WFP
World Food Programme

SAVING LIVES CHANGING LIVES

ANNEX II: Key Hazard Maps for Yemen

ANTICIPATORY ACTION

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INTRODUCTION

Yemen has a long history of natural hazards causing significant humanitarian and economic impacts. Recurrent flash floods, cyclones, and droughts have affected millions across the country over the decades. For example, in 2015 two rare tropical cyclones (Chapala and Megh) struck Yemen's coast in quick succession, displacing over 82,000 people and resulting in at least 26 deaths and 65 injuries. More recently, in 2020, unusually intense rains led to flash floods that killed nearly 150 people and left 300,000 others without homes across Yemen. Floods are the most frequent natural disaster in Yemen; from 1991 to 2023, floods (including flash floods) have been responsible for about 1,425 recorded fatalities and hundreds of injuries. Droughts, while less sudden, have a deep cumulative impact – Yemen endured four major drought events in the past 30 years (the most recent in 2007–2009), contributing to water scarcity, crop failures, and food insecurity.

These hazards are often exacerbated by Yemen's protracted conflict and fragile infrastructure, which amplify the damage. For instance, flooding in 2022 was 300% above average rainfall intensity, contaminating water sources and displacing over 100,000 people (especially in Hajjah, Al Hudaydah, and Marib governorates). This combination of extreme weather and high vulnerability has made Yemen one of the world's most disaster-prone and crisis-affected countries. Figure 1 below illustrates the rising trend of disaster impacts globally in recent years, underscoring the importance of understanding risk in contexts like Yemen.

In Yemen's case, the interplay of natural hazards with conflict and socioeconomic fragility has raised disaster risk to critical levels. History records the catastrophic collapse of the ancient Marib Dam (around the 6th century CE) after heavy rains, a flood remembered for forcing the mass migration of local communities. In modern times, extreme weather events have repeatedly devastated infrastructure and livelihoods: a 2008 tropical storm in Hadhramaut caused an estimated $1.6 billion in damage and 73 deaths, and seasonal flash floods routinely destroy homes, farms, and roads. Drought and chronic water scarcity, on the other hand, have eroded agricultural productivity and contributed to an annual loss of 3–5% of arable land. These events illustrate why systematically assessing multi-hazard risks is so important for Yemen.

The relevance of risk assessment and hazard mapping cannot be overstated - it forms the foundation for reducing disaster impacts. A comprehensive risk assessment enables evidence-based decision-making by identifying which areas and communities face the highest risk and why. According to UNDRR, such assessments allow local governments to target disaster risk reduction (DRR) interventions to where they will be most effective. Humanitarian agencies also benefit by using risk maps to prioritize early warning and emergency response for the most vulnerable populations. For example, knowing that Marib's displacement camps lie in flood-prone riverbeds (wadis) helps emergency managers pre-position aid and evacuation plans before heavy rains. Private sector stakeholders, such as infrastructure developers and insurers, likewise rely on hazard maps to guide resilient investments and protect assets. In short, robust risk mapping supports a wide range of actors – government planners, humanitarian responders, and businesses – in anticipating disasters and mitigating losses. By overlaying hazard data with exposure (people and assets at risk) and vulnerability factors, a multi-hazard risk assessment provides a "complete picture of the risk landscape". This informs not only immediate preparedness (e.g. early warning systems, disaster response planning) but also longer-term strategies like safer land-use zoning, resilient infrastructure design, and community awareness programs. Ultimately, the goal is to shift from reactive crisis management to a preventive approach: empowering Yemeni communities and institutions to reduce risks before disasters strike, thereby saving lives, safeguarding development gains, and improving overall resilience.

In the context of Yemen's ongoing humanitarian crisis, conducting a multi-hazard risk assessment for flooding and drought in Marib and Hadhramaut governorates is especially timely. These two regions have witnessed severe floods and water scarcity in recent years, highlighting the need for targeted risk analysis. This report presents such an analysis. It begins with an overview of Yemen's country context – geography, climate, and socioeconomic conditions that frame its hazard profile. It then outlines the specific objectives of the assessment, sand the methodology employed, including data collection, hazard mapping, exposure and vulnerability assessment techniques.

The core of the report details findings for Marib and Hadhramaut, respectively: covering each governorate's background, hazard history (flood and drought events), key drivers of risk, climate change projections (under low and high emission scenarios), vulnerabilities, and recommended Disaster Risk Reduction (DRR) and anticipatory action (AA) measures. The report concludes with overarching insights and next steps, emphasizing how risk information can be translated into practical interventions. By providing updated, evidence-based hazard maps and risk profiles, this assessment aims to support Yemeni authorities, humanitarian partners, and donors (such as the UK and ECHO) in designing effective programs that reduce disaster impacts and build resilience in Yemen's most at-risk communities.

OBJECTIVES OF THE RISK ASSESSMENT

This risk assessment was undertaken with four key objectives in mind, focused on flooding and drought risks in Marib and Hadhramaut governorates:

1. Identify Hazard-Prone Areas and Risk Hotspots: Map the geographical distribution of flood and drought hazards in the target governorates and determine which districts and communities are most exposed.
2. Assess Community Vulnerabilities and Capacities: Analyze the underlying vulnerabilities that heighten flood/drought impacts on the population – such as settlement patterns (e.g. informal IDP camps in flood-prone wadis). By linking hazard exposure with vulnerability, the assessment can identify who would suffer most in a flood or drought

event. This knowledge is crucial for designing targeted risk reduction measures. It also ties into Early Warning and Early Action, ensuring that warning systems and contingency plans reach those with the least capacity to cope.

3. Inform Disaster Risk Reduction (DRR) and Climate Adaptation Strategies: Provide an evidence base to develop scalable DRR interventions and climate adaptation projects in Marib and Hadhramaut.
4. Enable Anticipatory Action and Early Warning: By understanding hazard characteristics, we are able to identify key parameters to monitor and apply for early warning systems.

METHODOLOGY

To achieve the above objectives, the assessment employed a multi-step methodological framework consistent with international best practices for risk assessment. The process integrated qualitative and quantitative approaches, combining remote sensing and GIS analysis with community-level insights. The key components of the methodology were:

DESK REVIEW OF EXISTING DATA AND LITERATURE:

The team conducted an extensive review of available reports, historical disaster databases, and scientific literature on hazards in Yemen. Sources included the DesInventar database (which compiles Yemen disaster events from 1980 onward), the EM-DAT international disaster database, climate studies (e.g. World Bank Climate Change Knowledge Portal country profile), and previous risk assessments (such as UNDRR's 2024 probabilistic risk assessment for Yemen). This review provided baseline statistics on hazard frequency and impacts – for instance, recorded flood events per governorate, historical drought periods, and known high-risk locations. It also covered vulnerability information – demographics, poverty rates, infrastructure coverage – through sources like the Yemen Humanitarian Needs Overview and World Bank reports. By synthesizing this secondary data, the desk study identified patterns (e.g. Marib's spike in flood incidents post-2015 due to many IDP camps) and gaps to explore further.

STAKEHOLDER ENGAGEMENT AND FIELD DATA COLLECTION:

Recognizing that data gaps exist due to the conflict, the methodology placed emphasis on local knowledge gathering. Focus Group Discussions (FGDs) and key informant interviews were organized (remotely or in person where possible) with a range of stakeholders in Marib and Hadhramaut. These included community leaders, local government officials (e.g. governorate disaster management focal points), humanitarian workers, and residents (particularly those who have experienced floods or drought impacts). Through these discussions, qualitative information was collected on perceived hazards, community coping mechanisms, and recent changes. For example, participants in Marib described how sudden torrential rains in 2020 caused the Marib Dam to overflow for the first time in decades, flooding downstream areas. They highlighted which villages or IDP sites were affected and the aftermath. In Hadhramaut, local farmers detailed the drying of wells and loss of crops during the 2007–09 drought, and elders recounted the catastrophic 2008 floods. This participatory approach not only enriched the data (by capturing events or nuances not in official records) but also built community buy-in. It helped validate and ground-truth the hazard mapping with real-world experiences of where flood waters go or how communities prioritize risks.

HAZARD IDENTIFICATION AND MAPPING:

Using the information gathered, specific hazard scenarios for floods and droughts were identified for each governorate. Flood hazard mapping was carried out through a multi-criteria GIS-based analysis integrating topographic, hydrological, and soil-related parameters. Key datasets included elevation, slope, drainage density, plan and profile curvature, topographic wetness index (TWI), and clay content, each standardized to a common scale and spatial resolution. Weights were assigned to these parameters based on their relative influence on flood generation and accumulation. The combined weighted layers were analyzed in ArcGIS to produce a composite Flood Susceptibility Index (FSI), which was then classified into five susceptibility zones - very low, low, moderate, high, and very high.

Weighting of Parameters

Weights were assigned to each parameter based on their relative influence on flood generation and accumulation processes, drawing from expert judgment, regional hydrological studies, and established literature. The Analytic Hierarchy Process (AHP) was applied to validate the assigned weights and ensure logical consistency among criteria. In the absence of reliable rainfall data, greater emphasis was placed on terrain and soil factors that indirectly influence runoff and infiltration. Parameters such as TWI (22%), slope (18%), and drainage density (18%) were prioritized for their strong influence on water accumulation and flow concentration, while elevation (12%), clay content (15%), plan curvature (9%), and profile curvature (6%) were assigned moderate weights to maintain geomorphological balance.

EXPOSURE ASSESSMENT:

In parallel with the hazard mapping, an exposure assessment was undertaken to identify elements at risk within the delineated hazard zones. This involved overlaying population and asset data onto the flood hazard maps to determine the extent of human and infrastructural exposure. While high-resolution population datasets such as WorldPop were initially reviewed, it was observed that the dense population symbology obscured the visibility of underlying risk zones. Therefore, the analysis focused on the spatial overlay of internally displaced persons (IDP) locations, who represent the primary target group for project interventions and are among the most vulnerable populations in the study area. This approach provided a clearer and more relevant understanding of exposure, ensuring that the assessment directly informs targeted resilience and risk reduction planning for at-risk communities. Critical infrastructure layers (locations of hospitals, schools, roads, bridges, power plants, water wells, etc.) will be overlaid in subsequent analyses to determine levels of potential exposure and impact.

