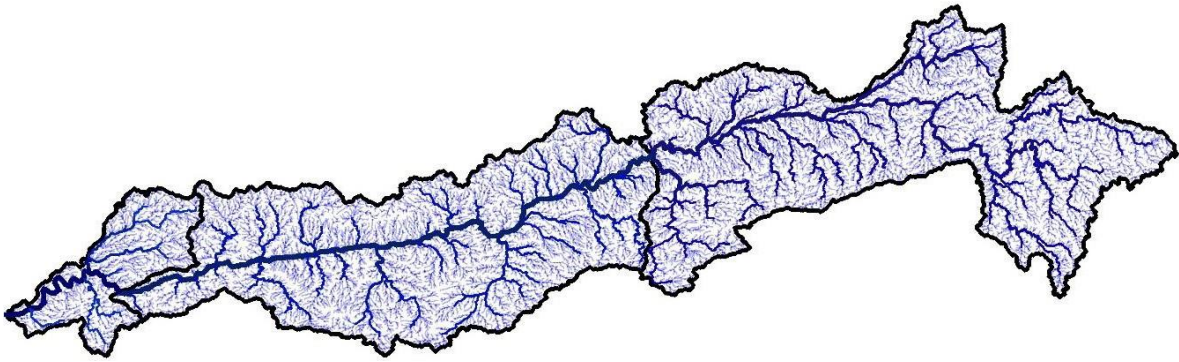




National River Conservation Directorate
Ministry of Jal Shakti, Department of Water
Resources,
River Development & Ganga Rejuvenation
Government of India

Climate Change Assessment Report



December 2025



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Narmada River Basin Climate Change Assessment Report



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National River Conservation Directorate (NRCD)

The National River Conservation Directorate, functioning under the Department of Water Resources, River Development & Ganga Rejuvenation, and the Ministry of Jal Shakti, provides financial assistance to the State Government for the conservation of rivers under the Centrally Sponsored Schemes of ‘National River Conservation Plan (NRCP)’. National River Conservation Plan to the State Governments/ local bodies to set up infrastructure for pollution abatement of rivers in identified polluted river stretches based on proposals received from the State Governments/ local bodies. (www.nrcd.nic.in)

Centers for Narmada River Basin Management Studies (cNarmada)

The Centres for Narmada River Basin Management Studies (cNarmada) is a Brain Trust dedicated to River Science and River Basin Management. Established in 2024 by IIT Gandhinagar and IIT Indore, under the supervision of cGanga at IIT Kanpur, the center serves as a knowledge wing of the National River Conservation Directorate (NRCD). cNarmada is committed to restoring and conserving the Narmada River and its resources through the collation of information and knowledge, research and development, planning, monitoring, education, advocacy, and stakeholder engagement. (www.cnarmada.org)

Center for Ganga River Basin Management and Studies (cGanga)

cGanga is a think tank formed under the aegis of NMCG, and one of its stated objectives is to make India a world leader in river and water science. The Centre is headquartered at IIT Kanpur and has representation from most leading science and technological institutes of the country. cGanga’s mandate is to serve as a think-tank in the implementation and dynamic evolution of the Ganga River Basin Management Plan (GRBMP) prepared by the Consortium of 7 IITs. In addition to this, it is also responsible for introducing new technologies, innovations, and solutions into India. (www.cganga.org)

Acknowledgments

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Disclaimer

This report is a preliminary version prepared as part of the ongoing Condition Assessment and Management Plan (CAMP) project. The analyses, interpretations and data presented in the report are subject to further validation and revision. Certain datasets or assessments may contain provisional or incomplete information, which will be updated and refined in the final version of the report after comprehensive review and verification.

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PREFACE

The Narmada River, often referred to as the lifeline of central and western India, holds unparalleled significance for the region's water resources, ecosystems, and communities. Its hydrological complexity, combined with its ecological and cultural heritage, underscores the critical need for its preservation and sustainable management.

This report, provides a basin-wide climate-socioeconomic analysis of water consumption and withdrawal in the Narmada River Basin. Based on gridded model results and scenario integration, it analyses projections for different sectors (irrigated agriculture, domestic, electricity, livestock, manufacturing and mining) over alternative futures (SSP scenarios). The aim is to convert model results into useful knowledge for basin decision-makers such as to highlight areas of water stress, to point to sectors that will shape future demand, and to offer a clear foundation for informed monitoring and adaptation.

