METHODOLOGICAL BRIEF

A Framework for Integrated Watershed and Climate Risk Hotspot Mapping to Support Adaptation Strategies in Refugee Camp Landscapes in Jordan

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Front cover photo: Water tank dispensing site within Jerash Camp (*photo*: Maha Al-Zu'bi/IWMI)
Back cover photo: A scenic overlook of Jerash Camp (*photo*: Maha Al-Zu'bi/IWMI)

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1. Introduction

1.1 Integrated Climate Hotspot Analysis for Refugee Camp Resilience

Water scarcity is a challenge faced by many countries in the Middle East and North Africa (MENA) region. This is intensified by climate change, population growth, and uneven resource distribution. Jordan provides a critical case, ranking among the world's most water-scarce countries with only 97 cubic meters of renewable freshwater per person annually[1]. Pressures from climate change have further strained systems, particularly in the Amman-Zarqa Basin, home to 60% of Jordan's population. Refugee camps like Jerash Camp established in 1968 for 11,500 Palestine refugees[2] highlight acute vulnerabilities, underscoring the urgent need for resilient water policies representing one of the most densely populated camps in Jordan (UNRWA, 2024). The camp's population composition and constrained legal status contribute to structural vulnerability, as many residents lack full civil documentation, limiting livelihood opportunities and access to public services (Tiltnes and Zhang, 2013). Furthermore, living conditions in Jerash Camp which is only 0.75 km² in area are shaped by aging infrastructure (Figure 1a), overcrowded housing (Figure 1b), and inadequate WASH systems with intermittent water supply, narrow streets, poor drainage, and deteriorating sewer networks heighten sanitation risks during extreme weather events (Al-Zu'bi et al., 2025). The camp lies in a semi-arid climate, experiences rising temperatures and reduced precipitation reliability which are all consistent with national climate trends (MOENV, 2021). Increasing heat extremes, declining groundwater availability, and intensifying flash-flood events also pose significant risks. These issues have not gone unnoticed by host countries such as Jordan and has led to initiatives such as the recently launched Climate–Refugee Nexus Initiative at COP27 by His Majesty King Abdullah II aimed brining refugee resilience into the discussion of climate policy and finance.

The International Water Management Institute (IWMI), in partnership with the United Nations Relief and Works Agency for Palestine Refugees in the Near East (UNRWA), has developed a comprehensive framework for integrated watershed assessment and climate risk hotspot mapping in conflict affected environments using the Jerash Camp as a pilot site. The methodology employs a multilayered watershed scale approach that combines spatially explicit water accounting with water accessibility modeling to evaluate both current and future vulnerability and risk conditions. The methodology is designed to be scalable and transferable to enable UNRWA readily adapt the workflows and modeling components to other UNRWA camps as well as in diverse refugee and internally displaced persons (IDP) landscapes. Furthermore, the methodology could be used to support national initiatives such as the Climate–Refugee Nexus Initiative in addressing long term adaptation planning for resilience in refugee and host landscapes.

(a) (b)

Figure 1. Landscape of the Jerash Camp showing; (a) aging infrastructure housing and (b) over crowded housing. (*photo*: Maha Al-Zu'bi)

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[1] https://www.worldbank.org/en/news/press-release/2023/06/18/estimated-1-6-million-people-in-jordan-to-benefit-from-new-project-to-tackle-jordan-s-water-crisis-and-build-climate-res

[2] Jerash Camp | UNRWA

2. Methodological Approach

To perform the climate hotspot analysis, a comprehensive watershed and climate risk hotspot assessment framework that integrates hydrological and environmental hazard analysis with socio-economic vulnerability assessment was developed to understand water access patterns in refugee-hosting contexts (Figure 2). This framework is adapted from established climate risk assessment methodologies to examine the intersection of water availability, accessibility, and population vulnerability to identify areas of heightened risk and inform targeted adaptation interventions (Jurgilevich et al., 2017; Papathoma-Köhle et al., 2016). The aim is to provide clear evidence to support decisions that improve resilience and resource management in these sensitive communities.

