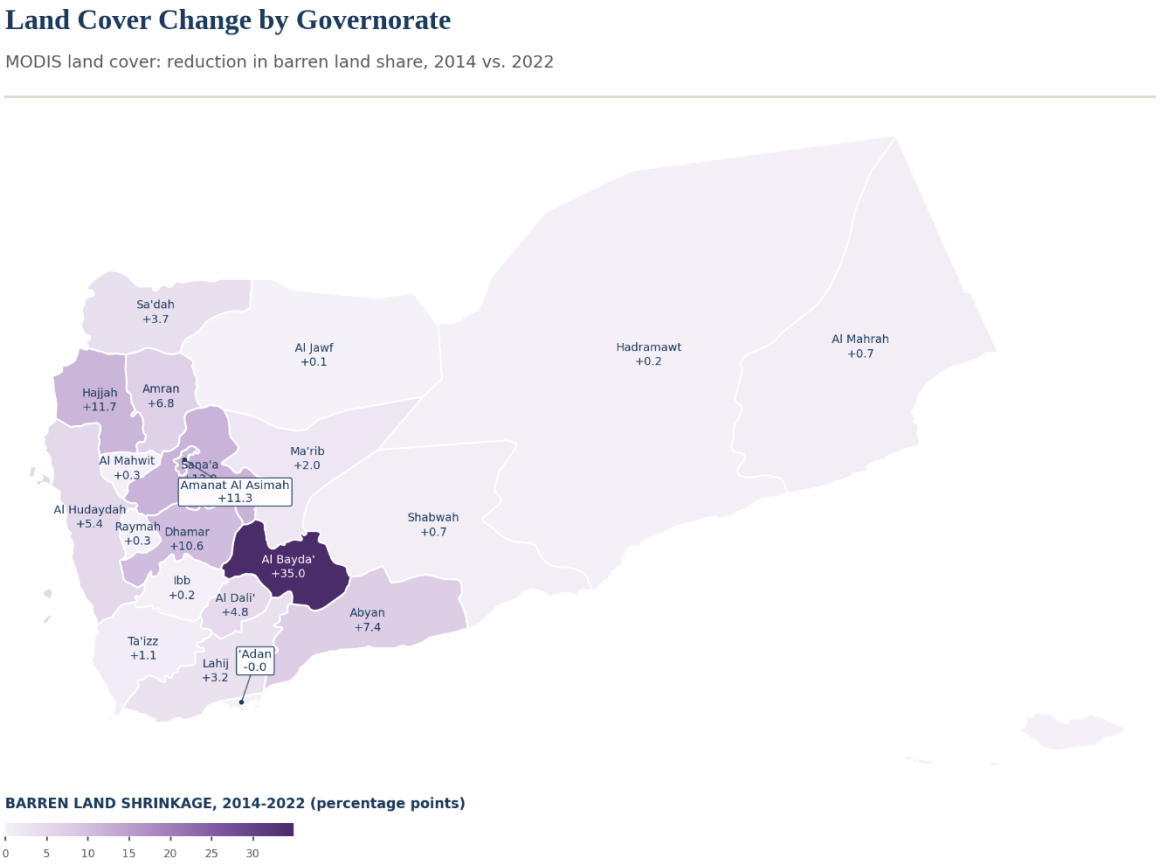


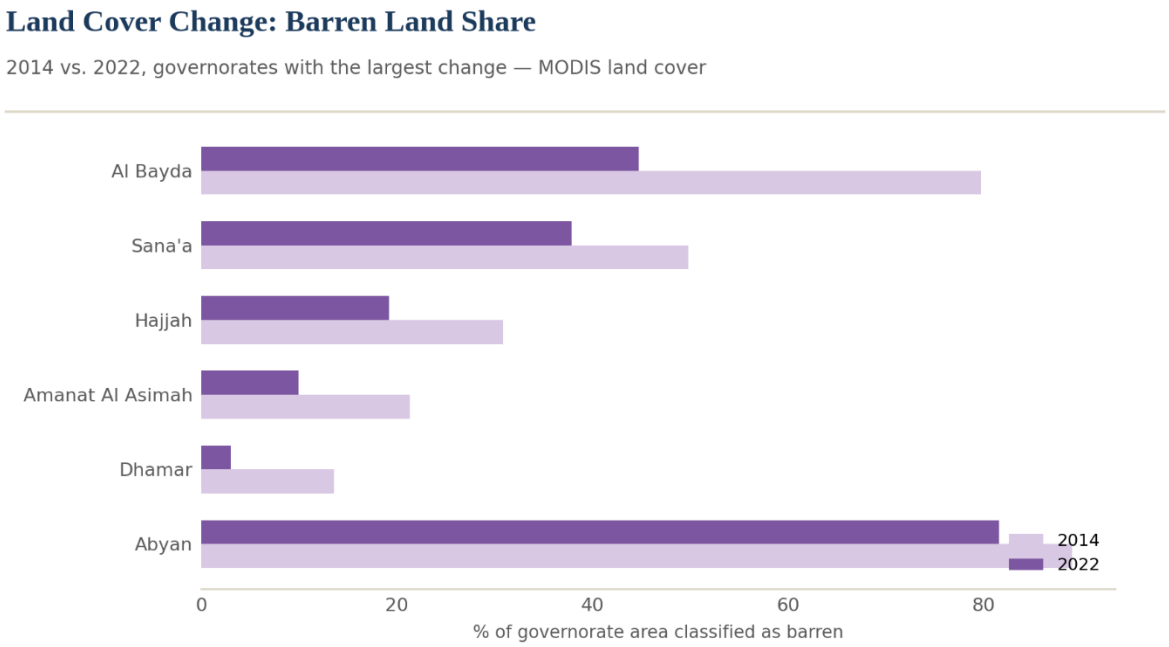
Table 3.2. Land cover change by governorate: cropland and barren land share, 2014 vs. 2022

Governorate	Cropland % (2014 -> 2022)	Barren % (2014 -> 2022)	Barren change (pct. points)
Sana'a	1.9% -> 4.4%	49.9% -> 37.9%	-12.0
Hajjah	2.7% -> 5.5%	30.9% -> 19.2%	-11.7
Dhamar	6.9% -> 8.1%	13.6% -> 3.0%	-10.6
Al Hudaydah	7.1% -> 9.6%	42.1% -> 36.7%	-5.4
Al Bayda	0.01% -> 0.03%	79.7% -> 44.7%	-35.0
Al Jawf	0.0% -> 0.0%	99.9% -> 99.8%	-0.1
Marib	0.0% -> 0.0%	99.1% -> 97.1%	-2.0
Hadramaut	0.0% -> 0.0%	97.0% -> 96.8%	-0.2

Source: Adaa Foundation original analysis, MODIS MCD12Q1 land cover classification, processed via Google Earth Engine.

Figure 3.3 presents this change directly for the six governorates with the largest shift.

Figure 3.3. Barren land share, 2014 vs. 2022, most-changed governorates



Three-way cross-validation

This is now the third independent NASA/satellite-derived dataset — following rainfall (CHIRPS) and vegetation (MODIS NDVI) — to show the same underlying geographic pattern: Yemen's northern highland and central governorates (Sana'a, Hajjah, Dhamar, Al Hudaydah) are simultaneously getting wetter, greener, and gaining cropland at the expense of barren land, while the arid eastern governorates (Hadramaut, Al Jawf, Marib, Shabwah) remain comparatively static. Three unrelated satellite products converging on the same spatial story is a genuinely strong evidentiary basis, well beyond what any single dataset alone could support.

Unlike the rainfall and vegetation trends, the land cover comparison above cannot be formally tested for statistical significance, since it relies on only two time points (2014 and 2022). A two-point comparison always produces a 'perfect' line with no way to estimate whether the observed change exceeds normal year-to-year variability. It is presented as a directional finding, made credible primarily by its agreement with the two statistically-tested datasets above, not as a standalone statistically confirmed result.