The findings and recommendations presented in this report are intended to serve as a guiding framework for policymakers, researchers, and practitioners committed to sustainable water management in the Narmada Basin.

We are deeply grateful to all individuals, organizations, and institutions that contributed to the preparation of this report. Their dedication, expertise, and support have been instrumental in shaping this study. It is our hope that this report will inspire collaborative efforts and meaningful action toward the long-term health and sustainability of the Narmada River and its Basin.

Centre for Narmada River Basin Management and Studies (cNarmada)

IIT Gandhinagar, IIT Indore

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Abbreviations & Acronyms

SSP	Shared Socioeconomic Pathway
GCAM	Global Change Analysis Model
Demeter	Demeter Model
Tethys	Tethys Model
Xanthos	Xanthos Model
NWIC	National Water Informatics Centre
NRCD	National River Conservation Directorate

1. Introduction

The Narmada River Basin extends from 21°40'12" to 23°41'24" N latitudes and 72°48'36" to 81°45'36" E longitudes, encompassing a total area of 97,560.80 sq. km, which constitutes about 3% of India's total geographical area (3,297,427.32 sq. km). Bounded by the Vindhyan ranges to the north, the Maikala hills to the east, the Satpura ranges to the south, and the Arabian Sea to the west, the basin lies at the northern extremity of the Deccan Plateau and covers significant portions of Madhya Pradesh and Gujarat, with smaller parts extending into Chhattisgarh and Maharashtra. The basin spans 39 districts, comprising 27 districts of Madhya Pradesh, six districts of Gujarat, four districts of Chhattisgarh, and two districts of Maharashtra. The Narmada Basin exhibits an elongated shape, stretching approximately 915.65 km east to west and about 236 km north to south. The basin experiences a tropical monsoon climate characterized by distinct wet and dry seasons, with an average annual rainfall ranging from 800 to 1,200 mm. The Narmada River, the longest west-flowing river in India, drains into the Arabian Sea near Bharuch in Gujarat and is further subdivided into Upper, Middle, and Lower Narmada River basins. The Narmada River Basin has a total population of 20,799,195 and spans several states and districts. The Upper Narmada Basin has a population of 8,603,425, while the Middle Narmada Basin has a population of 9,126,886. There is an uneven distribution of population in various districts of the Narmada Basin.

Apart from this, the Narmada River Basin is a watershed that is geographically and socio-economically diverse and spans across upland catchments, alluvial plains and populated urban areas. This rich diversity produces a widespread array of water uses such as: irrigated agriculture being dominant in fertile plains, rapidly expanding towns and industries concentrating on domestic and industrial withdrawals while energy sector cooling and mining operations imposing sporadic but intensive localized demands. Climate variability and long-term change add complexity to these demands and pressures by altering seasonal runoff, groundwater recharge and irrigation requirements. This report focusses on modeled sectoral water consumption and withdrawal trajectories for the Narmada basin across multiple SSP narratives, disaggregated at sub-basin scale where possible. The analysis emphasizes comparative trends (which sectors grow or shrink under different scenarios) and the principal drivers behind modelled changes (e.g., shifts in irrigated area, yield improvements, urbanization, or energy-system transformation). It is important to note that

the report does not treat model outputs as definitive predictions but as diagnostic tools which highlight vulnerabilities, can inform monitoring priorities and support adaptive, multi-sectoral water strategies.

2. Data and Model Suite

This study uses a global, gridded sectoral water-use dataset (Khan et al., 2023) designed to support long-term assessments of water demand under socioeconomic and climate uncertainty. The dataset provides monthly water withdrawal and consumption estimates at a $0.5^\circ \times 0.5^\circ$ spatial resolution for the period 2010-2100. Water use estimates are generated using an integrated modeling framework that couples multiple global models, each representing a distinct component of the human-water-land system. Sectoral water demands are first simulated within the Global Change Analysis Model (GCAM), which represents future socioeconomic development, energy, land use, and water demand across sectors. GCAM outputs are spatially disaggregated using the Demeter land-use downscaling model, which allocates sectoral demands to gridded land-use patterns consistent with SSP assumptions. Hydrologic constraints and water availability are represented through the Xanthos global hydrologic model, while spatial allocation of sectoral water withdrawals and consumption is performed using the Tethys water use downscaling model. The resulting dataset includes gridded estimates of water withdrawal and consumption for major sectors, including irrigated agriculture, domestic, industrial and manufacturing, electricity generation, livestock, and mining. In this study, the global gridded water use data are aggregated to the Narmada River basin using basin boundaries and grid-cell intersection methods to ensure complete spatial coverage without artificial gaps. Sectoral water use trajectories are analyzed across SSPs to assess how alternative socioeconomic futures influence the magnitude and evolution of basin-scale water demand.