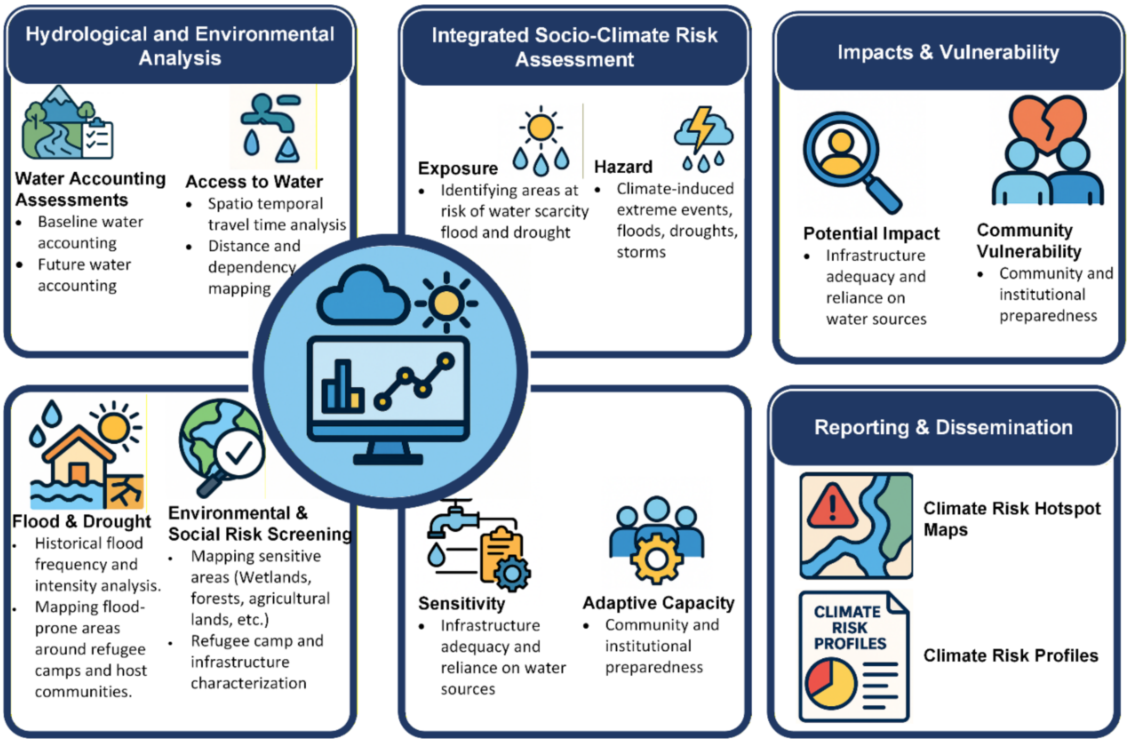

Figure 2. Framework for Mapping Watershed and Climate Risk Hotspots for Risk Resilience of Refugee Camps in Jordan. (*Source*: IWMI, 2025)

2.1 Data Collection and Initial Preparation

The foundation of the analysis depends on gathering comprehensive spatial and tabular data from multiple sources:

- **Climate Data:** Historical rainfall, temperature, and water evaporation data covering the period 2010-2024 collected from weather stations were obtained from Jordan Ministry of Water and Irrigation[3] and other government agencies. Satellite imagery of rainfall[4], temperature[5] and evapotranspiration[6] were obtained from climate data portals. Climate models projecting future scenarios of these variables under the NASA Earth Exchange Global Daily Downscaled Projections Coupled Model Intercomparison Project Phase 6[7] (CMIP6) SSP5-8.5 socioeconomic pathway were downloaded for three models ACCESS-ESM1-5; MPI=ESM1-2-HR and MRI=ESM2-0. These scenarios include different possible futures based on global

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[3] Ministry of Water and Irrigation Jordan
[4] Index of /products/CHIRPS/v3.0/monthly/global/tifs/
[5] Ministry of Water and Irrigation Jordan
[6] Monthly Actual Evapotranspiration (ET) | Early Warning and Environmental Monitoring Program
[7] NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6) | NASA Center for Climate Simulation

socio-economic pathways. The median ensemble of the three climate change models were computed under the SSP5-8.5 socioeconomic pathway for the period 2025-2100 and used for further analysis.

- **Geographical Data:** Maps detailing the location of refugee camp, nearby communities, roads, water sources (rivers, groundwater wells, reservoirs), and natural environments such as wetlands and forests were assembled from Jordan Ministry of Water and Irrigation. Land use data was obtained from the WaPOR[8] database. Information on soil properties from soilgrids250[9] database while terrain attributes-elevation and slope, were derived from a high-resolution Digital Elevation Model (30 m), FABDEM (Meadows et al., 2024). All GIS data were resampled to 90 m resolution for analysis and consistency.

