A SOCIO-ECOLOGICAL APPROACH TO COMBAT DESERTIFICATION FOR SUSTAINABLE FUTURE

EcoFuture

Work Package 3

Deliverable 3.5 Climate Change Adaptation Measures of the JV

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Executive Summary

The objective of this deliverable is to examine the impacts of climate change on precipitation and temperature in the Jordan Valley using SSP-based projections. These variables will serve as input data for the Soil and Water Assessment Tool (SWAT), enabling a comprehensive evaluation of how future climatic changes may influence the regional water balance and water availability. The results of this deliverable are taken under consideration in the formulation of a "Program of Measures" that if implemented will address provide water, energy and food security while protecting the environment.

The hydrological projections show strong temporal variability across models and scenarios. Under moderate emissions (SSP2-4.5), precipitation and available water may remain stable or slightly increase mid-century but generally decline towards 2100, leading to reduced water availability despite relatively small changes in evapotranspiration. Under high emissions (SSP5-8.5), precipitation, available water, evapotranspiration, and river flow decline more sharply after 2060, with the MPI model showing the strongest drying signal.

Relative to the average hydrologic conditions derived from observed meteorological data for the period 2000–2020: : 1225 Mm³/yr precipitation, 423 Mm³/yr available water, 719 Mm³/yr ET, 104 Mm³/yr river flow):

- **SSP2-4.5**: precipitation declines 10–17% (2020–2060) and 12–22% (2060–2100), causing a 14–61% drop in available water mid-century and 23–54% by late century; river flow ranges from a slight increase to a 28% decrease.
- **SSP5-8.5**: precipitation declines 7–10% (2020–2060) and 17–30% (2060–2100), causing an 11–53% drop in available water mid-century and 25–46% by late century; river flow shifts from a small early increase to an 11–42% decline by 2100.

The climate change simulation results exhibit a high variability in the projections of the hydrologic conditions in the Jordan Valley. Nevertheless, they all show a further decrease in all the components of the hydrologic budget, resulting in significant decrease of the available water and flow of Jordan River. This situation will exaggerate water scarcity and the impacts from the decline of water level of the Dead Sea.

The overall objective of the PRIMA-funded EcoFuture project is to develop a climate-change adaptation program to combat desertification oriented towards improving socio-economic welfare for people in the JV and it is based on WEFE nexus methodologies. A Strategic Plan was developed for Jordan and Palestine to address the impacts of desertification based on the WEFE Nexus. The Plan did not include the Israeli territory of the Jordan Valley, because Isreal's main strategy to address water scarcity is the use of desalinated water. The Strategic Plan outlines a clear, actionable path forward and has three interrelated strategic goals: Resource Security, Environmental Sustainability, and Socio-Economic Prosperity. Developed through an integrated, participatory framework, it reflects both scientific rigor and local knowledge, ensuring that proposed solutions are feasible, context-sensitive, and equitable. This Strategic Plan presents a portfolio of priority interventions derived from a thorough analysis of regional challenges and an inclusive consultation process with Jordanian and Palestinian stakeholders.

1. Introduction

Climate change, driven primarily by greenhouse gas emissions, refers to significant and long-term shifts in global climate patterns, particularly in temperature and precipitation (IPCC, 2021). These changes have profound implications for ecosystems, water resources, and human livelihoods, with water-scarce regions like the Middle East facing especially acute challenges. Water scarcity in these areas is not only an environmental issue but a multifaceted challenge with socio-economic and political ramifications, further exacerbated by rapid population growth and inefficient resource management (Ballard Brief). The Jordan River Basin, which spans Syria, Lebanon, Jordan, Israel, and Palestine, is one of the world's most fragile water systems, supporting agriculture, biodiversity, and human communities in the region (EcoPeace Middle East, 2022).

Located within the Jordan River basin, the Jordan Valley serves as a critical agricultural and water-resource hub, but its vulnerability to climate change is intensifying. Observations in the Jordan Valley reveal rising temperatures, declining precipitation, and increased extreme weather events, all of which exacerbate existing water scarcity challenges (Al-Bakri et al., 2013; Givati et al., 2017). Rainfed agriculture, a primary livelihood for many in the region, has been severely impacted by these changes, leading to reduced agricultural productivity (Al-Qatarneh et al., 2018). Additionally, surface water resources in the region continue to decline due to both climate change and human activities, further straining water availability and threatening the ecological balance (Salameh & Abdallat, 2020). The Azraq Basin, a vital component of Jordan's water supply, exemplifies the region's vulnerability, with decreasing water availability directly threatening local populations (Al-Qatarneh et al., 2018). These climatic challenges highlight the need for innovative approaches to manage and optimize water use. Managing water resources in such a fragile region requires a balance between ecological preservation and socio-economic needs. Addressing these intertwined challenges requires not only effective management strategies but also forward-looking analytical tools capable of anticipating future conditions under a changing climate. The intricate challenges underscore the complex interplay of environmental, social, and political factors in ensuring sustainable water management (The Water of the Jordan Valley, 2009; Al-Bakri et al., 2015). To assess the impacts of climate change, predictive tools are essential. The latest Shared Socioeconomic Pathways (SSPs) framework provides a robust approach for simulating future conditions by integrating socioeconomic development trajectories with greenhouse gas emissions (O'Neill et al., 2014). For the Jordan Valley, applying contrasting scenarios such as SSP2-4.5 (sustainable development with moderate emissions) and SSP5-8.5 (fossil-fueled development with high emissions) is particularly relevant. SSP2-4.5 represents a "middle-of-the-road" pathway, emphasizing climate resilience, sustainable development, and gradual mitigation efforts, whereas SSP5-8.5 explores a future dominated by rapid economic growth, intensive fossil fuel use, and limited climate mitigation. These scenarios have been widely applied in water-scarce regions, demonstrating their utility in assessing future water availability and climate risks (Riahi et al., 2017; Van Vuuren et al., 2011).

The objective of this deliverable is to examine the impacts of climate change on precipitation and temperature in the Jordan Valley using SSP-based projections. These variables will serve as input data for the Soil and Water Assessment Tool (SWAT), enabling a comprehensive evaluation of how future climatic changes may influence the regional water balance and water availability. The results of this deliverable are taken under consideration in the formulation of a "Program of Measures" that if implemented will address provide water, energy and food security while protecting the environment.

2. Literature Review

The Jordan Valley, a region of profound strategic and ecological importance, has long attracted scientific attention due to its acute vulnerability to climate change, water scarcity, and socio-economic pressures. This literature review synthesizes existing research on the environmental, hydrological, agricultural, and policy challenges affecting the Jordan Valley, while exploring potential strategies for sustainable development and equitable water resource management (Al-Bakri et al., 2010; EcoPeace Middle East, 2022; Al-Addous et al., 2023).

- **Impact of Climate Change on Water Resources -** Climate change exerts significant impacts on the hydrological systems of the Jordan Valley, manifesting primarily as reduced water availability, altered precipitation patterns, and rising temperatures. Al-Bakri et al. (2010) demonstrate that these changes have severely compromised rainfed agriculture, with notable reductions in crop yields as water stress and shifting growing seasons intensify. Similarly, Salameh and Abdallat (2020) highlight declining surface water availability, attributing it to heightened evaporation rates and diminishing runoff under a changing climate.Studies focused on the Yarmouk River Basin (Bashabsheh & Al-Zboon, 2024) further reveal how declining rainfall and mismanagement aggravate water scarcity in one of the Jordan River's most critical tributaries. Regional climate modeling by Givati et al. (2017) indicates that these hydrological stresses will likely worsen, with projected reductions in streamflow exacerbating water shortages. Additionally, the Red Cross Red Crescent Climate Centre (2022) emphasizes that shifting rainfall regimes also impede groundwater recharge, further restricting both surface and subsurface water supplies essential for agriculture and domestic use. Maintaining a sustainable water balance is therefore crucial to mitigating ecological risks, as underscored in *The Water of the Jordan Valley* (2009).
- **Water Scarcity and Resource Management Challenges -** Water scarcity in the Jordan Valley extends beyond environmental concerns to encompass deep socio-economic and political implications. Al-Qatarneh et al. (2018) illustrate how unsustainable groundwater extraction and reduced rainfall threaten the long-term viability of the Azraq Basin, a critical water source. Al-Addous et al. (2023) expand on these challenges, stressing the necessity of technological innovation and policy reform to secure a sustainable water future.The ecological consequences of water scarcity are profound, including degradation of the Jordan River ecosystem (EcoPeace Middle East, 2022) and increased vulnerability of marginalized communities. Socio-economic impacts include uneven water distribution, weak governance (Ballard Brief, n.d.), and heightened humanitarian risks (Red Cross Red Crescent Climate Centre, 2022). These dynamics underscore the urgent need for improved water governance, regional cooperation, and social equity in water distribution policies.
- **Agriculture and Water Efficiency -** Agriculture, the backbone of the Jordan Valley's economy, is particularly sensitive to water scarcity. Shtull-Trauring et al. (2016) demonstrate how high-resolution GIS and water footprint analyses can optimize irrigation practices, particularly for plantation crops, reducing water consumption without compromising yields. Similarly, the FAO (2014) identifies significant inefficiencies in water use throughout Jordan's agricultural supply chain and proposes strategies for improvement.Given the valley's reliance on irrigation, improving water use efficiency is critical to ensuring food security (Red Cross Red Crescent Climate Centre, 2022). Adoption of advanced irrigation technologies and precision farming techniques offers a path toward sustainable agricultural production under increasing water stress.

- **Biodiversity and Ecosystem Health -** Biodiversity in the Jordan Valley faces mounting threats due to water scarcity and habitat degradation. The *Jordan Biodiversity Analysis* (2019) links biodiversity loss directly to unsustainable water practices and the broader impacts of climate change, highlighting the urgent need for integrated conservation strategies. Reduced river flow, as documented by the Red Cross Red Crescent Climate Centre (2022), jeopardizes both aquatic and terrestrial ecosystems, leading to habitat loss, wetland degradation, and species decline. Protecting biodiversity requires coordinated water management policies that account for ecological sustainability alongside human and agricultural demands.
- **Integrated Approaches to Sustainability -** The interconnections between water, energy, and food security are central to addressing the Jordan Valley's climate challenges. The International Union for Conservation of Nature (IUCN) emphasizes the necessity of cross-sectoral strategies to mitigate climate impacts, highlighting how water scarcity exacerbates food insecurity and biodiversity loss. EcoPeace Middle East (2022) advocates for a regional, cooperative approach to water governance through its master plan for the lower Jordan River Basin, which emphasizes integrated water resource management as a foundation for sustainable development.Integrated strategies that connect water, energy, and food policies are also endorsed by the Red Cross Red Crescent Climate Centre (2022), which argues that only coordinated approaches can effectively address the region's complex climate-related challenges.
- **Strategies for Sustainable Water Management and Climate Adaptation -** Sustainable water management in the Jordan Valley requires comprehensive policy frameworks, strengthened regional cooperation, and innovative adaptation solutions. Institutional fragmentation and weak policy enforcement have historically limited water governance effectiveness (Al-Kharabsheh et al., n.d.). Climate adaptation strategies must therefore prioritize water-use efficiency, infrastructure development, and stakeholder engagement to secure long-term water security (Red Cross Red Crescent Climate Centre, 2022).
- **Nature-Based Solutions (NBS) —** such as reforestation, wetland restoration, and sustainable agricultural practices — have proven highly effective in enhancing climate resilience (UNEP, 2020). For example, the restoration of the Sharhabil Bin Hassneh EcoPark illustrates how NBS can restore ecosystems, support biodiversity, and mitigate climate impacts. Furthermore, the Jordanian government has made significant progress in promoting climate-smart agriculture and water conservation, including drip irrigation and wastewater reuse, as key strategies for managing water resources under future climate scenarios (UNEP, 2020).