3. Results: Sectoral Water Consumption & Withdrawal

3.1 Water consumption and withdrawal by agricultural crops in the Narmada basin:

3.1.1. Wheat Crops

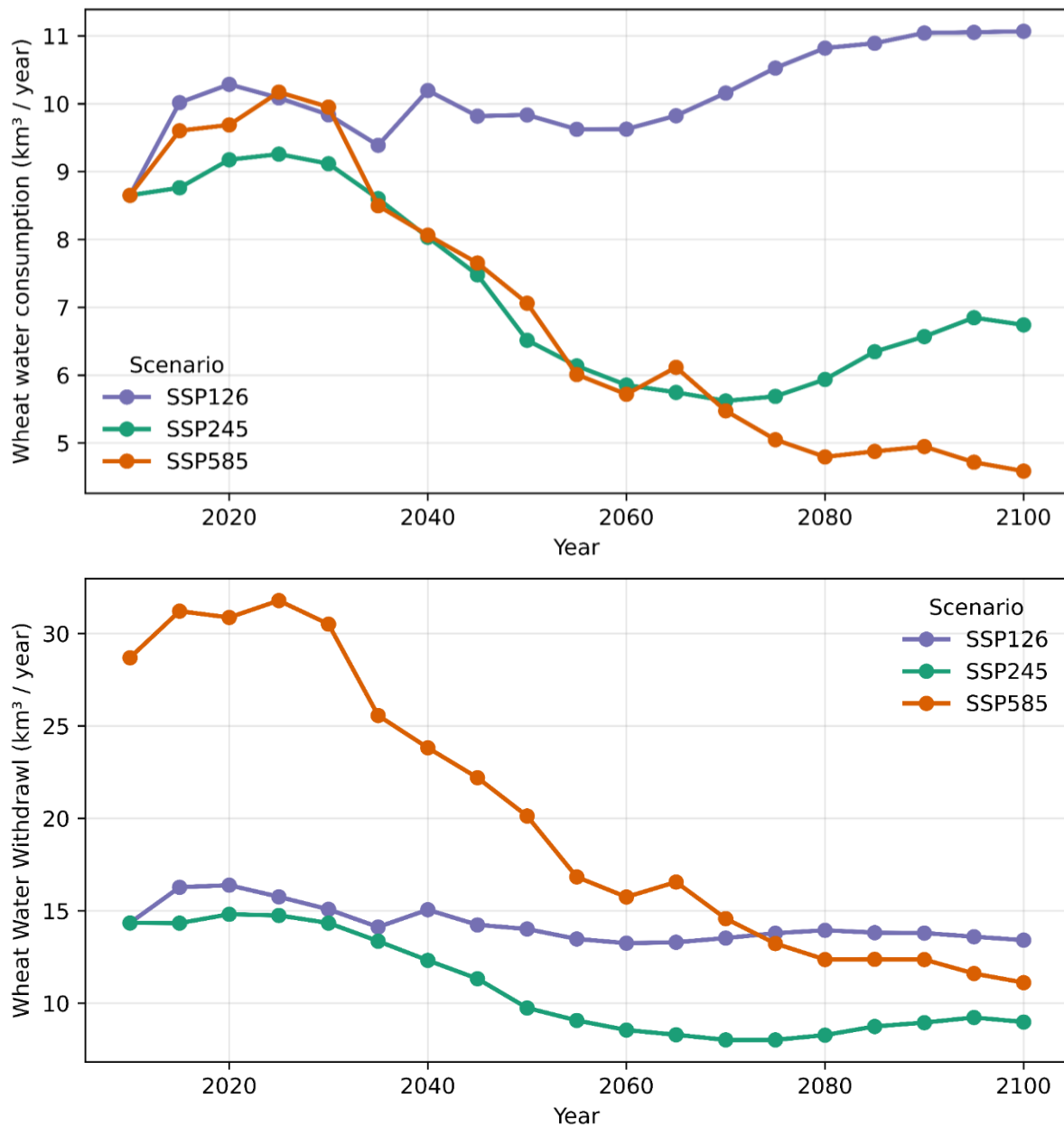


Figure 1 (a) Projected trends in irrigated wheat water consumption and (b) irrigated wheat water withdrawal in the Narmada basin under different socioeconomic pathways (SSP126, SSP245, and SSP585) from 2015 to 2100.

Figure 1 shows the long-term trends in irrigated wheat water consumption and withdrawal in the Narmada basin under three climate-socioeconomic scenarios (SSP126, SSP245, and SSP585) for the period 2015-2100. Figure 1(a) reveals a clear divergence in wheat water consumption across scenarios. Under SSP126, wheat water consumption remains relatively stable, increasing from approximately $8.7 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to about $11.1 \text{ km}^3 \text{ yr}^{-1}$ by 2100 (an increase of $\sim 27\%$), indicating sustained irrigation demand under lower climate stress. In contrast, SSP245 shows a decline in consumption from around $8.7 \text{ km}^3 \text{ yr}^{-1}$ to approximately $6.7 \text{ km}^3 \text{ yr}^{-1}$ by the end of the century (a reduction of $\sim 23\%$). The strongest decline is observed under SSP585, where consumption decreases from about $8.6 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to nearly $4.6 \text{ km}^3 \text{ yr}^{-1}$ by 2100, corresponding to a reduction of roughly 45-50% after the 2030s. A similar but more pronounced pattern is observed for wheat water withdrawal (Figure 1(b)). Under SSP585, withdrawals peak at approximately $32\text{-}33 \text{ km}^3 \text{ yr}^{-1}$ during the early 2020s and then decline sharply to about $11\text{-}12 \text{ km}^3 \text{ yr}^{-1}$ by 2100, representing a reduction of nearly 65%. SSP245 exhibits a more moderate decline, with withdrawals decreasing from around $14.5 \text{ km}^3 \text{ yr}^{-1}$ to approximately $9 \text{ km}^3 \text{ yr}^{-1}$ by the end of the century (a reduction of $\sim 35\text{-}40\%$). In contrast, SSP126 maintains comparatively stable withdrawal levels, decreasing only slightly from about $15\text{-}16 \text{ km}^3 \text{ yr}^{-1}$ to roughly $13\text{-}14 \text{ km}^3 \text{ yr}^{-1}$ over the same period (a reduction of $<15\%$). The stronger decline in withdrawals relative to consumption under SSP245 and SSP585 suggests improvements in irrigation efficiency and/or structural shifts in agricultural practices. Overall, Figure 1 indicates that future wheat irrigation in the Narmada basin is highly sensitive to socioeconomic and climate pathways, with higher-emission scenarios leading to substantial reductions in both water consumption and withdrawal by the end of the century.