VULNERABILITY EVALUATION:

Understanding that not all exposed communities are affected equally, the methodology evaluated vulnerability factors that influence the potential damage and loss. Key socio-economic indicators were compiled: poverty rates by district, nutrition and health statistics, access to services (water, sanitation, health care), education and literacy, and the presence of any social protection or coping mechanisms. Governance and conflict dynamics were also considered (e.g. is the area accessible to aid, is security stable enough for disaster response). This comprehensive view of vulnerability underpins risk analysis, since risk is a function of hazard, exposure and vulnerability.

QUALITY ASSURANCE AND OUTPUT PRODUCTION:

Given the importance of credible data, the methodology included cross-verification between sources. Where hard data was missing, conservative assumptions were made and noted. All maps were produced using GIS software and are accompanied by metadata explaining data sources and any uncertainties.

The next sections will present the findings for each target governorate – Marib and Hadhramaut – detailing the hazards, vulnerabilities, and recommended risk reduction measures identified through this methodology.

HAZARD AND RISK ANALYSIS FINDINGS.

Marib Governorate: Hazard Profile, Vulnerabilities, and Recommendations

Overview of Marib

Marib is located in northeastern Yemen, bordered by Al-Jawf, Hadhramaut, Shabwah, and Sana'a. Its geography transitions from highland foothills in the west to flat desert in the east, with a hot, arid climate and limited rainfall (100–250 mm/year). The key hydrological feature is Wadi Marib, historically significant for irrigation, particularly around the Marib Dam. Temperatures frequently exceed 40°C in summer, while winters are milder.

Economically, Marib is rich in oil, gas, and agriculture, contributing 7.6% of Yemen's national crop output. The fertile western districts support date palms and cereals, while the east is more pastoral. Once sparsely populated, the governorate has absorbed a dramatic influx of IDPs since 2015, rising from 300,000 residents to an estimated 1.5–2.4 million by 2022. Over 900,000 IDPs now reside in camps and informal sites, straining infrastructure and basic services.

Despite these pressures, Marib's economy has grown due to retained oil revenues and a border crossing with Saudi Arabia. The local government has used these resources to invest in infrastructure and pay salaries—an exception in war-torn Yemen. However, vulnerability remains high: around 80% of residents require humanitarian aid, and poverty has increased, especially in IDP communities. Marib now represents both a refuge and a pressure point, where economic potential is tempered by displacement, poverty, and exposure to natural hazards.

Historical Flood and Drought Events in Marib

Marib's hazard profile is dominated by flood risk, although drought and extreme heat are also concerns. Table 1 below summarizes some notable flood events in Marib's recent history:

Date	Event Description	Reported Impact	Sources
Jul-20	Heavy rains leading to widespread flash floods across Marib (particularly Marib City, Al Wadi, Sirwah, Madghal districts).	~17,000 families (over 100,000 people) affected; at least 17 deaths; flooding of 90+ IDP camps with over 3,500 shelters destroyed. Marib Dam overtopped its spillway for the first time since 1986, raising concerns about dam integrity. Extensive damage to farms, homes, and roads.	OCHA/ReliefWeb 2020 Situation Report; IOM Marib Briefing 2020.
Aug-22	Summer rainy season brought 300% above-average rainfall; flash floods in Marib and neighboring areas.	Dozens of small settlements flooded. Marib city saw streets inundated; ~9,800 families affected in Marib governorate (local reports). Floodwaters displaced additional IDPs on conflict frontlines in western Marib.	UNHCR Yemen Update 2022.

Apr-16	Flash floods following spring rains.	Thousands affected; the newly expanded IDP camps (post-2015) were hit hard, with shelters and food stocks washed away. Triggered an appeal by local authorities for drainage improvements in camps.	Local media, Marib Gov't press release (2016).
(Other years)	2019, 2021, and 2023 also saw seasonal floods.	Repeated damage to IDP sites (which expanded to ~140 sites by 2021). Yearly floods cause loss of shelter, livelihoods (e.g. livestock drowning, crop loss).	IOM, OCHA situation updates.

Table 1: Selected recent Historical Flood Events in Marib Governorate

Marib's floods are often flash floods due to intense downpours. The governorate's landscape – with dry riverbeds (wadis) that fill rapidly when it rains in the highlands – means floods can occur with little warning. The areas along Wadi Marib and its tributaries are particularly at risk.

Flood Risk Susceptibility map.

A flood susceptibility map is a spatial tool that identifies areas at varying risk of flooding based on environmental, topographic, hydrological, and soil-related factors. It highlights zones that are more likely to experience flooding by analyzing flood conditioning parameters. The conditioning parameters used in the flood susceptibility mapping of Marib were elevation, slope, rainfall, Soil clay content, drainage density, Topographic Wetness Index (TWI), Profile curvature and plan curvature. See table below for details.

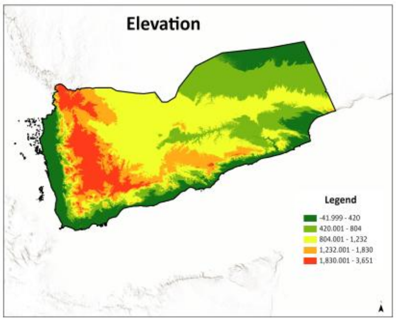
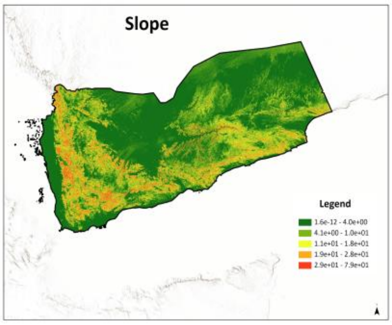
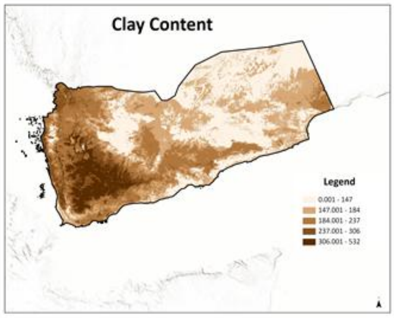
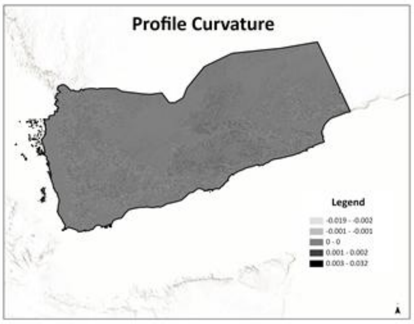
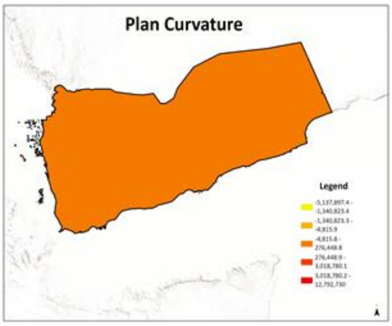
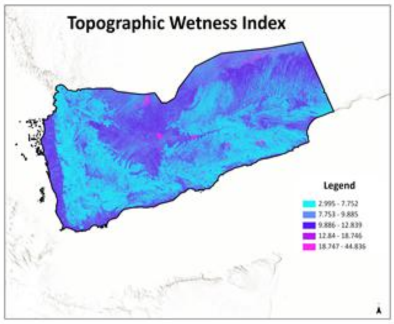
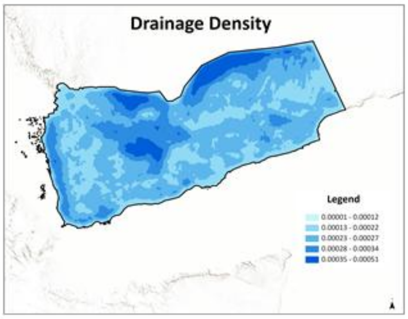
 Weight = 12%	 Weight = 18%	 Weight = 15%
 Weight = 6%	 Weight = 9%	 Weight = 22%
 Weight = 18%		

Table 2: Flood Conditioning parameters and their weights for flood risk zonation

These flood conditioning parameters were first standardized to a common numerical scale, typically ranging from 0 to 1, to normalize differences in units, magnitudes, and measurement formats. Standardization ensures that variables such as slope (measured in degrees) and rainfall (measured in mm/year) can be directly compared and meaningfully integrated in a multi-criteria analysis framework. Each parameter was then reclassified into categories (e.g., low, medium, high) based on their contribution to flood potential—for example, lower elevations and flatter slopes were assigned higher susceptibility scores due to their increased flood retention capacity. Following standardization, the parameters were assigned weights based on their relative influence on flood occurrence, drawing from both published hydrological studies and local expert judgment. The Analytic Hierarchy Process (AHP) was employed to systematically validate and refine these weights. AHP uses a pairwise comparison matrix to rank the importance of each parameter and calculate consistency ratios to ensure that the weighting process is logically sound and statistically consistent. This method enhances the objectivity and replicability of the susceptibility model.

The weighted parameters were then integrated using a GIS-based overlay analysis, where each raster layer representing a parameter was multiplied by its corresponding weight and summed to derive a composite flood susceptibility index. This index reflects the cumulative influence of all conditioning factors on flood risk in each spatial unit (e.g., grid cell or pixel). Finally, the index values were classified into distinct flood risk zones - typically categorized as very low, low, moderate, high, and very high susceptibility, using natural breaks or quantile classification methods. This final map provides a visual and analytical basis for identifying flood-prone zones and prioritizing risk mitigation interventions.

Assumptions that guided the analysis:

- The selected parameters represent the dominant natural factors influencing flood susceptibility in Yemen, and interactions between variables are minimal.
- Environmental conditions (topography and soils) are assumed to be static over the analysis period.
- In the absence of dynamic factors like rainfall data, terrain-based indices such as TWI and drainage density served as effective proxies for hydrological behavior.
- The weighted overlay approach is assumed to provide a valid approximation of flood-prone zones, recognizing that it represents relative, not absolute, flood likelihood.

