



Climate Risk Assessments

Guidance for UNEP Program Officers and Project Partners

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How to Use This Paper

This briefing note aims to bridge the science-policy gap by providing clear, accessible guidance on the development and application of Climate Risk Assessments (CRA) to inform and support adaptation planning for investment and policy-related decisions. As the technical complexity of climate projections often hinders their use in decision-making, the briefing note provides a simple, step-by-step breakdown of the CRA development process. It presents examples from across UNEP's work.

Both UN program officers and technical experts require different levels of insight to design, conduct, and operationalize CRAs. For technical assessment experts, the briefing note is a practical companion when navigating methodological choices, interpreting climate information, and structuring assessment processes.

This guidance note has been developed to provide practical, user-friendly guidance for developing and applying CRAs. The aim of this briefing note is to support programming teams to i) understand and question the analysis that you may come across in the course of your work and ii) to help you develop the analysis themselves. The briefing note outlines best practices for dealing with uncertainty and data gaps, and for synthesizing technical analysis into policy- and finance-ready recommendations.

Because climate risks cut across sectors, the guidance presented here is widely applicable to biodiversity, water, public health, infrastructure, and livelihood-focused programs alike, equipping practitioners with a general, cross-sector foundation for integrating climate risk insights into planning and investment decisions. Guidance covers four methodological areas: constructing detailed research questions, hazard modeling, exposure, vulnerability, and impact analysis. Together, these sections provide readers with a methodological roadmap for scoping, designing, and conducting CRAs.

UNEP's Mandate

Through technical guidance, capacity building, and readiness assistance, UNEP helps countries integrate climate risk into national development strategies and access financing from mechanisms such as the Green Climate Fund (GCF) and the Global Environmental Facility (GEF) funded Least Developed Countries Fund (LDCF). UNEP's adaptation portfolio spans over 90 projects in 50 countries, reaching millions of people.

A key pillar of UNEP's adaptation portfolio is its support for National Adaptation Plans (NAPs), which are instrumental documents that outline a nation's climate risks and adaptation plans. Similar to its programming support, UNEP officers help guide the NAP process by coordinating technical teams and reviewing input documents, such as CRAs, for robustness and completeness. Countries are mandated to complete their NAPs by conducting up-to-date assessments to fulfill the GGA (2030) decision.

Context

CRAs are essential for identifying key climate risks, informing adaptation planning, and establishing baselines to track progress. They can provide the evidence base for the National Adaptation Plan (NAP) climate risk chapter, climate rationales for Green Climate Fund (GCF) and Adaptation (AF) concept notes and proposals, and shape many of the national adaptation priorities required under the Global Goal on Adaptation (GGA).¹

¹The need to ramp up ambitions and prepare for increasing climate risks was underscored by the Adaptation Gap Report and by the CoP28 decision on the Global Goal on Adaptation (Decision 2/CMA.5, para. 10a), which establishes that, by 2030, "*...all Parties have conducted up-to-date assessments of climate hazards, climate change impacts and exposure to risks and vulnerabilities and have used the outcomes of these assessments to inform their formulation of national adaptation plans, policy instruments, and planning processes and/or strategies.*"

While CRA are technical, they are also deeply humanistic, reflecting the values and beliefs of the communities involved in their design. In ideal circumstances, CRAs are collaborative and multidisciplinary exercises that bring together technical and local sources of knowledge while building on-the-ground capacity to advance effective adaptation. The CRA is thus a starting point, designed to help governments plan, fund, and implement adaptation at scale, and is a vital component of UNEP's areas of work.

In the last three decades, various analytical methods have emerged to understand climate change impacts, but selecting the right approach and climate information for a CRA can be daunting. The rapid advancements made in climate modeling and the growth of Earth observation data require careful screening, cleaning, and processing before use. Various simulation techniques, bias correction methods, and observational datasets carry unique limitations and assumptions and, without proper guidance, can lead to misuse and even maladaptive responses.

At the same time, approaches to evaluating climate change impacts on societies and their systems have shifted, with a greater focus on non-climate drivers that influence people's vulnerability to climate hazards. Today, CRAs are designed to both characterize future climate risks and assess local social, political, ecological, and economic conditions that shape risks and influence adaptation options.

You need buy-in, and to do that, you need to understand the country context backed by both physical science and stakeholder input.
-UNEP Programme Officer

The final step of a CRA is often the most challenging: converting identified adaptation needs into practical, costed, scalable, and prioritized adaptation options. This briefing note outlines a structured approach that reflects the multidimensional nature of adaptation planning, from strengthening household, community, and ecosystem resilience to addressing climate finance, policy, and regulatory requirements, and reducing both physical and institutional climate risks.



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Glossary of Terms

KEY CRA CONCEPTS

Adaptive Capacity: The ability of a system, community, or society to adjust to actual or expected climate change and its effects, including moderating potential damages, taking advantage of opportunities, and coping with consequences. Adaptive capacity is shaped by a range of factors including institutional strength, financial resources, political and social capital, access to technology, and social equity. (IPCC AR6, Annex II Glossary)

Exposure: The presence of people, livelihoods, infrastructure, ecosystems, or economic and cultural assets in locations that could be adversely affected by a climate hazard. Exposure is distinct from vulnerability in that it refers to what and who is in harm's way, rather than how susceptible they are to damage. (IPCC AR6, Annex II Glossary)

Global Warming Levels (GWL): Specific thresholds of temperature increase (i.e., +1.5°C, +2°C, +3°C, etc.) relative to pre-industrial levels, 1850-1900. (IPCC AR6 (Annex VII Glossary)

Hazard: The potential occurrence of a natural or human-induced physical event or trend, such as a heatwave, flood, drought, or tropical cyclone, that may cause loss of life, injury, or other health impacts, property damage, or loss of livelihoods and services. In climate risk assessments, hazards refer specifically to climate-related physical events or conditions and how they are projected to change in frequency, timing, intensity, and spatial extent. (IPCC AR6, Annex II Glossary)

Impact Chain / Risk Chain / Situation Model: A structured diagram that maps the causal pathways connecting climate and non-climate stressors, through vulnerability factors, to their ultimate socioeconomic and environmental impacts. Impact chains consolidate existing knowledge of how hazards interact with local conditions to produce harm, making them a practical tool for scoping a risk assessment and identifying where adaptation interventions would be most effective. (ISO 14091, 2021)

Impact Storyline / Event Storyline: A narrative reconstruction of a significant historical climate-related event, combining quantitative data with local testimony, and used to understand how a specific combination of meteorological and socioeconomic conditions led to observed impacts. Storylines provide a credible, locally informed baseline for projecting how similar or more severe future events might unfold and help engage stakeholders by grounding abstract projections in familiar experience (Shepard *et al.*, 2018)

Low-Regret Options/Action: Adaptation interventions that deliver meaningful benefits across a wide range of plausible future climate scenarios, regardless of which specific trajectory materializes. Because they reduce risk under all plausible futures, low-regret options are particularly valuable in contexts where model projections carry high uncertainty (GIZ, 2017)

Maladaptation: Actions taken in response to climate change that inadvertently increase vulnerability, risk, or greenhouse gas emissions, often by creating development path dependencies that are difficult and costly to reverse. Maladaptation commonly results from short-term or narrowly scoped decision-making that fails to account for broader system interactions or longer-term climate trajectories. (IPCC AR6, Annex II Glossary)

Multi-Criteria Analysis (MCA): A prioritization technique that evaluates and ranks options against multiple, factors such as cost-effectiveness, urgency, co-benefits, equity considerations, and ease of implementation. In the context of adaptation planning, MCA enables assessment teams and communities to systematically compare and prioritize adaptation actions in a transparent and participatory way (USAID, 2014).

Nature-based Solutions (NbS): Actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (IUCN, 2016).

SMART Criteria: A widely adopted framework for designing robust performance indicators, requiring that each metric be Specific, Measurable, Attainable, Relevant, and Time-bound (SMART) (Doran, G.T., 1981). In the context of climate risk assessments and adaptation planning, SMART criteria ensure that monitoring and evaluation indicators are practically useful for tracking adaptation progress across successive planning cycles

Theory of Change (ToC): A structured, causal framework that articulates how and why a set of interventions is expected to lead to desired long-term outcomes, tracing the logical pathways from near-term activities and outputs through to broader structural changes in vulnerability and resilience. In adaptation planning, a robust ToC helps ensure that indicators are logically linked to adaptation goals and supports meaningful evaluation of progress over successive planning cycles (Fayolle, V. and Dhanjal; M., 2020)

Vulnerability: The propensity or predisposition of a human or ecological system to be adversely affected by climate-related hazards, encompassing sensitivity to harm and a lack of capacity to cope and adapt. (IPCC AR6, Annex II Glossary)

TECHNICAL METHODS AND DATA SETS

Bias Correction: A post-processing technique applied to raw climate model output to reduce systematic errors (biases) that arise from a model's simplified representation of physical processes and its coarse spatial resolution. Corrections are derived by comparing model output against observed historical climate data, then applying statistical adjustments to bring model output closer to observed conditions before using it for impact assessment (Copernicus/ECMWF)

CMIP6 (Coupled Model Intercomparison Project Phase 6): A coordinated global effort, led by the World Climate Research Program, in which climate modeling centers run their models under a common set of experimental conditions to allow systematic comparison of results. CMIP6 provides the primary database of Global Circulation Model simulations underpinning the IPCC Sixth Assessment Report (AR6). It is widely used as the basis for climate projections in national and sub-national risk assessments.

CORDEX (Coordinated Regional Climate Downscaling Experiment): A World Climate Research Program initiative that dynamically downscales GCM outputs to finer regional scales across 14 domains worldwide, producing standardized, higher-resolution climate projections suitable for local and national impact assessments. Because CORDEX simulations incorporate local terrain, coastlines, and weather phenomena, they are generally preferred over statistical downscaling for complex landscapes, though their availability for the latest CMIP6 models remains limited.

Downscaling: A method for deriving local or regional climate information from the coarser-resolution GCM outputs. Two main approaches exist: dynamical downscaling, which uses a Regional Climate Model (RCM) embedded within a GCM to simulate fine-scale physical processes; and statistical downscaling, which uses observed historical relationships between large-scale and local climate variables to translate GCM outputs to finer scales based on statistical relationships. (IPCC AR6, Annex II Glossary)

Global Circulation Models (GCM): Mathematical representations of the Earth's climate system, including the atmosphere, oceans, land surface, and sea ice, used to simulate past climate and project future conditions under different scenarios. Because GCMs operate at coarse spatial resolutions (typically 50–200 km), their outputs often need to be downscaled before use in climate risk assessments.

Multi-Model Ensembles: A collection of climate model simulations, spanning multiple models, carrying distinct biases, used together to capture the range of plausible future climate outcomes. Using an ensemble rather than a single model reduces the influence of any one model's unique biases and provides a fuller picture of uncertainty; and when individual model results are analyzed, helps identify changes and signals where multiple models agree.

Regional Climate Model (RCM): A high-resolution climate model that simulates atmospheric and surface processes at the regional scale, typically driven by boundary conditions from a GCM. By incorporating detailed representations

of local topography, coastlines, and weather phenomena, RCMs produce more spatially refined projections than GCMs, making them better suited for assessing climate risks at the sub-national or watershed level.

Reanalysis Data (e.g., ERA5): A reconstruction of past weather and climate conditions produced by combining historical observations from weather stations, satellites, and other sources with a numerical weather model, to generate a consistent, spatially complete dataset covering decades of atmospheric conditions. Reanalysis products, such as ERA5 (produced by the European Center for Medium-Range Weather Forecasts), are widely used in climate risk assessments as observational baselines against which model outputs are evaluated and corrected.

Representative Climate Futures (RCFs): A reduced set of climate model outputs, selected through clustering analysis, that captures the full range of plausible future climates projected by a multi-model ensemble, such as a hot-dry future, a warm-wet future, and an intermediate case. RCFs allow assessment teams and decision-makers to explore distinct but plausible scenarios without having to process every individual model, making stakeholder engagement and public communication efforts more transparent (Clark et al., 2011)

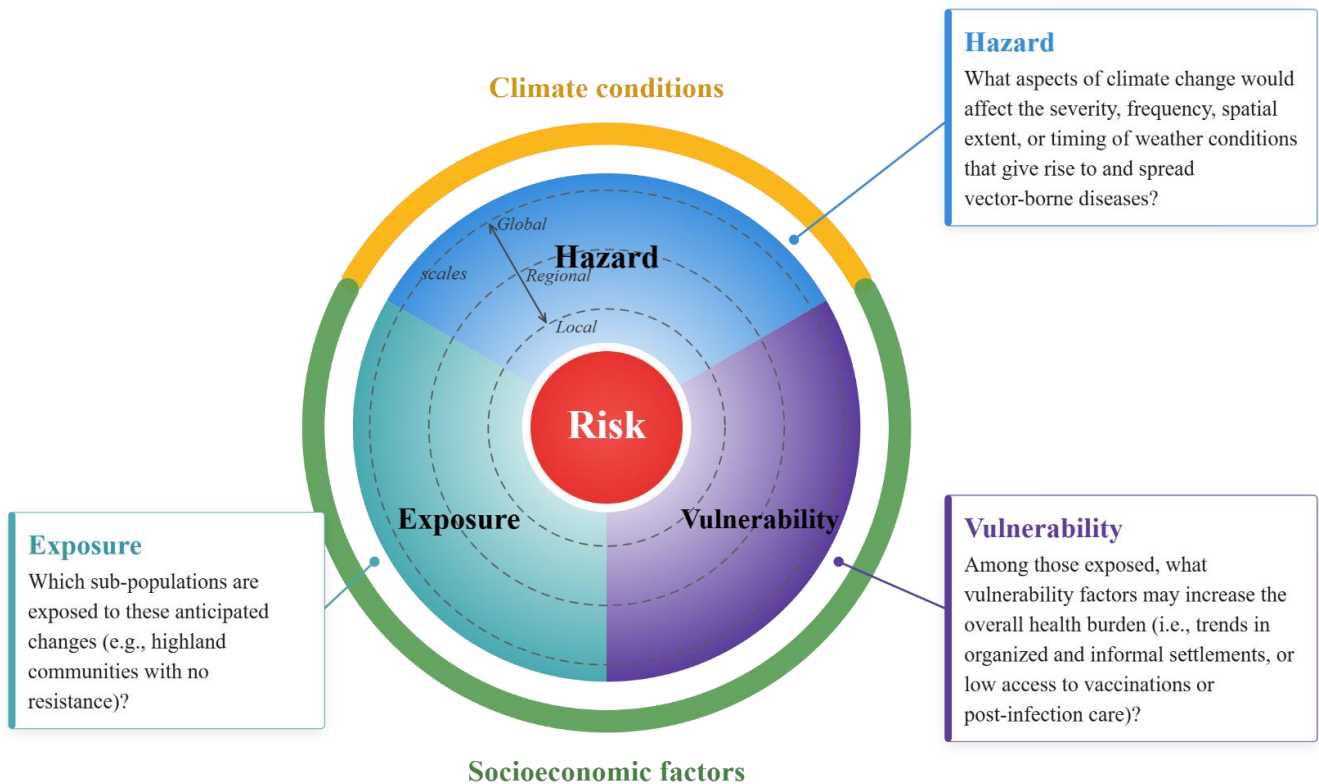
SSP-RCP Scenarios (Shared Socioeconomic Pathways / Representative Concentration Pathways): Paired emissions and socioeconomic scenarios used in the IPCC AR6 to represent a range of plausible futures, from aggressive mitigation pathways (e.g., SSP1-2.6) to high-emission trajectories (e.g., SSP5-8.5). The SSP component describes how societal factors such as population, economic growth, and technological change influence emissions. In contrast, the RCP component specifies the resulting level of atmospheric greenhouse gas concentration and radiative forcing.