3.5 Response

Yemen's National Adaptation Programme of Action (2009) proposed the restoration and rehabilitation of degraded terraces, promotion of drought- and salinity-resistant crops, and sustainable land management measures to combat desertification. Current donor-funded programs, including GEF-supported climate-smart agriculture projects across 21 districts and FAO-implemented irrigation and seed-system support, continue this agenda, though the Ministry of Agriculture's own historical Anti-Desertification Unit has been reported as chronically underfunded relative to identified need.

This report's cross-validated finding — that rainfall, vegetation, and cropland are moving together across the same governorates — establishes a robust correlational pattern, not a causal one. Several distinct,

non-exclusive mechanisms could plausibly contribute to the observed cropland expansion beyond rainfall alone, including irrigation expansion, groundwater pumping, conflict-driven land abandonment and subsequent reclamation, the spread of solar-powered irrigation pumps, and shifts in agricultural policy or land tenure. Disentangling the relative contribution of each driver would require a dedicated causal analysis beyond this report's current scope, and is flagged here as a direction for future work rather than a claim this report makes.

Chapter 4: Coastal and Marine Zones

4.1 Driving Forces and Pressures

Yemen's 2,200-kilometer coastline along the Gulf of Aden, Arabian Sea, and Red Sea, together with island territories including Socotra, exposes a significant share of the country's population, infrastructure, and economic activity to sea-level rise, storm surge, and coastal erosion, compounding pressures from unregulated fishing and coastal urbanization.

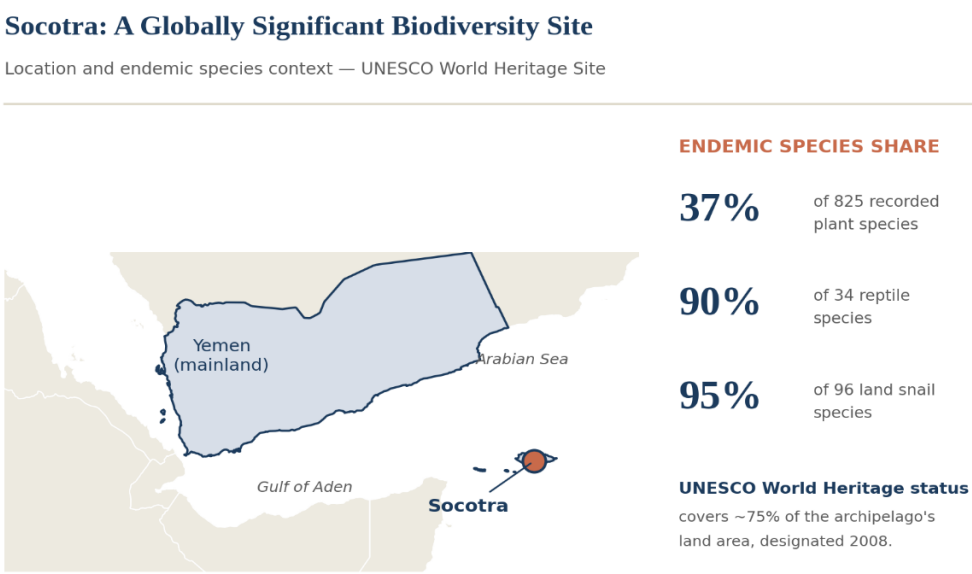
4.2 State

More than 50% of Yemen's coastal land area is estimated to be at risk from sea-level rise and intensifying storm surge. Yemen's own 2025 NDC 3.0 Vision projects a temperature anomaly of +1.18 degrees Celsius specifically for Socotra Island, reflecting the distinct, monsoon-influenced climate of this globally significant biodiversity site. Documented coastal ecosystem impacts over the past two decades include mangrove degradation, coral reef loss, and the loss of sea turtle nesting grounds.

4.2.1 Biodiversity: Socotra

Socotra is a UNESCO World Heritage Site of exceptional, globally significant biodiversity, often described as the 'Galapagos of the Indian Ocean.' Of its 825 recorded plant species, 37% (307 species) are endemic — found nowhere else on Earth — a figure that rises to 90% among its 34 reptile species and 95% among its 96 land snail species. Its marine environment supports 253 species of reef-building coral and 730 species of coastal fish. UNESCO's World Heritage designation covers approximately 75% of the archipelago's total land area. Socotra's location relative to mainland Yemen, and the scale of its endemic biodiversity, are shown in Figure 4.1.