- **Social and Infrastructure Data:** Population density, water usage patterns, the condition of water infrastructure (wells), and community characteristics were obtained from a variety of sources – including in-person surveys that combined (i) semi-structured interviews with residents (both within and outside the camp), UNRWA staff, municipal and national authorities, and representatives of NGOs and community-based organizations (CBOs); (ii) a review of academic and grey literature; (iii) direct field observations of housing, roads, water and waste systems, informal settlements, and youth programs (Al-Zu'bi et al., 2025). Domestic water sourced outside the basin and imported into the basin was estimated from governorate level reported data following (Amdar et al., 2024) and (Leh et al., 2024). Wastewater return flow from treatment plants discharged into to streams was estimated from treated wastewater database effluent data as described by Leh et al., (2024).

2.2 Hydrological and Environmental Analysis

The next stage after data collection involves Hydrological and Environmental Analysis, which quantifies four key biophysical indicators that underpin the overall risk evaluation. These indicators highlight unique dimensions of the risk assessment framework:

1. Water accounting assessment
2. Water-accessibility assessment
3. Environmental and social risk screening and
4. Flood and drought hazard analysis

- Water Accounting Assessment

Understanding current and future water availability is central to the analysis. Water Accounting provides standardized methodologies for quantifying water resources, flows, and consumption patterns at basin and sub-basin scales (FAO, 2016). Existing water supply and demand were quantified, along with projections under future climate conditions using the Scale Invariant Water Accounting Plus (SIWA+) approach (Owusu et al., 2025). Building on a customized water accounting framework developed for the Amman Zarqa basin (Amdar et al., 2024; Leh et al., 2024), remote sensing data was used to estimate water consumption, water availability, water imports, and wastewater reuse across the basin under baseline (2010-2022) and future conditions (2025-2050).

- Water-accessibility assessment

Water access was estimated by using the Access to Water Tool-ACWA of (Akpoti et al., 2025). The ACWA tool integrates water availability assessment, travel time analysis, and population needs to evaluate a locations potential in supporting SDG 6.1.1 monitoring objectives. The method uses water resources assessment under water accounting encompassing both river flows and groundwater abstraction; water availability and access analysis incorporating per capita water supply calculations and travel time modeling; and water access service level classification enabling systematic evaluation of service adequacy across different population groups and

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[8] FAO WaPOR

[9] SoilGrids250m 2.0

geographic areas. Maps were created highlighting distances to groundwater and surface water sources and dependencies on these sources.

- Environmental and social risk screening

The functionality and reliability of water delivery infrastructure were assessed to understand the challenges facing refugees and host populations.

- Flood hazard analysis

The flood hazard assessment for Jerash Refugee Camp and the basin employs a physically based, spatially distributed hydrological modeling approach using the openLiSEM model (Nabukulu et al., 2024). Designed for localized flood simulation, openLiSEM represents key hydrological processes—including infiltration, overland flow, surface ponding, and channel routing—through formulations such as the Green–Ampt infiltration model and Darcy's Law for subsurface dynamics (Chen et al., 2016). Its capacity to incorporate high-resolution topography, land-cover characteristics, and soil attributes enables precise delineation of flow paths, accumulation zones, and inundation extents in complex urbanized environments such as refugee camps (Toufik et al., 2024). Soil parameters were derived from SoilGrids250 while terrain attributes- slope and elevation from the 30-m FABDEM elevation model (Meadows et al., 2024; van den Bout and Jetten, 2020). Rainfall forcing was generated using Intensity-Duration-Frequency (IDF) curves derived from long term (42 years) of CHIRPS satellite rainfall data (Okacha et al., 2023). Daily rainfall was aggregated across the Amman–Zarqa watershed and converted to sub-hourly intensities using the Indian Meteorological Department reduction formula (Kumar et al., 2024):

$$Pt = P24(t/24)^{(\frac{1}{3})}$$

where Pt is the required rainfall depth in mm at t-h duration, P24 is the daily rainfall in mm, and t is the duration of rainfall for which rainfall is required in hr.