3. Methodology

This study employs climate projections from the Coupled Model Intercomparison Project Phase 6 (CMIP6) to assess future climate scenarios in the Jordan Valley. Specifically, it utilizes three global climate models (GCMs): EC-Earth3-CC (Europe), HadGEM3-GC31-LL (UK), and MPI-ESM1-2-LR (Germany), focusing on two Shared Socioeconomic Pathways (SSPs) — SSP2-4.5 and SSP5-8.5. These scenarios represent medium and high greenhouse gas concentration pathways, respectively, and are crucial for understanding potential future climate trajectories. The EC-Earth3-CC model is recognized for its comprehensive representation of the Earth system, including atmospheric, oceanic, and land components, enhancing its suitability for regional climate projections (Döscher et al., 2021). HadGEM3-GC31-LL, developed by the UK Met Office, is known for its high-resolution simulations and has been widely used in climate impact studies (Andrews et al., 2020). MPI-ESM1-2-LR, developed by the Max Planck Institute, provides a detailed representation of the Earth's climate system, contributing to robust future projections (Mauritsen et al., 2019). Collectively, these models provide a spectrum of possible future conditions, essential for assessing climate change impacts in the Jordan Valley, particularly with respect to temperature and precipitation dynamics. Figure 1 illustrates the spatial distribution of grid points from the three climate models — EC-Earth3-CC, HadGEM3-GC31-LL, and MPI-ESM1-2-LR — relative to the study watershed. Each subplot displays the geographic location of the model grid points (black dots), allowing direct comparison of spatial resolution and coverage. Clear differences are evident: EC-Earth3-CC offers the highest spatial resolution with the densest grid, HadGEM3-GC31-LL shows an intermediate distribution, while MPI-ESM1-2-LR exhibits the sparsest grid. Given the differences in spatial resolution and distribution among the climate models, subsequent processing steps were essential to bias-correct their outputs, thereby ensuring their consistency and reliability for hydrological simulations within the SWAT model

Daily precipitation and temperature time series were bias-corrected prior to use in climate-impact modeling. For precipitation, the procedure began with a calibration step on the historical overlap between observations and model output. The LOCI (Local Intensity–Occurrence) method (Schmidli et al., 2006) was applied on a monthly basis to correct wet-day frequency, ensuring that the simulated number of wet days (days exceeding 0.1 mm d^{-1}) matched observations and reducing the common drizzle bias in climate models. To adjust precipitation amounts, we then applied Quantile Delta Mapping (QDM) (Cannon et al., 2015) using 201 quantiles and constant safe-tail extrapolation, which corrects the full distribution of precipitation while preserving relative climate change signals and preventing unrealistic behavior in the extremes. In future simulations, a step was added to preserve the model's change in wet-day frequency by enforcing a month-specific target wet fraction using a top-k selection procedure, whereby only the k largest daily values per month are retained. Finally, a change-locking step was applied so that period-mean percentage changes (e.g., 2015–2050 and 2051–2095 relative to 2000–2012) in the corrected series matched those in the raw model, thereby ensuring that long-term trends were preserved. For temperature (both Tmin and Tmax), daily series were corrected using additive QDM (Cannon et al., 2015) on a monthly basis with safe-tail extrapolation. This aligns the distribution of modeled temperatures with observations while retaining projected shifts across the full range. A final additive change-locking step was then applied to guarantee that mean temperature changes (°C) for each future period remained consistent with the raw model output.

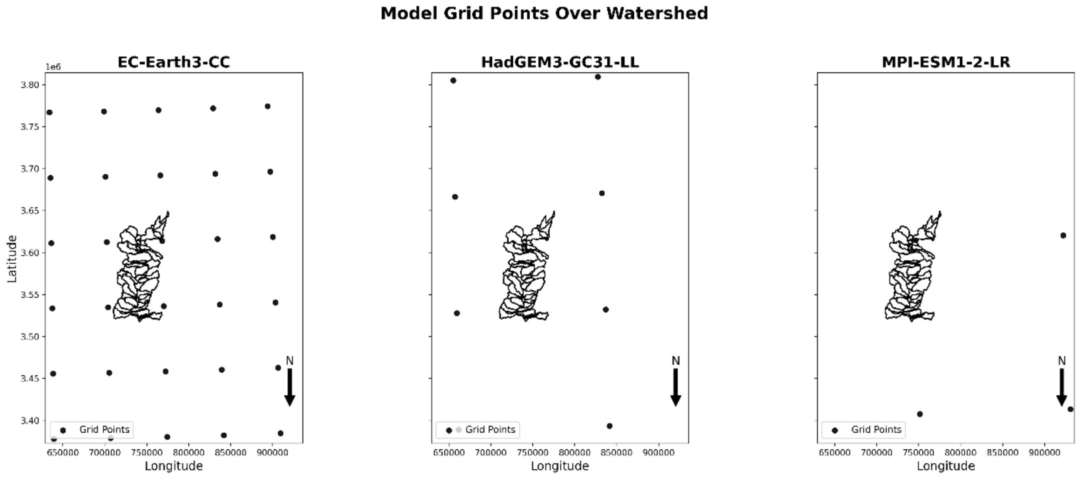

Figure 1.Spatial distribution of climate model grid points from EC-Earth3-CC (Europe), HadGEM3-GC31-LL (UK), and MPI-ESM1-2-LR (Germany) over the study watershed.

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4. Results of Climate Change Projections

Appendix Figures A1–A3 provide precipitation model–observation comparisons for stations with available records. The results of maximum (Tmax) and minimum (Tmin) temperature projections for the period 2020–2100 at Mid Ghor and North Ghor are presented in Figures 2, 3, and 4, based on simulations from the EC-Earth3-CC (Europe), HadGEM3-GC31-LL (UK), and MPI-ESM1-2-LR (Germany) climate models under the SSP2-4.5 and SSP5-8.5 emission scenarios. These two stations were selected because they are strategically located to represent both the central and northern parts of the Jordan Valley, thereby capturing the spatial variability of climatic conditions across the study area. All three models consistently project a significant warming trend for both Tmax and Tmin, with the magnitude of warming being higher under the high-emission SSP5-8.5 scenario. Among the models, HadGEM3-GC31-LL (Figure 3) shows the steepest warming rates, in some cases exceeding +0.7 °C per decade, while MPI-ESM1-2-LR (Figure 4) projects more moderate increases. Minimum temperature projections follow a similar pattern to maximum temperature, indicating a consistent warming of both daytime and nighttime conditions. Collectively, Figures 2–4 demonstrate a robust and persistent warming signal throughout the 21st century, with potentially significant consequences for regional climate dynamics, hydrological processes, and agricultural productivity in the Jordan Valley.

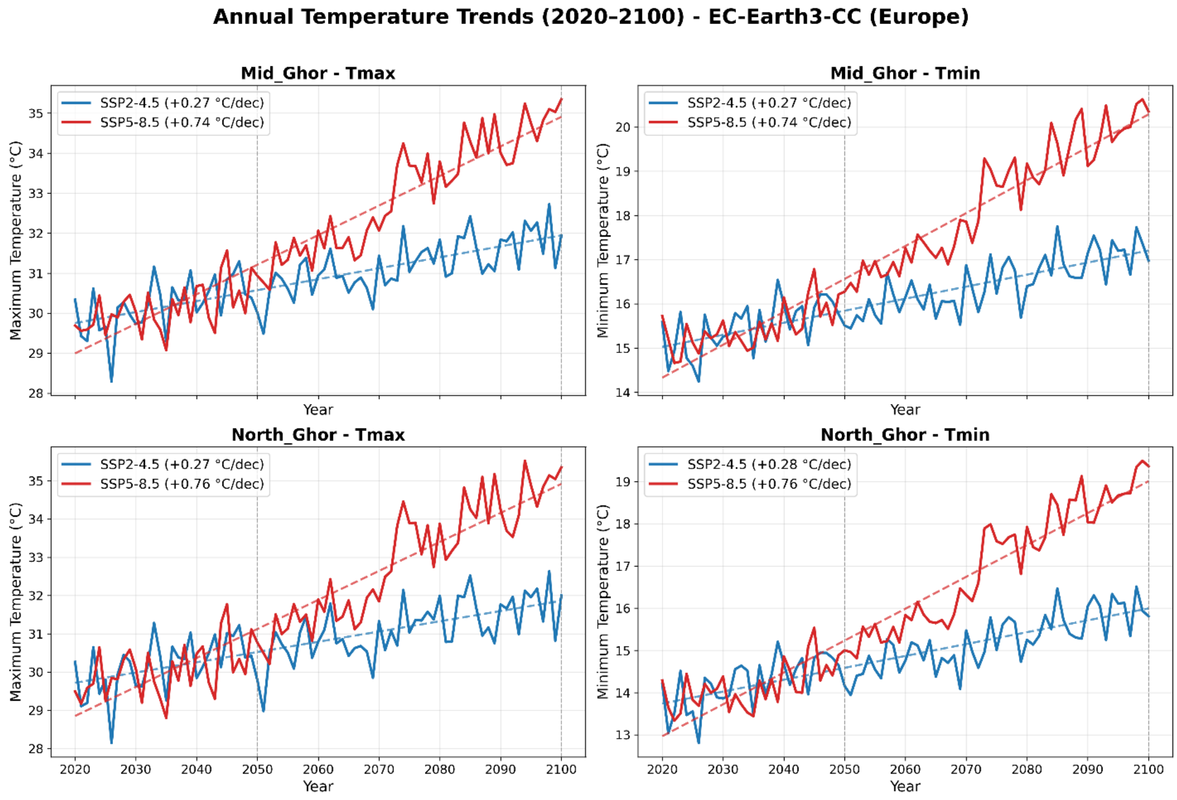

Figure 2. Annual Tmax and Tmin trends (2020–2100) for EC-Earth3-CC (Europe) at Mid Ghor and North Ghor under SSP2-4.5 (blue) and SSP5-8.5 (red).