1. Setting the Context

1.1 Developing Detailed Research Questions

Every CRA is guided by a handful of research questions stemming from three dimensions of climate risk: hazard (Section 2), exposure (Section 3), and vulnerability (Section 4). Understanding the baseline and changing dynamics of each dimension is critical to understanding climate impacts (Section 5). Hence, each CRA must seek to answer how the climate is changing in an area of interest (i.e., hazards), who or what is exposed to such hazards (i.e., exposure), and what existing factors make them vulnerable (i.e., vulnerability).² Using this framework, CRA teams can formulate research questions that address each risk dimension. As an example, three guiding research questions are formulated in Figure 1, each seeking to understand the state and changing dynamics of health burdens arising from climate-related change in vector-borne diseases across three dimensions of climate risk.

Figure 1. Research questions related to dimensions of climate risk. Adapted from Roa et al. (2025)



1.2 Historical Event Analysis

² Although not examined in this brief, it may also be useful to examine how decisions made because of climate change, known as 'responses', could lead to unintended consequences, amplifying risks (e.g., populations migrating into non-endemic zones due to climate change).

As a starting point, an analysis of observed loss and damage events helps identify the nature of the hazard and the exposure and vulnerability factors that led to the impact. Assessment teams can then formulate more specific questions by examining the drivers and impacts of historical events. Several exercises exist to surface details from stakeholders about past events.

Impact narratives (also referred to as event *storylines* or *narratives*) deconstruct the impacts of historical events and the vulnerability factors that give rise to them. They represent plausible, relevant, and risk-informative snapshots of how risk drivers can lead to socioeconomic impacts, both through memorable narratives and potentially useful quantitative thresholds. These storylines reveal important characteristics of events (e.g., the severity or duration of floods or droughts) and transmission pathways (e.g., market or infrastructure failures) that lead to relevant impacts (e.g., loss of livelihood or life).

Assessment teams can then project these experiences and conditions into the future, supplemented by trends and climate model outputs, using these real episodes as analogs for plausible future impacts. The storyline builds buy-in and focuses the analysis on the most consequential risk drivers. Later, it helps teams surface priority adaptation options as the storyline reveals where interventions would be most effective. Results from this exercise can be made operational immediately. In 2024, Lagos experienced a deadly heat wave. The CRA team deconstructed the heat wave according to exposure (Lagos population), hazard (5-day humid heat wave), vulnerability (lack of cooling and outdoor working conditions), and impact transmission pathways, such as the power supply cuts that left millions without electricity to cool buildings. The combination of these variables helped guide the CRA team to explore the non-climate factors that must be addressed through adaptation actions.

Textbox 1. Lesotho Storylines: As part of Lesotho's National Adaptation Plan process, the Lesotho Meteorological Services (LMS) and United Nations Environment Programme (UNEP), developed the impact storylines unpacking the meteorological conditions lead up to and the impacts following three major weather events: the 2010–2011 floods, the 2015–2016 drought, and the 2024 heavy snowfall. These events served as baseline for the projections and helped the assessment team understand how specific hazards interact with local systems, ultimately helping decision-makers ground the assessment in concrete, lived experiences.

Based on the role that El Niño–Southern Oscillation (ENSO) and the Southern Annular Mode (SAM) played in these events; the assessment team developed a specific question regarding evolving hazards: *how large-scale climate drivers influence local variability?* Across all impact narratives, the heavy dependence on rain-fed agriculture and livestock, which employs most of the rural population, makes rural livelihoods extremely sensitive to rainfall extremes or deficits making irrigation and livelihood diversification a top adaptation priority.

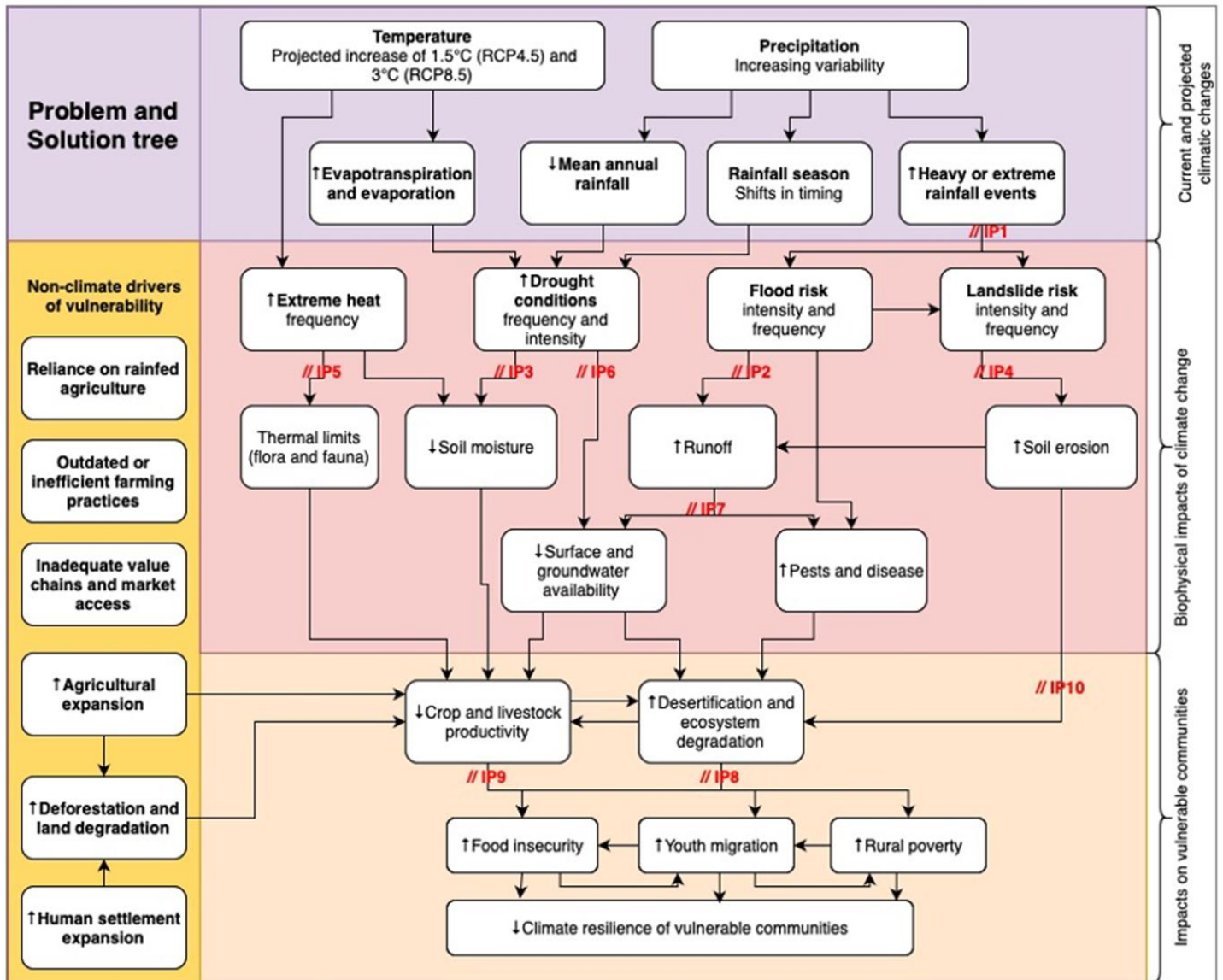
Based on Lesotho's post-hoc analysis of the September 2024 cold snap, Lesotho Red Cross Society (LRCS) now activates an Early Action Protocol (EAP) when maximum daytime temperatures are forecasted to drop below 2°C for two consecutive days, citing cold snaps and snowstorms as one of the most impactful hazards stretching back to the early 19th century, deserving its own trigger within Lesotho's early warning system.¹

Impact Chains are another useful tool for scoping and identifying a range of research questions. Instead of cataloging the characteristics of specific events, these simple illustrations (see Figure 2) map out an *a priori* understanding of climate risks for an area and consolidate the risk-modifying factors. Inputs are largely heuristic, leveraging published research, expert input, and local input. They illustrate the perceived causal relationships among climate and non-climate stressors, vulnerability factors, and the linkages between risk modifiers and climate impacts.

International Standard (ISO) 14091, Guidelines on vulnerability, impact, and risk assessment (2021), now recommends impact chains as a core component of the pre-planning process, providing an opportunity to address all relevant factors and to kick-start the participatory process. Studies show their importance in finding practical and

effective adaptation options, even before projections are run.³ They can also help identify and fill knowledge gaps through local consultations, leveraging established methods that solicit input from local communities about hazards, historical events, seasonal calendars, and perceived vulnerabilities and adaptation options.

Figure 2: Example of an impact chain illustrating the impact pathways connecting climate drivers and their effects on climate-vulnerable communities in Ethiopia. Borrowed from UNEP-supported GCF Concept Note.



Emerging hazards lack historical analogs, meaning they may not be identified through approaches that rely solely on past observations. Unprecedented, emerging risks are vital to understand because their impacts may lie outside the adaptive range of local ecosystems and communities, and societies lack the infrastructure and planning to deal with them. Storylines and situation models can help illustrate useful context around emerging hazards, linking physical aspects of climate change to lived experience while addressing uncertainty and surfacing compound and vulnerability factors important for stress-testing and ‘what if’ scenario planning.

³ Pasquini *et al.*, (2019)

An assessment team can investigate these potential blind spots through desktop research, long-term modeling, and stress-testing exercises exploring how emerging hazards - often secondary impacts like wildfires or saltwater intrusion, which arise after primary hazards - like drought conditions or sea level rise, become a mainstay of the local climate. In Iraq, for example, the combination of rising sea levels and reduced streamflow allows saltwater to encroach farther inland, affecting waterways, crops, and communities with limited capacity to cope due to a lack of historical precedent.

1.3 Linking Historical Events, Emerging Risks, and Research Questions

For example, the UNEP Climate Risk Dashboard includes six country profiles that examine changes in the risk drivers that led to recent climate events and in the chronic stressors unfolding today. Table 1 below presents a non-exhaustive list of examples of the research questions developed by the UNEP team to guide their research, identifying the appropriate exposure unit, hazard indicators, and vulnerability factors, many of which are integrated into the following research questions.

Table 1. Deconstructing research questions from six UNEP case studies.

Country	Historical Climate Event	Vulnerability and Exposure Factors	Research Question
Nigeria	In 2024, a 5-day humid heat wave occurred over Lagos.	Electricity blackouts, electricity-dependent cooling, informal settlements with poor ventilation	<i>How will similar events change in frequency (i.e., probability), severity, and duration in future climate conditions, and what is the size, extent, and type of sub-populations most vulnerable?</i>
Laos	In July of 2017 and 2018, intense flooding in Xekong province affected rural farming livelihoods, damaging crops and roadways.	Key transport nodes (roadways and bridges) are highly vulnerable to flooding, serving as chokepoints that cut off rural populations during and after floods.	<i>How will precipitation intensity change (e.g., 1- day, 5-day, and 95th percentile rainfall events) under future climate conditions, and how would this affect transportation and economic access of rural livelihoods?</i>
Lesotho	A September 2024 snowfall and cold snap blocked mountain passes and led to livestock deaths.	Isolated highland communities and their livestock lacking winter preparedness: no existing EWS and limited shelters to warm livestock	<i>Are similar events (i.e., 2 days $\leq 2^{\circ}\text{C}$) more likely under future climate conditions? What is the number of isolated highland communities located within the snow and cold snap zones, and what is the size of their populations and livestock?</i>
Pakistan	In the last thirty years, monsoon-related rainfall events have intensified, and now, combined with upstream glacier snowmelt,	Population growth and agricultural lands are highly concentrated along riverways with no flood defenses.	<i>How will rainfall-induced flood events change in timing and intensity, and what is the expected spatial distribution of flooding under current flood protection</i>

	riverine flooding is becoming more widespread.		<i>levels? What seasonal patterns give rise to concurrent heavy rainfall, snowmelt/ high heat events? What riverine-adjacent areas will be affected, and what percent of this population/ agricultural area is at highest risk?</i>
Malawi	Recent cyclones Ana (2022), Gombe (2022), and Freddy (2023) have led to catastrophic flooding and landslides.	Soil erosion and degradation amplify agricultural (and income) losses during increasingly intense rainfall events.	<i>How is the severity of such events expected to change in future climate conditions (i.e., 100m > 1 day), especially over Malawi's hilly agricultural lands?</i>
Iraq	Recent heat waves in southern Iraq have reached temperatures exceeding 50°C, posing significant heat-related health risks.	Poor access to cooling and fragile energy infrastructure limits cooling capacity of both urban and rural populations	<i>How will extreme heat events change in frequency and duration, especially nighttime heat stress - a strong proxy for health risks? What percent of the population has access to reliable cooling?</i>

2. Preparing the Hazard Data

CRA teams must collect and prepare hazard data from a range of sources, including climate modeling projections, historical observations for the area(s) of interest, and, for areas with poor observational networks, a combination of narratives and reanalysis or remote sensing products. At each step, CRA teams must make decisions that influence the rigor and completeness of the approach while balancing time, budget, and resource constraints. Making these decisions early can help streamline the sometimes lengthy hazard modeling phase of CRAs and avoid costly delays without sacrificing precision or accuracy.

2.1 Incorporating Triggers and Thresholds

The Expert Team on Climate Change Detection and Indices (ETCCDI)⁴ provides more than 30 standardized metrics for tracking changes in chronic and acute climate conditions, many of which rely on statistical thresholds that facilitate comparability in academic analyses. However, assessment teams that have codeveloped impact narratives, causal chains, and storylines often benefit from complementing these statistical metrics with thresholds grounded in local experience. In many contexts, the number of days exceeding the temperature–humidity conditions of a recent, memorable heatwave offers a more intuitive and decision relevant signal than the number of days above the local 95th percentile. Using thresholds known to have triggered real impacts in the past also strengthens the assessment's local credibility by anchoring future projections to events that communities recognize as consequential.

Assessment teams can derive locally meaningful heatwave thresholds directly from recent heatwaves that communities remember as disruptive, then extracting the conditions that made them consequential, characterize these events along multiple dimensions: severity (peak temperature, humidity, nighttime minima), duration (number of consecutive days above a stress threshold), timing (occurrence early in the season when acclimatization is low), and

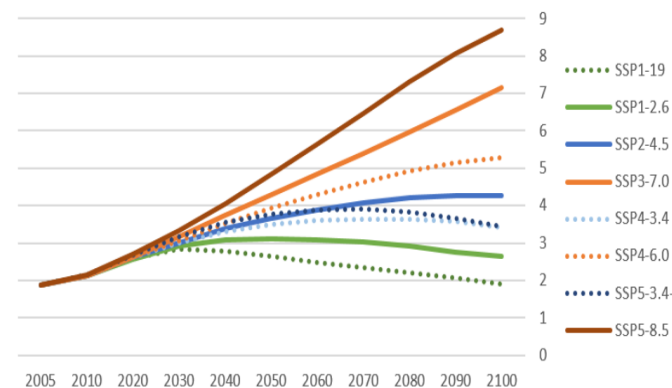
⁴ <https://www.wcrp-climate.org/etccdi>

spatial extent (how widely the extreme conditions were experienced). By combining these characteristics, technical teams can construct a relevant composite threshold that reflects the actual conditions that triggered impacts in the past.