3.1.2. Corn Crop

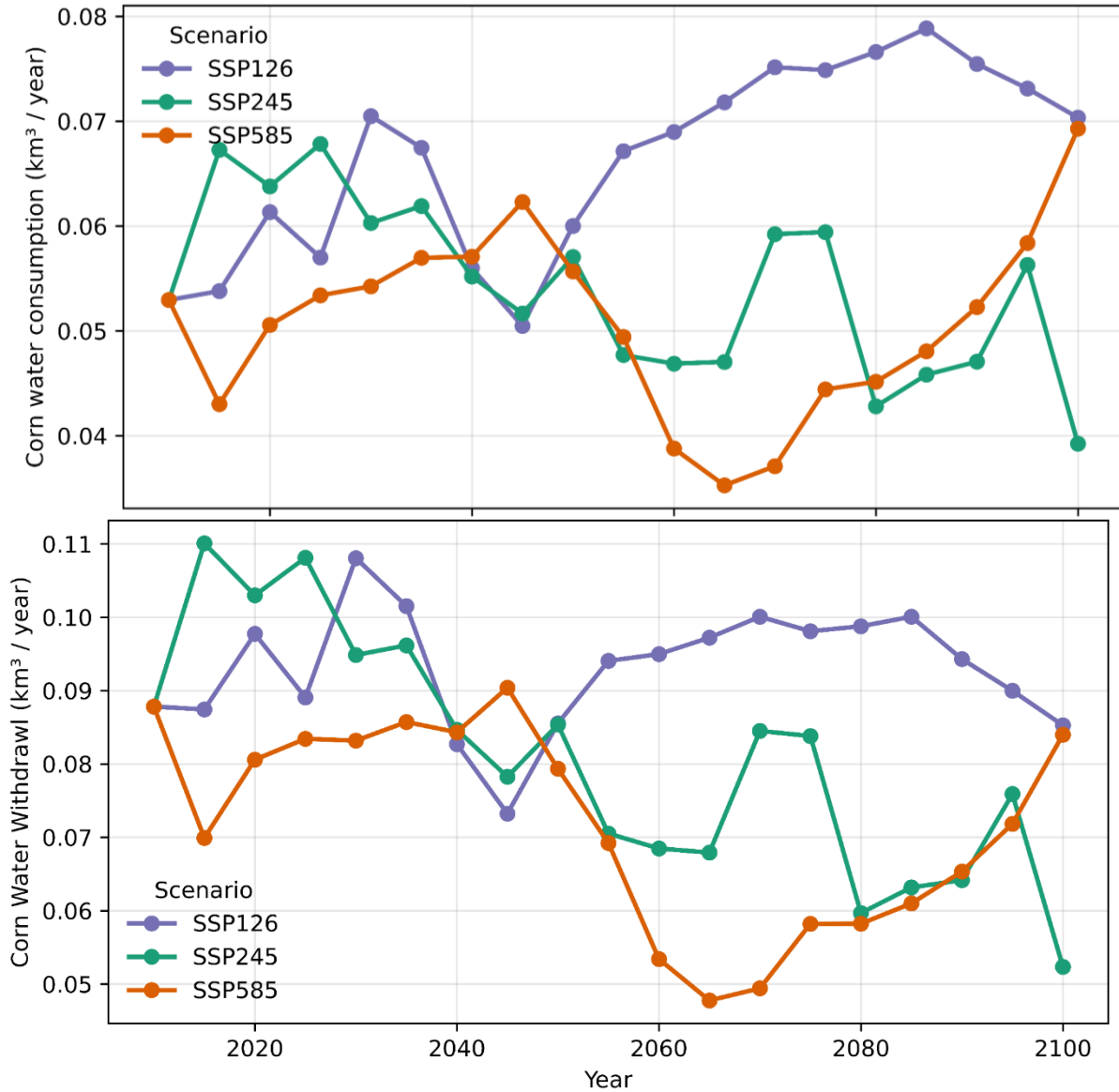


Figure 2. (a) Projected trends in irrigated corn water consumption and (b) irrigated corn water withdrawal in the Narmada basin under different socioeconomic pathways (SSP126, SSP245, and SSP585) from 2015 to 2100.

Figure 2 presents the projected long-term trends in irrigated corn water consumption and withdrawal in the Narmada basin under three climate-socioeconomic scenarios (SSP126, SSP245, and SSP585) for the period 2015-2100. Figure 2(a) shows that corn water consumption exhibits substantial interannual variability across all scenarios, with distinct long-term trajectories emerging over the century. Under SSP126, consumption increases from approximately 0.053 km³