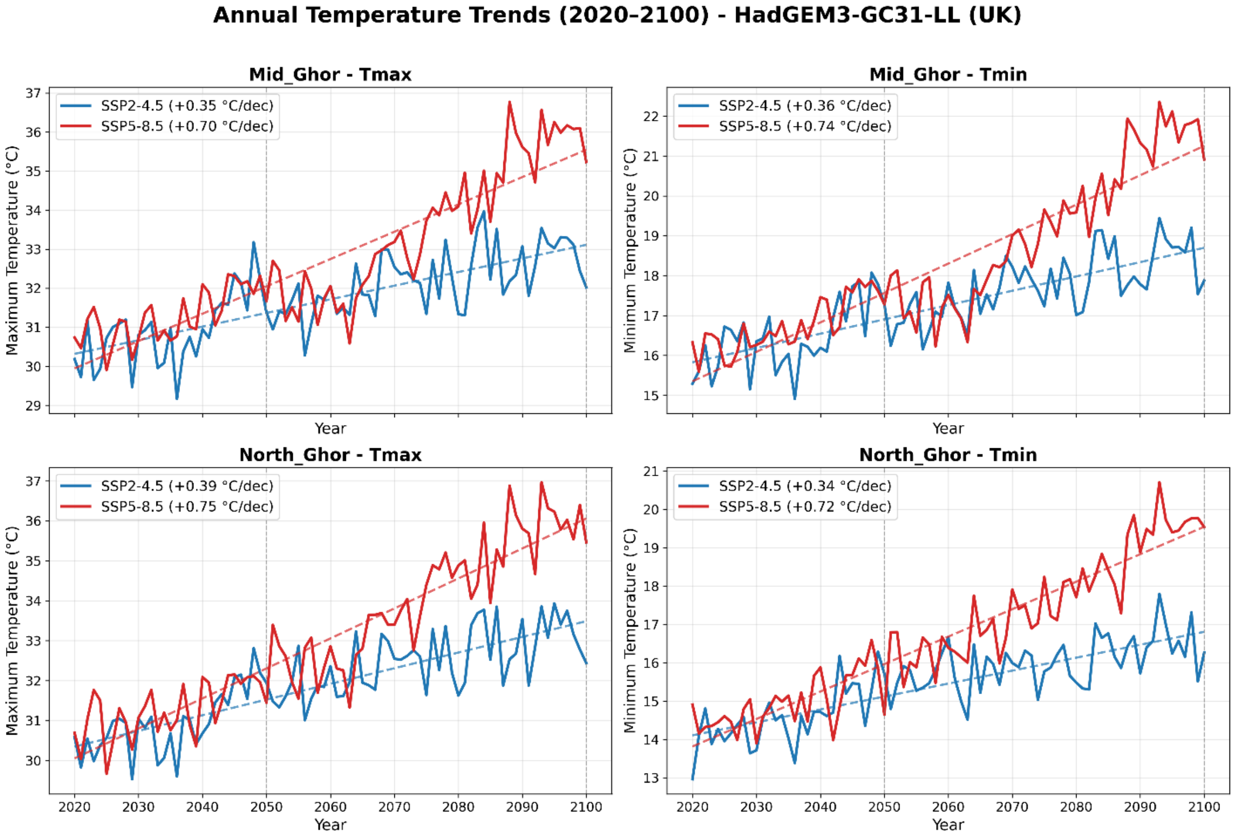

Figure 3. Annual Tmax and Tmin trends (2020–2100) for HadGEM3-GC31-LL (UK) at Mid Ghor and North Ghor under SSP2-4.5 (blue) and SSP5-8.5 (red).

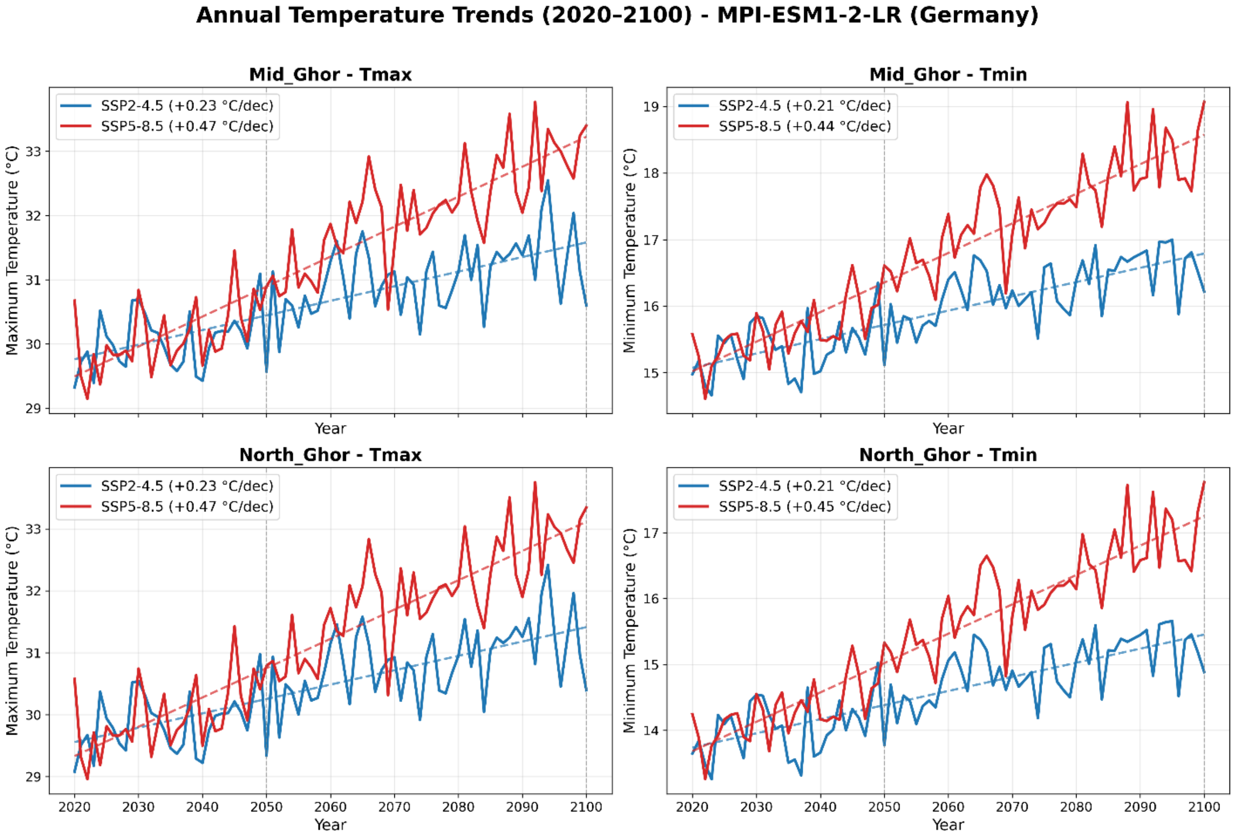

Figure 4. Annual Tmax and Tmin trends (2020–2100) for MPI-ESM1-2-LR (Germany) at Mid Ghor and North Ghor under SSP2-4.5 (blue) and SSP5-8.5 (red).

The analysis of projected hydrological components for the period 2020–2100 reveals substantial changes in precipitation, evapotranspiration, hydrological flow, and available water under both SSP2-4.5 (medium-emission) and SSP5-8.5 (high-emission) scenarios, with notable differences among the three climate models examined.

Precipitation (Figure 5) demonstrates marked interannual variability throughout the 21st century, highlighting the complexity of future rainfall regimes. Under SSP2-4.5, the EC-Earth3-CC (Europe) model projects a slight positive trend of +7.58 MCM/decade, suggesting potential stability or even slight increases in rainfall input. In contrast, HadGEM3-GC31-LL (UK) and MPI-ESM1-2-LR (Germany) simulate decreases of −3.94 and −33.04 MCM/decade, respectively. The divergence among models becomes more pronounced under SSP5-8.5, where all simulations consistently indicate decreasing precipitation, with MPI-ESM1-2-LR showing the steepest decline (−36.61 MCM/decade) followed by HadGEM3-GC31-LL (−33.04 MCM/decade). These results underline the heightened uncertainty surrounding future precipitation dynamics, while the general trend toward decreasing rainfall under high emissions suggests reduced freshwater inputs, potentially intensifying water scarcity risks.

To further investigate precipitation seasonality and distribution, Appendix Figure A4 provides a detailed breakdown of projected monthly precipitation patterns under both emission scenarios, illustrating the pronounced concentration of rainfall in the winter months and the extended dry periods characteristic of the Jordan Valley.

Projected evapotranspiration (ET) trends (Figure 6) exhibit a predominantly downward trajectory over the study period, although the extent of change differs across models and scenarios. Under SSP2-4.5, EC-Earth3-CC and HadGEM3-GC31-LL predict minimal decreases (−0.04 and −0.28 MCM/decade, respectively), whereas MPI-ESM1-2-LR indicates a more substantial reduction (−13.47 MCM/decade). This decline becomes more pronounced under SSP5-8.5, with reductions ranging from −3.64 MCM/decade (EC-Earth3-CC) to −19.64 MCM/decade (MPI-ESM1-2-LR). These trends likely result from combined decreases in precipitation and soil moisture availability, leading to reduced vegetation water use and altered land–atmosphere feedbacks in a warmer climate. The findings emphasize the sensitivity of evapotranspiration to climate forcing and its critical role in regulating water availability.

Additional insights into seasonal evapotranspiration behavior are provided in Appendix Figure A5, which illustrates the monthly distribution of ET throughout the 21st century, showing peaks during spring and early summer and significant reductions during the dry season.

Hydrological flow (Figure 7) projections reveal a consistent declining pattern across scenarios, although interannual variability remains substantial due to fluctuations in precipitation and catchment dynamics. Under SSP2-4.5, EC-Earth3-CC indicates a modest decline (−1.23 MCM/decade), HadGEM3-GC31-LL shows a slight increase (+1.95 MCM/decade), and MPI-ESM1-2-LR projects a more significant decrease (−6.67 MCM/decade). Under SSP5-8.5, all models consistently predict reduced flow, with declines ranging between −3.37 and −5.69 MCM/decade. These results point to a likely reduction in river discharge and runoff potential, driven by reduced precipitation and increased evaporative demand. Such changes could significantly affect the seasonal distribution and total volume of water resources, posing major challenges for water supply, irrigation, and ecosystem stability. Similarly, available water projections (Figure 8) indicate a persistent downward trend, underscoring the growing risk of water scarcity under future climate conditions. Under SSP2-4.5, EC-Earth3-CC projects a slight increase (+7.62 MCM/decade) and HadGEM3-GC31-LL shows relative stability (+3.66 MCM/decade), whereas MPI-ESM1-2-LR suggests a pronounced decline (−19.57 MCM/decade). Under SSP5-8.5, however, all models indicate declines, with reductions reaching up to −16.97 MCM/decade. This decrease reflects the combined impacts of lower precipitation, diminished runoff, and declining soil moisture, resulting in reduced water availability for human consumption, agriculture, and ecosystems.