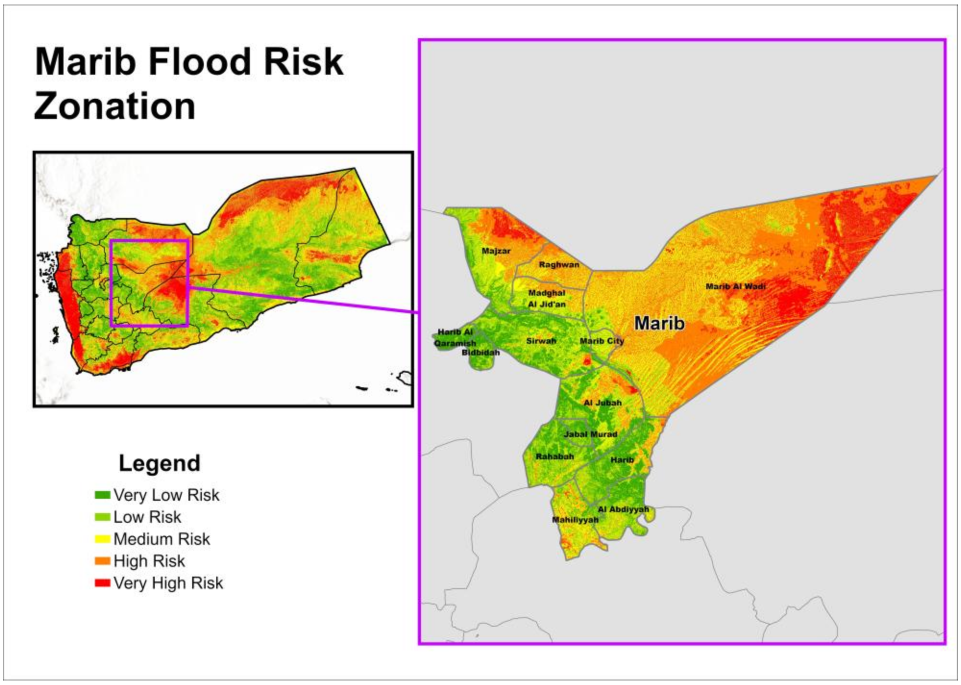


Figure 1:Flood Risk Zonation of Marib Governorate

The mapping identified the Western part of Marib as very highly susceptible to floods, with Marib Al Wadi, Raghwan and Majzar districts being the most highly susceptible.

Drivers of Hazard Risks in Marib and Humanitarian Impacts.

Several factors contribute to the high exposure and impact of floods in Marib:

Sudden, Intense Rainfall:

Marib is prone to short, heavy cloudbursts, especially during rainy seasons, which generate flash floods due to dry soil and limited vegetation. The area's erratic rainfall patterns mean long droughts can be interrupted by extreme rainfall in a single day. This intensifies flood risks, especially as climate change increases the frequency and severity of such events. Communities often have little time to prepare or respond.

Topography and Hydrology:

Flat plains and numerous wadis make Marib highly susceptible to flooding, particularly in districts like Al-Wadi, Al-Jubah, and Harib. These wadis carry water from upstream highlands and often overflow during heavy rain. Settlements near these channels face severe flood risks due to a lack of control infrastructure. In 2020, floods from Wadi Dhana and Wadi Harib caused extensive damage.

Degraded Infrastructure:

Years of conflict have damaged flood management infrastructure in Marib. Drainage systems are often blocked or broken, while irrigation canals and bridges are in disrepair. Urban expansion has outpaced sewage and runoff management, leading to pooling during rain. Damage to the Marib Dam's auxiliary systems has also limited its ability to regulate floodwater, worsening the 2020 floods.

Population Pressure and Displacement:

Mass displacement has pushed thousands into flood-prone areas such as dry riverbeds and low plains. Many IDP camps are located in wadis due to available land, despite the risks. In 2020, major floods inundated camps like Al Jufainah and others in Sirwah. Makeshift shelters are easily destroyed, leaving displaced populations highly vulnerable and often subject to repeated displacement.

Environmental Degradation:

Deforestation, overgrazing, and charcoal production have reduced vegetation cover, increasing runoff and erosion. Loss of trees and soil stability near wadis worsens flash flood intensity and speed. Sediment build-up in riverbeds from upstream erosion has raised wadi levels, making overflows more frequent. These factors collectively make flooding in Marib more widespread and dangerous than in previous decades.

The humanitarian impacts.

The impacts of these hazards in Marib are severe and multifaceted:

Loss of Life and Property:

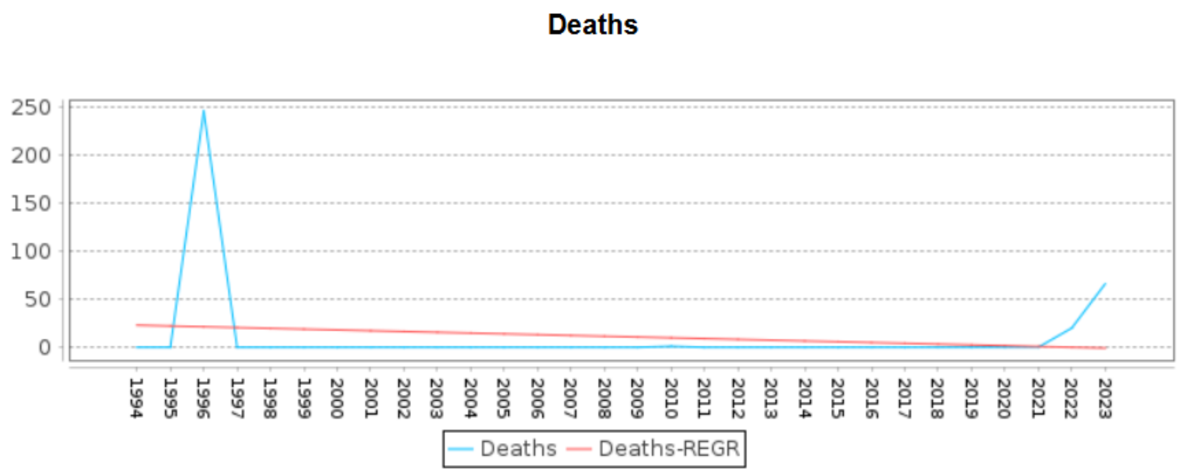


Figure 2: Flood Hazard Related deaths in Marib. Source: DesInventar

Floods directly cause deaths and injuries, especially when they catch people by surprise at night. In 2020, at least 17 people died in Marib due to flooding, including children who drowned in wadis.

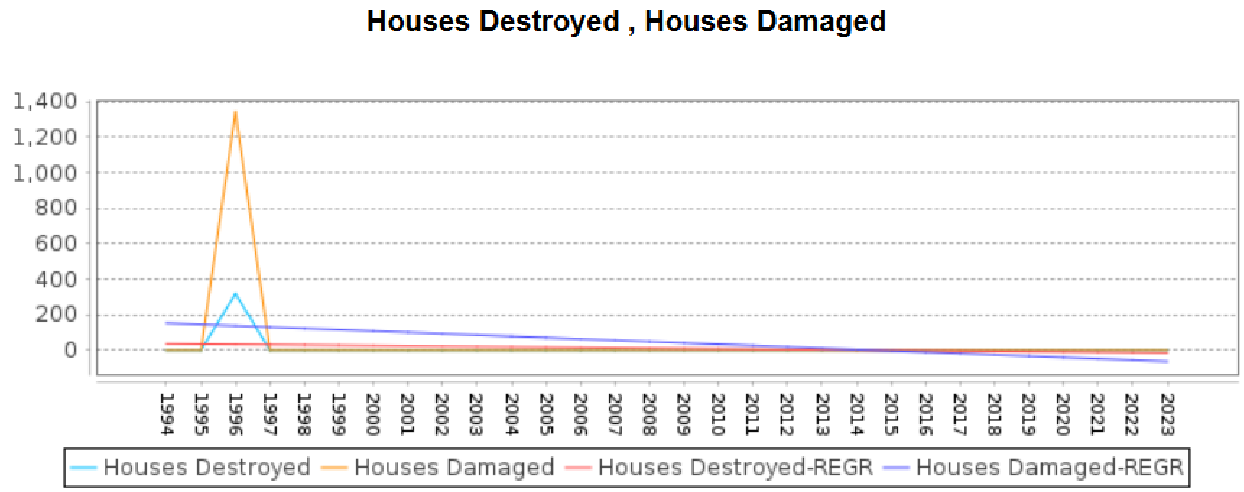


Figure 3: Property damage due to flooding in Marib

Houses – often simple mud-brick or tents are destroyed, and essential household assets are lost. For IDPs, even their few belongings (mattresses, cooking utensils, documents) can be washed away, exacerbating their suffering. The Marib government reported that the 2020 floods destroyed 66 houses and damaged 165 farms in one event. In rural areas, livestock losses were common (animals tied or in pens drowned). Each flood sets affected families back to zero, eroding any gains since their displacement.

Secondary Displacement:

Tragically, flood events often force already displaced people to move yet again. When an IDP camp is flooded, families may have to relocate to higher ground or to other camps, sometimes in the middle of the crisis. This was seen when camps on the Sirwah frontline were evacuated not only due to conflict but also flooding. Secondary displacement increases the humanitarian caseload and puts extra pressure on host communities and aid providers.

Moreover, the IDP sites in Marib are close to flood prone areas (see map below). When selected IDP sites in Altasamuh, Tadamen and Mneen Al-Haddad were overlayed on the flood the flood susceptibility map of Marib district, they were found to fall within high flood risk zones, posing a great potential humanitarian dilemma.