2.2 Selecting Scenarios

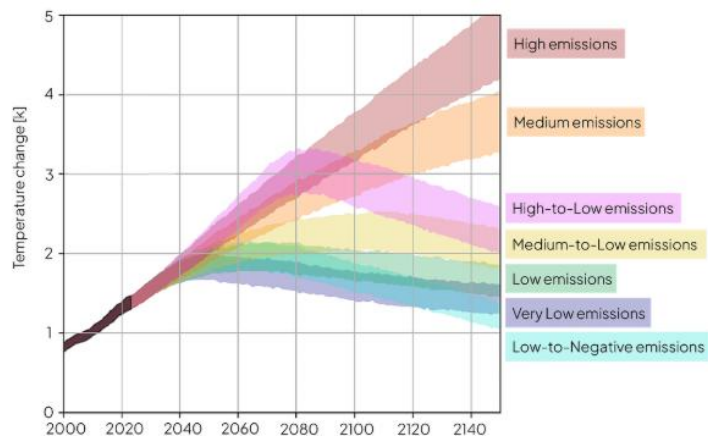
Before selecting models, it is important to choose several Shared Socioeconomic Pathways Representative Concentration Pathways (SSP-RCP), or *physical climate scenarios*. There are eight scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP4-3.4, SSP4-6.0, SSP5-3.4, SSP3-7.0, and SSP5-8.5) developed and updated through AR6⁵, each with a different set of narrative assumptions and emissions trajectories. The SSP narratives reflect different socio-economic, geopolitical, and technological assumptions and trends influencing emissions. The RCP families (i.e., 1.9, 2.6, 4.5, 3.4, 7.0, and 8.5) were developed and named according to their total radiative forcing (in W/m²) at 2100, spanning RCP1.9, which assumes a peak in emission and rapid decline in CO₂ concentrations in the mid-21st century, to RCP8.5, which reflects steadily increasing CO₂ concentrations, leading to the highest projected changes in surface temperatures by 2100 and beyond.

Figure 3. CMIP5 and CMIP6 SSP-RCP Forcing Radiative Pathways (W/m²) and average global temperature increase above pre-industrial averages (y-axis).



In April 2026, van Vuuren et al. (2026) published an updated set of scenarios for CMIP7, formulated as emission pathways, independent of SSPs used in CMIP6. Over the next few years (as of this writing), Earth system models will be run to project future climate outcomes, and downscaled projections will typically follow within two to three years.

Figure 4. CMIP7 scenarios. Adapted from van Vuuren et al. (2026)



⁵ IPCC's Sixth Assessment Report (AR6) available at <https://www.ipcc.ch/assessment-report/ar6/>

Assessment teams should select at least three scenarios, representing:

1. A **low scenario** where robust mitigation action significantly limits future warming. (Note that studies suggest the Paris-aligned SSP1-1.9 scenario is now likely out of reach, having breached the threshold for three consecutive years⁶ Some prominent research groups suggest SSP1-2.6 is also implausible without immediate, significant emission reductions.⁷). The three lowest-emission pathways formulated for CMIP7 fall between 1.5 °C and 2.5 °C of relative warming by end-of-century, but vary depending on when emissions and subsequent warming begin to decline.
2. An **intermediate scenario**, either SSP4-3.4, SSP2-4.5, or SSP4-6.0 under CMIP6, reflects a peak and decline in radiative forcing within the 21st century, assuming significant emission reduction efforts, even if delayed. Conversely, CMIP7 offers a “Medium Emissions” scenario where emissions and Global Warming Levels (GWL) continue unabated, and a “High-to-Low” emissions scenario where the GWL peaks in the latter half of the century before falling, assuming significant, but delayed emission reduction.
3. A **high scenario** (SSP3-7.0 in CMIP6 or “High Emissions” in CMIP7) leads to the greatest projected changes in surface temperatures by 2100 and beyond. In these scenarios, emission levels and radiative forcing steadily increase throughout the century.⁸ The RCP 8.5 emission pathway under CMIP6 is believed by some researchers to best reflect the likely pace of change and the risk of runaway climate change triggered by tipping points.⁹ Most recently, however, CMIP7 dropped RCP8.5, judging the emissions pathway implausible for this century, but not the outcome, bringing the GWL down from about 4.4 °C to about 3.5 °C in the new CMIP7 scenarios.¹⁰

Assessment teams may ultimately make their selection based on the number of models offering scenarios. To leverage the greatest number of models in the CMIP6 experiment and its derivative products, assessment teams may choose to use legacy scenarios that are more widely available across models and CMIP experiments, thereby providing a more robust ensemble (see Section 2.4).

2.3 Selecting A Downscaling Method

Each Global Circulation Model (GCM) represents future climates differently and imperfectly. GCMs are governed by established laws of physics but also carry model-specific assumptions. For example, two models may share the same parameters but may differ in their understanding of initial conditions,¹¹ reproducing historical meteorology differently. This is one type of model bias that cannot be corrected. Since no one model can perfectly reproduce the past or project the future, it is important to use multiple, distinct models. Many modeling groups generate multiple models (e.g., GFDL, MIROC, HadCM). If they originated from the same institution, they carry similar biases and pass on similar source code, even when producing new models and versions.¹² To address this, assessment teams can select models among the 35 CMIP6 models,¹³ available from different research institutions to bolster diversity and reduce some of the model bias associated with similar family trees.

⁶ ECMWF (2025)

⁷ Hansen, et al., (2025)

⁸ O'Neill et al., (2016).

⁹ Hansen, et al., (2025) and Ripple et al. (2024), point out the limitations of GCMs when depicting climate impacts stemming from several tipping points (e.g., collapse of the West Antarctic and Greenland ice sheets, thawing of Arctic and boreal permafrost, large-scale dieback of the Amazon rainforest, shutdown of the North Atlantic overturning circulation: loss of low-latitude coral reefs and Barents Sea ice). GCMs fail to capture non-linear dynamics, which means they do not incorporate the occurrence or cascade of events that follow the trigger of these tipping points, making it especially difficult to model impacts at any one location through GCMs. Unfortunately, few practical options exist for those conducting CRAs that rely on GCMs, other than incorporating a view of how climate risks move through a system to create a cascade of impacts.

¹⁰ Explainer: Scenarios for CMIP7 - Coupled Model Intercomparison Project: <https://wcrp-cmip.org/explainer-scenarios-for-cmip7/>

¹¹ Initialization is the dominant source of uncertainty in the first few years of model spin-up. Different starting values can lead to different outcomes in the model's predictions in the initial years with each model family taking a slightly different view on the starting values for slow-evolving components (e.g., temperature, salinity, density, sea level, and wind).

¹² Knutti et al., (2013a)

¹³ CMIP Model and Experiment Documentation - Coupled Model Intercomparison Project (<https://wcrp-cmip.org/cmip-model-and-experiment-documentation/>)

A major source of bias is the disparity between a spatially coarse GCM simulation (~100 km) and the resolution needed to understand impacts at finer scales. To achieve finer resolution, two bias-correction methods are applied, known as downscaling:

Dynamical downscaling (DD) generates finer-scale simulations by incorporating physical characterization of the local terrain and coastal and convective effects, using a regional climate model run within the larger global model. The CORDEX project dynamically downscales and provides simulations for 14 zones across the globe,¹⁴ though the latest CMIP6 models are not widely available due to massive processing requirements.

- **Advantages:** Physics-based representation allowing explicit simulation of local, complex processes; better for complex terrain (i.e., microclimates in mountains, islands, and coastal zones); can capture emergent hazards, and is typically higher spatial and temporal resolution.
- **Disadvantages:** Computationally expensive to run in new areas (i.e., not covered by CORDEX), limited availability, smaller ensembles, and requires specialized expertise for interpretation, bias-correction, and skill-testing.

Statistical downscaling (SD) achieves finer spatial resolution by establishing an empirical relationship between observed local climate data and the climate model's output over the same historical period. These relationships are then assumed to remain stationary in future climates. Where data is sparse, and no CORDEX project has been established, statistical downscaling projects such as NASA-GDDP-CMIP6¹⁵ is a suitable alternative.

- **Advantages:** Computationally inexpensive, high availability and global coverage, pre-processed and generally easy to use, suitable for most screenings, some methods (e.g., LOCA) show limited sensitivity to the parent GCM's historical biases.
- **Disadvantages:** Assumes statistical relationships will hold in the future; dependent on high-quality observations; limited ability to capture emergent phenomena (e.g., convective storms, mesoscale circulations, or coastal/orographic processes); does not simulate physics, only propagates patterns from parent GCM; and may dampen tails of distributions, limiting ability to project acute and extreme events.

The appropriate choice of a downscaling method depends on a few considerations, including:

- region(s) of interest,
- hazards and variables of interest,
- computing or financial resources,
- user and audience expertise,
- and the spatial scale of exposure units (i.e., 5 kilometers or 25 kilometers)

¹⁴ <https://cordex.org/domains/>

¹⁵ <https://www.nasa.gov/nasa-earth-exchange-nex/gddp/downscaled-climate-projections-nex-gddp-cmip6/>

The main benefits of SD projections are their wide availability across all regions, their coverage of various GCMs and scenarios, and their hourly or daily data with fine resolution (~25 x ~25 kilometers), making them suitable for broad screening. Conveniently, products such as NASA-NEX-GDDP6 are pre-processed and available for download or cloud computing on several open-source platforms (e.g., Google Earth Engine or Copernicus' Climate Data Store). However, the main methodological drawback of SD projections is the assumption that observed statistical relationships will hold in the future (i.e., stationarity). SD also depends on robust, long-term observations for training, and in regions with poor data coverage, may overly rely on reanalysis data (e.g., ERA5). SD simulations can also fail to capture emergent hazards and local extremes, especially for events like intense convective storms.

It is generally advisable to leverage DD products such as CORDEX when available, given their locally informed, physics-based construction, especially for complex terrain and coastal areas. DD projects are trained on local orographic effects, land-sea contrasts, and local weather phenomena (e.g., thunderstorms) that SD projections can miss. Most DD datasets offer sub-daily estimates, necessary for extreme event analysis, and provide simulations at resolutions (~4 x 4km) that are much finer than SD, making them more suitable for assessing climate risks in smaller areas such as infrastructure, neighborhoods, and watersheds. The main drawback of DD is the expertise required for interpretation, which may not always be available or necessary, depending on the assessment type (e.g., designing infrastructure for 100-year floods vs. showing shifts in climate zones or growing seasons) and the audience (e.g., engineers vs. policymakers).

There are clear advantages to debiasing and downscaling. However, they also introduce uncertainties driven not only by methodological choices, but also by the selection of the observational or reanalysis data used for debiasing. For example, when models are bias-corrected using reanalysis data like ERA5, structural uncertainties generated by interpolation - a technique used by reanalysis products to correct data gaps - carry over into the bias-correction process, over-smoothing spatial gradients, masking extremes, or misrepresenting sub-daily variability. To mitigate ERA5 bias, CRA teams can use multiple reanalysis datasets (e.g., ERA5, MERRA-2, JRA-55), quantify uncertainty relative to local observations, or use analysis only for bias correction where absolutely needed. In data-poor regions, or when including basin-scale wind or precipitation variables, CRA teams should identify local observational datasets that better reflect the true climate rather than a reanalysis product that relies on few direct observations.

Programme officers can ask technical teams why a particular downscaling method was chosen, understanding the tradeoffs. For example, an oceanic climate risk assessment should opt for dynamically downscaled projections with better ocean-atmosphere coupling and sacrifice a large ensemble with many GCMs, similar to what is offered statistically downscaled experiments, for better physics-based representation of the oceans. In either case, programme officers should encourage teams to explore both options and provide a strong methodological rationale based on the pros and cons of SD and DD, as listed above.

Toolbox 1. ML-Hybrid Models

Alternatively, teams could leverage several hybrid, physics-machine learning climate models that have been downscaled through experiments such as NVIDIA's ClimSim Online, allowing teams to use large ensemble of dynamically-downscaled models without the cost or computational requirements of traditional physics-based models. Some of these models can emulate thousands more years of events, compared to the original climate model, though the extent to which they can surface 'out-of-sample' events is still an open research question. As such, these models still require validation and skill testing (more on this in Section 2.4) before being used for CRAs given their experimental state.

Main Takeaway: Many national climate meteorological agencies will have pre-selected and made available local, bias-corrected models for researchers. However, when no national SD or DD data sets are available, assessment teams may opt for SD for broad screenings, and DD for detailed, more localized risk assessments focused on extremes.

- Use SD for national or sector-wide screening, large multi-model ensemble statistics, regions with no CORDEX coverage, time or budget-constrained CRAs.
- Use DD infrastructure design, flood/heatwave/wind extremes, mountainous or coastal regions

2.4 Selecting Climate Models

The IPCC AR6 report is the authoritative source for references on individual CMIP6 models and recommends using a large number of GCMs when modeling physical hazards, given the unique biases and approximations of each model. This ensures assessments span a range of physical process representations and emergent climate sensitivities, thereby providing a fuller spectrum of plausible climate futures. Over large areas, multimodal ensemble mean and median generally outperform any individual model across all indices.¹⁶

However, in some cases, it may be justified to curate and select individual models. This is the case when depicting complex hazards that GCMs struggle with, such as precipitation extremes, tropical cyclones, wind extremes, humidity, and fire weather. Another situation in which an assessment team may choose not to use a full ensemble is when the area of interest has complex rainfall dynamics. In these cases, model skill testing is required to justify excluding models with known bias or over-weighting more skillful models. Refinements to the ensemble group can be conducted using model skill tests that measure a model's ability to reproduce past conditions.

A GCM or RCM's skill is tested using high-quality observational datasets like reanalysis products (e.g., ERA5, MERRA-Class 2), satellite observations (e.g., MODIS, CERES), or in-situ observation products (e.g., HadCRUT, GHCN). It is also tested by examining multiple variables (e.g., surface temperature, precipitation, sea-level pressure) across multiple timescales (e.g., 30-year climatology, seasonal cycles, interannual variability) for the region of interest. In most cases, measures of skill - often depicted by root mean square error (RMSE), correlation coefficient, and Mean Absolute Error (MAE)-based model skill scores¹⁷ have previously been evaluated by researchers or national meteorological agencies. These measures can be referenced to ensure ensemble members skillfully represent past conditions.

Before excluding or weighting individual GCMs from the ensemble group, reference these studies. Then assessment teams can reasonably answer why they trust the model(s) to simulate plausible future climates.