Overall, the results from Figures 5–8 reveal a consistent pattern of climate-induced hydrological stress under both medium- and high-emission scenarios. The projected reductions in precipitation, evapotranspiration, flow, and available water point to a future characterized by greater hydrological variability and increasing scarcity, particularly under the SSP5-8.5 scenario. These findings highlight the urgent need for adaptive water resource management strategies to mitigate the impacts of climate change on water security, agricultural productivity, and ecosystem resilience in the Jordan Valley.

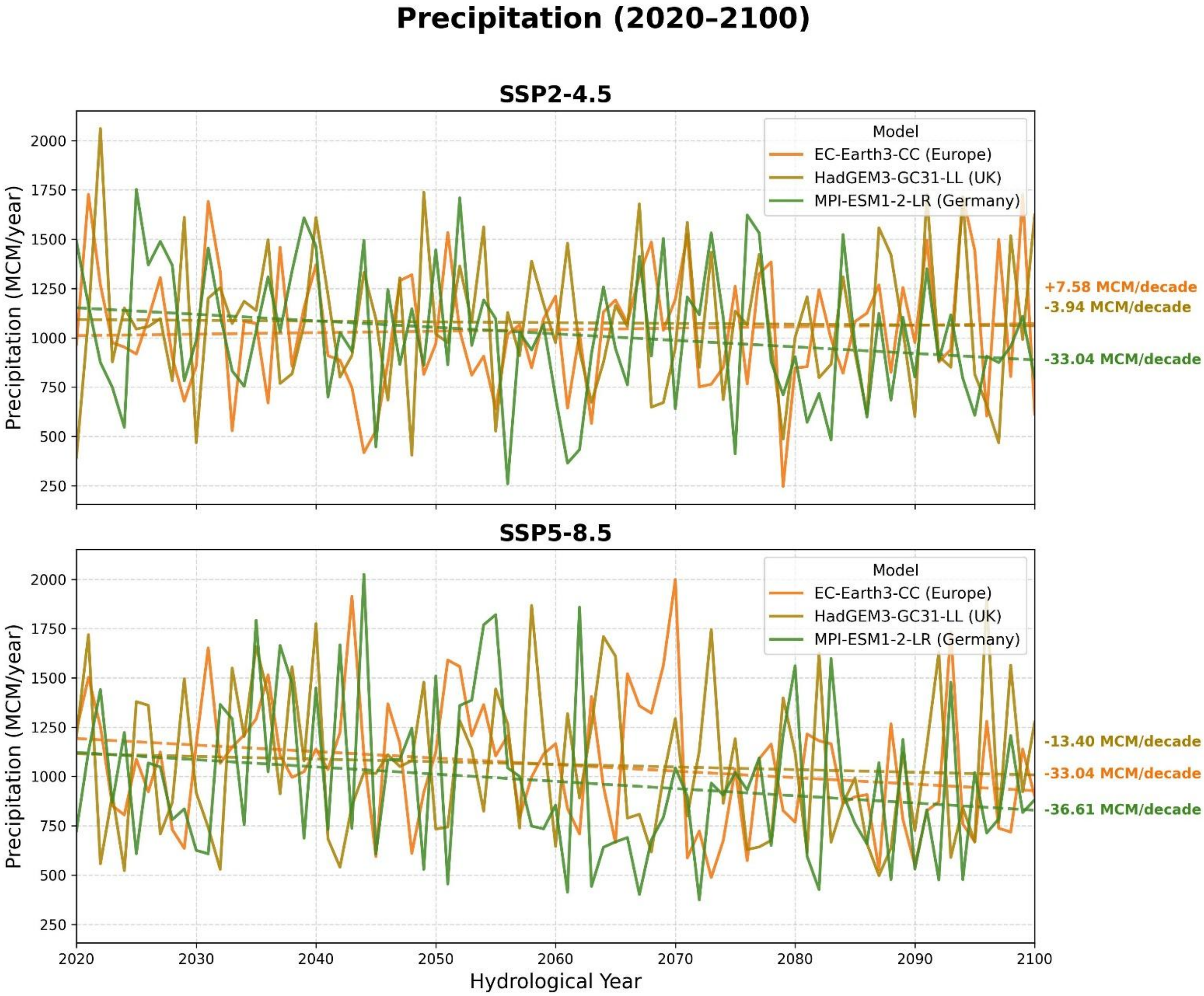

Figure 5. Projected annual precipitation under SSP2-4.5 and SSP5-8.5 scenarios for three climate models (2020–2100).

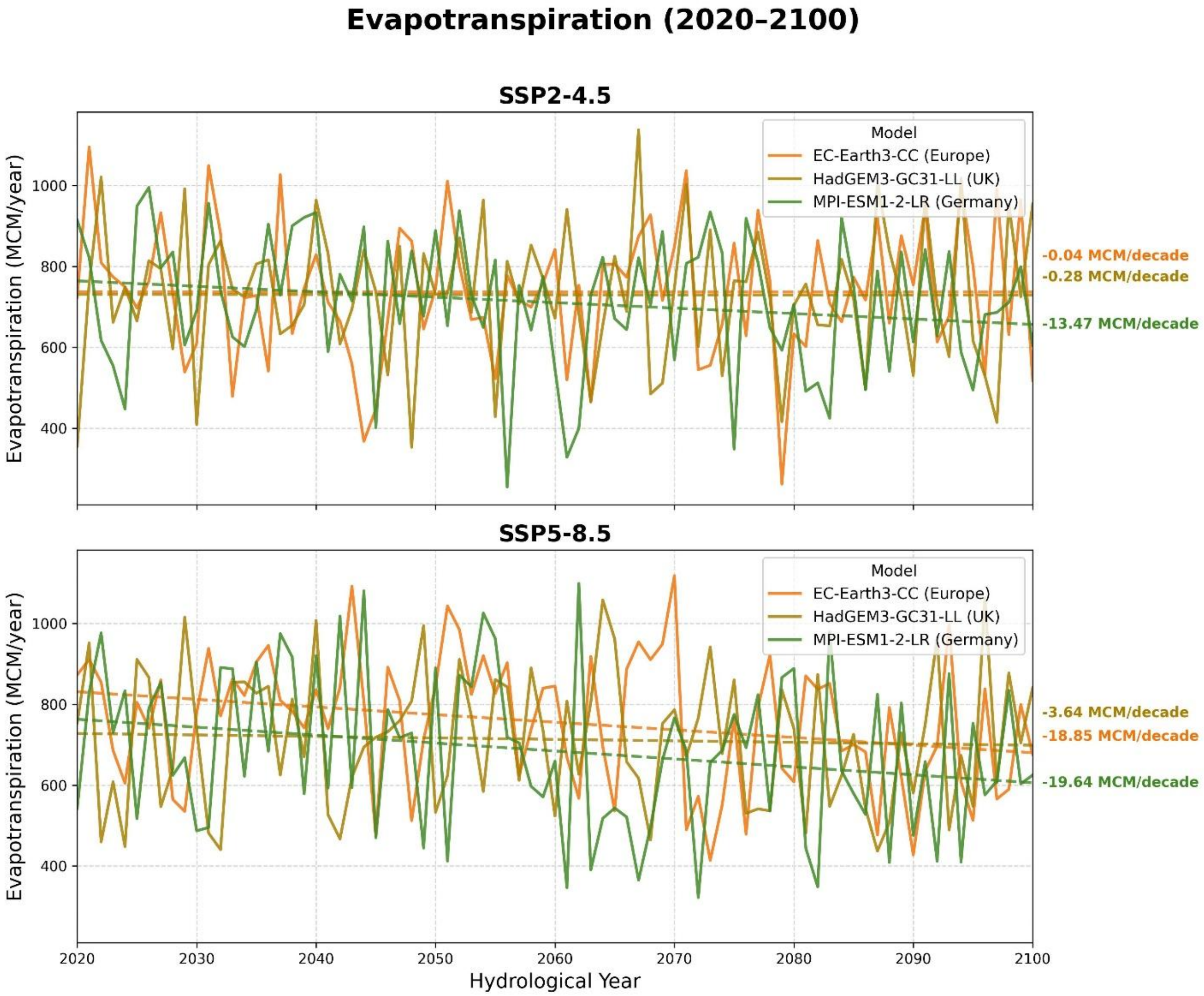

Figure 6. Evapotranspiration trends (2020–2100) under SSP2-4.5 and SSP5-8.5 scenarios for three climate models (2020-2100).