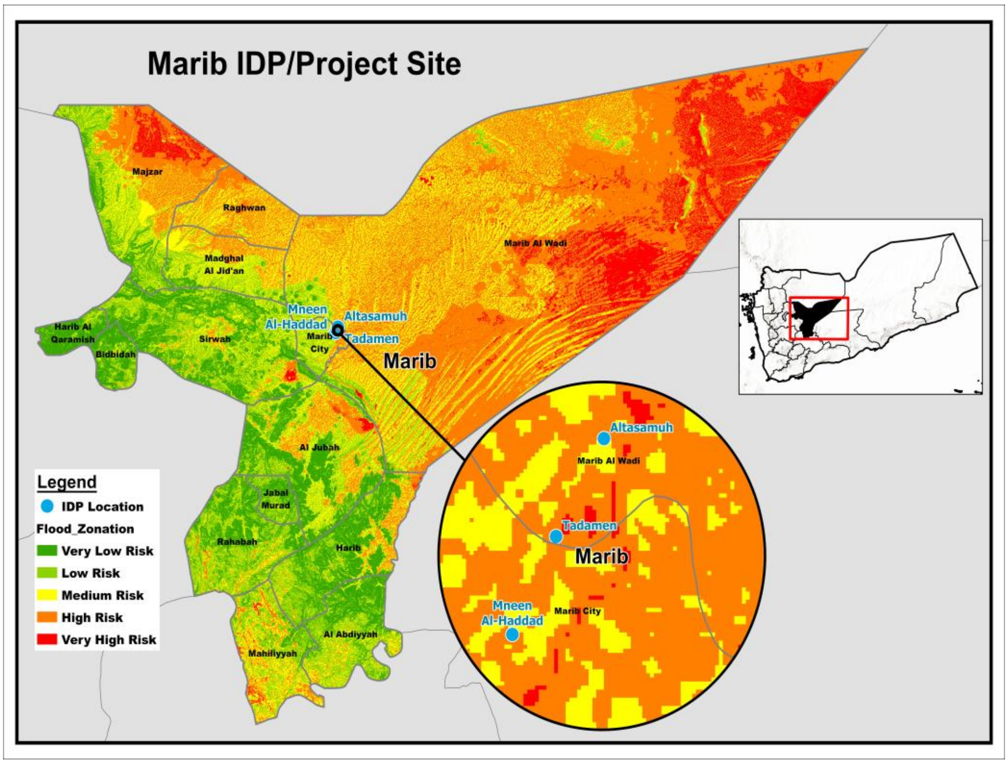


Figure 4:Overlay of IDP locations and on flood risk Zones

Livelihood and Food Security Impacts:

According to assessments, many areas of Marib are in IPC Phase 3 “Crisis” food insecurity, and without humanitarian aid would slip into emergency. Hazards make this worse by causing spikes in food prices (for example, if floods cut off the road from Marib to Sana’a, food supply is affected). Additionally, when families lose assets to floods, they often must spend scarce money to recover, leaving less for food. There have been reports of increased malnutrition cases in flood-affected communities post-disaster.

Future Climate Trends and Projections for Marib (RCP2.6 vs RCP8.5).

Looking ahead, climate change is expected to alter hazard patterns in Marib, with different outcomes depending on global emission pathways. We consider two scenarios roughly equivalent to the RCP2.6 (low emissions) and RCP8.5 (high emissions) trajectories (using updated SSP scenarios as a proxy: SSP1-2.6 vs SSP5-8.5). The projections for the mid-21st century (around 2050) and late century (2080–2100) suggest:

Temperature Rise:

Under a low-emission scenario (RCP2.6), global warming is limited – in Marib’s region this might mean an average increase of around +1.0 to +1.5°C by mid-century. High-emission (RCP8.5) scenarios would lead to much greater warming; by 2050 Marib could be ~+2.5 to +3°C hotter on average than baseline, and by 2100 possibly +4–5°C if unabated.

The difference is stark: RCP8.5 would mean extreme heat becomes a norm – more frequent days above 45°C, and harsher, longer heatwaves. Under RCP2.6, such extremes would still increase but to a lesser degree. For Marib, higher temperatures exacerbate drought (via evaporation and higher water demand) and heat stress on people and livestock. By 2060, under a high scenario, Marib could experience many additional days of "high heat index" dangerous conditions each year.

Rainfall Patterns:

Projections of precipitation for Marib (and Yemen's interior) carry uncertainties. However, climate models broadly indicate that extreme rainfall events are likely to become more intense under higher warming. RCP8.5 scenario entails a warmer atmosphere that can hold more moisture, so when conditions trigger rain, it could fall in heavier bursts. This means flash floods may become more frequent or severe. Some models project an increase in mean annual rainfall in Yemen under high emissions (due to more monsoon moisture), but the distribution is uneven – Marib might see slightly wetter wet seasons but also potentially longer dry spells. Under RCP2.6, changes in total rainfall might be minimal, and any increase in extremes would be smaller. In practical terms: by late century RCP8.5, a storm that now might drop 50 mm could drop 70–80 mm, intensifying flood risk. RCP2.6 would curtail the warming and likely moderate such changes, though some increase in heavy rainfall could still occur due to committed warming.

Drought and Water Scarcity:

Interestingly, even if average rainfall rises, the variability will likely increase, so drought risk remains. Under RCP8.5, higher evapotranspiration (due to heat) means soils dry faster, and groundwater recharge may decline unless rainfall comes steadily (which it likely won't). Thus, Marib could face more intense droughts in terms of severity and frequency – a warmer climate means the same rainfall deficit has a worse impact. RCP2.6 would still see warming but hopefully maintain closer to current variability, potentially limiting additional drought frequency after mid-century. However, given the range of models, drought episodes are expected to continue under all scenarios. The high scenario just makes them more damaging (because each drought occurs in a hotter context).

Sandstorms and Dust:

With higher temperatures and possibly prolonged aridity under RCP8.5, Marib might see increased desertification of marginal lands and more dust storms. Already, dust storms are a hazard in Marib; climate change could worsen them if vegetation cover is lost and soil dries out further. RCP2.6's mitigation of extreme heat could slightly reduce this risk.

Adaptation Uncertainty: It's worth noting that these outcomes assume climate change pathways, but actual impacts will also depend on adaptation measures taken. If Marib invests in water management, irrigation efficiency, and flood defenses, it can reduce the damage under either scenario. However, under RCP8.5, the magnitude of change might outpace the adaptation capacity in a fragile state context.

Marib's future climate under a low-emission scenario is one of moderate warming and roughly similar rainfall patterns (with some improvement in extremes), whereas under a high-emission scenario it faces a much hotter, possibly wetter-but-more-erratic climate with higher risk of both floods and droughts. For planning purposes, this means Marib should prepare for an amplification of current hazards. The prudent approach, given the uncertainty, is to adopt no-regrets measures that strengthen resilience to both extremes (e.g. water storage helps for droughts, while drainage infrastructure helps for floods).

Vulnerabilities in Marib.

Marib's vulnerability to flood and drought hazards is shaped by a complex interplay of social, economic, and infrastructural factors. Key vulnerability aspects include:

Livelihood and Economic Vulnerability:

Marib's economy is stronger than many parts of Yemen due to oil and agriculture, but this wealth is unevenly distributed. Many internally displaced persons (IDPs) depend on aid or insecure informal jobs, with limited financial resilience. Farmers and herders face total income loss if seasonal hazards occur, as they rely on single harvests or livestock. Economic fragility persists due to inflation, high fuel prices, and conflict-related market distortions. Most low-income households lack savings or assets, making them unable to recover from floods or droughts without external support.

Poverty and Inequality:

Poverty in Marib has surged due to conflict and displacement; pre-war rates were around 26%, but current levels may range from 60% to 80%. Long-term residents often fare better than newer, marginalized IDPs. Female-headed households are particularly at risk, struggling to access income and basic needs. Many live in the most hazard-prone areas because safer housing is unaffordable. Poverty increases vulnerability to disasters by limiting access to risk reduction measures and safe shelter.

Infrastructure and Housing:

Marib's infrastructure has not kept pace with its growing population. Many people live in tents or poorly constructed shelters that are highly susceptible to floods and storms. Rural areas often lack roads, and flooding can cut off communities, delaying aid. Water and sanitation systems are underdeveloped, with many rely on unsafe sources like wadis or shallow wells. The Marib Dam, while beneficial, also poses flood risks if mismanaged or overwhelmed.

Governance and Institutional Capacity:

Local authorities in Marib have demonstrated leadership but are under-resourced and overstretched, especially in conflict-affected districts. Disaster response systems exist but rely heavily on international support and lack operational capacity. Early warning dissemination is limited and informal, with no robust communication infrastructure. Coordination challenges between tribal and formal authorities hinder cohesive disaster management. Regulatory enforcement around land use and risk-sensitive planning remains weak.

Vulnerable Groups:

Key vulnerable groups include IDPs, who often lack documentation and live in unsafe camps; women and children, who face mobility, protection, and health challenges; and nomadic pastoralists, whose livelihoods are directly tied to climate conditions. Urban poor migrants also face instability, often without family or social safety nets. The elderly and disabled are often overlooked in planning and face greater difficulties in evacuating or accessing assistance. These groups suffer disproportionately during disasters.

Economic Systems and Safety Nets:

While Marib has modest revenue from oil and a growing local market, formal safety nets are extremely limited. Humanitarian cash assistance (from WFP and UN) offers minimal support but is insufficient for large-scale shocks. Traditional tribal support mechanisms provide some relief, but are overwhelmed by the scale of displacement. There is potential to build on local governance and market activity, but current systems cannot adequately protect vulnerable populations in disasters.

DRR and Anticipatory Action Recommendations for Marib

1. Strengthen Flood Protection Infrastructure and Wadi Management:

Immediate investment is needed in physical flood defenses. This includes reinforcing Marib Dam and its spillways, constructing small embankments and check dams in flood-prone corridors, and clearing and deepening wadis to improve water flow. Urban storm drainage and sanitation infrastructure, especially in Marib city and IDP camps, must be upgraded. Soil conservation and afforestation efforts upstream can reduce runoff and stabilize landscapes.

2. Implement Effective Early Warning Systems (EWS):

Flood EWS should be developed using upstream rain and river gauges, linked with communication tools like mobile alerts and sirens. Community-based observers can provide real-time data to trigger alerts. For droughts, forecast-based systems using rainfall and vegetation monitoring should trigger anticipatory aid (e.g. cash transfers, livestock feed) before conditions deteriorate. Public education, preparedness drills, and seasonal awareness campaigns can enhance community readiness and reduce casualties.

3. Improve Safety and Infrastructure in IDP Camps:

Relocate the most at-risk IDP sites away from wadis and flood zones or elevate sections within camps to reduce flood exposure. Upgrade shelter designs using elevated platforms and ensure proper drainage systems are in place. Invest in water infrastructure like boreholes, solar pumps, and community cisterns to build drought resilience. Access roads should be improved for emergency response, and local teams trained in basic disaster response and first aid.

4. Promote Climate-Resilient Livelihoods:

Introduce climate-smart farming practices such as drought-tolerant crops and efficient irrigation systems. For herders, establish fodder reserves and protected grazing schemes, along with expanded veterinary services. Scale up cash-for-work programs that build DRR assets while supporting household income. Explore risk financing options, including micro-insurance or parametric insurance models, to help vulnerable groups recover from hazard-induced losses.