2.5 Selecting Time Periods

There are a few best practices for selecting time periods of interest:

A **reference period** is the historical overlap between the reference reanalysis (e.g., ERA5) dataset and the GCMs or RCMs. It is common practice to select a 30-year period that precedes the start of the projection period (see below). Thirty-year periods are considered the minimum length to reflect the climatological norm of an area and are long

¹⁶ Sillmann, *et al.*, (2013)

¹⁷ Johnson, *et al.*, (2011)

enough to smooth out interannual variability. For example, with a projection period starting in 2020, a reference period of 1990 - 2020 can be used.

Future projection periods should use windows no shorter than ten years, centered on a year indicative of that year's climate (e.g., 2040 = 2035-2045). This is necessary since not all GCMs or RCMs produce large ensembles of output needed to estimate distributions that capture extreme values, which require multiple years of data. Given the uncertainty in future climate projections, projections within a +/- ten-year window are representative of the central year. To do this, assessment teams should:

1. Ensure the time periods span at least 10 years or longer (e.g., 2050-2060) to account for natural and interannual variability that models are designed to emulate on a year-to-year basis.
2. Select periods that are relevant for planning in the near, medium, and long-term, while including periods beyond the typical planning horizon (e.g., 2080).

2.6 Selecting Time Steps

Due to intra-daily oscillations in wind, temperature, and humidity, sub-daily time steps are necessary to capture maximum, minimum, and diurnal ranges. Ideally, assessment teams should extract model data at 3- or 6-hour intervals, depending on availability.

2.7 Selecting the Appropriate Spatial Resolution

In most cases, when using dynamically (e.g., COREDX) or statistically (e.g., NASA-GDDP) downscaled datasets, assessment teams do not need to perform additional downscaling for extreme heat, drought, or water stress, as these phenomena unfold at the larger, more regional scales.

However, some hazards require additional data layers to depict risk unfolding at finer spatial scales. Hazards such as floods, coastal storms, and wildfires are especially localized, requiring a spatial resolution that approximately matches the resolution of the area of interest, which could range from buildings (e.g., ~30 x 30 meters), to neighborhoods (e.g., ~1 x 1 km), to natural landscapes (>1 km). While topographic overlays enable finer hazard modeling, finer resolution is not always better.

Although overprecision tends to produce errors, especially when topographic products carry sampling or inherent uncertainties, for example, digital elevation models (DEMs) are often used to improve the resolution of inland and coastal flood inundation models. However, even some of the leading DEMs are known to generate vertical uncertainty ranges of up to 1 meter. Teams must carefully examine the types and dispersion of uncertainty across all products - those used for bias-correction or enhanced topographic detail - when determining the added value of depicting finer spatial resolution.

2.8 Dealing with Uncertainty

In the initial decades of climate simulations, model variability - or the dispersion of individual model results - is often greater than differences between the SSP-RCPs and represents the largest source of uncertainty initially. Some models may indicate more rain, while others less. Neither is incorrect. In fact, model variability adds richness to the simulations, though it requires post-processing to illustrate disagreements among models across variables.

Clustering is a technique that assessment teams can use to make sense of individual model results by quantifying the level of model agreement/disagreement across key variables. It indicates which models project a given direction and

degree of change, and how many, enabling assessment teams to produce best- and worst-case scenarios and Representative Climate Futures (RCF).¹⁸

Configuring the full range of individual model results (for a given scenario and future time period) allows clustering them into categories defined by two climate variables (usually temperature and rainfall change) or another set of extreme indices, such as dry and wet days. Then, model agreement can be quantified across categories if, say, 65% of models indicate warmer and drier conditions versus 20% colder and wetter, and 15% with no consensus.

Australia’s Commonwealth Scientific and Industrial Research Organization (CSIRO) has developed its Climate Futures Framework around this technique (Figure 4). This framework enables downstream users and researchers to select representative, best-fit models for a certain future climate, greatly reducing processing requirements. Without assigning discrete probabilities to certain climate futures, assessment teams can point to the higher levels of model agreement as a proxy of confidence.

Figure 5. Model clustering technique for selecting climate futures based on model agreement and variability (CSIRO, 2024).

		Annual Surface Temperature (°C)			
		Slightly Warmer < +0.5	Warmer +0.5 to +1.5	Hotter +1.5 to +3.0	Much Hotter > +3.0
Annual Rainfall (%)	Much Wetter > +15.0				
	Wetter +5.0 to +15.0		2 of 30 GCMs +	9 of 30 GCMs 1 of 6 DS +	2 of 30 GCMs +
	Little Change −5.0 to +5.0			12 of 30 GCMs 4 of 6 DS +	3 of 30 GCMs +
	Drier −15.0 to −5.0			2 of 30 GCMs +	
	Much Drier < −15.0				

The UNEP and LMS-led assessment team (see Text Box 1) used cluster analysis to reduce the dimensionality of multiple GCMs with Self-Organizing Maps (SOMs), a neural network-based clustering technique. One advantage of SOMs over traditional clustering techniques is that most clustering methods assume a normal bell-shaped distribution of model results. In practice, CMIP projects often deviate from normal distributions, especially for projections of heterogeneous climates and of rainfall, humidity, and wind speed.

Finding Signal to Noise. In climate science, a signal refers to a consistent, meaningful trend emerging from physical model simulations. In contrast, noise refers to the background variability and model-specific differences that can obscure that trend. Distinguishing the two is essential, because many projected changes are small relative to natural variability. The IPCC therefore guides researchers on what constitutes a robust climate signal, specifying that “at least two-thirds of all simulations agree in the direction of change and at least two-thirds of the simulations must pass a suitable statistical significance test (e.g., U-Test or Mann-Whitney-Wilcoxon Test)”.¹⁹ Model agreement can likewise add confidence to the direction and degree of change for key variables. Where a similar number of models project both higher and lower rainfall totals, assessment teams must exercise caution due to uncertainty. If models disagree on

¹⁸ Whetton, et al., (2012)
¹⁹ Hennemuth et al., (2017)

the direction of change, representative climate futures can be developed to depict multiple, equally plausible futures (e.g., cold-wet and hot-dry).

Alternatively, when there is strong agreement in the direction of change, but low agreement about the size of change, then assessment teams should consider leveraging a ranked probability skill score,²⁰ judging robustness based on how well each model performs against the reference period, whereas higher model spread and smaller signals imply lower robustness.

When Uncertainty Persists. Despite uncertainties in climate projections, different storylines share common impacts, providing a basis for identifying low-regret adaptation options. In the Iraq climate risk assessment, two storylines were constructed for the Persian Gulf and Shatt Arab region: ‘Hot-humid and less extreme precipitation’ and ‘Hot-humid and more extreme precipitation’, with common climatic hazards:

- increased temperature and humidity levels
- higher sea levels
- very likely decreased precipitation in the North of Iraq, with a resulting decrease in flow of the Tigris and Euphrates rivers and the Shatt Al-Araba and Shatt Al-Basra rivers.

As a result, both climate storylines are equally plausible but diverge on precipitation intensity. Storyline A (blue) trends drier and steadier, while Storyline B (red) trends more volatile, swinging between periods of drought and intense rainfall, leading to the following sectoral impacts (Table 2). CRA teams will then devise low-regret options to address these future impacts (See Section 6.2).

²⁰ Weigel, et. al., (2007)

Table 2. Sectoral impacts in Iraq, under two different but equally plausible climate futures.

Hazards Shared by Both Storylines		<ul style="list-style-type: none"> Rising temperature and humidity across the region 	<ul style="list-style-type: none"> Higher sea levels pushing salinity inland 	<ul style="list-style-type: none"> Declining precipitation in northern Iraq, cutting flow of the Tigris, Euphrates, Shatt al Arab and Shatt al Basra
		A Hot and humid, less extreme precipitation		B Hot and humid, more extreme precipitation
 Water Salinity, scarcity, and floods		<ul style="list-style-type: none"> Steadily declining river flow and rainfall deepen chronic scarcity; salinity intrusion up the Shatt al Arab becomes persistent. Lower precipitation reduces groundwater replenishment and reserves, leading to abandonment and displacement. 		<ul style="list-style-type: none"> Violent swings between drought and intense downpours; flash floods contaminate supplies and damage water infrastructure. Erratic, intense rain runs off rather than recharging depleted aquifers, so net reserves keep falling despite floods.
		<ul style="list-style-type: none"> Protein deficiencies as livestock numbers fall with drought and fish stocks fall with saltwater intrusion. Increasingly severe sand and dust storms drive higher rates of respiratory illness, especially the very young and old. 		<ul style="list-style-type: none"> Flood events trigger waterborne disease outbreaks and contaminate drinking water alongside ongoing heat stress. Standing water after extreme rainfall expands sandfly and mosquito breeding, causing surges in vector borne disease.
 Health Disease, nutrition and air		<ul style="list-style-type: none"> Forced adoption of costly drought resistant crops as rainfall steadily declines. Reduction in grazing area due to lower precipitation and feed stock. 		<ul style="list-style-type: none"> Crops hit from both sides: drought losses punctuated by flood damage to fields and stored harvests. Unpredictable rainfall makes planting calendars unreliable; grazing land degrades through erosion and waterlogging.
		<ul style="list-style-type: none"> Heat and humidity stress reduce the supply and productivity of manual labor across rural work and urban heavy industry. Sustained water and heat stress slowly erode the viability and diversity of rural livelihoods. 		<ul style="list-style-type: none"> Heat stress plus recurring flood and drought shocks repeatedly disrupt incomes and damage productive assets. Sharper decline in rural livelihood viability and diversity; displacement spikes after extreme flood events.
 Agriculture Crops, grazing and pests				
 Livelihoods Labor, heat and migration				



Low-regret adaptation options (see Section 6.2)

3. Preparing the Exposure Data

In this context, *exposure* refers to the presence of people, ecosystems, infrastructure, and assets in places that could be adversely affected by climate hazards. Exposure data refers to physical objects of interest, including their spatial extent and attributes. After the assessment team drafts impact narratives and chains with local stakeholders, they are ready to collect and prepare the exposure data, now with a baseline understanding of the project area, the relative level of importance of different objects, and the features of the populations or landscape that shape risk. Teams are now ready to depict the location and spatial patterning of a wide range of human and natural characteristics to inform vulnerability analysis (Section 4). Teams will face several methodological choices along the way: resolution choices, upsampling or downscaling, and how to standardize spatial units, to name a few. To help initially narrow the focus, teams must first define the project boundary and the spatial units.

Geospatial mapping is a powerful tool that integrates vulnerability factors spatially and across the approaches mentioned so far. Geospatial data, including remote sensing data, adds value by providing consistent, spatially explicit physical factors (e.g., land cover, vegetation health, surface water, and urban heat patterns) that shape place-based risk.

3.1 Supplementing Project Boundaries

Political boundaries are convenient but poor spatial delineators. When deciding how to divide a large area, such as a country, into smaller areas, consider how climates, ecosystems, and livelihoods differ. Microclimates, for example, are loosely linked to habitat types and livelihoods, as temperature and precipitation govern the suitability of flora, fauna, and people. There is no standard practice for delineating a large area into smaller ones for a CRA; much of it depends on the system under evaluation. For natural resources projects, consider ecosystems. For water resources management, consider watersheds or basins. For wildlife management projects, consider using habitat types and zones. For livelihoods, consider using livelihood zones enriched with linear and asset-specific markers, such as roadways and commercial hubs. Each boundary is contingent on planning and financing structures.

While the spatial units described above may be the most appropriate for the object of measure, they are almost always incompatible with political boundaries. For this reason, it is advisable to show both natural and political boundaries on CRA maps, which may lead to a new transboundary management effort. For NAPs and related planning processes, resource allocation and prioritization decisions typically follow administrative delineations. Although it is always preferable to use spatial boundaries as defined by the country and relevant agencies, the Database for Global Administrative Areas (GADM) provides a free, up-to-date spatial file for every country and subdivision.²¹

Climate Zones and Climatology offer another boundary that harmonizes closely with the climate projection data. The Köppen-Geiger classifications consist of 30 sub-climates based on the seasonality of monthly temperature and precipitation. Classifications are also available for future periods through the end of the century, across five RCP-SSP scenarios.²² Despite the number of sub-climates available, the Köppen-Geiger classifications are often too coarse. They fail to consider important climatic variables such as humidity, wind, soil

Textbox 2. Ghana's Climate Zones: As part of Ghana's National Adaptation Plan process, UNEP, acting as a Delivery Partner for Ghana's Environmental Protection Agency (EPA), delineated four homogeneous climate zones based on relative changes in mean annual temperature and precipitation between the 2040-2071 period compared to 1981-2010 period, based on the median of the 24-member CORDEX ensemble. Delineations were based on hierarchical clustering according to changes in year-to-year variability of annual rainfall and temperature, rather than magnitude, resulting in delineations that were spatially consistent with Ghana's main geographic regions: coastal, Ashanti plains, Volta basin and northern plain.

²¹ <https://gadm.org/>

²² <https://koppen.earth/>

moisture/evapotranspiration, and local effects such as coastal breezes, lake effects, and mountain microclimates. As such, they may not map well to hazards or livelihoods. For example, Ghana has several types of savannahs and tropical forests, influenced by non-temperature variables such as humidity and wind, which affect habitats and farming suitability throughout the year (see Textbox 2). For broader assessments, methods for delineating a larger area into smaller ones will depend on the meteorological variables (e.g., humidity, seasonal rainfall patterns) and statistical functions (e.g., magnitude vs. variability) that govern the climate.

Livelihood zones detail how most individuals within a spatial boundary earn an income. For research questions characterizing the impacts of future climate on the viability and diversification of livelihoods, the Famine Early Warning Systems Network (FEWS-NET)²³ provides a rich tapestry of livelihood zones for 48 countries with a history of food insecurity, based on factors such as agroclimatology, elevation, land cover/use, market accessibility, sources of food and cash income, and major economic activities.

3.2 Enriching Project Areas with Spatial Exposure Data

Demographics: Most research questions will explore how many people are exposed to a particular hazard. Assessment teams will need to leverage a population data set, of which many exist (at the time of writing, over 20 high-resolution, mostly global population data sets were available on the Google Earth Engine data catalog.²⁴, including additional demographic factors that can help CRA teams identify subpopulations (e.g., sex, age, indigenous peoples, building types, and levels of access to wealth, education, and health). A wide range of demographic information is also available in regularly maintained, peer-reviewed, open-access datasets (Table 3).