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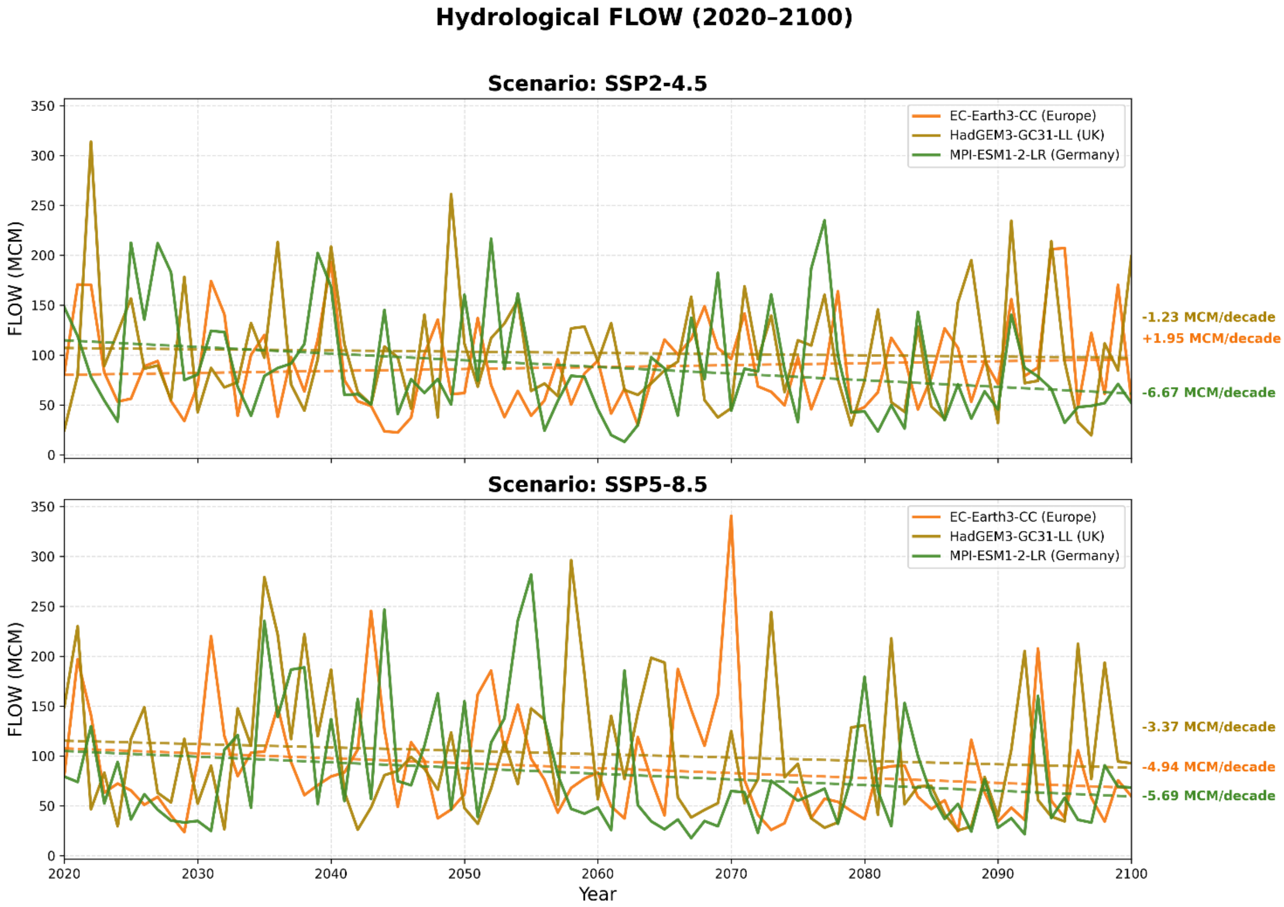

Figure 7. Annual hydrological flow trends (2020–2100) under SSP2-4.5 and SSP5-8.5 scenarios for three climate models(2020-2100).

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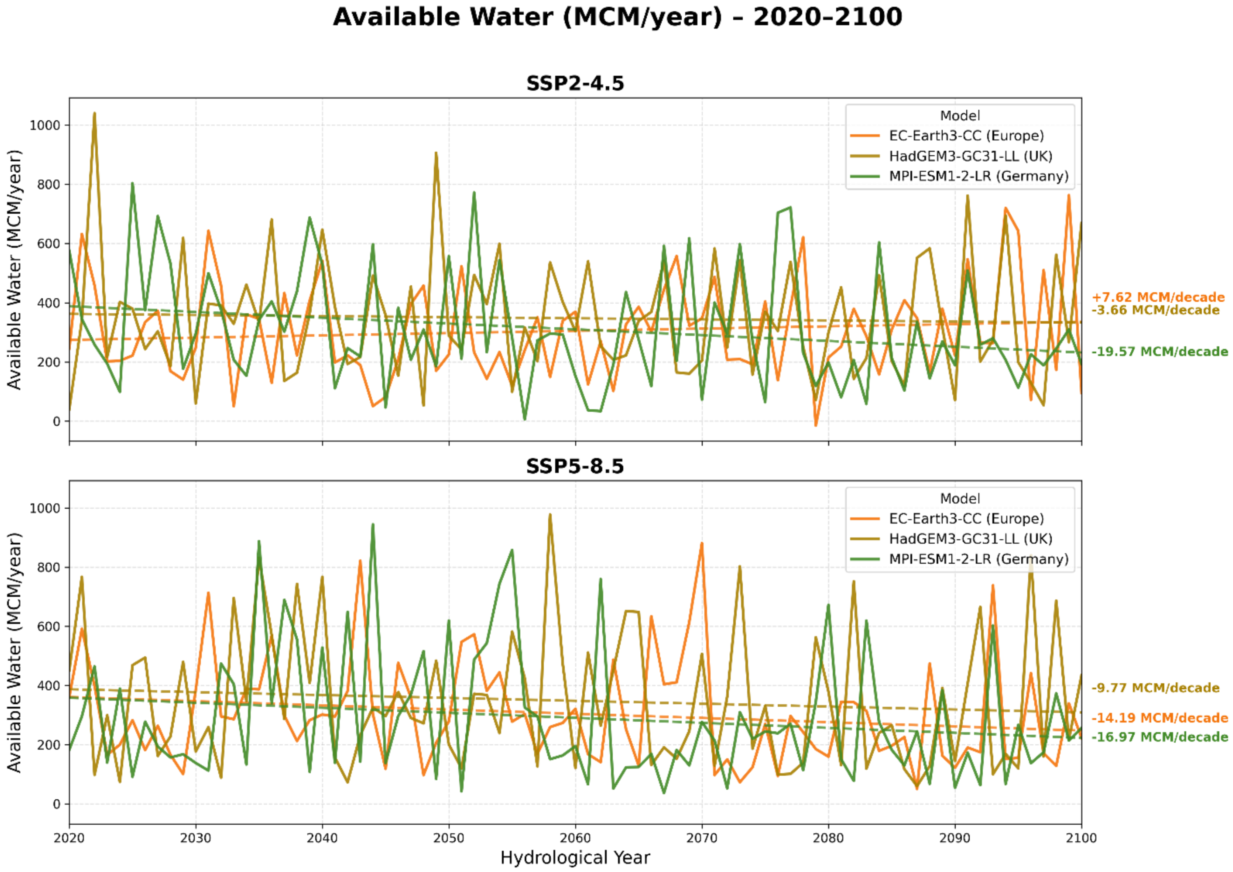

Figure 8. Available water projections (2020–2100) under SSP2-4.5 and SSP5-8.5 scenarios for three climate models(2020-2100).

The analysis of mean annual hydrological components presented in Table 1, Table 2, and Table 3 reveals significant temporal variability in the projected water balance components under both SSP2-4.5 and SSP5-8.5 scenarios for the periods 2020–2060 and 2060–2100. According to Table 1 (EC-Earth3-CC), precipitation and available water show an overall increase towards the end of the century under SSP2-4.5, accompanied by a moderate rise in evapotranspiration and flow. However, under the high-emission SSP5-8.5 pathway, both precipitation and available water decline notably after 2060, indicating heightened water stress despite earlier mid-century increases. A similar pattern is observed in Table 2 (HadGEM3-GC31-LL), where precipitation and flow slightly decrease towards the end of the century, especially under SSP5-8.5, while evapotranspiration remains relatively stable or slightly lower, reflecting a potential reduction in soil moisture availability and runoff. Projections from Table 3 (MPI-ESM1-2-LR) indicate an even more pronounced drying signal, with substantial declines in precipitation, available water, evapotranspiration, and flow under both scenarios — particularly SSP5-8.5 — suggesting a heightened sensitivity of this model to future climate forcing. Collectively, these results highlight that while moderate emissions may support stable or slightly increasing water availability, high-emission trajectories could lead to significant reductions in hydrological resources, posing serious challenges for water management and ecosystem sustainability in the region.

Table 1.Summary of mean annual hydrological components (2020–2060 and 2060–2100) for EC-Earth3-CC (Europe) under SSP2-4.5 and SSP5-8.5 scenarios.

Scenario	Period	Precipitation (MCM/yr)	Available water (MCM/yr)	ET (MCM/yr)	FLOW (MCM/yr)
SSP2-4.5	2020–2060	1014.57	283.31	731.26	82.08
SSP2-4.5	2060–2100	1078.62	331.27	747.36	94.41
SSP5-8.5	2020–2060	1136.54	335.27	801.28	97.56
SSP5-8.5	2060–2100	988	276.29	711.71	78.75

Table 2.Summary of mean annual hydrological components (2020–2060 and 2060–2100) for HadGEM3-GC31-LL (UK) under SSP2-4.5 and SSP5-8.5 scenarios.

Scenario	Period	Precipitation (MCM/yr)	Available water (MCM/yr)	ET (MCM/yr)	FLOW (MCM/yr)
SSP2-4.5	2020–2060	1096.73	362.74	734	106.82
SSP2-4.5	2060–2100	1043.35	323.72	719.63	94.87
SSP5-8.5	2020–2060	1103.47	377.51	725.96	110.95
SSP5-8.5	2060–2100	1014.39	317.34	697.05	92.87

Table 3. Summary of mean annual hydrological components (2020–2060 and 2060–2100) for MPI-ESM1-2-LR (Germany) under SSP2-4.5 and SSP5-8.5 scenarios.

Scenario	Period	Precipitation (MCM/yr)	Available water (MCM/yr)	ET (MCM/yr)	FLOW (MCM/yr)
SSP2-4.5	2020–2060	1094.79	351.2	743.58	101.66
SSP2-4.5	2060–2100	950.88	271.41	679.47	75.23
SSP5-8.5	2020–2060	1100.06	356.23	743.83	104.1
SSP5-8.5	2060–2100	853.02	226.64	626.38	60.62

Table 4 presents the percent decrease of precipitation, available water, ET and river flow for the two scenarios (SSP2-4.5 and SSP2-8.5), for the 3 climate models for the 2020-2060 and 2060-2100 projection periods. The average hydrologic conditions for the period 2000–2020, derived from observed meteorological data, were as follows: average annual precipitation volume 1225 Mm^3/yr, available water 423 Mm^3/yr, ET 719 Mm^3/yr and river flow 104 Mm^3/yr. The variability in the climate change impacts on the hydrologic budget was as follows:

- **For the the SSP2-4.5 scenario -** The precipitation decline for the 2020-2060 period will be between 10-17% from the historical average and for the 2060-2100 the decrease will 12-22%. Most of the decrease of precipitation will happen in the first 40 years of the projection period. This decline in precipitation will cause a 14-61% decline in the available water for the 2020-2060 period and a

23-54% decline in the 2060-2100 period while the ET exhibits small changes and the river flow from 3% increase to 21% decrease in the 2020-2040 period and 9-28% decrease in the 2060-2100.

- **For the the SSP2-8.5 scenario -** The precipitation decline for the 2020-2060 period will be between 7-10% from the historical average and for the 2060-2100 the decrise will 17-30%. Most of the decrease of precipitation will happen in the second 40 years of the projection period. This decline in precipitation will cause a 11-53% decline in the available water for the 2020-2060 period and a 25-46% decline in the 2060-2100 period while the ET exhibits small changes and the river flow from 7% increase to 6% decrease in the 2020-2040 period and 11-42% decrease in the 2060-2100.

Table 4. Percent decrease of precipitation, available water, ET and river flow from the 2000-2020 average hydrologic conditions.