5. Strengthen Coordination and Policy Integration:

Create a dedicated DRR working group in Marib involving government, donors, UN, NGOs, and tribal leaders to coordinate efforts. Embed DRR into local development plans, including land-use regulations to prevent construction in flood-prone zones. Empower community committees to manage preparedness efforts and ensure inclusive participation, especially of women. Establish systems to monitor progress and document success stories for continued donor engagement and learning

Governorate of Hadhramaut: Hazard Profile, Vulnerabilities, and Recommendations

Overview of Hadramawt

Hadhramaut, Yemen’s largest governorate by area, stretches from the Arabian Sea coast through high plateaus to the Rub’ al Khali desert. It is geographically divided into Coastal Hadhramaut, centered around the port city of Mukalla, and Wadi Hadhramaut, a prominent inland valley home to towns like Seiyun, Tarim, and Shibam. The region includes rugged highlands, arid deserts, and a narrow coastal strip, with most settlements concentrated in wadis and along the coast.

The climate is arid to hyper-arid, with very low annual rainfall (50–100 mm in the interior). Coastal areas experience hot, humid conditions influenced by the Indian Ocean monsoon, while the interior endures extreme heat in summer. Rainfall is rare but intense, often leading to flash floods in dry wadis. Hadhramaut is increasingly exposed to tropical cyclones from the Arabian Sea, such as Cyclone Chapala (2015), which brought destructive rainfall and coastal flooding.

Economically, Hadhramaut holds strategic value due to its oil fields in the Masila basin, fishing along the Arabian Sea, and agriculture in the wadis (notably dates and cereals). The region also benefits from remittances and cross-border trade through the Al-Wade'a border crossing with Saudi Arabia. Major towns like Mukalla and Seiyun have continued to provide basic services despite Yemen's broader conflict, thanks to relative stability and local revenue streams.

Socially, the population (estimated 1.5–1.8 million) faces moderate poverty (around 60%) and humanitarian needs, with about 1 million people requiring aid as of 2023. Hadhramaut hosts roughly 450,000 IDPs, but they are more dispersed and better integrated than in other regions. Governance structures remain functional, and local leadership has maintained order in most areas since 2016. Strong community networks and tribal cohesion support local resilience and offer a foundation for disaster risk reduction.

Hadhramaut combines economic potential and relative peace with vulnerability to climate hazards such as floods, cyclones, and drought. Its geographic and climatic diversity, functioning governance, and social cohesion position it well for targeted DRR and adaptation investments to protect livelihoods and infrastructure from worsening climate risks.

Historical Flood and Drought Events in Hadhramaut.

Hadhramaut has experienced several significant floods and droughts, making it one of Yemen's most hazard-prone regions. The 2008 tropical storm caused catastrophic flooding in Wadi Hadhramaut, killing at least 73 people and resulting in $1.6 billion in damages, affecting over 700,000 people. Cyclone Chapala (2015) brought storm surge and torrential rains, severely flooding Mukalla and displacing tens of thousands. Subsequent cyclones, including Luban (2018), and intense seasonal rains in 2020 and 2021, caused additional flash flooding in both urban and rural areas. Meanwhile, prolonged droughts have undermined agriculture and water availability, with notable dry periods in the early 2000s and 2015–2017, contributing to water scarcity and reduced crop yields.

In terms of affected areas:

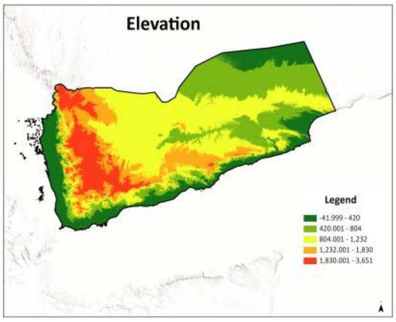
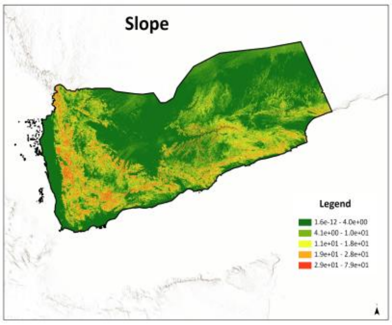
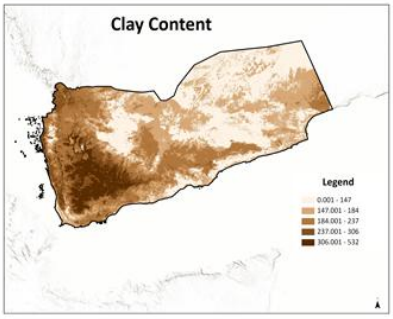
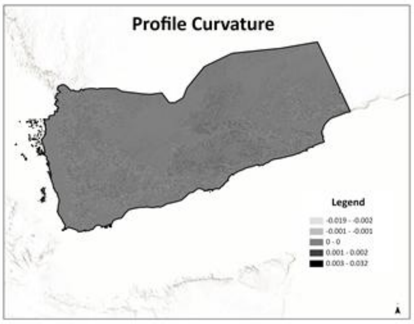
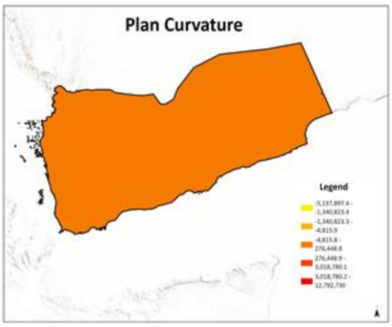
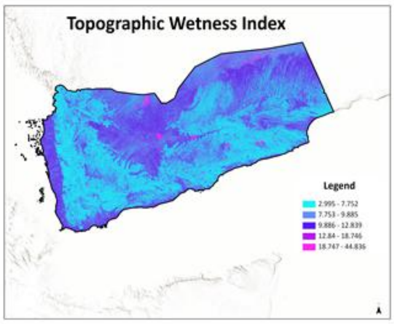
Wadi Hadhramaut (districts like Seiyun, Shibam, Tarim) have seen repeated flood impacts: 1980s had some floods, 2008 was the worst, and some flooding recurred in 2010 and 2013 (less severe though). The wadis are clearly flood plains.

Coastal Hadhramaut (Mukalla, etc.) faces two threats: flash floods from interior valleys that drain to the sea (in 2020, a flood came down Wadi Bana to the coast), and direct coastal storms. Mukalla city, bisected by a khor (creek), can flood if the creek barriers are overtopped, which happened in Chapala.

Northern Desert: hazards here revolve more around infrequent rain causing ephemeral floods in normally dry wadis that can strand nomads, and of course, the persistent drought and occasional sandstorms.

Flood Risk Susceptibility map.

The same geospatial approach used for Marib was applied to identify areas at varying risk of flooding based on environmental, topographic, hydrological, and soil-related factors in Hadhramaut. The conditioning parameters used in the flood susceptibility mapping of Hadharamaut were elevation, slope, Soil clay content, drainage density, Topographic Wetness Index (TWI), Profile curvature and plan curvature. See table below for details.

 Weight = 12%	 Weight = 18%	 Weight = 15%
 Weight = 6%	 Weight = 9%	 Weight = 22%

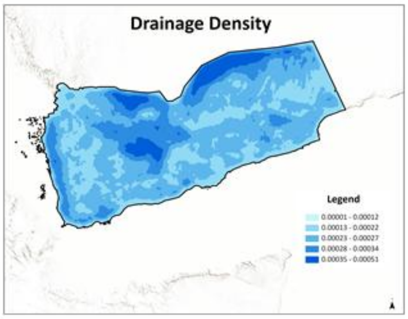
 Weight = 18%		

Table 3: Conditioning factors and their weights for flood risk zonation in Hadhramaut

The parameters were initially normalized to a uniform scale to allow for meaningful comparison. Each was then given a weight reflecting its relative contribution to flood risk, guided by expert insights and existing literature. To support the reliability of these weights, the Analytic Hierarchy Process (AHP) was also applied. The weighted layers were subsequently integrated through overlay analysis in a GIS environment to generate a composite flood susceptibility index, which was categorized into risk zones ranging from low to high, as illustrated below.

The same analytical assumptions applied in the overall flood susceptibility assessment were adopted for the Hadhramaut analysis to maintain methodological consistency. It was assumed that the selected parameters represent the dominant natural factors influencing flood susceptibility, with minimal interaction between variables. Environmental conditions such as topography and soils were considered static over the analysis period. In the absence of dynamic rainfall data, terrain-based indices like the Topographic Wetness Index (TWI) and drainage density were used as proxies for hydrological behavior. The weighted overlay approach was likewise assumed to provide a valid representation of relative flood susceptibility across the governorate.