Table 3. Sample list of open access databases offering demographic data

Institution/ Data Set	Primary Variables	Geographic Resolution	Update Frequency	Data Portal
WorldPop (Univ. of Southampton)	Population counts, density, age–sex, births, pregnancies, urban change	100m–1km grid; national & subnational	Annual	https://www.worldpop.org
UN Population Division – World Population Prospects (WPP)	National population totals, age–sex structures, fertility, mortality	National only (no subnational)	Biennial	https://population.un.org/wpp
UNICEF Data Warehouse	Child population, births, mortality, education, WASH	National; some subnational depending on DHS/MICS	Annual	https://data.unicef.org
World Bank – Subnational Population & Socioeconomic Indicators	Population, poverty, education, health, nightlights, admin boundaries	Admin1–Admin2 (varies by country)	Annual	https://data.worldbank.org
World Bank – LSMS Surveys	Household demographics, income, consumption	Survey clusters; subnational	3–5 years	https://microdata.worldbank.org
Global Data Lab (Radboud Univ.)	Subnational HDI, education, fertility, mortality, wealth	Admin1–Admin2	Annual	https://globaldatalab.org
OECD Local Data Portal	Population, migration, aging, labor, municipal indicators	Regions & municipalities (41 countries)	Annual	https://localdata.oecd.org
Humanitarian Data Exchange (HDX)	Official admin-level population tables (Admin0–Admin4)	Admin0–Admin4	Annual or more frequent	https://data.humdata.org

²³ <https://fdw.fews.net/data-explorer/>

²⁴ <https://gee-community-catalog.org/projects/>

CIESIN – Gridded Population of the World (GPWv4/GPWv5)	Population counts, density	1km grid	~5 years	https://sedac.ciesin.columbia.edu/data/collection/gpw-v4 (sedac.ciesin.columbia.edu)
EC JRC – Global Human Settlement Layer (GHS-POP)	Population density, built-up areas	250m–1km grid	~5 years	https://ghsl.jrc.ec.europa.eu
NASA SEDAC – Urban/Rural, Settlement Layers	Population, urban extent, settlement patterns	1km grid	Multi-year	https://sedac.ciesin.columbia.edu (sedac.ciesin.columbia.edu)
LandScan (ORNL)	Ambient population	~1 km grid	Annual	https://landscan.ornl.gov
DHS Program	Household demographics, fertility, mortality, health	Survey clusters; subnational	5 years	https://dhsprogram.com
MICS (UNICEF)	Household demographics, child health, education	Survey clusters; subnational	3–5 years	https://mics.unicef.org
Eurostat	Population, migration, age–sex, municipal indicators	NUTS0–NUTS3; LAU	Annual	https://ec.europa.eu/eurostat
African Development Bank – Socioeconomic Database	Population, poverty, education	Admin1 (selected countries)	Annual	https://dataportal.opendataforafrica.org
Asian Development Bank – Key Indicators	Population, urbanization, age–sex	National; some subnational	Annual	https://kidb.adb.org
Latin America – CEPALSTAT	Population, migration, age–sex	National; some subnational	Annual	https://statistics.cepal.org

Land Cover, Use, and Ecosystems data and classifications allow assessment teams to extract boundaries and variables that can help inform how hazards interact with landscapes, and which features are sensitive or resilient to acute and chronic climatic changes. When combined with hazard and vulnerability data, they eventually help inform where nature-based adaptation solutions are most viable.

From ecosystem classification products (IUCN GET, NatureServe IVC, WWF Ecoregions, FAO GEZ, USGS WTE), teams can derive ecosystem type, functional traits, ecosystem regimes, and condition or integrity indicators. These variables help distinguish systems with different sensitivities and adaptive capacities, such as fire-adapted shrublands, flood-buffering mangroves, or drought-sensitive rainfed savannas.

Land-cover datasets (ESA WorldCover, Copernicus) assign land cover class, and measure vegetation density, impervious surface extent, agricultural type, and wetland or coastal ecosystem extent. These characteristics can help teams trace and quantify the impact pathways (see impact chains in Section 1) of certain hazard-landscape interactions, including how impervious surfaces amplify heat and runoff; how dense vegetation shapes fire behavior; how cropland type influences drought vulnerability; and how wetlands or mangroves modulate storm-surge exposure. Similar to ecosystem classification, land cover types can help teams sharpen their adaptation actions (see Section 6), distinguishing, for example, heat reduction efforts in urban heat islands, soil and sedimentation control efforts in timbered and sloped areas, or where to focus shoreline protection programs in low-lying coastal agricultural zones.

Table 4. Sample list of open access databases offering land cover, use, and ecosystem classification data

Institution / Dataset	Primary Variables	Geographic Resolution	Update Frequency	Data Portal
IUCN – Global Ecosystem Typology (GET)	Global ecosystem types (Level I–V), functional groups	Global; polygon-based typology	Periodic (major releases)	https://iucnrle.org/
NatureServe – International Vegetation Classification (IVC)	Vegetation formations, alliances, associations	Global; polygon + class hierarchy	Periodic	https://www.natureserve.org/international-vegetation-classification
WWF – Terrestrial Ecoregions of the World	867 ecoregions; biomes; habitat types	Global; polygon	Static (2001 baseline)	https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world
FAO – Global Ecological Zones (GEZ)	Ecological zones (forest types, climate zones)	Global; polygon	Periodic	https://www.fao.org/forest-resources-assessment/explore-data/gez/en/
USGS – World Terrestrial Ecosystems (WTE)	431 ecosystem types integrating climate, landform, lithology, land cover	250m grid	2020 release	https://www.usgs.gov/centers/geosciences-and-environmental-change-science-center/science/world-terrestrial-ecosystems
Copernicus Global Land Cover (CGLS-LC100)	23-class LCCS land cover	100m grid	Annual	https://lcviewer.vito.be
ESA WorldCover (Sentinel2)	11-class land cover	10m grid	2020, 2021, 2023	https://esa-worldcover.org
FAO – GLC-SHARE	11-class harmonized land cover	~1km grid	Static	https://www.fao.org/geospatial/resources/detail/en/c/1022718/
Copernicus Global Land Service – Dynamic Land Cover	Annual LCCS land cover	100m grid	Annual (2015–present)	https://land.copernicus.eu/global/products/lc
MODIS MCD12Q1 Land Cover	IGBP, LCCS, UMD land cover schemes	500m grid	Annual	https://lpdaac.usgs.gov/products/mcd12q1v061/
ESA Climate Change Initiative (CCI) Land Cover	22-class land cover	300m grid	Annual (1992–2015)	https://www.esa-landcover-cci.org
NASA SEDAC – Global Land Cover (GLC),	Land cover, urban extent,	1km grid	Multi-year	https://sedac.ciesin.columbia.edu/

Urban Extents	impervious surfaces			a.edu
Harmonized World Soil Database (FAO/IIASA)	Soil types, land suitability	Polygon + 1km grid	Periodic	https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/en/
GlobCover (ESA)	22-class land cover	300m grid	2005–2009 (historical)	http://maps.elie.ucl.ac.be/CCI/viewer/download.php

Geomorphological, topographic, and hydrographic datasets reveal how the landscape is shaped, how it changes, and where adaptive resources such as rich soils and floodplains are located. Elevation, slope, aspect, and terrain morphology determine where floods accumulate, where landslides initiate, and can even influence how wildfire spreads. Hydrographic datasets represent water bodies and their drainage, allowing teams to delineate hydrologically critical areas such as upstream catchments, floodplains, or drought-sensitive headwaters. Geological and soil datasets can identify landslide risk zones or reveal potential groundwater recharge zones critical for water-security assessments.

When combined with hazard and vulnerability factors, these geomorphological, topographic, and hydrographic features allow assessment teams to contextualize their adaptation options and offer more targeted recommendations: “steep, deforested slopes above settlements,” “low-lying alluvial plains with clay soils,” or “coastal deltas with shallow groundwater and high subsidence.” Terrain and geomorphology also guide the feasibility of interventions. Slope and soil determine where nature-based solutions like reforestation or terracing are viable; basin boundaries define where flood retention or watershed restoration is most effective; and geological conditions inform where groundwater recharge and management efforts are most suitable.

Textbox 3. Ethiopia Flood Exposure:

In a UNEP-led feasibility study for the Green Climate Fund (GCF), the research team mapped several physical attributes in Ethiopia. To understand flood exposure, they mapped the digital elevation and land class types to identify flood-exposed areas by using remote-sensing to depict flood-sensitive land classes (rice fields, rubber plantains, and urban areas) situated below 3 meters in elevation.

Table 5. Sample list of open access databases offering geomorphological, topographic, and hydrographic data

Institution / Dataset	Primary Variables	Geographic Resolution	Update Frequency	Data Portal
NASA / USGS – ASTER GDEM	Elevation, slope, terrain morphology	30m	Periodic	https://asterweb.jpl.nasa.gov/gdem.asp
Copernicus DEM (EU)	Elevation, slope, hydrological conditioning	30m–90m	Periodic	https://spacedata.copernicus.eu
USGS HydroSHEDS/HydroRIVERS/HydroBASINS	Sub-basin boundaries (i.e., watersheds and basins), river reaches, lake shorelines, DEM	15s–3s (~12m–500m)	Periodic	https://www.hydrosheds.org
FAO – Global Soil Map (HWSD)	Soil type, texture, depth, organic carbon	1km	Periodic	https://www.fao.org/soils-portal

ISRIC – SoilGrids	Soil properties (pH, carbon, bulk density, texture)	250m	Annual	https://soilgrids.org
USGS Global Geologic Maps	Lithology, faults, bedrock type	Country/global mosaics	Periodic	https://www.usgs.gov
OneGeology (Global Consortium)	Geological maps, lithology, faults	Varies by country	Continuous	https://www.onegeology.org
JRC – Global Surface Water	Water occurrence, seasonality, change	30m	Annual	https://global-surface-water.appspot.com
GRDC – Global Runoff Data Center	River discharge, hydrological regimes	Station-based	Continuous	https://www.bafg.de/GRDC
GEBCO – Global Bathymetry	Ocean depth, coastal bathymetry	15 arc-sec	Periodic	https://www.gebco.net
NOAA – Coastal DEMs	Coastal elevation, inundation modeling	1–10m (varies)	Periodic	https://coast.noaa.gov

Asset-level datasets provide locations for critical infrastructure, most often represented in point-based or linear polygons. Assets such as roads, bridges, substations, hospitals, airports, and water treatment plants are the critical lifelines that sustain communities and economies. Household-level or settlement-level data go beyond population data by revealing the contours of where people live relative to hazard zones such as floodplains, steep slopes, coastal surge areas, or wildfire-prone interfaces. Protected areas, cultural heritage sites, and natural parks are high-value assets whose hazard-driven losses would have ecological, cultural, or economic consequences. Together, these datasets provide the mapping units needed to trace the cascade of risks, linking hazards to critical lifelines (e.g., a substation outage affecting hospitals and water systems).

These variables also sharpen vulnerability analysis by linking asset features (e.g., condition or age) to vulnerability. For example, bridges on erodible soils are more sensitive to extreme rainfall; hospitals in flood zones face critical disruption risks; wastewater plants near coasts are vulnerable to coastal floods and salinization; and informal settlements along rivers face disproportionate exposure to flash floods.

Dependency and accessibility further shape vulnerability. For example, mapping roadways to services can help teams assign a level of criticality to roadways connecting remote settlements to a healthcare facility. By integrating asset-level data, assessment teams can better prioritize adaptation options and sharpen recommendations such as elevating substations, reinforcing bridges, relocating critical facilities, upgrading drainage around hospitals, or protecting cultural sites from floods or erosion.

Table 6. Sample list of open access databases offering asset data

Institution / Dataset	Primary Variables	Geographic Resolution	Update Frequency	Data Portal
OpenStreetMap (OSM)	Roads, buildings, bridges, hospitals, schools, airports, utilities, land use	Point/line/polygon, varies by country	Continuous (crowdsourced)	https://www.openstreetmap.org

Humanitarian Data Exchange (HDX)	Critical facilities, health centers, schools, admin buildings, shelters	Admin0–Admin4; point/polygon	Continuous	https://data.humdata.org
UN OCHA – Common Operational Datasets (CODs)	Settlements, facilities, transport networks	Admin-level	Periodic	https://data.humdata.org
World Bank – Global Facility for Disaster Reduction and Recovery (GFDRR)	Critical infrastructure, schools, hospitals, transport, exposure datasets	Country-level; point/polygon	Periodic	https://www.gfdr.org
World Bank – LSMS / Microdata Library	Household locations (clustered), dwelling characteristics	Survey clusters	3–5 years	https://microdata.worldbank.org
UNEP-WCMC – World Database on Protected Areas (WDPA)	National parks, reserves, protected areas	Global polygons	Monthly	https://www.protectedplanet.net
UNESCO World Heritage List	Cultural and natural heritage sites	Global points/polygons	Periodic	https://whc.unesco.org
ICAO / OurAirports	Airports, runways, aviation facilities	Global points	Continuous	https://ourairports.com
Global Power Plant Database (WRI)	Power plants, fuel type, capacity	Global points	Periodic	https://datasets.wri.org
Open Infrastructure Map	Power lines, substations, telecoms	Global lines/points	Continuous	https://openinframap.org
FAO AQUASTAT	Dams, irrigation systems, water infrastructure	Global points/polygons	Periodic	https://www.fao.org/aquastat
GResD (Global Reservoir and Dam Database)	Reservoirs, dams, storage capacity	Points and polygons	Periodic	https://globaldamwatch.org/grand
UNICEF / WHO – WASH Facilities	Water points, sanitation facilities	Country-level; point data	Periodic	https://washdata.org
Global Roads Inventory Project (GRIP)	Road networks	Global lines	Static	https://sedac.ciesin.columbia.edu/data/set/grip-global-roads
NASA SEDAC – Population & Urban Extents	Settlements, built-up areas	1km grid	Multi-year	https://sedac.ciesin.columbia.edu

Even though all datasets listed in Tables 3–6 are global in coverage, spanning nearly every country, teams may still encounter data-poor environments where essential localized information is missing. In such cases, programme officers can fill gaps and supplement global datasets with open-source satellite imagery and geospatial repositories, which provide high-resolution optical, radar, and elevation data that can be processed to extract land-use patterns, shoreline change, flood exposure, and other relevant indicators. Widely used platforms include Google Earth Engine, a cloud-based catalog hosting Landsat, Sentinel-1/2, MODIS, and dozens of climate and land datasets;²⁵ Microsoft Planetary Computer, a curated repository of Sentinel-1/2, Landsat, NAIP, and global environmental datasets;²⁶ NASA Earthdata, the primary portal for MODIS, VIIRS, ICESat-2, SMAP, and other mission data;²⁷ and the ESA Copernicus Open Access Hub, with free access to Sentinel-1 SAR, Sentinel-2 optical, Sentinel-3 altimetry, and

²⁵ <https://earthengine.google.com>

²⁶ <https://planetarycomputer.microsoft.com>

²⁷ <https://www.earthdata.nasa.gov>

Sentinel-5P atmospheric data.²⁸ Additional global imagery sources include USGS EarthExplorer (Landsat, DEMs, and global orthophotos),²⁹ NOAA Data Access Viewer (coastal LiDAR, bathymetry, and aerial imagery,³⁰ and OpenAerialMap (community-contributed high-resolution aerial imagery)³¹. These platforms allow teams to derive localized information in contexts where national datasets are unavailable or incomplete.

3.2 Harmonize

Harmonizing spatial data to a common spatial unit, either through interpolation or extrapolation, is sometimes necessary. For example, if the assessment teams choose to conduct an indicator-based approach to evaluating vulnerability (see Section 4), then exposure units and attributes will need to be expressed evenly across a common spatial unit (e.g., city, grid cell, watershed, etc.). Best practice is to treat interpolation and extrapolation not merely as resampling, but as a careful and diligent effort to preserve the integrity of the underlying data. Interpolation should only be applied when the variable of interest is expected to vary smoothly across space. Methods should be chosen to match the data generating process (e.g., simple areal weighting for population counts, kriging for spatially autocorrelated environmental variables, or thematic mapping when ancillary data, such as land cover or nighttime lights, can refine distributions within a boundary. All interpolation outputs should be validated through crosschecks against independent datasets or known spatial patterns to avoid introducing artificial precision.