yr⁻¹ in 2015 to about 0.074-0.076 km³ yr⁻¹ by the late 2070s, before slightly declining to around 0.068 km³ yr⁻¹ by 2100, representing an overall increase of roughly 25-30% relative to the initial period. This trend indicates sustained or increasing irrigation demand under lower climate stress. In contrast, SSP245 shows a gradual decline in corn water consumption after the 2030s, decreasing from about 0.065 km³ yr⁻¹ in the early decades to approximately 0.039-0.045 km³ yr⁻¹ by 2100, corresponding to a reduction of roughly 30-40%. The SSP585 scenario exhibits the strongest mid-century decline, with consumption decreasing from around 0.052 km³ yr⁻¹ in 2015 to a minimum of approximately 0.035-0.038 km³ yr⁻¹ during the 2060s (a reduction of nearly 30-35%), followed by a partial recovery to about 0.068-0.070 km³ yr⁻¹ toward the end of the century. Similar but amplified patterns are observed for corn water withdrawal (Figure 2(b)). Under SSP126, withdrawals remain relatively stable, fluctuating between 0.085 and 0.100 km³ yr⁻¹ for most of the century before declining slightly to around 0.085 km³ yr⁻¹ by 2100 (a net reduction of <10%). SSP245 shows a more pronounced decline, with withdrawals decreasing from approximately 0.11 km³ yr⁻¹ in the early 2020s to about 0.053 km³ yr⁻¹ by 2100, representing a reduction of nearly 50%. The SSP585 scenario exhibits the sharpest mid-century reduction, with withdrawals falling from roughly 0.088 km³ yr⁻¹ to a minimum of about 0.048-0.050 km³ yr⁻¹ during the 2060s (a decline of ~40-45%), followed by a gradual increase toward 0.085 km³ yr⁻¹ by 2100. The divergence between consumption and withdrawal trends, particularly under SSP245 and SSP585, suggests improvements in irrigation efficiency, changes in crop management practices, and/or adjustments in cultivated area over time. Overall, Figure 2 indicates that future corn irrigation in the Narmada basin is highly sensitive to socioeconomic and climate pathways, with higher-emission scenarios leading to greater variability and pronounced mid-century reductions in irrigation water use.