Figure 4.1. Socotra: location and endemic species context



This globally significant biodiversity is directly exposed to the climate pressures documented elsewhere in this report. Tropical cyclones Chapala and Mekunu, in 2015 and 2018 respectively — part of the broader pattern of intensifying storm activity discussed in Chapter 1 — caused direct damage to reefs, triggered soil erosion, and harmed Socotra's endemic tree populations, including the iconic dragon's blood tree. A UNESCO assessment further found that bark beetle infestation, itself linked to drought and heat stress, has damaged an estimated 30% of the archipelago's dragon's blood and frankincense tree populations. Conflict-driven economic isolation compounds these pressures: the high cost and low availability of cooking gas on Socotra has been linked to increased deforestation as households turn to wood fuel, directly connecting the island's conflict-era economic conditions to its accelerating environmental degradation.

4.3 Impact

Storm surge intensification threatens infrastructure in low-lying coastal cities, with Aden specifically identified as at risk of flooding to key infrastructure including hospitals, schools, and its airport, alongside seawater intrusion into coastal aquifers already straining urban water supply. Yemen's fisheries sector, contributing an estimated 2.4% of GDP and supporting approximately 80,000 fishermen, faces compounding pressure from both climate-driven species mortality and long-standing unregulated fishing, including by large-scale international fleets operating within Yemen's exclusive economic zone. More than 105,000 internal displacements since 2008 have been linked to coastal risk factors.

4.4 Response

Yemen's 2009 NAPA prioritized integrated coastal zone management and mangrove restoration as core adaptation measures; enforcement of fisheries protection and coastal ecosystem management remains a documented, persistent institutional gap rather than a resolved issue. Socotra itself was formally declared a nature reserve in 2000 (Republican Decree No. 275), comprising 27 marine and 12 terrestrial reserves, with UNESCO Man and Biosphere Reserve status conferred in 2003 and full World Heritage Site status in 2008 — a relatively strong formal protection architecture that, consistent with the broader institutional pattern documented in Chapter 5, faces significant enforcement and resourcing constraints.

Chapter 5: Institutional and Policy Context

5.1 Policy History

Yemen signed the UNFCCC in 1996 and ratified the Kyoto Protocol in 2004. Its Initial National Communication (2001) was followed by the National Adaptation Programme of Action (NAPA, April 2009), which identified three core vulnerable sectors (water resources, agriculture, coastal zones) and three secondary sectors (biodiversity, health, tourism), prioritizing 38 adaptation projects. Yemen subsequently submitted its Second National Communication (2013) and an Intended Nationally Determined Contribution setting a 14% emissions reduction target below business-as-usual by 2030 (2015), followed by its first Biennial Update Report (2017) and its Third National Communication (2018), which updated the mitigation scenario to a target 26% reduction of 2010 emissions by 2040. A Technology Needs Assessment followed in 2022, and a 2025 NDC 3.0 Vision. Yemen is currently preparing its Fourth National Communication and a new NDC, and transitioning to Biennial Transparency Reporting under the Paris Agreement's Enhanced Transparency Framework.

5.2 Institutional Architecture

- The Environmental Protection Authority (EPA) is Yemen's UNFCCC Operational Focal Point.
- The Ministry of Water and Environment (MWE) houses a dedicated Climate Change Unit (established June 2024), which has presented a multi-year climate finance pipeline exceeding USD 200 million.
- The National Climate Change Committee (NCCC), first launched in 2009 and updated in 2023, has a formally endorsed three-tier structure: a high-level Council/Board chaired by the Minister of Planning and International Cooperation or the Minister of Water and Environment; a Technical Committee chaired by the EPA Chairman; and Sub-technical Committees covering areas including adaptation/disaster risk and low-emission development. As of this report, however, only the Climate Change Unit itself (serving as the Committee's executive secretariat) has actually been established, despite the full structure's formal endorsement.
- The Ministry of Agriculture and Irrigation is the key sectoral counterpart for climate-smart agriculture and food security programming.
- The Civil Aviation and Meteorology Authority (CAMA) provides weekly weather and climate bulletins across both Houthi- and IRG-controlled areas, though international capacity-building support (e.g. from the World Meteorological Organization) has been unevenly distributed, benefiting CAMA Aden and Hadramawt more than CAMA Sana'a.