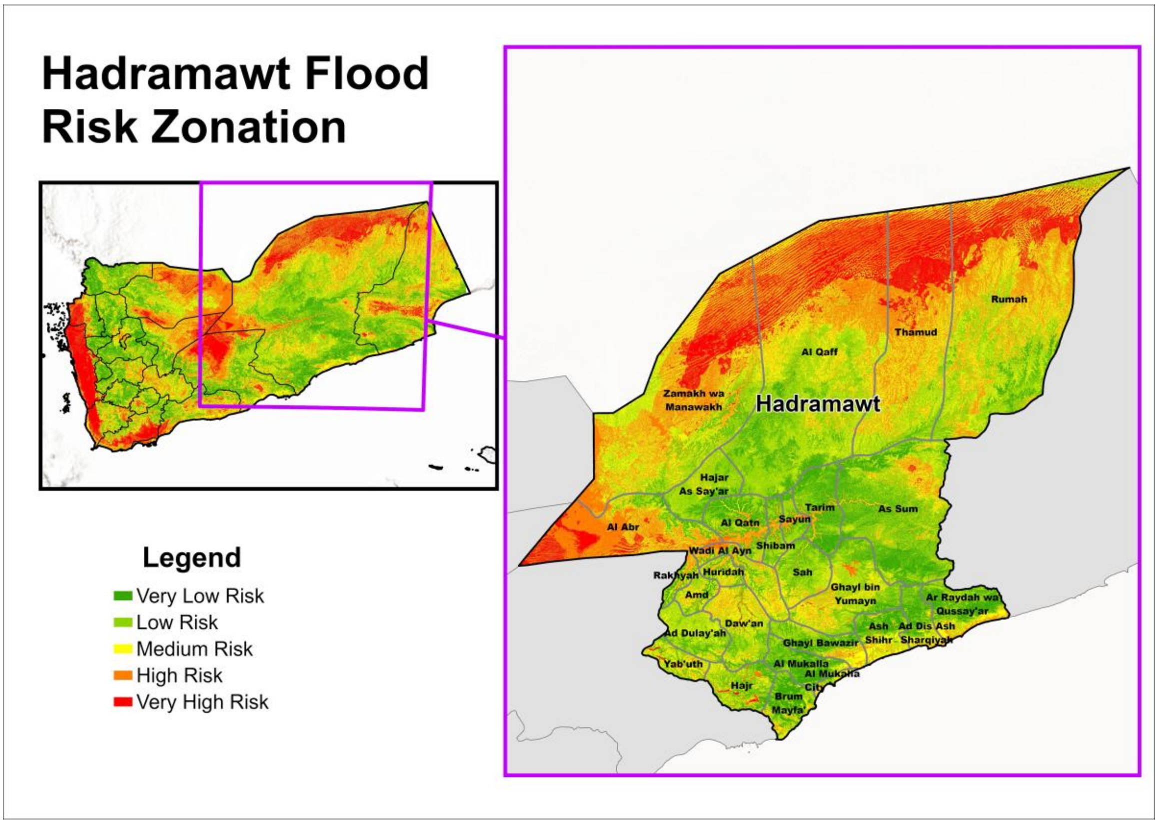


Figure 5: Flood Risk Zonation of Hadhramaut Governorate

The mapping identified the northern part of Hadharamaut as very highly susceptible to floods, with Thumad, Al Qaff, Al Abr and Zamakh wa Manawakh districts being the most highly susceptible.

Drivers of Hazard Risks in Hadhramaut.

Several factors contribute to the high exposure and impact of floods in Marib:

Several interlinked environmental and human factors intensify hazard risks in Hadhramaut. The region's rugged terrain channels rainfall rapidly into wadis, producing sudden flash floods that threaten valley towns and farms.

Limited soil infiltration and the merging of tributaries amplify water volumes, offering little time for warning.

Vegetation loss due to aridity, overgrazing, and deforestation further exacerbates runoff, erosion, and sedimentation, making floods more severe and frequent.

Climate change is altering rainfall patterns, increasing the frequency and intensity of extreme downpours and cyclones.

Rising sea surface temperatures contribute to stronger storms, while erratic precipitation raises the risk of both floods and prolonged droughts. Infrastructure remains ill-equipped for such hazards: outdated or weak flood defenses, vulnerable mudbrick housing, and roads crossing wadis are easily damaged during floods, isolating communities. Additionally, coastal cities like Mukalla face rising sea levels, storm surges, and saltwater intrusion, all of which threaten infrastructure, water supplies, and livelihoods.

These combined drivers underscore the urgent need for climate-resilient planning and disaster mitigation in Hadhramaut.

The humanitarian impacts.

Loss of Life and Property:

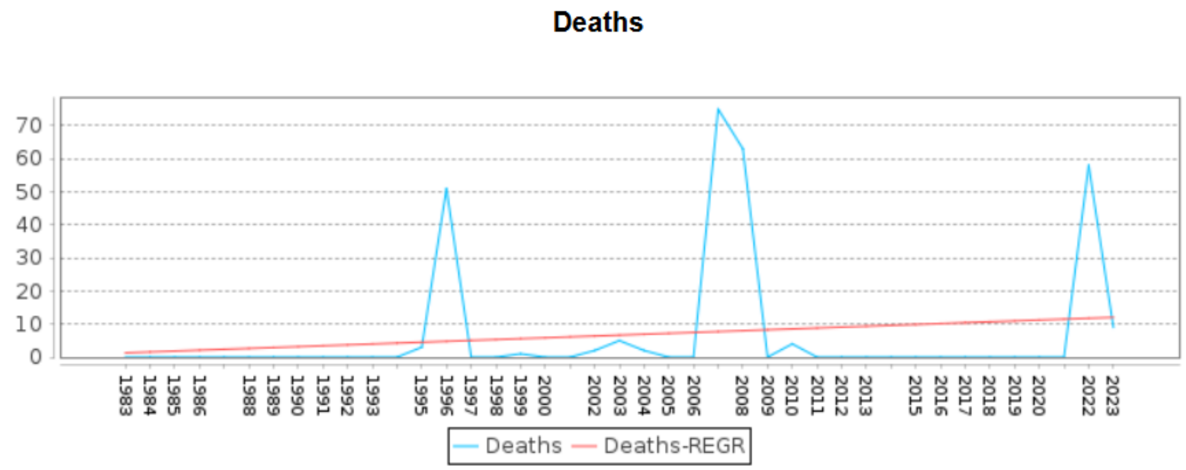


Figure 6: Flood Hazard related deaths in Hadhramaut. Source: DesInventar

As seen in 2008 and 2015, major floods in Hadhramaut cause fatalities and destroy critical infrastructure (roads, bridges, power lines). The widespread damage ($1.6 billion in 2008) has long-term economic impacts – it diverted resources to reconstruction and slowed development.

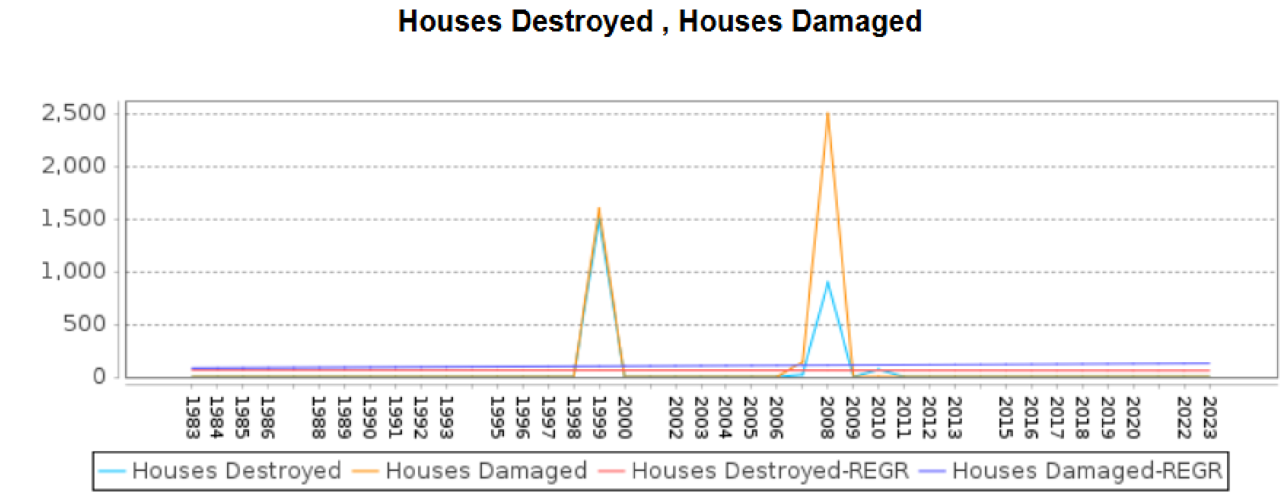


Figure 7: Property damage due to flooding in Hadhramaut. Source: DesInventar

Recurrent floods mean repeated setbacks. For example, some families in Wadi Hadhramaut lost their homes in 2008, rebuilt on the same site, only to face lesser floods in subsequent years damaging them again.

Displacement: In 2008, thousands were temporarily displaced, with many moving from destroyed villages to stay with relatives or in public buildings. Some never returned, migrating to cities or out of the region. Cyclones in 2015 and 2018 also caused people to flee coastal homes (some moved to higher ground or into schools/mosques as shelters). While Hadhramaut's displacement due to conflict is moderate, climate disasters can create new displacements that sometimes become permanent if livelihoods are lost. The overlay of IDP locations in Mushta and Aidid on the flood risk zones indicated that although they are close to moderate flood risk zones, the districts are largely low risk zones, implying less humanitarian impacts (see map below).

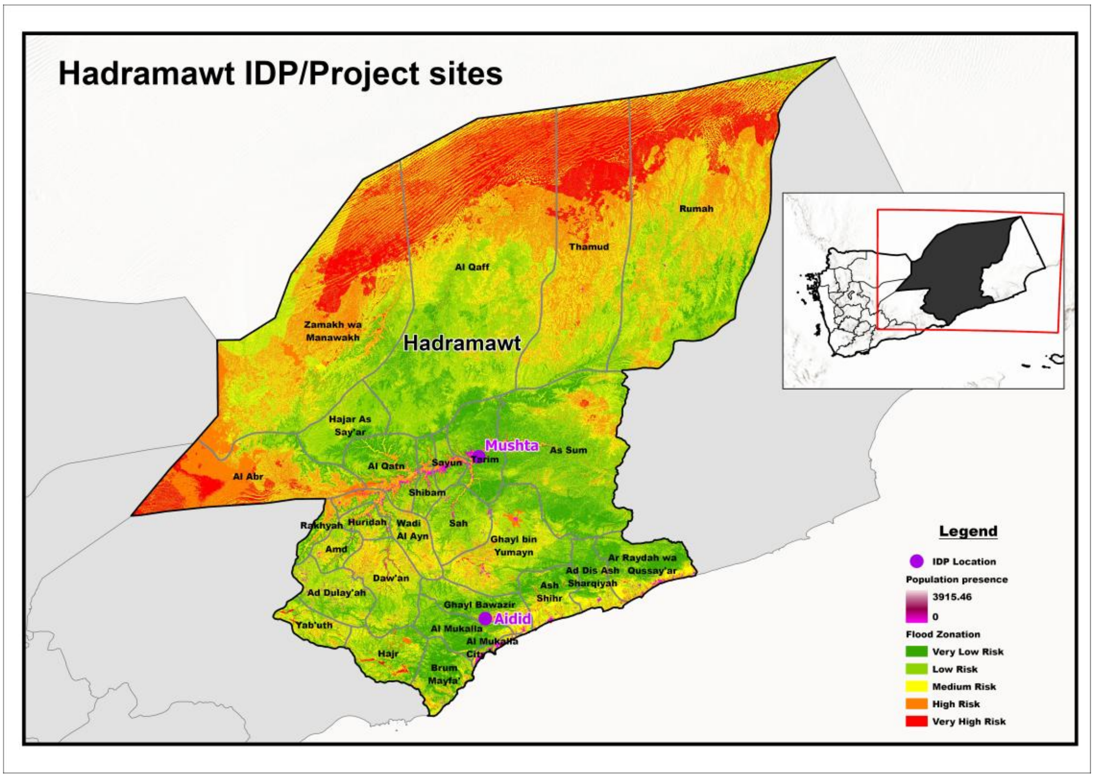


Figure 8:Flood Hazard Population and IDP exposure in Hadhramaut

Livelihood and Food Security Impacts:

Hadhramaut, being relatively more stable, often receives less humanitarian focus than warfront regions. However, when disasters strike, it suddenly requires significant assistance – as in 2008, when emergency relief had to be mobilized for tens of thousands. If climate hazards become more frequent, it could strain local authorities and require more frequent humanitarian interventions. Already, WFP and others support some areas due to climate impacts on food security (especially after bad agricultural years).