EC-Earth3-CC (Europe)

Scenario	Period	Precipitation (%)	Available water (%)	ET (%)	FLOW (%)
SSP2-4.5	2020–2060	17	61	-2	21
SSP2-4.5	2060–2100	12	54	-4	9
SSP5-8.5	2020–2060	7	53	-11	6
SSP5-8.5	2060–2100	19	35	1	24

HadGEM3-GC31-LL (UK)

Scenario	Period	Precipitation (%)	Available water (%)	ET (%)	FLOW (%)
SSP2-4.5	2020–2060	10	14	-2	-3
SSP2-4.5	2060–2100	15	23	0	9
SSP5-8.5	2020–2060	10	11	-1	-7
SSP5-8.5	2060–2100	17	25	3	11

MPI-ESM1-2-LR (Germany)

Scenario	Period	Precipitation (%)	Available water (%)	ET (%)	FLOW (%)
SSP2-4.5	2020–2060	11	17	-3	2
SSP2-4.5	2060–2100	22	36	5	28
SSP5-8.5	2020–2060	10	16	-3	0
SSP5-8.5	2060–2100	30	46	13	42

The climate change simulation results exhibit a high variability in the projections of the hydrologic conditions in the Jordan Valley. Nevertheless, they all show a further decrease in all the components of the hydrologic budget, resulting in significant decrease of the available water and flow of Jordan River. This situation will exaggerate water scarcity and the impacts from the decline of water level of the Dead Sea.

5. Climate Change Adaptation Measures

The Mediterranean region is considered a “Hot Spot” susceptible to the threat of climate change. Many regions are prone to desertification, reduced water, loss of fertile soil, and degradation of the ecological services provided. In addition, Jordan, the Palestinian Authority, and Israel are in midst of political conflict. The JV faces a complex set of development challenges stemming from chronic water scarcity. In scarce water environments, the most vulnerable and poorest communities suffer the most due to economic and social impacts. Internally displaced people and those living in formal and informal settlements generally lack adequate and reliable access to water and sanitation facilities and services. The situation is aggravated by climatic conditions, geography, and the region's geopolitical environment. Limitations on water place strains on agricultural systems, undermining the capacity to provide food security, and support livelihoods in the region. These challenges demand urgent, coordinated, and practical adaptation measures tailored to the valley’s environmental and socio-political realities.

The PRIMA EcoFuture project places climate adaptation at the center of its strategy. Using the WEFE Nexus approach, the project has identified, tested, and prioritized adaptation measures that can reduce vulnerability, improve resource security, and build resilience across the JV. A detailed analysis of the measures and the Multi-Criteria Decision Analysis (MCDA) methodology for the prioritization is presented in Deliverable D2.3 “Evaluation of WEFE alternatives”. Below the key adaptation measures arisen from this methodology are presented:

Key Adaptation Measures

1. Water Security and Efficiency

Water scarcity is the JV’s most critical challenge, worsened by climate-driven declines in rainfall. Adaptation measures focus on reducing losses, increasing efficiency, and diversifying sources:

- Rainwater harvesting (W3.1): Large-scale collection from plastic greenhouses could yield more than 7 million m^3 annually, while mitigating salinization and improving soil quality.
- Smart irrigation systems (W2.2): Mobile applications and soil moisture sensors (W2.1) enable irrigation based on plant needs, reducing water use by up to 50%, as demonstrated in pilot projects.
- Infrastructure repair (W1.1): Technology-driven monitoring prevents significant water losses in networks.
- Reuse of treated wastewater: Decentralized treatment units, tested in the West Bank, expand irrigation sources and alleviate deficits despite political and infrastructure constraints.
- Groundwater desalination (W4.1): Solar-powered reverse osmosis can improve both water and soil quality by reducing salinity.

2. Soil Restoration and Fertility

Degraded soils are a major barrier to adaptation. Measures emphasize regeneration, carbon enrichment, and reduced dependency on chemical inputs:

- Organic fertilizer production (E3.2): Compost and biomass residues improve soil fertility, reduce costs, and close nutrient loops.
- Carbon addition through compost and manure: Jordanian pilot trials raised tomato yields by 35% (from 6.5 to 8.8 tons/dunum).
- Terrace construction and maintenance (Ec5.1): Reduces erosion, retains soil moisture, and stabilizes landscapes.
- Circular economy fertilizer strategy: Recycling manure, biosolids, and organic waste can fully supply the JV’s nutrient demand, reducing reliance on imported fertilizers.

3. Sustainable Agricultural Practices

Adaptation in agriculture requires a paradigm shift toward efficiency, diversification, and resilience:

- Precision agriculture (H1.4): Data-driven practices optimize inputs and minimize losses.
- Permaculture and agroforestry (F1.2): Integrates trees with crops, improving soil health, diversifying income, and sequestering carbon.
- Agrivoltaics (E1.2): Co-locating solar panels with agriculture provides renewable energy, shade, and additional farmer income.
- Professional training of farmers and breeders (H1.1): Strengthens capacity to adopt new technologies and practices.

4. Bundled Interventions

To maximize climate adaptation, interventions are most effective when bundled. Rather than implementing individual solutions in isolation, bundling can help enhance feasibility, address technical or institutional weaknesses, align with policy and funding mechanisms, and generate cross-sectoral synergies. Several measures that ranked highly in some criteria in the MCDA analysis but performed moderately in others can benefit from strategic bundling with complementary interventions.

- The combination of smart irrigation, rainwater harvesting and soil moisture monitoring create a comprehensive water efficiency package.
- The combination of agroforestry, organic fertilizer, agrivoltaics and training deliver multi-benefit resilience strategies, linking food security with renewable energy and soil restoration.

Overall, the implementation of the participatory MCDA process, facilitated through the TLL, was a core strength of the EcoFuture project. The TLL successfully engaged a wide range of Jordanian and Palestinian stakeholders (policy makers, scientists and farmers) creating a shared space for learning, deliberation, and co-design. This participatory approach enhanced transparency, promoted cross-sectoral dialogue, and ensured that the selected measures reflect local knowledge, values, and practical experience. The MCDA process also strengthened ownership over the resulting strategies and fostered a stronger foundation for cross-border collaboration. Given these benefits, it is recommended that participatory MCDA be institutionalized in national and regional planning frameworks, especially where resource conflicts, climate vulnerabilities, and development trade-offs intersect.

Demonstrated Adaptation Benefits

EcoFuture pilots clearly illustrate the climate adaptation potential of the recommended measures:

EcoFuture pilot demonstrations in Jordan and Palestine have shown the efficacy of these solutions. Water harvesting from greenhouses has shown to be an affordable and highly effective solution to provide agriculture with good quality irrigation water since there are 75000 plastic houses in the JV and collectively can harvest over 7 million m3 of water per year. Additional benefit of harvested rainwater is soil quality improvement of salinization. On the other hand, the results from the EcoFuture Jordanian pilot have demonstrated that smart irrigation based on the need of the plants reduces irrigation rates by at least 50%. Greenhouse grown tomato experiments have shown irrigation needs of 300 m3/dunum which is less than half the average irrigation rates of 640 m3/dunum applied in the JV.

The quality of groundwater can be improved using reverse osmosis technologies with solar energy to cover energy needs. RO treated groundwater improves also the quality of the soil by reducing its salinity. On the other hand, carbon addition in the form of compost and manure improves soil fertility and increases plant productivity. The Jordanian pilot of EcoFuture project has shown increases in tomato production from 6.5 tons/dunum in the control treatment compared to greenhouses where organic matter was added and produced up to 8.8 tons per dunum.

The Jordanian pilot is an exemplary case study demonstrating the optimization of the WEFE Nexus in a way that improves the socio-economic conditions of the farmers. Similarly, the EcoFuture Palestinian pilot has focused on demonstrating the need to increase the reuse of wastewater for irrigation by overcoming the geopolitical difficulties even during the on-going regional conflict. Compact and scalable treatment units can provide irrigation water for agriculture, increasing the limited available water and thus reducing the water deficit in the West Bank.

The proposed interventions are also based on the premises of circular economy. EcoFuture studies have shown that recycling of organic residues (livestock excreta/manure, biosolids from wastewater treatment plants, composting of the organic fraction of municipal solid wastes and olive mill wastewater) has the potential to cover the C, N, P, K demand of the two territories of the JV. In other words, the valley can be fertilized by using only the manure produced by its livestock, eliminating the reliance to imported fertilizers. Of course, this will require significant changes in livestock farming which in combination with regenerative agricultural practices can improve the financial viability of the farmers.

To maintain the relevance and responsiveness of strategic planning over time, investment in data systems, monitoring infrastructure, and adaptive evaluation mechanisms is essential. Reliable and up-to-date local data are critical for accurately assessing performance, detecting emerging risks, and refining implementation pathways. Periodic re-evaluation of prioritized measures using updated criteria and stakeholder inputs will support iterative learning and enable more agile responses to climate, economic, and political changes.

The implementation of the new agricultural paradigm requires the governments of the two nations to spearhead initiatives with extensive farmer training and capacity building in order to overcome the legislative, technological and financial barriers and inertia for change from the current agricultural practices. The new sustainable agricultural paradigm can be used as a marketing tool to access new markets and showcase how JV can be revitalized for the generations to come.

The socio-economic benefits of the new agricultural paradigm are:

- Reduced costs & higher yields: Smart irrigation cuts water use by up to 50%; improved soil fertility raised tomato yields by 35% in pilots.
- New water sources: Rainwater harvesting from greenhouses could supply 7 million m^3/year.
- Reduced dependency on imports: Recycling organic residues can meet the Valley’s fertilizer needs locally.
- Improved farmer livelihoods: Diversified income streams (e.g., reuse of wastewater, agroforestry, agrivoltaics) reduce risk and create new markets.
- Peacebuilding potential: Cross-border cooperation on water, food, and energy fosters resilience and stability.

Looking ahead, the successful implementation of this strategic plan will depend on sustained political commitment, cross-border collaboration, and the development of adaptive governance frameworks capable of responding to emerging risks and opportunities.

The EcoFuture strategy positions climate change adaptation measures as the basis of JV development. Looking forward, four urgent actions are required:

first, to formally adopt the new agricultural paradigm at the highest levels of government, embedding principles of regeneration, circularity, and sustainability at the core of policy; second, to pursue legislative and institutional reforms that reflect this shift and align investment frameworks accordingly; third, to launch coordinated capacity-building efforts that extend beyond farmers to include government officials, extension services, and private-sector actors; and finally, to establish “lighthouse” initiatives, i.e. demonstration hubs that serve as centres for ongoing farmer training, technical assistance, and peer learning. These actions will help operationalize the proposed paradigm, enabling the Jordan Valley to serve not only for combating desertification but also as a regional model for integrated, climate-adaptive development.