5.3 The Current National Adaptation Plan Process

Yemen's live NAP establishment process (April 2025-July 2029, GCF-funded, UNDP-implemented) builds on the NAPA, INDC, National Water Sector Strategy, Third National Communication, and Technology Needs Assessment, expanding priority sectors from three to four (adding health). As of this report, the NAP's specific indicator framework, adaptation monitoring and evaluation system, and cross-sectoral finance strategy are still being designed, representing a live institutional process rather than a completed system.

5.3.1 Why Health Was Added: The Climate-Health Link

The addition of health as a fourth NAP priority sector is not a procedural formality; it reflects a documented, recurring pattern already visible elsewhere in this report. Two of Yemen's largest disease

outbreaks in the past decade trace directly to climate-linked water and sanitation collapse: the 2016-2017 cholera outbreak (Chapter 2), the largest in modern recorded history at over 2.5 million suspected cases and 3,997 deaths, followed a collapse in water and sanitation infrastructure; and the 2024 flood-driven cholera outbreak (Chapter 1), exceeding 186,000 suspected cases, followed the same climate-water-disease pathway triggered by a distinct hazard (flooding rather than drought-linked infrastructure failure). Read together rather than as two isolated statistics, these events describe a single recurring mechanism — climate hazard, water/sanitation system failure, disease outbreak — that the NAP's formal inclusion of health as a fourth priority sector is explicitly designed to address.

5.4 The Development-Conflict-Climate Nexus

The World Bank's 2024 Country Climate and Development Report frames Yemen's situation through three scenarios — 'Peace and Prosperity,' 'Status Quo,' and 'Escalation and Intensification' — reflecting how climate outcomes in Yemen are inseparable from its political and conflict trajectory. The ongoing conflict affects approximately 80% of Yemeni households directly. Yemen ranks as the 27th most climate-vulnerable country globally and the most vulnerable in the Middle East and North Africa region, while simultaneously ranking among the least ready globally to respond.

5.5 Persistent Institutional Gaps

The World Bank's own 2022 assessment of Yemen's climate change governance functions found that, of ten specific governance functions assessed, only one — a basic coordination mechanism — was rated as fully in place. All nine others, including a climate change framework law, a long-term strategy or 2050 climate plan, climate-informed local risk assessments, climate-informed fiscal risk statements and budget guidelines, tracked climate expenditures, climate-informed project screening, and green public procurement (both in strategy and in law), were rated as absent. This transcription has been independently verified against the primary source document (World Bank CCDR, Figure 2.3).

Table 5.1. Yemen's Climate Change Governance Indicators, 2022

Governance function	Status (2022)
Climate Change Framework Law	Not in place
Long-term strategy / 2050 climate plan	Not in place
Coordination mechanism	In place
Climate-informed local risk assessments	Not in place
Climate-informed fiscal risk statements	Not in place
Climate-informed budget guidelines	Not in place
Climate expenditures tracked in budget	Not in place
Climate-informed project screening	Not in place
Green public procurement (in plans/strategies)	Not in place
Green public procurement (in law)	Not in place

Source: World Bank Yemen Country Climate and Development Report (2024), Climate Change Governance Indicators, 2022.

This is presented visually in Figure 5.1.

Figure 5.1. Yemen's climate governance functions at a glance, 2022

This precisely documented governance gap, combined with the severe degradation of Yemen's hydro-meteorological monitoring network (of 354 stations operated by the National Water Resources Authority in 2010, an estimated 70% are no longer operational, destroyed, or stolen) helps explain why Yemen receives an estimated 80-90% less climate finance than countries with the lowest climate vulnerability, despite having among the highest need. This is compounded by unclear fund-distribution criteria, bureaucratic complexity exceeding local institutional capacity in some cases, and donor preference for loans over grants.