Extrapolation requires even greater caution because it is effectively extending measures beyond the domain of observed data. It should be used sparingly and only when supported by defensible assumptions about spatial continuity (i.e., validated by recent areal imagery) or functional relationships. When extrapolation is unavoidable, such as extending ecosystem attributes across unmapped areas or projecting building characteristics into partially surveyed regions, teams should explicitly document assumptions, quantify uncertainty, and flag extrapolated areas as lower confidence zones.

Harmonization can also be extended to summary statistics, when converting counts to rates or when developing z-scores for aggregation purposes. Across all these steps, transparency is essential. Assessment teams should record the method used, parameters selected, datasets applied, and any validation results.

3.3 Establish a Workflow

Exposure data is notoriously messy, requiring structured workflows to ensure quality, rigor, and completeness. A generalizable workflow might follow three steps: define, harmonize, and validate. Assessment teams should first define exposure units and required attributes, selecting spatial units that both reflect the object of measurement and align with related planning processes, resource allocation, and prioritization decisions. If needed, teams should harmonize datasets by reprojecting, resampling, clipping, and extracting attributes using methods appropriate to each variable's behavior, patterning, and data quality. Lastly, all outputs should be validated through crosschecks with other datasets or imagery, assigned measures of uncertainty, and accompanied by clear metadata documentation.

²⁸ <https://scihub.copernicus.eu>

²⁹ <https://earthexplorer.usgs.gov>

³⁰ <https://www.ncei.noaa.gov/maps/data-viewer>

³¹ <https://openaerialmap.org>

Figure 6. Example workflow for exposure analysis



4. Analyzing Vulnerability

A CRA that fails to identify what drives vulnerability fails to identify any usable adaptation solutions (see Section 6.2): For example, Pakistan’s national level impacts analysis focuses on losses without examining the conditions that produced them, leaving practitioners with no insight into where or who would benefit most from interventions. Conversely, the Laos and Mozambique examples described in this section link specific hazards to systemic vulnerabilities at the sector and even building levels. Without a clear diagnosis of what is shaping vulnerability, there can be no credible pathway to solutions. This section presents several leading methods for analyzing vulnerability factors.

In this context, *vulnerability factors* refer to the set of qualitative and quantitative information that captures the sensitivity of systems to climate hazards and their capacity to cope with and adapt to impacts, including underlying social, economic, institutional, and environmental drivers. Vulnerability factors are identified through a mix of qualitative and quantitative methods, including stakeholder consultations, peer review and grey literature, indicators, model-based approaches, and geospatial and remote sensing methods (see previous section). These methods are typically combined to capture a wider understanding of physical, social, economic, and environmental vulnerabilities (Figure 7).

No single approach is sufficient on its own; instead, CRA teams typically combine participatory engagements, desk reviews, indicator-based scoring, model-based simulations, and geospatial analysis to build a coherent understanding of how climate hazards interact with existing vulnerabilities (Figure 5).

Participatory methods surface the lived realities of communities that existing literature, models, or remote sensing cannot capture or might overlook. Desk reviews help consolidate this evidence, especially in data-rich contexts, while indicator-based approaches offer easy-to-communicate, comparable metrics when time or data are limited.

Model-based approaches are necessary to quantify how systems and sectors respond to shocks and stressors in response to known triggers, accounting for nonlinearity and existing vulnerability factors. Geospatial and remote-sensing methods are especially useful for mapping convergence of physical vulnerabilities.

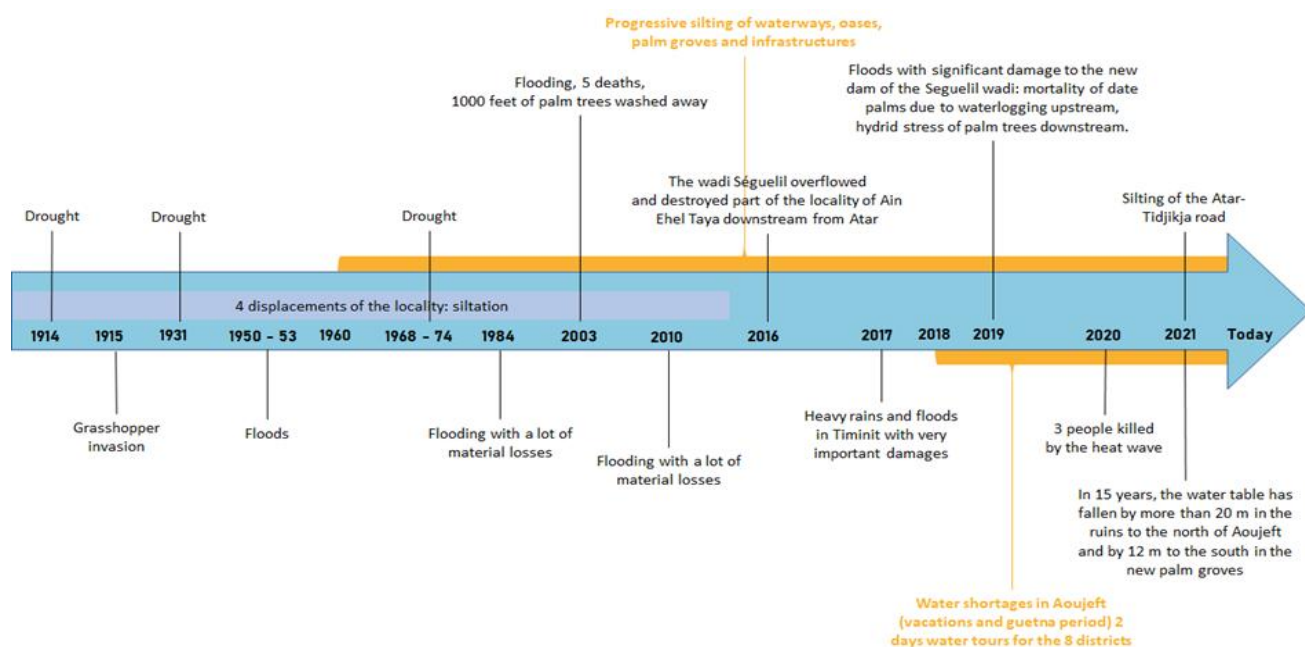
4.1 Participatory Approaches

Participatory approaches center local communities in the process, drawing on local knowledge and experiences to reveal vulnerability factors - land tenure insecurity, gendered labor burdens, or information asymmetries - that technical approaches often miss. Community workshops and expert consultations require skilled facilitation and existing familiarity with community context, language, and norms.

Deciding how and where to facilitate these conversations is often limited by logistics. Workshops may be most suitable where communities regularly gather and freely exchange ideas and opinions. In contrast, household interviews often capture more detail, and less-structured approaches like snowball interviews can help expand the number of participants with less planning required. With a large enough sample size, responses are disaggregated by age, gender, and livelihood, with facilitators walking participants through several exercises:

- Hazard Maps: Identifying community livelihoods, required resources, and where hazards intersect with them.
- Historical Timelines (Figure 7) and Seasonal Calendars: Analyzing hazard trends, historical events, and seasonal changes based on community perceptions.
- Daily Clocks and Household Decision-Making Pile Sorting: Exploring gender differences in daily tasks and household decision-making power to surface social vulnerabilities.
- Impact Chains: Assessing the direct and indirect cascading impacts of hazards on local livelihoods.
- Vulnerability Matrices: Identifying priority livelihood assets and assessing the specific degree of impact that various hazards have on them.
- Venn Diagrams: Mapping out which institutions interact with community members and what services they provide.

Figure 7. Historical timeline for Aoujeft, Mauritania in the “Producing Climate Change Scenarios and Risk Assessments for Africa: Trend Analysis Report.”



The goal of these engagements is to expose systemic vulnerabilities and dependencies, such as the extent of rainfed subsistence farming or power asymmetries, particularly those stemming from landlessness, severe poverty, and racial or political marginalization of underrepresented groups, all of which increase sensitivity to hazards and make adaptation more challenging. In Lesotho, priority was given to actions that support female-headed households, who are disproportionately affected by climate impacts, and farmers reliant on rain-fed subsistence farming; the district-level workshops revealed that they have limited savings and coping mechanisms to absorb even moderate fluctuations in rainfall patterns. Work through local government and trusted NGO partners whenever possible.

Textbox 3. Mapping Iraq's Vulnerability Factors:

In Iraq, the CRA team consulted with expert groups on how climate hazards may propagate through livelihoods based on existing vulnerabilities. They co-developed a cascade map of economic damages, starting with inevitable rises in extreme heat and humidity, which would decrease labor productivity and capacity especially in key sectors like agriculture, construction, and manufacturing, leading to loss of rural employment and crop production directly contributing to rising inflation, household debt and increased burden on the national welfare systems.

Toolbox 2. Participatory Tools for Urban Contexts:

CityRAP by UN-HABITAT contains a suite of training exercise to help planners and researchers kick-start a participatory resilience study at the municipal-level, including self-assessments, collecting asset inventories, participatory risk mapping, ground-truthing data, identifying social drivers, and action planning for a variety of sectors.

Resource: <https://unhabitat.org/tool/the-city-resilience-action-planning-tool>

Toolbox 3. Participatory Tools for Rural Contexts:

CARE International's Climate Vulnerability and Capacity Assessment (CVCA) Handbook provides a standardized, process-based guide for developing each of the exercises in bullet-points listed above. The main limitation is that these workshops require significant planning and time, and results are difficult to generalize and aggregate across communities.

Resource: <https://careclimatechange.org/cvca/>

4.2 Desk Review

Targeted **desk reviews** are sometimes sufficient in data-rich environments where recent, similarly scoped assessments have been conducted. For example, the CRA team in Laos reviewed 176 peer-reviewed papers and 86 reports (grey literature, statistical records, and geospatial analyses developed by another CRA only a few years earlier). The purpose is to reframe this research within the IPCC's conceptual framework, triangulating the evidence to date and linking exposure, hazards, vulnerability, and response into a coherent CRA report.

As an example, the World Bank Group's Country Climate and Development Reports (CCDR)³² quantify the sector's vulnerability to projected climate impacts, drawing on economic metrics such as sector-level employment and revenue, to identify key economic sectors that are both crucial to livelihoods and highly sensitive to climate change. The CRA team in Ghana focused its efforts on livelihood risks in agriculture, forestry, and fisheries, given the high employment rates in these sectors and their sensitivity to climate impacts. In Lesotho, the realization that water sales to South Africa represented a major revenue opportunity meant watershed preservation and restoration became a key focus of the CRA and later, the NAP.

4.3 Indicator-based Approaches

Indicator-based approaches aggregate summary statistics to arrive at a high-level view of vulnerability, using regional- or national-level indicators. They are rather simplistic, generalizing environmental, economic, social, and physical patterns across large areas, often using proxies. Even the most spatially granular approaches suffer from indicator selection bias and often introduce subjectivity through decisions about aggregation and weighting.³³ However, they can work well in data-limited environments or CRA's with strict time and budget constraints. Indicators are typically normalized to a common scale and weighted, either equally or through expert judgment or statistical techniques such as principal component analysis.

Once aggregated, they produce composite vulnerability indices that can be compared across regions, sectors, or population groups. Results are transparent and easy to communicate to policymakers but lack the robustness of participatory or model-based approaches. The strength in indicator-based approaches lies in the aggregation process, which identifies the co-occurrence of high hazard, exposure, and vulnerability. Typically, indicator-based approaches are used to illustrate spatial differences in one or more dimensions of risk for prioritization purposes.

³² <https://www.worldbank.org/en/publication/country-climate-development-reports>

³³ Xi Jiao et al., (2017)

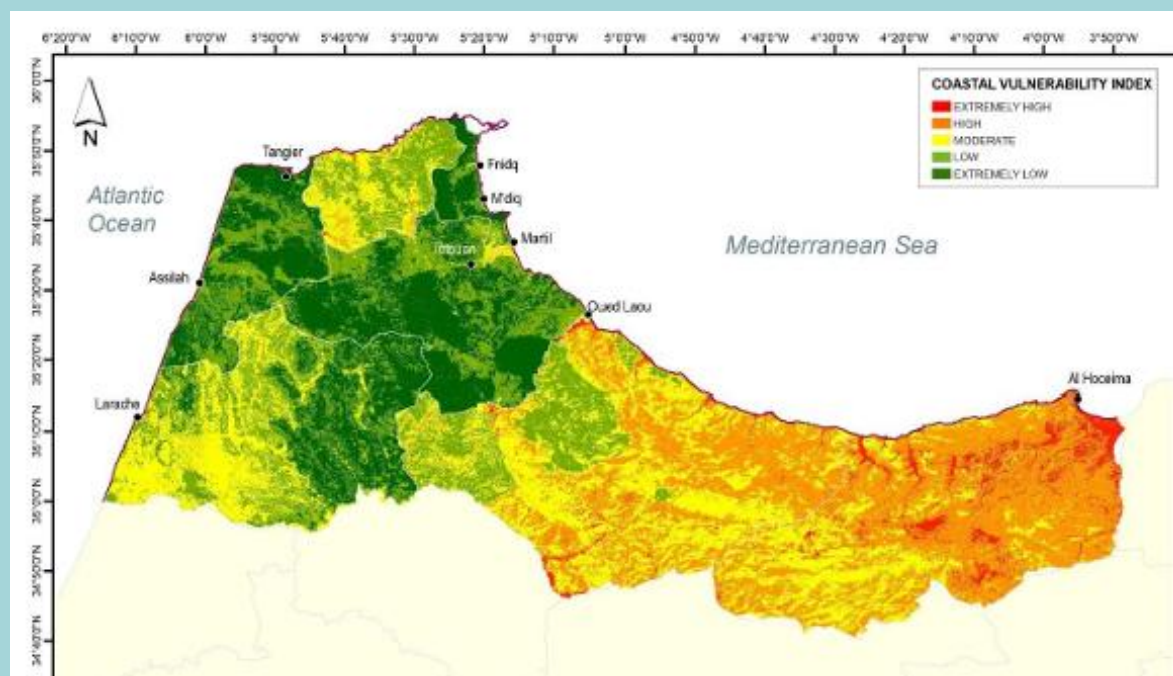
Textbox 3. Evaluating Coastal Vulnerability in Morocco:

The CRA team that developed the *Gender-sensitive Climate Risk Assessment of Tangier-Tétouan-Al Hoceima Region* took an indicator-based approach to identifying regions most vulnerable to coastal hazards based on geomorphological features, high hazard projections, and socioeconomic vulnerability, assigning a 1 to 5 scale to each of variable based on its relative contribution to generate risk, as determined by natural distribution of the variables themselves (e.g., coastal slope ranges from $>20\%$; $0\% = 1$ and $5 = <2\%$) and expert judgement. The dimensionless scores are turned into weightings and combined with other variables, and normalized to fit a range spanning extreme low to high vulnerability (Figure 8)

Coastal Vulnerability Indicators selected for Tangier-Tétouan-Al Hoceima

- Elevation: Extreme physical vulnerability is assigned to coastal areas with a critically low elevation <2 meters
- Coastal Slope: Low-lying coastal topography with a flat slope of less than 2% represents highest end of risk for inland wave run-up and tidal flooding.
- Land Roughness: Minimal surface resistance to overland water flow, characterized by a Manning's coefficient of less than 0.02
- Distance from the Shoreline: Extreme exposure to immediate coastal hazards is designated for coastal zones located within a critical distance of less than 200 meters from the shoreline.
- Ecosystems Health: The complete absence of natural protective barriers, such as sand dunes and wetlands, denotes the highest vulnerability class
- Illiteracy Rate: Socioeconomic vulnerability is considered highest where the gender-disaggregated illiteracy rate among the population aged 10 and over exceeds 20%, reflecting severe structural constraints in adaptive capacity.
- Other indicators: Life expectancy, labor gender gap, education and poverty rate

Figure 8. Coastal vulnerability index map derived from weighted indicators



4.4 Model-based Approaches

Model-based approaches are perhaps the most quantitative, simulating how systems respond to shocks or stress under different climate conditions. These can be statistical models (e.g., dose-response curves), process- or agent-based models (e.g., tracking disease vectors), or sector-specific tools such as hydrological, crop, or economic models. For example, the Soil and Water Assessment Tool (SWAT) is an ecohydrological model that has been used in over 5,000 peer-reviewed studies to date, many of which examine the hydrological response to climate change (e.g., peak runoff or drought). For SWAT and other models, implementation first requires defining key parameters that influence system performance - e.g., soil moisture thresholds, heat stress limits, reservoir storage capacity - and then running simulations under baseline and projected climate scenarios.