Future Climate Trends and Projections for Hadhramaut (RCP2.6 vs RCP8.5)

Hadhramaut's future hazard profile will be shaped by global climate change trends. Based on scenario projections akin to RCP2.6 (low emissions) and RCP8.5 (high emissions), we can anticipate:

Temperature Increase:

Similar to Marib, Hadhramaut will experience warming. Under RCP2.6, average temperatures might rise by ~1–1.5°C by mid-century. Under RCP8.5, by 2060 a rise of 2–3°C is likely and by

2100 potentially 4°C or more. Given Hadhramaut already has very high summer temperatures, this additional heat will increase heat stress and evaporation. Coastal areas will also get hotter and more humid. This exacerbates drought (higher evapotranspiration) and health risks (heat stroke, etc.). RCP2.6 would limit the worst of this, making adaptation more manageable.

Precipitation and Extreme Rainfall:

Climate models for Yemen indicate a possible increase in the intensity of heavy rainfall events by mid-to-late century, especially under high emissions. For Hadhramaut, this suggests that while total annual rainfall might not dramatically increase, when rain comes it could be in more intense bursts. Flash flood risk could therefore rise.

High emissions (RCP8.5) scenario would amplify the kind of extreme events like cyclones and intense convective storms. There could also be changes in seasonality – e.g. an extended monsoon influence or shifting of rainy periods. Conversely, low-emission scenario might see more modest changes, with perhaps slight increases in rainfall but not dramatic.

Climate models project a possible increase in tropical cyclone activity in the Arabian Sea (as already observed) – warmer sea surfaces under RCP8.5 mean potentially more frequent and stronger cyclones hitting Yemen's coast. For Hadhramaut, that could mean what was a once-in-30-year cyclone could happen maybe every decade or more often by late century. RCP2.6, by stabilizing global warming sooner, might keep cyclone frequency closer to historical norms (still higher than pre-2000 because some change is locked in, but not escalating).

Sea Level Rise:

With high emissions, global sea levels could rise ~0.6–1.0 m by 2100. Yemen's coast would likewise see significant rise. Even mid-century under RCP8.5, perhaps 20–30 cm rise is possible. This will worsen coastal erosion and flooding in Hadhramaut's low-lying coastal areas. Mukalla's waterfront and areas like the fishing town of Al-Shihr would see more frequent inundation just from high tides or minor storms. Under RCP2.6, sea level rise might be limited to ~0.3–0.5 m by 2100, which is easier (though still costly) to manage with coastal defenses.

Drought and Water Scarcity:

Higher temperatures will intensify drought impacts. Under RCP8.5, even if rainfall increases a bit, the net effect might be drier soils because evaporation increases a lot. Hadhramaut's chronic water scarcity could worsen – aquifers recharging less reliably if rain comes in downpours (more runoff, less percolation). On the other hand, if extreme rains do become more common, they might occasionally replenish wadis and aquifers in big bursts. The uncertainty is high, but likely droughts will continue and potentially become more frequent if variability increases. RCP2.6 might help by limiting the increase in evaporation and keeping climate more similar to historical patterns, but the region's baseline aridity means adaptation is needed under any scenario.

Storm Intensity:

Under high emissions, not only cyclones but also local thunderstorms could be more intense due to greater energy in the atmosphere. One projection suggests by late century under a high scenario, 5-day maximum rainfall could be significantly larger than now. For Hadhramaut, that implies multi-day wadi floods (like 2008's) might become more probable. Low emissions scenario would hopefully restrain those extremes, resulting in less dramatic changes in flood peaks.

Secondary Effects:

For example, warmer, moister conditions at times could increase locust outbreaks (we saw large locust upsurges in the Horn of Africa and Yemen around 2019–2020 fueled by unusual rains). Under RCP8.5, such ecological disruptions could be more frequent, hitting agriculture. Under RCP2.6, fewer extremes might mean less of those side effects.

Vulnerabilities in Hadhramaut.

Hadhramaut's vulnerabilities to flood and drought hazards stem from various social, economic, and infrastructural factors, many of which differ somewhat from Marib's context:

Livelihood Sensitivity:
Hadhramaut's population depends heavily on climate-sensitive sectors like agriculture and fishing. Farmers rely on spate floods or shallow groundwater, making them vulnerable to both floods and droughts. Fishing communities face damage to boats and livelihoods during cyclones, while oil-related jobs are limited and unstable. Most rural residents lack alternative income, exposing them to poverty when climate shocks hit. This dual vulnerability—being harmed by both flood and drought—is a defining challenge.

Poverty and Economic Challenges:
As of 2014, Hadhramaut's poverty rate was 60%, likely higher now. Many families survive at subsistence level, especially in wadi villages, and rising fuel costs make pumping water or moving goods harder. Coastal communities suffer similar poverty, especially when storms damage fishing infrastructure. Though markets function due to relative stability, humanitarian aid is limited, and remote areas suffer from multidimensional poverty, lacking services like education and healthcare.

Infrastructure and Services:
Interior infrastructure is poor, with unpaved roads that wash out and limited health and education facilities outside urban centers. Water systems rely on pumps, which fail during floods or power outages, and drought makes access harder when fuel or electricity is unavailable. Main towns like Seiyun and Mukalla have better coverage, but rural areas remain highly vulnerable. Schools and clinics are often damaged or repurposed during disasters, reducing service availability. Communications and transport can also be cut, isolating communities during emergencies.

Governance and Institutional Capacity:
Hadhramaut's local governance is functional but constrained by geography and dependence on central funding. Wartime conditions have reduced budget flows, forcing reliance on limited oil revenue and diaspora support. Disaster response capacity is low, with no strong civil defense or early warning systems in place. Coordination across districts is difficult due to long distances and tribal divides. However, diaspora and community organizations are active in local development and could be mobilized for resilience-building.

Vulnerable Population Groups:
Rural farmers face risks from both floods and drought, and lack secure land tenure, complicating recovery. Bedouin nomads are highly exposed due to their mobility, isolation, and weak support networks. The coastal urban poor, especially informal settlers, are at risk of storm damage and flooding. Women face added burdens and barriers in disaster response, including limited mobility, water-fetching burdens, and reduced access to education and health services. Households without diaspora connections are especially vulnerable due to lack of financial fallback.

Economic Systems and Social Support:
Hadhramaut's economy is diverse (agriculture, oil, fishing), which adds some resilience, especially when markets remain functional. However, buying power drops sharply after disasters, limiting the effectiveness of local markets. Formal safety nets are scarce, and while mosques and local charities offer short-term relief, they are not equipped for large-scale disasters. In 2008, external aid was critical; similar shocks today would again overwhelm local systems without stronger contingency planning. Enhancing infrastructure, diversifying income, and boosting local response capacity are essential to reducing vulnerability.

DRR and Anticipatory Action Recommendations for Hadhramaut.

1. Flood Risk Mitigation and Wadi Management in Inland Areas
To reduce flood risks, Hadhramaut should install automated rain and river gauges in upstream wadis and link them to a central early warning center, such as in Seiyun. These systems should deliver alerts via SMS, radio, and mosque loudspeakers, enabling downstream communities to evacuate in time. Protective infrastructure such as reinforced embankments

in Shibam and Seiyun, dry dams, and check dams should be constructed to buffer flash floods and recharge groundwater. Urban drainage in Mukalla must be upgraded through improved stormwater systems, khor dredging, and better planning to account for runoff, while coastal protection should include seawalls and, where feasible, mangrove restoration.

2. Sustainable Land and Water Management (Drought and Flood Co-benefits)

A "Green Hadhramaut" initiative should focus on reforesting degraded rangelands and upper catchments with drought-tolerant species like acacia and moringa. Terracing and contour bunding in suitable agricultural areas can reduce flash floods and promote soil moisture retention. Expanding efficient irrigation methods like drip systems and promoting rainwater harvesting through cisterns and rooftop tanks will help address both drought and flood challenges. Groundwater management must be enhanced through local water user groups, monitoring well levels, and regulating borehole drilling, including managed aquifer recharge strategies.

3. Livelihood Diversification and Resilience Programs

Climate-resilient agriculture should be promoted through the introduction of drought-tolerant crops and enhanced value chains for products like dates, honey, and frankincense. Livestock herders would benefit from the establishment of fodder banks, veterinary outposts, and sustainable grazing training, with potential donor support for livestock insurance. Community savings groups and microfinance initiatives, including Islamic finance models, can provide small-scale financial buffers and recovery loans. Emergency employment through cash-for-work programs should be launched quickly after disasters to restore livelihoods while rebuilding community assets such as canals and cisterns.

4. Strengthening Disaster Preparedness and Response Capacity

Community-based disaster risk management committees should be trained in preparedness planning, evacuation, and first aid, tailored to both coastal and inland contexts. Annual disaster simulations—for floods or cyclones—should be held to test local response systems and highlight any coordination gaps. Pre-positioned relief supplies, including water purification kits, non-perishables, and medical supplies, should be strategically stored at governorate and district levels. An Emergency Operations Center in Hadhramaut should coordinate actors, supported by resilient communication tools like satellite phones to maintain operations during telecom failures.