This gap between Yemen's substantial documented policy architecture and its persistent capacity, data, and governance constraints is the direct rationale for Adaa Foundation's proposed institutional and governance gap assessment (a companion study), and for this report's own contribution toward closing the documented climate data gap.

Conclusions and Recommendations

Yemen's environmental and climate condition reflects the compounding interaction of a naturally arid, water-scarce geography; more than a decade of armed conflict; and a changing climate that is intensifying rainfall variability, temperature, and coastal risk simultaneously across an already fragile system. This is well documented in international literature; what remains persistently underdeveloped is Yemen's own sustained capacity to generate, maintain, and act on this evidence base independently.

- Yemen's institutional and policy architecture for climate action is genuinely substantial — spanning NAPA, multiple National Communications, an INDC, a Technology Needs Assessment, and a 2025 NDC 3.0 Vision — but is not matched by sustained data and monitoring systems.
- The clearest, most immediately actionable gap is the continuously updated, locally-produced climate and environmental data this report itself begins to address.
- Yemen's current National Adaptation Plan process explicitly still needs its indicator framework and monitoring/evaluation systems built — a live opportunity for technical contribution, not a closed process.
- Original analysis in this report demonstrates that credible, defensible climate and environmental data can be produced today using free, open data sources, without requiring new field infrastructure or ministry data-sharing agreements — though a genuine ceiling exists where administrative/activity data (as opposed to physical/satellite-observable data) is required.

Priority areas for monitoring and intervention: Cross-referencing the governorates statistically significant in both the rainfall and vegetation datasets (14 of 21) against those showing the largest land cover shifts identifies Hajjah, Dhamar, and Al Hudaydah as the governorates with the strongest, most consistently evidenced pattern of change across all three original analyses. These three, alongside the fuller set of 14 governorates significant in at least the two formally tested datasets (see Chapter 1, Figure 1.2 and the underlying data), represent a reasonable starting list for prioritized monitoring — though this is offered as a preliminary indication rather than a full climate vulnerability ranking, which would need to incorporate exposure, sensitivity, and adaptive capacity factors beyond the scope of this report.

This report is intended as a first, standalone contribution to Yemen's climate evidence base, and as a demonstration of the technical and analytical capability Adaa Foundation can bring to this sector going forward.

Methodology Note

This report combines a structured review of existing international literature (World Bank, UNDP, Sana'a Center for Strategic Studies, UNFCCC submissions, IOM, and others) with original data analysis conducted by Adaa Foundation using open, freely available datasets.

Original analysis conducted for this report

- Rainfall trend analysis (2014-2024), national and governorate-level: CHIRPS v2.0 Global Annual Precipitation, precisely masked to Yemen's administrative boundaries (Natural Earth 10m Admin-0/Admin-1 datasets).
- Historical greenhouse gas emissions (1850-2024): Our World in Data CO2 and Greenhouse Gas Emissions dataset.
- Sector-level 2024 emissions: Climate TRACE API (v6), an independent satellite- and AI-based global emissions monitoring initiative.
- Vegetation trend analysis (2014-2024), governorate-level: MODIS MOD13Q1 NDVI, processed via Google Earth Engine and exported by Adaa Foundation directly.
- Land cover change analysis (2014 vs. 2022), governorate-level: MODIS MCD12Q1 land cover classification, processed via Google Earth Engine.
- Surface water extent trend (2014-2021), governorate-level: JRC Global Surface Water Yearly History, processed via Google Earth Engine.

Statistical methodology

All original trend estimates (rainfall, vegetation, surface water) were tested for statistical significance using ordinary least squares linear regression, reporting the slope, p-value, and R-squared for each governorate rather than relying on the raw trend magnitude alone. Trends are described as significant only where $p<0.05$ (95% confidence level). This process identified and corrected an early-draft error in which the four largest-looking rainfall trends (Amanat Al Asimah, Sana'a, Amran, Al Mahwit) were found, on formal testing, not to be statistically significant; this is documented explicitly in Chapter 1 rather than silently corrected. Land cover change (2014 vs. 2022) could not be tested for significance, as only two time points exist for that dataset.