Synthetic storm events representing 2- to 100-year return periods were constructed using the alternating-block method. Model simulations produced spatially explicit flood depth and velocity layers, from which a Flood Hazard Index defined as :

Flood Hazard Index = *(velocity + 0.5)* × *depth*

was calculated (Rossi et al., 2024). This index supports hazard classification and provides a robust basis for targeted flood-risk mitigation and emergency response planning in refugee camp settings (Attar et al., 2025).

- Drought and water scarcity analysis

Frequency and severity of droughts were estimated from long-term rainfall using the Standardized Precipitation Index (SPI) at 1-, 3-, 6-, 9-, and 12-month time scales to capture short (1-6 month) - and long-term (7-12 month) precipitation anomalies. Monthly rainfall totals were aggregated to each accumulation period, and fitted to a probability distribution to compute SPI as:

$$SPI = \frac{X_i - \bar{X}}{\sigma}$$

where X_i is the normalized precipitation value, $\bar{X}$ is the long-term mean, and σ is the standard deviation. Resulting SPI maps and time series were used to identify drought onset, severity, and duration across scales.

2.3 Integrated Socio-Climate Risk Assessment

- Vulnerability Assessment : Vulnerability (V) refers to how susceptible refugee communities are to climate hazards. It was broken down into a multiplicative indicator of exposure and sensitivity terms damped by the adaptive capacity:

$$Vulnerability = \{Exposure\ x\ Sensitivity - Adaptive\ Capacity\}$$

- Exposure (*E*): Determining if a community or infrastructure lies within hazard-prone zones for floods, droughts, or water scarcity.

- Sensitivity (*S*): Sensitivity aggregates socioeconomic and infrastructure stressors (e.g., population exposure density, poverty, unemployment, WASH and health stress, education interruption, informal housing, infrastructure stress). Sensitivity indicators were derived from published and grey literature sources[10] including UNRWA, UNICEF, World Bank etc. Full details of the sensitivity indicators together with their justifications are presented in Table S1 and Table S2 of Annex 1.

- Adaptive Capacity (*AC*): Analyzes the community and institutional ability to respond and recover, including social networks, local governance, access to information like early warnings, and availability of technology or funding for adaptation. Adaptive capacity aggregates response-oriented indicators (early warning, social protection, health access, education continuity, governance/DRR planning, climate-finance access, service proximity) Adaptive Capacity indicators together with their justifications are presented in Table S3 and Table S4 of Annex 1.

Risk Hotspot Assessment: All the above components were integrated to produce maps showing "hotspots" — areas where climate hazards coincide with higher vulnerability and low adaptive capacity. These maps provide actionable insights for targeting aid and resilience-building measures. Climate risk data layers were determined as a multiplicative factor of Hazard maps and the Vulnerability layer:

$$Climate\ Risk\ Hotspot = \{Vulnerability\ x\ Hazard\}$$

High-Risk Zones that were identified due to multiple factors were visually highlighted, creating a prioritized map for intervention. The final climate-risk mapping was conducted only at the refugee-camp scale, where detailed exposure and settlement data were available, while the basin-level map therefore illustrates relative vulnerability patterns across the wider landscape.

3. Results

3.1 Basin Level Vulnerability

Snap shots of the results of the Amman Zarqa Basin wide vulnerability and Jerash Camp Climate Risk hot spot maps are shown in Figure 3 and Figure 4 respectively below and discussed briefly below. The reader is referred to Khalifa et al., (2025) for a detailed discussion on the results of the assessment and climate risk profile. Vulnerability and risk maps, associated infrastructure and flood hazard maps can be assessed from the Amman Zarqa basin and Jerash Camp map gallery. Results are shown for baseline conditions and projected future conditions (2025-2050).

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[10] Annex 1: Proposed and selected Sensitivity and Adaptive Capacity indicators used in the integrated watershed and climate risk hotspot mapping in the Amman Zarqa Basin.