For example, the UNEP Climate Risk Dashboard, leverages historical triggers with known impacts (e.g., $SPI \leq -1.5$ for 3 months reduced national GDP of Malawi by 5-10% during an El Nino-induced drought in 2023/4), and model the effects forward with projections and impact chains to understand how specific, hazard- and sector-specific vulnerability factors, such as maize and rain-fed farming, may shape future outcomes. By analyzing which parameters drove the largest changes in past impacts, CRA teams can model where adaptation actions can influence existing vulnerabilities - such as where crop substitutes, drought-resilient seeds, or improved irrigation techniques are most needed. Context-specific models are especially useful for capturing nonlinear responses and sector-specific vulnerability factors that indicator approaches may miss. However, they require specialized expertise and reliable input data typically reserved for situations where data is extensive and can be validated or sourced through community-level dialogue.

Text Box 4. Model-based approaches:

In Mozambique, the CRA team classified the strength of building, wall, and floor materials for individual buildings across Mozambique's coastal cities, assigning weights to these vulnerability factors, and after normalizing them to a common scale, aggregated them against building-specific flood hazard estimates. The CRA team was then able to estimate district-level flood damages and simplified flood risk scores, enabling prioritization.

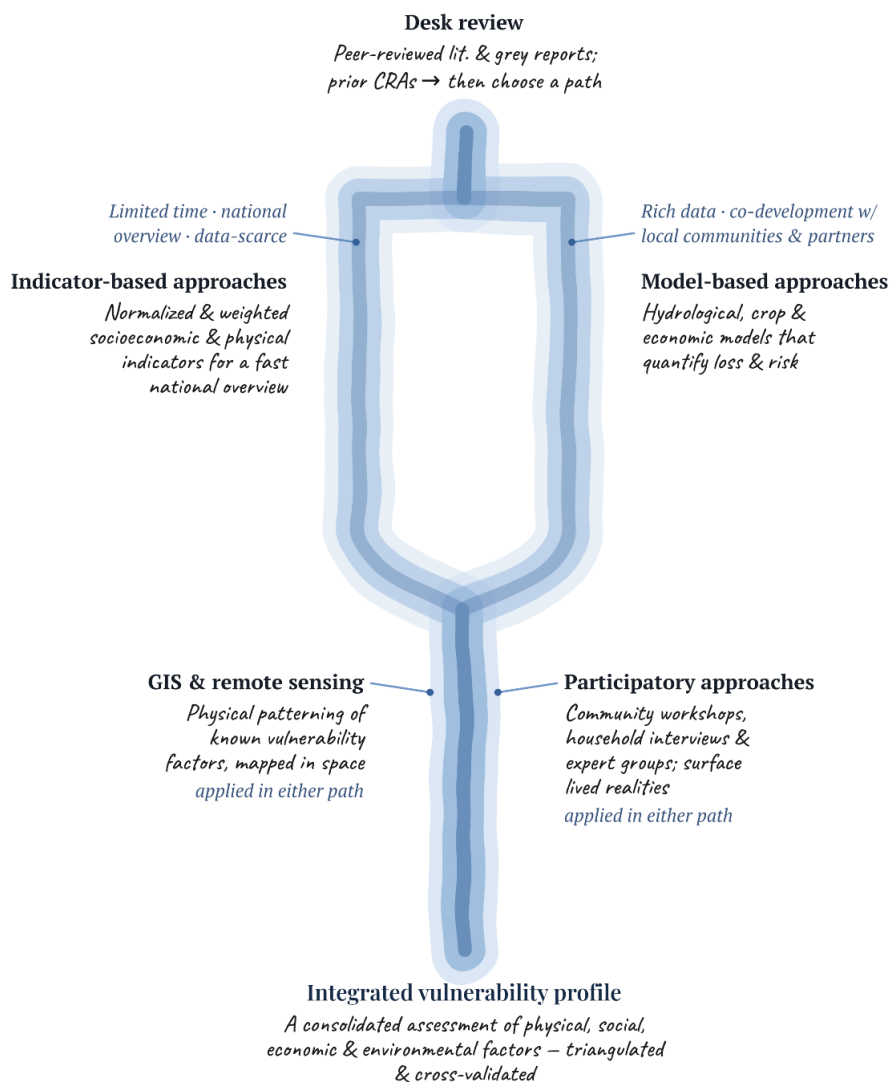
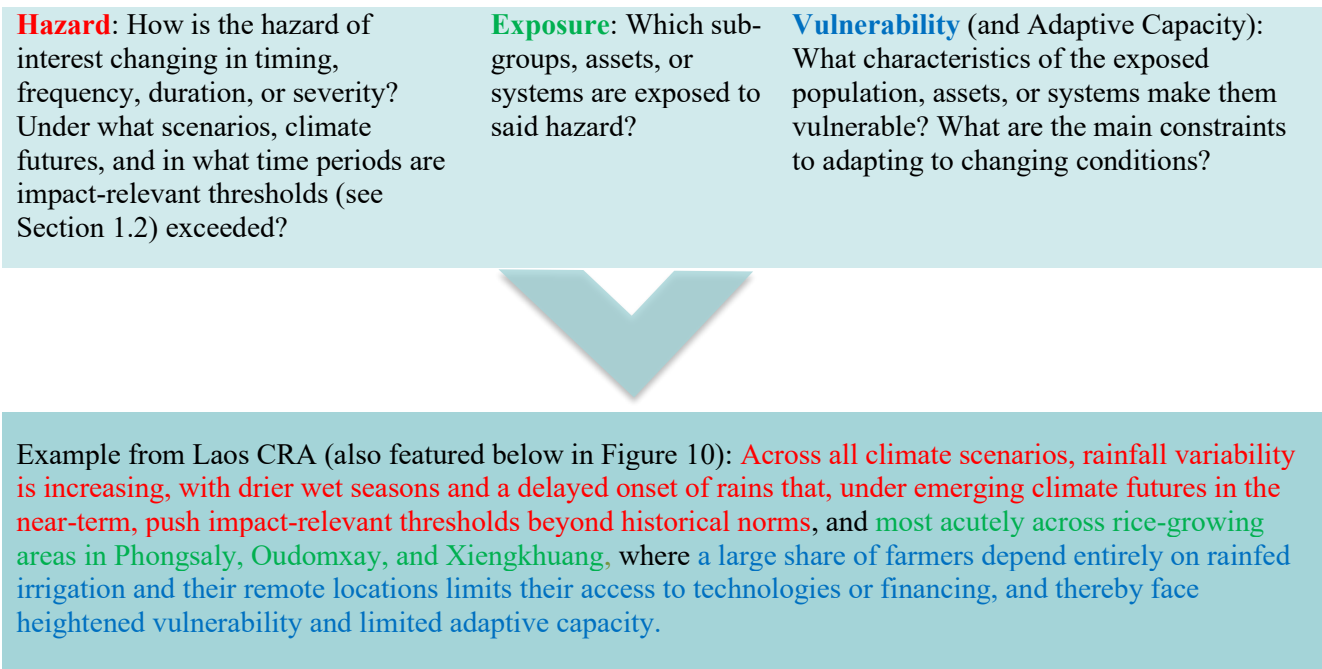


Figure 9. Simple decision-tree for selecting the appropriate methodology

5. Impact and Risk Analysis

Now that they have arrived at the conceptual coverage of the three dimensions of risk, CRA teams must link their findings to how the changing climate affects a particular group of people, assets, or systems; what exposures place them at greatest risk; and what vulnerability factors compound climate risk. In some cases, quantifying losses – either through an impact-based modeling approach or by extrapolating from historical losses – can help the team prioritize which risks are most urgent to address.

When formulating a risk statement, the CRA team should add as much detail as possible from the three dimensions of risk:



Linking each of the risk dimensions, the Laos CRA team (UNEP and University of Reading), developed an impact table, presenting two climate storylines (one hotter and with more seasonal precipitation, and the other hotter but with less seasonal precipitation), the vulnerability factors most relevant rice growing (low access to irrigation or drought-resilient seed), and the provinces most exposed (Figure 10).

Figure 10. Climate change impacts on rice across provinces in Laos. Adapted from Table 15, Laos CRA

Risk table legend									
Impacts:		Climate storyline (CS) associated with the described hazard:				Exposed provinces:			
<div>negative</div> <div>positive</div>		<div>hotter and wetter</div> <div>hotter and drier</div>				<div>is exposed</div> <div>is not exposed</div>			
		Likelihood association with the CS? (based on expert judgement)							
		<div>very likely</div> <div>possible</div>							

Impacts on rice	Climate driver		Vulnerability		Type exposed	Exposure in the focus provinces (4R,17R,LE)					
	Hazard	CS	Environmental	Socio-economic		Oudomxay	Phongsaly	Xiangkhouang	Khammouan	Champasack	Xekong
Reduction in quality and quantity of wet season rice production (or failed harvest) due to decline of rainfall in wet season or drought (10R,35R).	Decline in rainfall in wet season.	<div></div>	Brown spot disease favoured by scarce water.	Low or no access to irrigation.	Upland rainfed						
	Drought in wet season.	<div></div> <div></div>	Low rainfall and high temperatures lead to increased soil salinity.	Low access to finance, limited technical knowledge limits adoption of drought-resilient rice varieties.	Lowland rainfed						
	Change in onset of the rainy season.	<div></div> <div></div>	Rice is especially sensitive to low water during reproductive stages (especially flowering) (35R).		Lowland irrigated						

In some cases, loss estimates are possible and can help with prioritization. In Mozambique, a UNEP-led CRA was conducted to help inform ecosystem restoration plans across several estuaries. To determine where risks translated into the highest possible losses, the team used building- and crop-specific damage curves to estimate potential losses under various flood depths, finding that flood severity and frequency increased substantially only under the highest emission scenario, RCP 8.5. Risk statements were thus made according to the magnitude of risk and overall potential impact, in terms of damages stemming from existing flood exposure and vulnerability factors, such as poor building materials, infrastructure numbers, dependency, and low-lying agricultural lands.

The Zambezi estuary presents a complex convergence of risks, where coastal districts such as Chinde face compounded threats from freshwater flooding and seawater inundation, and interior areas like Morrumbala contend with transport isolation due to damaged road networks. The analysis shows high infrastructure exposure; over 100000 km of roads within the broader Zambezi system are at risk, implying that floods can severely affect access, delay emergency response, and isolate communities during critical windows (this may affect > 72000 people). Economic losses, as implied by infrastructure damage costs, are significant under T50 scenarios.

-Insert from “Building resilience of coastal communities through Ecosystem-based Adaptation approaches in Mozambique” (Page 87)

Instead of quantifying risk, CRA teams may ask project and community stakeholders to rank risks, perhaps based on a sense of urgency not captured in the hazard, exposure, or vulnerability analysis. Doing so requires extreme caution and recognition of the bias and power dynamics that may shape the outcomes of such approaches.

The national-level CRA conducted for Pakistan followed this logic, developing “risk grids” for districts across each province that combined hazard exposure and vulnerability indices and sorted results into five deciles. The framework was then presented to stakeholders so they could select their preferred indices and effectively determine the magnitude and location of risks themselves. While this approach can increase ownership and surface locally perceived priorities, it also introduces clear limitations: stakeholder rankings may reflect short-term concerns, political incentives, or unequal power dynamics rather than underlying drivers of vulnerability; districts with stronger voices or better representation may disproportionately influence outcomes; and the absence of a consistent, quantitative method makes results difficult to compare across regions or replicate over time.

6. Construction and Prioritization of Adaptation Options

6.1 Building Blocks of Adaptation Action

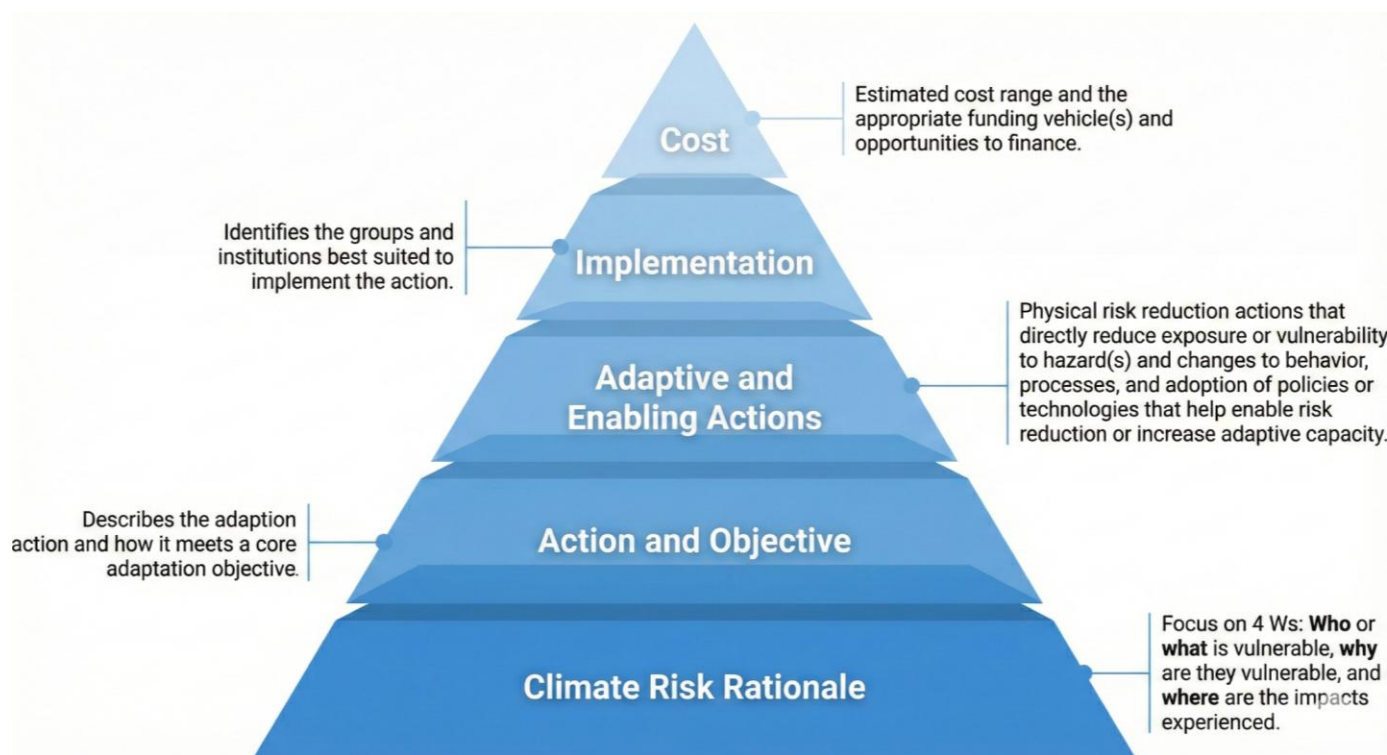
Adaptation actions combine detailed characterization of risks with a vision for addressing them, based on the assessment team’s understanding and stakeholder engagement. While there is no standard method for constructing adaptation actions, key building blocks guide policy and funding efforts (Figure 11).