Secondary sources synthesized

- World Bank: Yemen Country Climate and Development Report (2024); Charting the Course: A Water Security Diagnostic for Yemen (2024).
- Yemen government/UNFCCC submissions: National Adaptation Programme of Action (2009); Third National Communication (2018); NDC 3.0 Vision (2025).
- Sana'a Center for Strategic Studies: Yemen Environmental Bulletin series; 'Conflict and Climate' (2025); 'Unlocking Climate Finance for Fragile States' (2025).
- Disaster and displacement reporting: ReliefWeb, ACAPS, UNHCR, IOM (2024 flood reporting and environmental migration desk review).

Known limitations

- The 11-year satellite rainfall record, while methodologically sound, is short relative to standard climate-trend timeframes (typically 30 years) and is presented with this caveat throughout, even where individual trends are statistically significant within that window.

- Land degradation figures in Chapter 3 (Section 3.2) have been updated to a December 2024 UNDP report specifically commissioned for UNCCD COP16, replacing an earlier, poorly-dated figure; NAPA and the Sana'a Center series were still reviewed via detailed secondary excerpts rather than complete primary documents.
- Surface water figures for coastal governorates are judged to include sea/ocean pixels within the governorate boundary and are excluded from the main analysis for that reason (see Chapter 2).
- Land cover classification (2022) reflects the most recent year available in the MODIS product at time of analysis; a true 2024 comparison was not yet possible.
- The World Bank CCDR and Water Security Diagnostic have now been reviewed in full (not via search snippets); NAPA, the Sana'a Center series, and disaster reporting sources were reviewed via detailed secondary excerpts rather than complete primary documents in every case.
- Statistical testing does not correct for multiple comparisons across the 21 governorate-level regressions run for rainfall and vegetation, and does not test for serial autocorrelation in the underlying annual time series; both are noted as caveats in Chapter 1 rather than formally corrected, consistent with the scale and consistency of the overall pattern found.

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Consolidated Bibliography

Sources are listed alphabetically by publishing organization. Full citation details (specific page/figure references) are noted where used for a specific figure in this report; general web access details are omitted for brevity but are available in the accompanying source inventory log.

- Green Climate Fund (GCF). Building Capacity for the National Adaptation Planning Process in Yemen. Project document, approved April 2025.
- International Organization for Migration (IOM). Report on Migration, Environment, and Climate Change in Yemen. Desk review, 2024.
- Our World in Data / Global Carbon Project. Yemen CO2 and Greenhouse Gas Emissions dataset. Accessed 2026.
- Climate TRACE. Yemen sectoral greenhouse gas emissions estimates, API v6. Accessed 2026.
- ReliefWeb / ACAPS / UNHCR. Yemen 2024 flood disaster response reporting. Various publications, 2024.
- Sana'a Center for Strategic Studies. Yemen Environmental Bulletin series. Various publications, 2020-2026.
- Sana'a Center for Strategic Studies, with Columbia Law School Human Rights Clinic. Conflict and Climate: The Need for Green Transitional Justice in Yemen. February 2025.
- Sana'a Center for Strategic Studies. Unlocking Climate Finance for Fragile States: The Case of Yemen. 2025.
- Sana'a Center for Strategic Studies. Socotra: Climate Change and Memory in Photos. The Yemen Review, July-September 2025.
- UNESCO World Heritage Centre. Socotra Archipelago, World Heritage decision documentation (Criterion x biodiversity assessment).
- United Nations Development Programme (UNDP) / Frederick S. Pardee Institute for International Futures, Josef Korbel School of International Studies, University of Denver. Land Degradation and Human Development in Yemen. December 2024.
- Yemen, Republic of. National Adaptation Programme of Action (NAPA). April 2009.
- Yemen, Republic of. Third National Communication to the UNFCCC. 2018.
- Yemen, Republic of. NDC 3.0 Vision, submission to the UNFCCC. 2025.
- World Bank Group. Yemen Country Climate and Development Report. November 2024.
- World Bank Group. Charting the Course: A Water Security Diagnostic for Yemen. November 2024 (underlying analysis dated 2023).
- World Bank Climate Change Knowledge Portal. Yemen country climate data and CMIP6 projections. Accessed 2026.