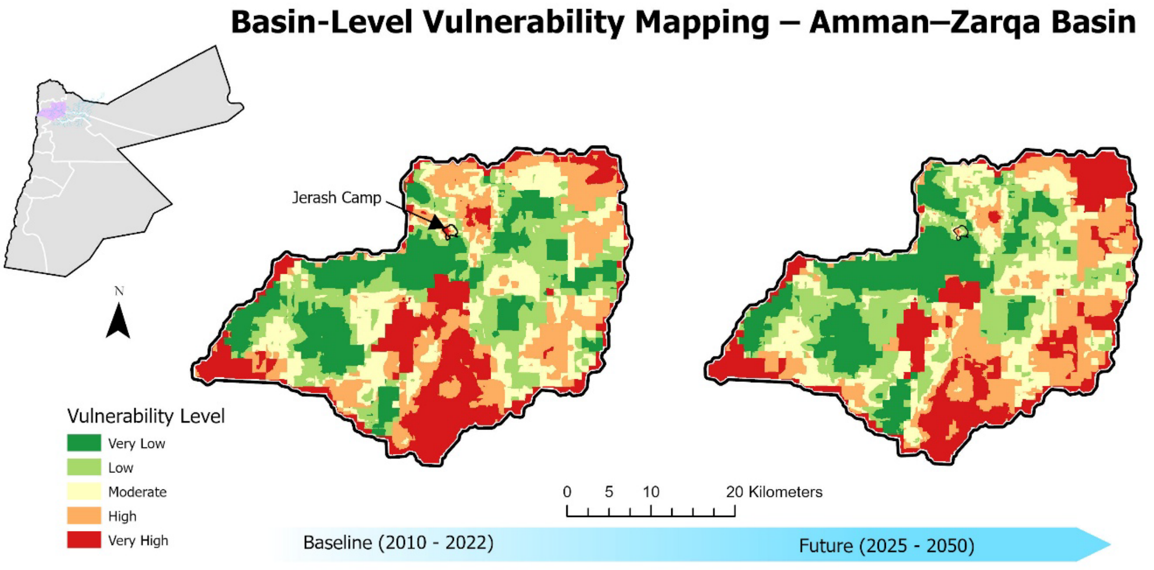
The comparison between the Baseline and Future (2025–2050) vulnerability maps reveal a clear intensification of vulnerability at the basin scale.

3.1.1 Baseline vulnerability (2010-2022)

- Large areas exhibiting low to moderate vulnerability (green to yellow), particularly in the central and eastern zones,
- High to very high vulnerability (orange to red) is primarily concentrated in the southern and northeastern regions of the basin.

3.1.2. Future Vulnerability (2025-2050)

- Significant expansion of high and very high vulnerability zones, becoming more dominant along the eastern, southern, and parts of the central corridors.
- This shift reflects increasing climate and environmental pressures, including rising temperature extremes and declining water availability, which heighten exposure and sensitivity in areas previously considered less vulnerable.
- Very low and low vulnerability zones (green) shrink considerably, particularly in the north and southwest, indicating declining resilience.
- Overall, projections point to a clear upward trend in vulnerability from 2025 to 2050.



The basin-scale vulnerability map was developed using a multi-component vulnerability framework that integrates exposure, social and environmental sensitivity, and adaptive capacity across the Amman–Zarqa Basin. Spatial indicators including water availability, settlement characteristics, vegetation condition, infrastructure quality, drought and flood exposure were normalized and weighted to generate a composite vulnerability index. The basin map therefore illustrates relative vulnerability patterns across the wider Amman-Zarqa landscape.

Figure 3. Basin scale vulnerability level of the Amman Zarqa highlighting areas of high and low vulnerability in Jordan. (*Source*: IWMI, 2025)