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Annex

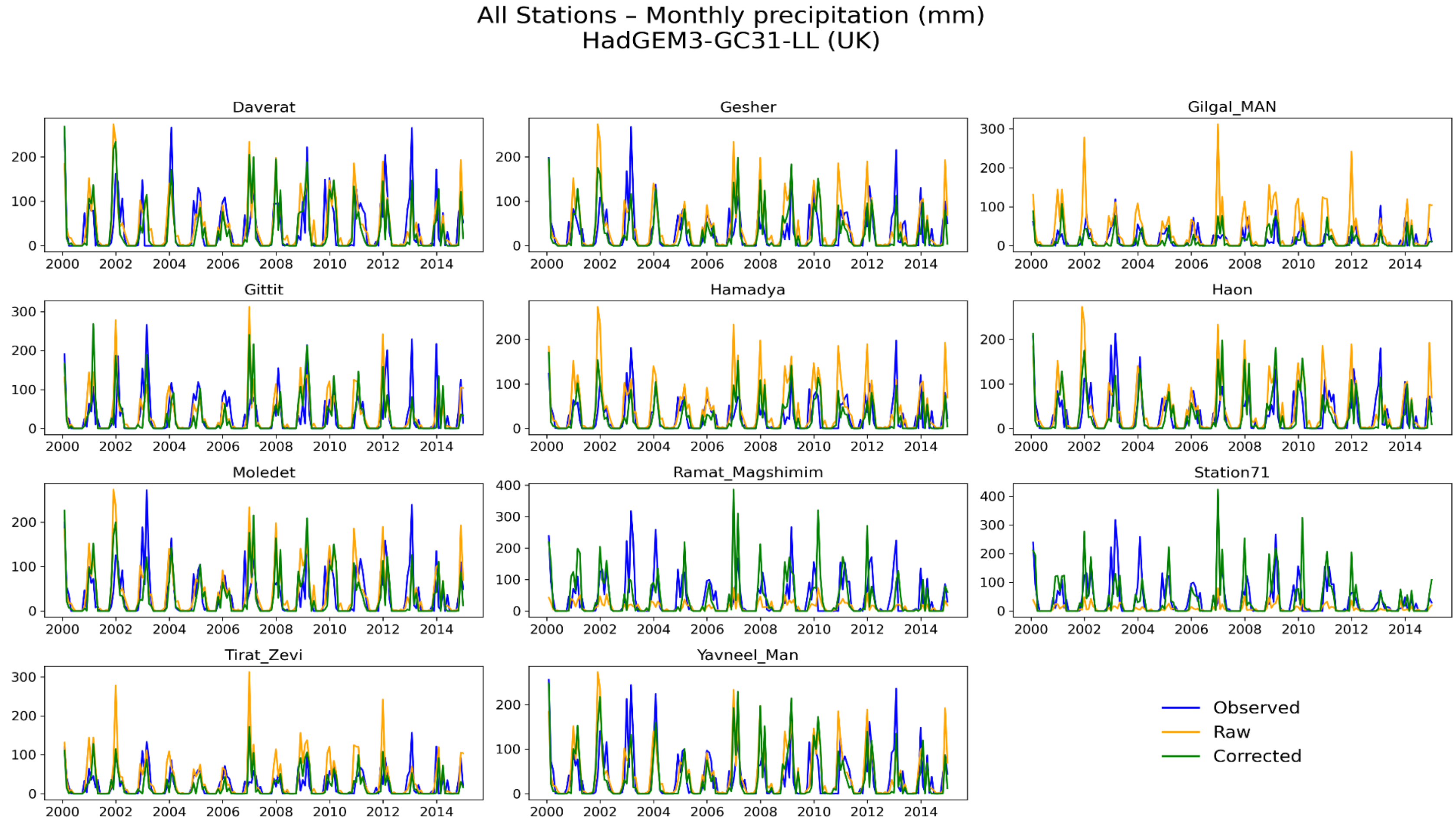

Figure A 1. Model–observation comparison of monthly precipitation (mm) for the historical period 2000–2014 at stations with available records, using the HadGEM3-GC31-LL (UK) climate model

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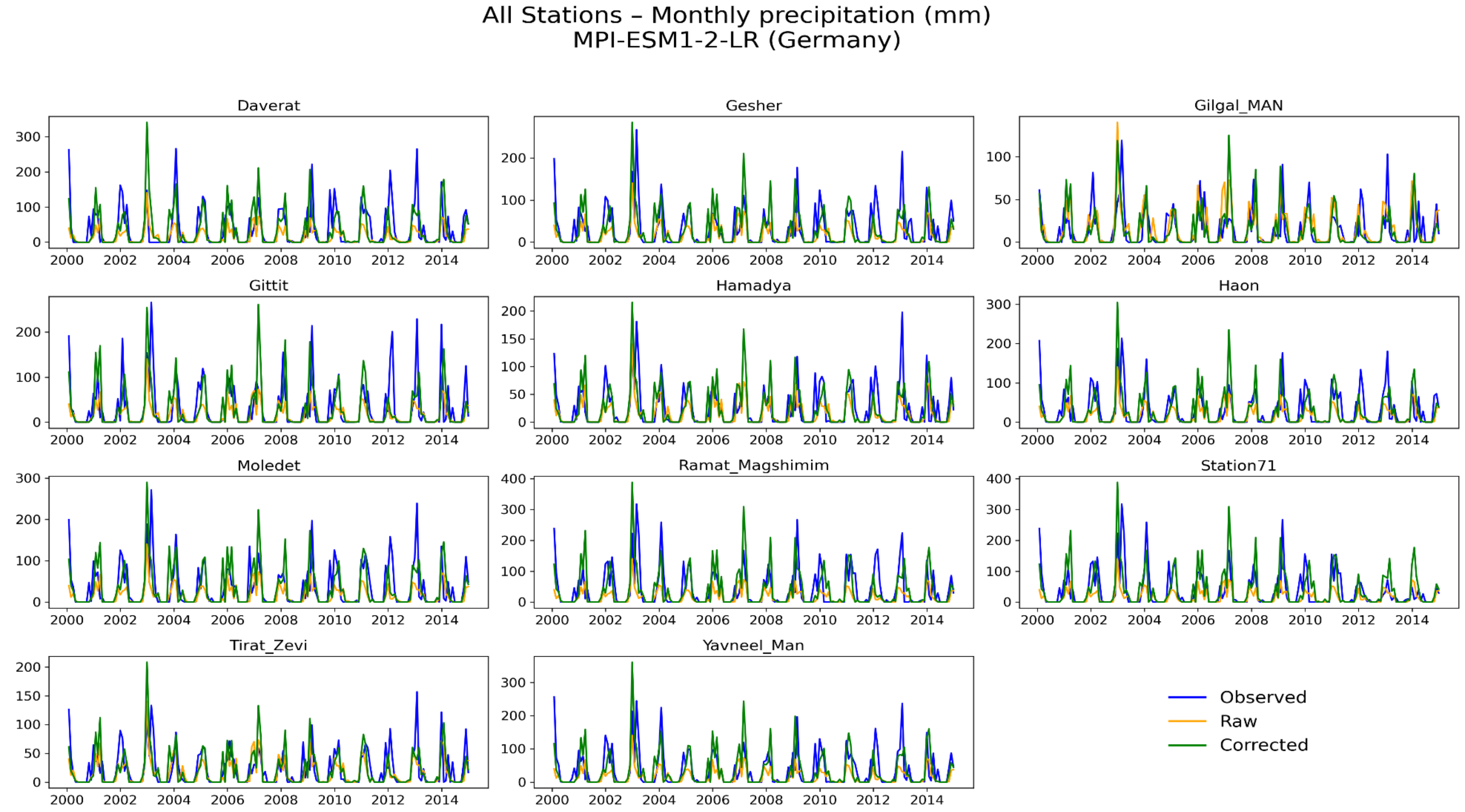

Figure A 2. Model–observation comparison of monthly precipitation (mm) for the historical period 2000–2014 at stations with available records, using the MPI-ESM1-2-LR (Germany) climate model

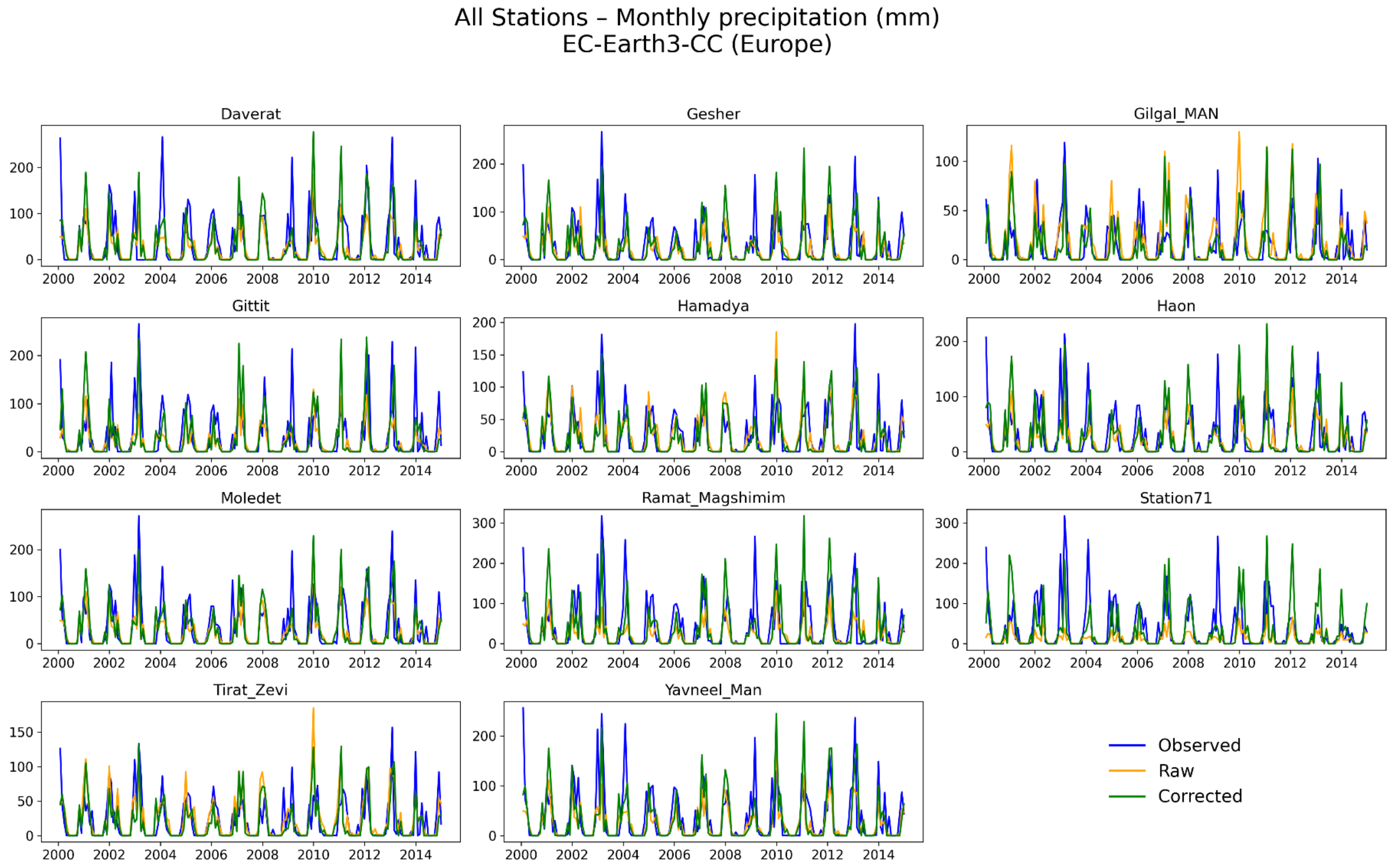

Figure A 3. Model–observation comparison of monthly precipitation (mm) for the historical period 2000–2014 at stations with available records, using EC-Earth3-CC (Europe) climate model