Each action (or intervention) is a response to a risk identified in the CRA. The first building block is the characterization of risk, detailing who or what is vulnerable to a changing climate (or to responses to climate change), followed by a description of the drivers of vulnerability and the existing limits of adaptive capacity (see Section 5). Proposed adaptation options are then drafted, each linked to an objective (e.g., diversifying livelihoods, expanding flood controls, providing early warning). Each action can be categorized as:

- **Adaptive measures**, which seek to reduce physical vulnerability, typically by altering the built or natural environment; and
- **Enabling measures**, which cover a myriad of changes to behavior, institutions, or boost the adoption of technologies or policies that enable the risk-reducing efforts to succeed.

Risk avoidance through evacuation during extreme events, or the managed retreat of settlements and built infrastructure, will also be important in situations where loss and damage cannot be avoided, and costs are too high to bear. How these measures are implemented, by whom, and over what timeframe are critical ingredients for the next phase of prioritization. Finally, an estimate of cost requirements (e.g., taxes, debt, concessional finance, investment, blended finance, etc.) helps match and link existing or future funding opportunities with the right funding vehicles.

Figure 11. Building blocks of adaptation action



6.2 Developing Usable Adaptation Options

In addition to ensuring each adaptation option is complete, addressing each building block in Figure 10, CRA teams must also ensure adaptation options follow a simple criterion:

- **Specific:** Does the indicator capture all core building blocks of an adaptation option, clearly identifying who or what is at risk, why they are at risk, under which climate scenarios and timeframes risks emerge, and providing a well reasoned justification for the adaptive and enabling actions proposed? Does it specify the expected implementation pathway, the time horizon for achieving results, the actors responsible for delivery, and the anticipated costs required to sustain the intervention?
- **Measurable:** Is progress measurable? If so, develop specific, and when possible, quantifiable metrics that define what will be measured, how often, and with what data sources. This may include quantifying income stability during seasonal drought periods; monitoring downstream flood heights following wetland or riparian restoration; tracking reductions in crop losses during dry monsoon years; or counting the number of households receiving early warning alerts within the required lead time.
- **Attainable:** Is the action realistically achievable under current institutional, financial, and social conditions? If not, does the action identify the constraints that must be addressed first, such as limited local government capacity, insufficient operating budgets, restrictive land use regulations, or social norms that limit participation by women or marginalized groups? Options should also reflect whether enabling conditions exist (e.g., trained extension officers, functioning water user associations, or conflict resolution processes) and whether the action can be implemented without requiring major policy reform or long-term capital investments that are not yet secured.
- **Relevant:** Does the action directly reduce climate risk or address the root causes of vulnerability? Actions should demonstrate a clear causal link between the action and the risk pathway, such as reducing exposure to

flash floods through upstream watershed management, reducing vulnerability by diversifying livelihoods, or addressing structural drivers, such as insecure land tenure, that prevent farmers from investing in soil conservation.

- **T**ime-bound: Assign timeframes to feasibility, planning, implementation, or evaluation phases to ensure effort is earmarked and tracked over successive planning cycles.

The Specific, Measurable, Attainable, Relevant, and Time-bound (SMART) criterion is a widely adopted framework for development performance indicators.³⁴ It serves as a useful validation exercise for CRA teams when finalizing the list of adaptation options.

6.3 Prioritizing Adaptation Options

Following the impact analysis phase, teams will undoubtedly have constructed several adaptation actions that will require prioritization. It is thus important to analyze options against a set of agreed-upon criteria relevant to the political, funding, and decision-making context. Once teams have agreed on a criterion, an evaluation method must be selected to systematically prioritize actions. Several options exist, including traditional cost-benefit analyses, triple-bottom-line assessments, decision analysis/decision trees, and multi-criteria analysis (MCA).

Multicriteria analysis (MCA) is a structured decision support method used to compare and prioritize adaptation options when decisions must balance multiple, often non-commensurable factors, allowing teams to evaluate, debate, and prioritize adaptation actions across diverse criteria, such as effectiveness, cost, feasibility, co-benefits, gender and social inclusion, environmental impact, and alignment with policy priorities.

Building on the SMART feasibility exercise, teams can then build an MCA criterion and arrive at a defensible ranking of adaptation options. As a starting point, most MCAs include at least four considerations: effectiveness, feasibility, affordability, and timing.

CRA teams may assign scores based on the extent to which an adaptation option is (1) effective in reducing the underlying risks or improving the systemic vulnerabilities under current conditions as well as under climate change; (2) feasibility according to technical, data, financing, policy, or social considerations; (3), affordable, primarily in financial terms, but also considering social and environmental costs; and (4) time required for implementation. Several countries have used the OECD Development Assistance Committee (DAC) criteria in their NAP for assessing development interventions, which include six criteria: (5) relevance, (6) coherence, (7) operational effectiveness, (8) efficiency, (9) impact, and (10) durability/ sustainability.³⁵, as illustrated below in Table 8.

Other key considerations may include equity, flexibility, the number of co-benefits, whether the action was developed or will be led by national entities or rely on external actors, and whether the action performs well under a multitude of climate futures; all of which can be weighted according to country and/ or regional priorities. When using weighting, it is important to run simple sensitivity tests to ensure top picks remain stable as weights are adjusted to a reasonable degree.

³⁴ Doran, G.T., (1981)

³⁵ OECD, 2021

Table 8. Hypothetical application of MCA to a shortlist of flood adaptation options

Criteria	Drainage Upgrades	Wetland Restoration	Early Warning System	Building Code Enforcement
1. Effectiveness	4, reduces peak flows and urban flooding but limited upstream impact	5, restores 50 ha of flood-adaptive land cover and slows runoff	3, improves preparedness but does not reduce hazard	4, reduces structural losses but not hydrological drivers
2. Feasibility	3, requires engineering designs, permits, and land access	4, technically straightforward with strong community support	5. Uses existing telecom networks; minimal regulatory barriers	2, enforcement capacity weak; compliance historically low
3. Affordability (inverted)	2, ~\$12M capital cost and high O&M	4, ~\$3M; low O&M; nature-based	5, ~\$0.8M; very low operating costs	3, ~\$5M for staffing, inspections, training
4. Implementation Time (inverted)	2, 4–6 years for design + construction	3, 3–4 years for restoration + hydrological recovery	5, 1 year for installation + training	3, 2–3 years to strengthen enforcement systems
5. Relevance	4, directly addresses CRA identified drainage bottlenecks	5, targets upstream drivers of flood exposure	5, highly relevant for communities with limited lead time	3, relevant but secondary to hydrological risks
6. Coherence	4, aligns with municipal infrastructure plans	5, aligns with national wetland and watershed policies	4, fits national DRM and early warning strategies	3, requires alignment with housing and land use reforms
7. Operational Effectiveness	4, proven engineering solution with predictable performance	4, effective if maintained; ecological variability manageable	5, high reliability; automated alerts	3, dependent on consistent enforcement and inspections
8. Efficiency	3, high cost per beneficiary	4, strong cost-benefit ratio with multiple co-benefits	5, very low cost per person reached	3, moderate benefits relative to administrative cost
9. Impact	4, protects ~180k people in flood-prone neighborhoods	5, adds 500 ha of adaptive land cover; reduces flooding for ~220k people downstream	3, alerts ~120k people; reduces losses but not hazard and last-mile delivery unknown	3, reduces structural losses for ~80k households
10. Durability	3, requires ongoing maintenance; risk of underfunding	5, self-sustaining ecosystem once established	4, requires periodic upgrades and high O&M burden	3, enforcement systems must be continuously funded
Total (equal-weighted)	33	45	44	31

6.4 Low-Regret Adaptation Options

Given the uncertainty discussed in Section 1 and the plausibility of several climate futures, CRA teams can apply a final check to their shortlist of adaptation options to ensure they remain effective under multiple climate futures, otherwise known as “low-regret options.” Teams should perform a simple stress test in which each candidate option is qualitatively or semi-quantitatively assessed under each Representative Climate Future, and those that remain desirable across futures are tagged as low regret.

Low regret options are those that: (i) perform reasonably well across multiple climate futures (e.g., different SSPRCs or Representative Climate Futures such as hot-dry, warm-wet, intermediate), (ii) generate clear co-benefits (for

livelihoods, ecosystems, health), (iii) avoid strong technological or spatial lock-in that could become maladaptive, and (iv) involve manageable sunk costs if conditions evolve differently than expected.

Take, for example, the top two candidates from Table 10: wetland restoration and early warning systems. Wetland restoration performs well under both hot-dry and warm-wet conditions: it stores water during droughts and attenuates floods during extreme rainfall events. The option generates clear co-benefits for livelihoods (fisheries, grass harvests), ecosystems (biodiversity, soil moisture retention), and potential health benefits (improved water quality). It avoids technological or spatial lock-in because wetlands can expand or contract naturally, without requiring fixed infrastructure that might become maladaptive as climate patterns shift. Sunk costs are manageable because wetlands continue providing ecosystem services, carbon sequestration, and water-quality benefits under all but the most extreme conditions, in which case land use alternatives (i.e., groundwater recharge zones) could be put in place.

Early warning systems (EWS) are a common low-regret option because they reduce human and economic losses regardless of the hazard and generally help safeguard livelihoods (protecting assets and crops), health (reducing injury and mortality), and can improve local governance (strengthening disaster response coordination). If designed properly, they can avoid technological lock-in because systems can be upgraded, expanded, or recalibrated as climate information or delivery mechanisms (radio vs. SMS) evolve. Sunk costs are low; even if hazard patterns shift, the communication infrastructure, training, and institutional capacity built through EWS build-out remain valuable for multiple types of emergencies.

6.5 Linking CRAs to MEL:

To understand whether implementing the selected EbA measures is achieving these adaptation goals, monitoring and evaluation (M&E) are critical. Indicators should track the climate baseline as well as outcome change. For example, adaptation measures to protect maize production that is closely correlated with rainfall or reduction of vector-borne diseases that are closely correlated to temperature and rainfall variability can only be assessed for effectiveness if the change in outcome (i.e., progress) is compared to the underlying weather variability. Other indicators measuring outcome changes can be perception-based (around vulnerability reduction), typically using scorecard approaches.

Environmental and social safeguards should be established to ensure that the adaptation measures do not inadvertently increase vulnerability to climate change, for example, groundwater extraction to serve immediate water needs that deplete the resource.

When it comes to output-level indicators, these alone do not reveal whether an intervention meaningfully reduces vulnerability. While the metrics may look successful on paper, they say little about the quality and durability of the intervention. For example, statistics on the number of people trained or farmers receiving climate information do not indicate whether farmers understand the forecasts; these statistics merely indicate the reach of a particular program. To understand whether adaptation efforts are truly working, teams need to pair quantitative metrics with qualitative insights that capture how and why conditions are shifting, drawing on stakeholder interviews that point to attributable impact from interventions, positive or negative.

In addition, the adaptation measures themselves should be resilient to changing climate conditions, for example in the materials used, the design specification and the location of the measures. Teams should select indicators based on hazard exposure (e.g., flood-prone households, drought affected livestock, heat stress morbidity), the leading adaptation option (e.g., early warning uptake, water efficiency measures, climate responsive planning tools), and the objective/outcomes (e.g., reduced flood losses, increased climate resilient crops, improved access to safe water, land under climate-resilient management) in an integrated Theory of Change based on the climate impact chain (Fig.2). Indicators should then be contextualized with metrics specifying the target of measure (i.e., the affected group), within what geographic boundary, under what climate conditions (e.g., during dry years or following a flood event). For

example, a team may select generic but relevant indicators from one of the many repositories, shifting it from “percentage of households at reduced flood risk” into a more detailed “percentage of households in the Lower Mekong floodplain with reduced flood risk due to upgraded drainage and early-warning access, ” contextualizing adaptation progress indicators.

Conclusion

Pairing historical experience with projections through impact storylines can add rich context to risk framing. Because most inputs are backward-looking, storylines and causal impact chains leverage lived experiences to understand how past events affected systems and livelihoods, then use these insights as a baseline for anticipating future impacts under multiple climate futures. This narrative method supplements that historical hazard information, surfacing the meteorological and socioeconomic “triggers” that shaped past events even when formal data are limited.

When preparing exposure data, teams must reconcile political boundaries with natural ones, recognizing that resourcing decisions are made along administrative lines even when the spatial patterning of climate, environmental, and population dynamics is transboundary. Teams should make diligent efforts to preserve data integrity when processing and refining spatial data, as it influences how vulnerability factors are identified and quantified.

A robust diagnosis of vulnerability is perhaps the most critical but overlooked dimension of CRA development. Participatory approaches are uniquely capable of surfacing hidden or highly localized drivers of vulnerability; model-based approaches are ideal for quantitative-led direction, but only under the right data environment; and indicator-based approaches are useful in data-scarce environments but suffer from a range of biases and limitations. All approaches can be enhanced by geospatial imagery and mapping and stakeholder interviews, culminating in an understanding of the relative magnitude and differences in vulnerability across spatial areas and the populations, economies, and natural systems that inhabit them.

Linking all these dimensions – hazards, exposure, and vulnerability – CRA teams can then draft detailed risk statements that explain how and which characteristics of the changing climate affect a particular group of people, assets, or systems; what exposures place them at greatest risk; and what vulnerability factors compound climate risk. In some cases, quantifying losses, either through an impact-based modeling approach or by extrapolating from historical losses, can help the team prioritize which risks are most urgent to address.

Teams can then generate adaptation options and integrated strategies with concrete implementation details, including costs, timelines, and responsible parties. Final selections should be scrutinized using SMART criteria and stress-tested against multiple climate futures to identify those that remain effective under multiple climate futures and, therefore, low-regret. adaptation progress indicators that track the climate baseline and progress over time, and discern why and how conditions are shifting. .

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