3.2 Jerash Camp Climate Risk Hotspots

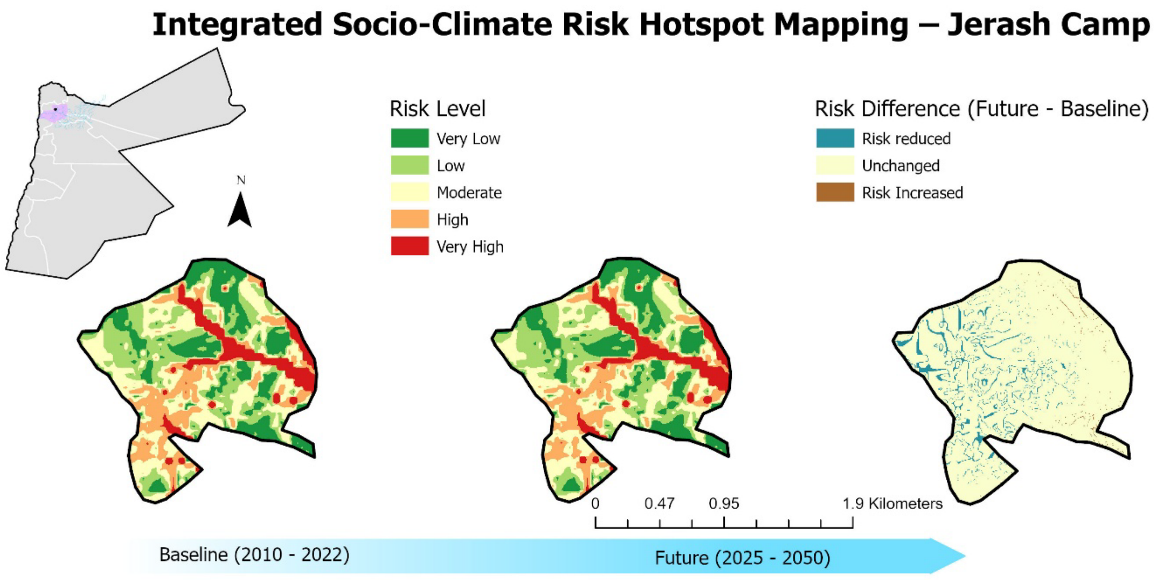
At the camp level, a comparison the Baseline and Future (2025–2050) maps highlights a less obvious change in climate-related risks.

3.2.1. Baseline risk (2010-2020)

- The camp exhibits a mix of vulnerability levels, ranging from low to very high.
- Moderate to high-risk zones (yellow to red) are mainly concentrated in the central, southern, and eastern sections.
- Low to very low-risk areas (green shades) dominate the northern areas and several peripheral zones.

3.2.2. Future risk (2025-2050)

- The overall spatial pattern remains similar, with no major expansion of high or very high-risk hotspots.
- However, eastern and southern boundary areas are projected to shift into higher risk categories.
- These changes indicate growing exposure to climate-induced hazards, including extreme heat, declining water availability, and potential flash-flood events.



The maps were produced through a multi-criteria socio-climate risk assessment that integrates hazard (flood, drought, and water scarcity), exposure, sensitivity, and adaptive capacity indicators. Spatial weighting was applied using expert judgment and normalized indices to generate composite risk scores. For the future scenario (2025–2050), adaptive capacity factors were weighted under an optimistic scenario, reflecting the potential effect of planned adaptation measures. These hotspots reflect zones where flood, drought, and water-scarcity hazards converge, underscoring priority areas for targeted resilience and adaptation interventions.

Figure 4. Integrated Mapping of Climate Risk Hotspots for Risk Resilience in the Jerash Camp in Jordan. (*Source*: IWMI, 2025)

Overall, the spatial distribution reveals that climate risks in Jerash Camp are projected to continue into 2050, with notable clustering of high-risk hotspots in the south and east. These patterns underscore the urgency for localized adaptation planning, improved infrastructure resilience, and targeted early-warning systems to safeguard vulnerable communities.

4. Conclusion

This methodological brief introduces an integrated spatially explicit framework designed to assess water-related climate risks in refugee-hosting landscapes through a combined hydrological, environmental, and socio-climate risk assessment approach. The study systematically integrates multi-source datasets—including climate projections, remote sensing datasets, and socio-economic indicators—to produce a comprehensive picture of vulnerability across both basin scale (Amman Zarqa Basin) and local scale (Jerash Camp). The methodology builds upon established climate risk assessment principles but links Scale Invariant Water Accounting Plus (SIWA+) framework, access to water (ACWA) tool, and socioeconomic vulnerability indicators to capture the interactions between water availability, accessibility, and adaptive capacity.

By merging hydrological modeling, flood and drought hazard mapping, with social exposure and infrastructure sensitivity analyses, the framework identifies climate risk “hotspots” where hazards intersect with limited resilience and adaptive capacity. Stepwise integration—from data collection and baseline accounting to vulnerability mapping and climate scenario modeling—ensures transparency, replicability, and scalability to other regions. The resulting outputs, including climate risk hotspot maps and vulnerability indices, serve as powerful tools that can inform prioritization of interventions. Ultimately, this methodological approach provides a robust foundation for targeted adaptation strategies, supporting evidence-based decision-making aimed at enhancing water security, resilience, and climate preparedness in Jordan’s refugee and host communities and can be replicated in similar environments.

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