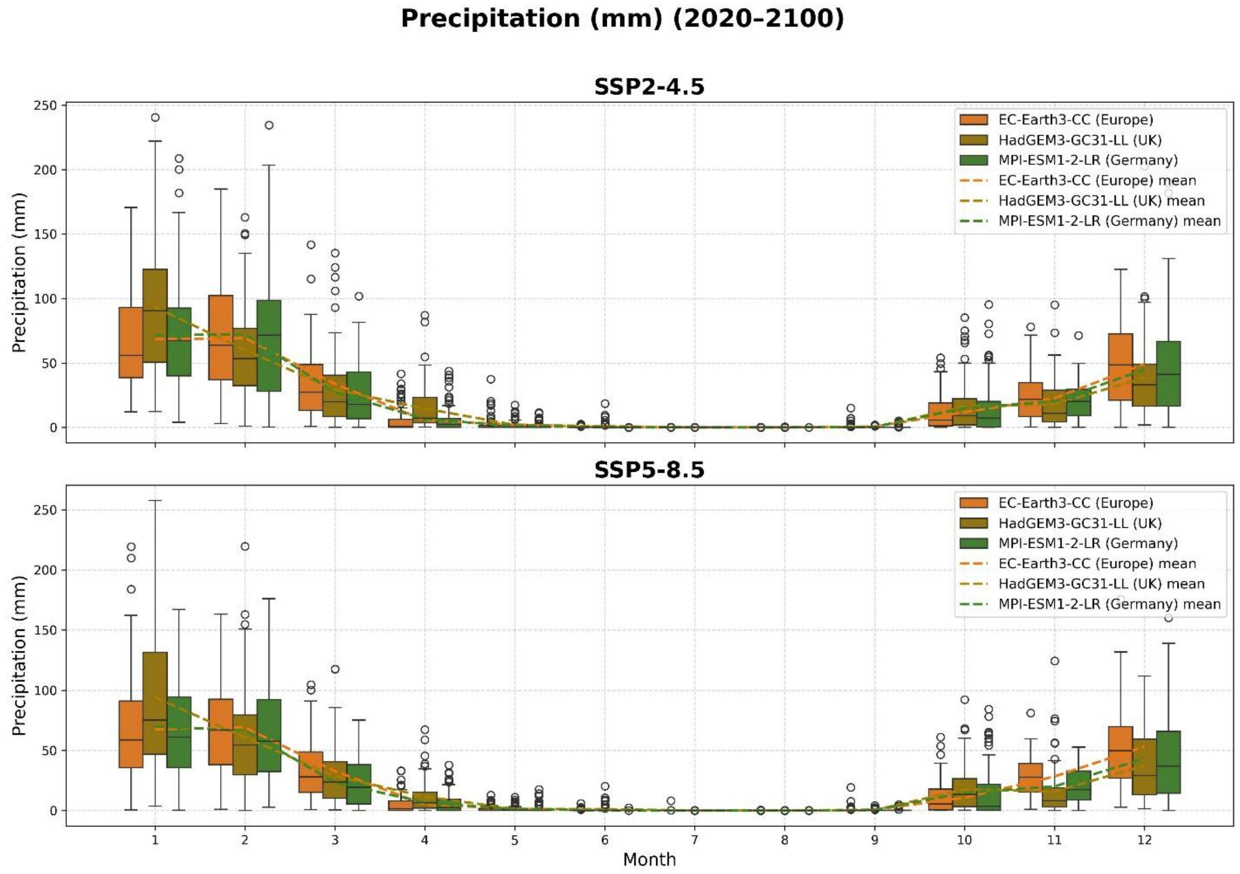

Figure A 4.Monthly precipitation distribution (2020–2100) under SSP2-4.5 and SSP5-8.5 scenarios from three climate models.

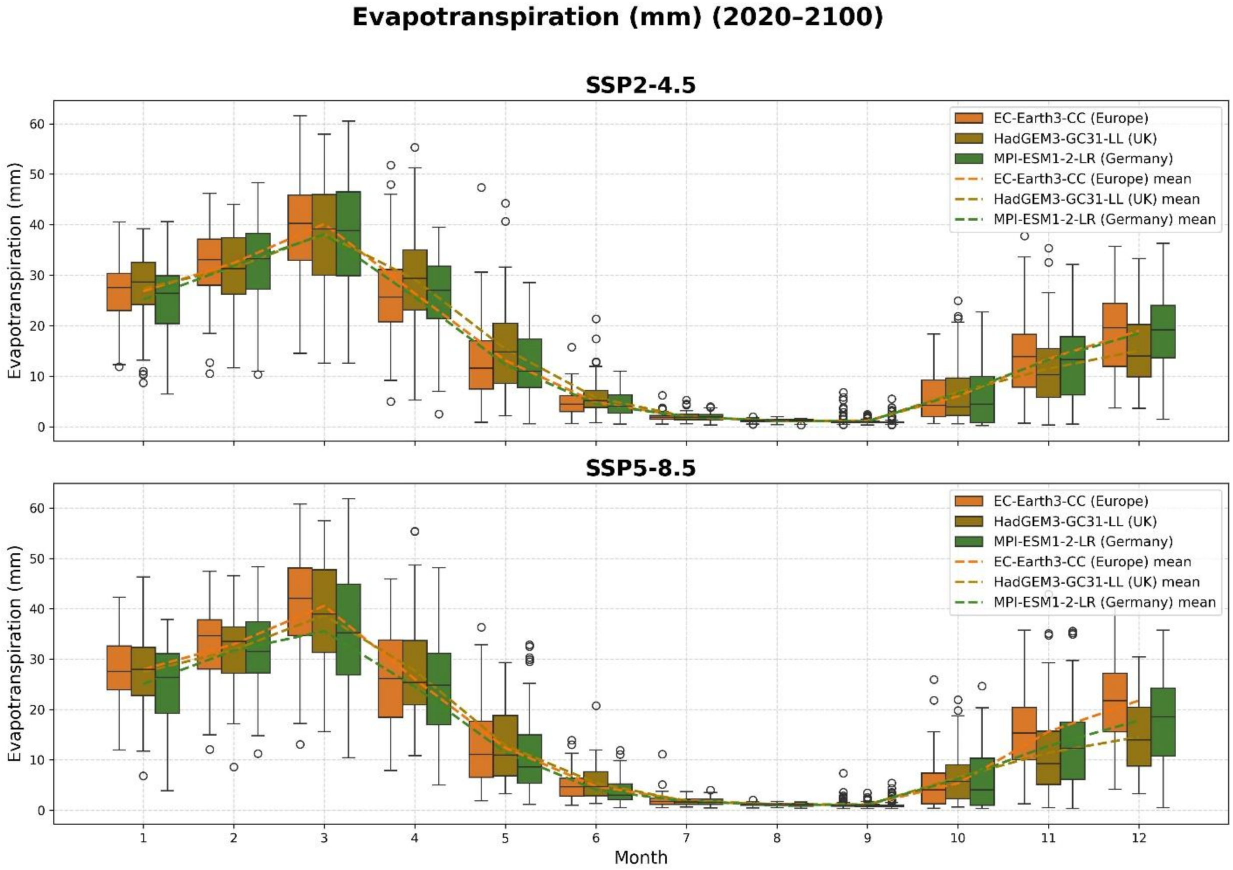

Figure A 5.Monthly evapotranspiration distribution (2020–2100) under SSP2-4.5 and SSP5-8.5 scenarios from three climate

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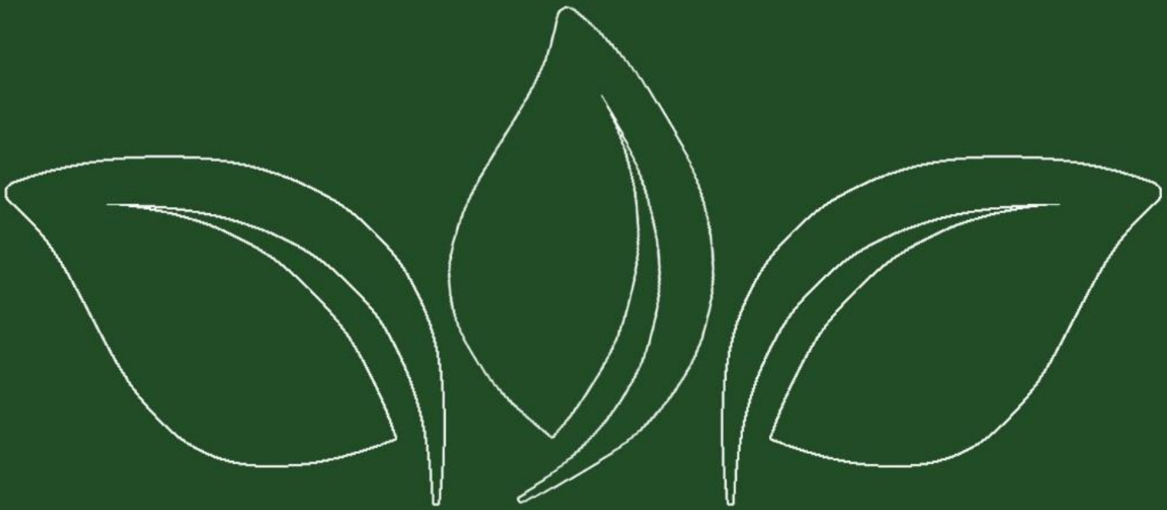
Project Coordinator

Project Partners



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