3.1.3. Sugarcane Crop

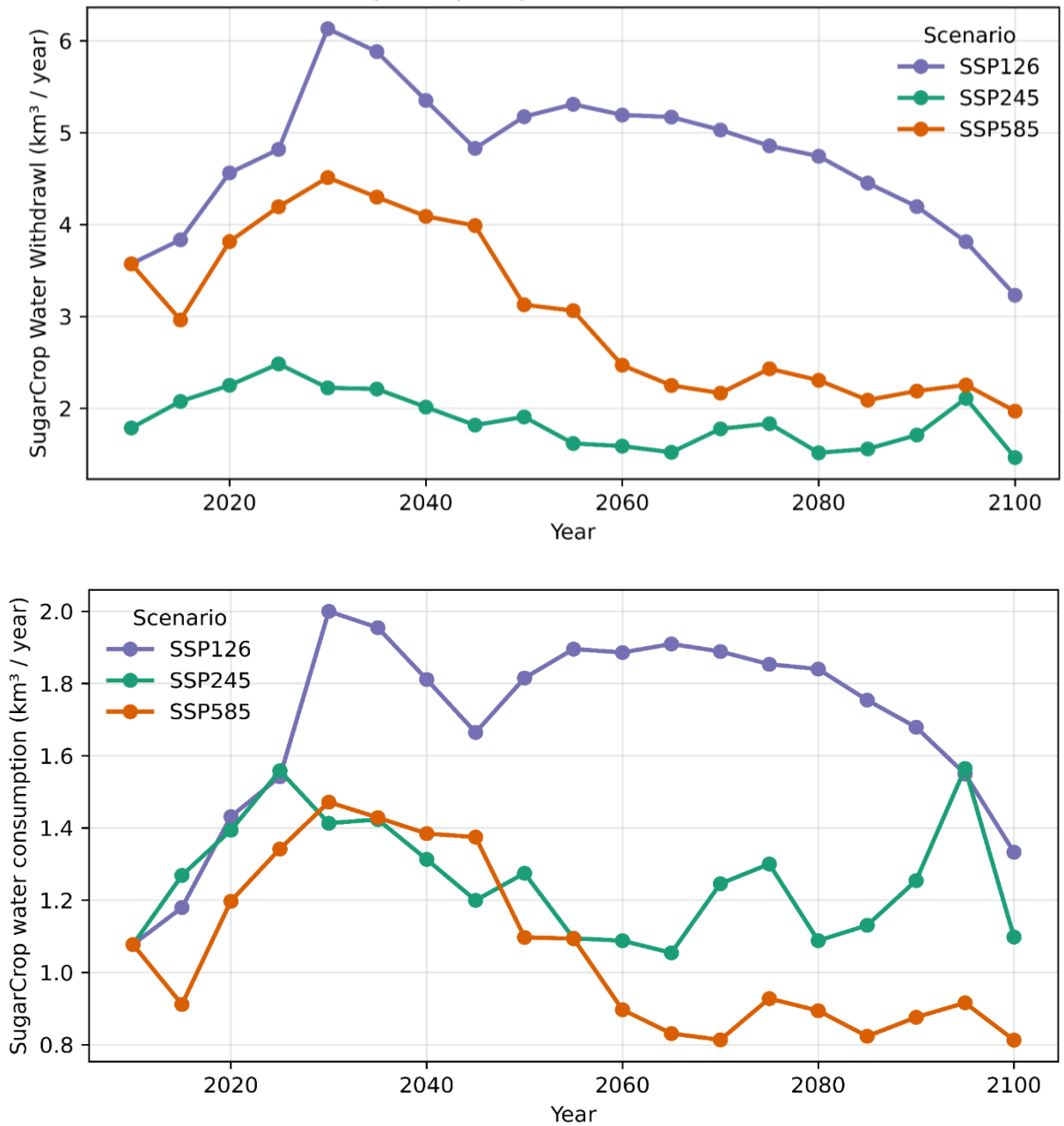


Figure 3 Projected trends in irrigated sugarcane (sugar crop) water consumption and (b) irrigated sugarcane water withdrawal in the Narmada basin under different socioeconomic pathways (SSP126, SSP245, and SSP585) from 2015 to 2100.

Figure 3 shows the long-term evolution of irrigated sugarcane water consumption and withdrawal in the Narmada basin under three climate-socioeconomic scenarios (SSP126, SSP245, and SSP585) over the period 2015-2100. Figure 3(a) shows that sugarcane water consumption is consistently highest under SSP126 throughout most of the century. Under this scenario,

consumption increases from approximately $1.1 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to a peak of about $2.0 \text{ km}^3 \text{ yr}^{-1}$ during the early 2030s, before gradually declining to around $1.3\text{-}1.4 \text{ km}^3 \text{ yr}^{-1}$ by 2100, representing a net increase of roughly 20-25% relative to the initial period. This pattern reflects sustained irrigation demand under lower climate stress conditions. Under SSP245, sugarcane water consumption exhibits moderate interannual variability, increasing from about $1.1 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to approximately $1.5 \text{ km}^3 \text{ yr}^{-1}$ in the early 2020s, followed by a gradual decline after the 2030s. Consumption reaches a minimum of around $1.05 \text{ km}^3 \text{ yr}^{-1}$ during the mid-century period before partially recovering to about $1.1\text{-}1.2 \text{ km}^3 \text{ yr}^{-1}$ toward the end of the century, corresponding to an overall reduction of roughly 10-15%. In contrast, SSP585 shows a pronounced and persistent