5. Policy and Institutional Measures

Disaster risk reduction must be integrated into all new development initiatives, including enforcing land-use plans and building codes that consider flood and cyclone exposure. The Hadhrami diaspora can play a critical role in funding local DRR projects through structured engagement and designated DRR contribution mechanisms. Climate adaptation funds, such as the Green Climate Fund, should be tapped to support large-scale infrastructure and water resource management programs. Finally, a monitoring and evaluation system should track

DRR progress, collect community feedback, and document the best practices to inform future planning and secure continued donor investment.

Hazard Impact Reduction in Southern Yemen

1. **Development of Early Warning Systems:** Establishing comprehensive early warning systems is essential for the targeted four governorates that are continuously prone to natural hazards and effects of climate change. These systems will provide timely alerts to residents about impending floods and torrents, enabling safe and effective evacuations. Utilizing modern communication technologies, such as mobile alerts and community radio broadcasts, can enhance the efficiency and reach of these systems.

2. **Construction of Dams and Barriers:** Strategically designed dams and barriers are crucial for protecting residential and agricultural areas from flooding. Such infrastructure acts as a frontline defense, mitigating the effects of extreme weather events and sustaining agricultural productivity, which is vital for local economies.

3. **Building Climate-Resilient Infrastructure:** Infrastructure, including buildings, roads, and bridges, must be designed to withstand floods and severe weather conditions. Implementing resilient construction standards and practices will ensure that vital infrastructure remains functional during adverse weather events, thereby enhancing community safety and connectivity.

4. **Sustainable Water Management Practices:** Implementing sustainable water management practices across both regions is imperative. This includes developing rainwater harvesting systems and efficient irrigation techniques, as well as protecting existing water sources. Ensuring the availability of water for agriculture, drinking, and industrial use will enhance community resilience and support economic development.

5. **Sustainable Coastal Land Management:** In coastal areas, preserving wetlands and coral reefs is essential to mitigate the effects of sea-level rise. These natural barriers provide critical protection against coastal erosion and flooding, while also supporting local biodiversity.

6. **Afforestation Initiatives:** Engaging in tree planting campaigns will be beneficial for both regions, contributing to soil stabilization and reducing the effects of desertification. Promoting the planting of native tree species can also enhance biodiversity and restore ecosystems, providing long-term environmental benefits.

7. **Vegetation Protection and Management:** Measures should be taken to protect natural vegetation and encourage the planting of trees and shrubs in flood-prone areas. Protecting existing vegetation helps stabilize soil and reduces runoff, while new plantings can enhance natural barriers against flooding.

8. **Community Awareness Programs:** Educating communities in the targeted four governorates that are continuously prone to natural hazards and effects of climate change. These awareness programs shall discuss the impacts of climate change, and the importance of adaptive measures is vital. Awareness programs should include workshops and educational materials that empower residents to take proactive steps in protecting themselves and their properties against climate-related hazards.

9. **City Planning with Flood Risk Considerations:** Urban planning must prioritize flood risk assessments. New developments should avoid low-lying areas prone to flooding, and existing infrastructures should be retrofitted to reduce vulnerability. Smart zoning regulations can help manage growth in a way that minimizes risk.

10. **Strengthening International Cooperation:** Engaging the international community is essential for securing financial and technical support for Yemen. Such collaboration can facilitate the implementation of effective hazard impact reduction strategies, enhance local disaster preparedness, and contribute to overall community resilience.

11. **Integration of Traditional Knowledge:** Incorporating traditional knowledge and practices related to environmental management enriches proposed solutions. Local communities often possess valuable insights into sustainable practices that have been effective over generations, which can complement modern approaches to hazard impact reduction.

12. **Monitoring and Evaluation Framework:** Establishing a robust monitoring and evaluation framework is critical to assess the effectiveness of implemented strategies. Regular assessments will help identify areas for improvement and ensure that measures adopted remain responsive to evolving challenges posed by climate change and natural disasters.

By implementing these integrated strategies, these targeted governorates that are continuously prone to natural hazards and effects of climate change can enhance their resilience to hazards, safeguard their communities, and promote sustainable development in the face of climate change.

Conclusion

Yemen's governorates of Marib and Hadhramaut stand at the frontline of the country's battle with natural hazards in the era of climate change. This comprehensive risk assessment has highlighted that both regions face multi-dimensional risks from floods, compounded by the vulnerabilities of a nation in protracted humanitarian crisis. Historical evidence – from Marib's devastating flash floods submerging displacement camps, to Hadhramaut's massive 2008 inundation and recurring cyclone strikes underscores that these hazards are neither rare nor isolated events. Rather, they form part of a **recurring pattern** that threatens lives, livelihoods, and hard-won development progress.

Key findings of the assessment can be summarized as follows:

- Yemen's natural hazard history is marked by frequent floods and periodic droughts that have affected millions. In Marib, floods have become more frequent and damaging in the last decade due to conflict-driven societal changes (e.g. the concentration of vulnerable IDPs in flood zones). In Hadhramaut, rare but extreme events (like tropical storms) have caused outsized destruction, while quiet drought emergencies steadily erode community resilience.

- The country context characterized by a fragile economy, widespread poverty (approximately 80% of Yemenis live below the poverty line), and weakened infrastructure – amplifies the impact of these hazards. Governance capacity, while present in these two governorates, is stretched thin in responding to disasters on top of ongoing basic needs.

- We identified four clear objectives for risk assessment (hazard mapping, vulnerability analysis, DRR planning, and anticipatory action) and employed a robust methodology involving data analysis, GIS mapping, and community engagement to meet them. The resulting hazard and risk maps (see Annex II) provide an evidence base for action, pinpointing high-risk areas such as the wadi networks of Marib and the cyclone-prone coasts of Hadhramaut.

- In Marib, high exposure to floods is driven by heavy rains, poor infrastructure, and concentration of displaced populations in floodplains. Drought risk is also present, given the arid climate and water demands of a swelling population. Marib's vulnerabilities – poverty, inadequate housing, and limited health services for IDPs – mean that even moderate floods cause significant humanitarian crises (loss of shelter, disease outbreaks, secondary displacement). Climate projections indicate that without intervention, these problems could worsen under scenarios of more extreme rainfall and prolonged dry spells.

- In Hadhramaut, a combination of rugged terrain and climatic extremes yields a dual hazard of catastrophic flash floods and chronic drought. The governorate's drivers of risk include environmental degradation (loss of vegetation, leading to faster runoff) and rising sea levels (threatening coastal communities). The relative stability and functioning institutions in Hadhramaut provide an opportunity – local authorities have maintained services and can integrate DRR into ongoing recovery. However, vulnerabilities such as remote populations with limited services, and critical infrastructure susceptible to weather (e.g. mudbrick houses, roads along wadis), persist. Future climate change under high emissions could intensify cyclones and heat stress, making current coping mechanisms insufficient.

- Across both governorates, certain common themes emerge: the need for better early warning systems, the importance of infrastructure improvements (dams, dikes, drainage) coupled with nature-based solutions (reforestation, water harvesting), and the urgency of strengthening local capacities and livelihoods to absorb shocks. Both regions also highlight how disaster risk is intimately linked to development – risk reduction must go hand-in-hand with improving water supply, healthcare, education, and economic opportunity.

From these findings, we developed targeted recommendations for each governorate. For Marib, key recommendations include installing flood early warning systems, relocating and flood-proofing IDP camps, building flood protection works around high-risk sites, and scaling up anticipatory actions like cash transfers before forecasted floods or droughts. We emphasized measures that donors can fund immediately (e.g. cash-for-work to improve wadis, community training for first responders) which also lay the groundwork for long-term resilience (like enhanced land-use planning and data systems). For Hadhramaut, recommended actions focus on multi-purpose infrastructure (e.g. small dams that recharge groundwater and mitigate floods), better cyclone preparedness for coastal cities, sustainable land management to combat both flooding and drought, and livelihood diversification (such as promoting drought-resilient crops and strengthening fishing infrastructure against storms). In both cases, the recommendations balance structural solutions with community-based approaches, ensuring that technology and engineering are paired with local knowledge, awareness, and ownership.

Finally, this assessment underscores a broader point: multi-hazard risk mapping and analysis are invaluable tools for strategic planning in Yemen. By understanding where and why disasters happen, government and partners can be proactive rather than reactive. It is therefore highly recommended that in the future, similar comprehensive assessments have to be done for all the hazards that affect the region in order to achieve a Multi hazard Disaster Management framework.

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Annexes.

Annex 1: Survey questionnaire

QUESTIONNAIRE ADMINISTERED
Questions about the history of floods and damages:
Has your home or property been flooded before?
How many times has your home been flooded in the past ten years?
What was the most severe flood you experienced, and when did it occur?
What kind of damage was done to your home or property as a result of the floods?
How long did it take for the water to recede from your home after the last flood?
Questions about the level of awareness of risks:
Do you follow weather and flood warnings?
Do you know which areas in your neighbourhood are most prone to flooding?
Do you know what actions to take in case of a flood?
Questions for assessing personal risk:
Based on your experience, what is the likelihood of your home being flooded again in the future?
How worried are you about your home being flooded?
Do you think you are prepared to deal with potential future floods?
What are the three most important factors that make your home vulnerable to flooding?
Questions about social and economic impacts:
Has your ability to work or study been affected by previous floods?
Have floods caused you significant financial losses?

Do you think floods affect the value of your property?
Questions about needs related to early warning and disaster response:
Would you like to receive early warnings about floods?
What is the best way to receive these warnings?
Do you know where to go in case a flood warning is issued?
Questions to assess flood risk using indicators:
How high is your house above street level?
What materials is your house built with?
Is there a river or waterway near your house?
What is the nature of the soil around your house?

Annex 2: Geospatial Data Sources.

Data Source	**Data type**
USGS (United States Geological Survey)	SRTM 90m Digital Elevation Model
WorldClim	Temperature and Rainfall data
World Bank Climate Knowledge Portal	Climate Trends
Humanitarian Data Exchange	Yemen Administrative boundary shapefiles, Population data
SoilGrids	Soil Parameters
HydroSHED	Drainage network and basins

Annex 3: Photographs from flood affected areas.

Figure 9: Flood impact on houses

Figure 10: Flood management structures.


Figure 11: Vulnerable housing structures to floods.

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