decline in sugarcane water consumption after mid-century, decreasing from approximately $1.1 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to about $0.8\text{-}0.9 \text{ km}^3 \text{ yr}^{-1}$ by 2100, representing a reduction of nearly 25–30%. Similar trends are observed for sugarcane water withdrawal (Figure 3(b)), though with larger absolute magnitudes. Under SSP126, withdrawals increase from roughly $3.6 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to a maximum of about $6.1 \text{ km}^3 \text{ yr}^{-1}$ in the early 2030s, before steadily declining to approximately $3.2 \text{ km}^3 \text{ yr}^{-1}$ by 2100, corresponding to a reduction of about 45-50% from the peak. SSP245 exhibits lower overall withdrawals, decreasing from around $1.8 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to approximately $1.5 \text{ km}^3 \text{ yr}^{-1}$ by 2100, with moderate interannual variability and a net decline of roughly 15-20%. The SSP585 scenario shows the strongest reduction, with withdrawals declining from approximately $3.5 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to around $2.0 \text{ km}^3 \text{ yr}^{-1}$ by the end of the century, representing a decrease of nearly 40-45% after the 2040s. The sharper decline in withdrawals relative to consumption under SSP245 and SSP585 suggests improvements in irrigation efficiency and/or reductions in irrigated sugarcane area over time. Overall, Figure 3 highlights the high sensitivity of sugarcane irrigation water use in the Narmada basin to socioeconomic and climate pathways, with higher-emission scenarios leading to substantial long-term reductions in both water consumption and withdrawal.

3.1.4. Rice Crop

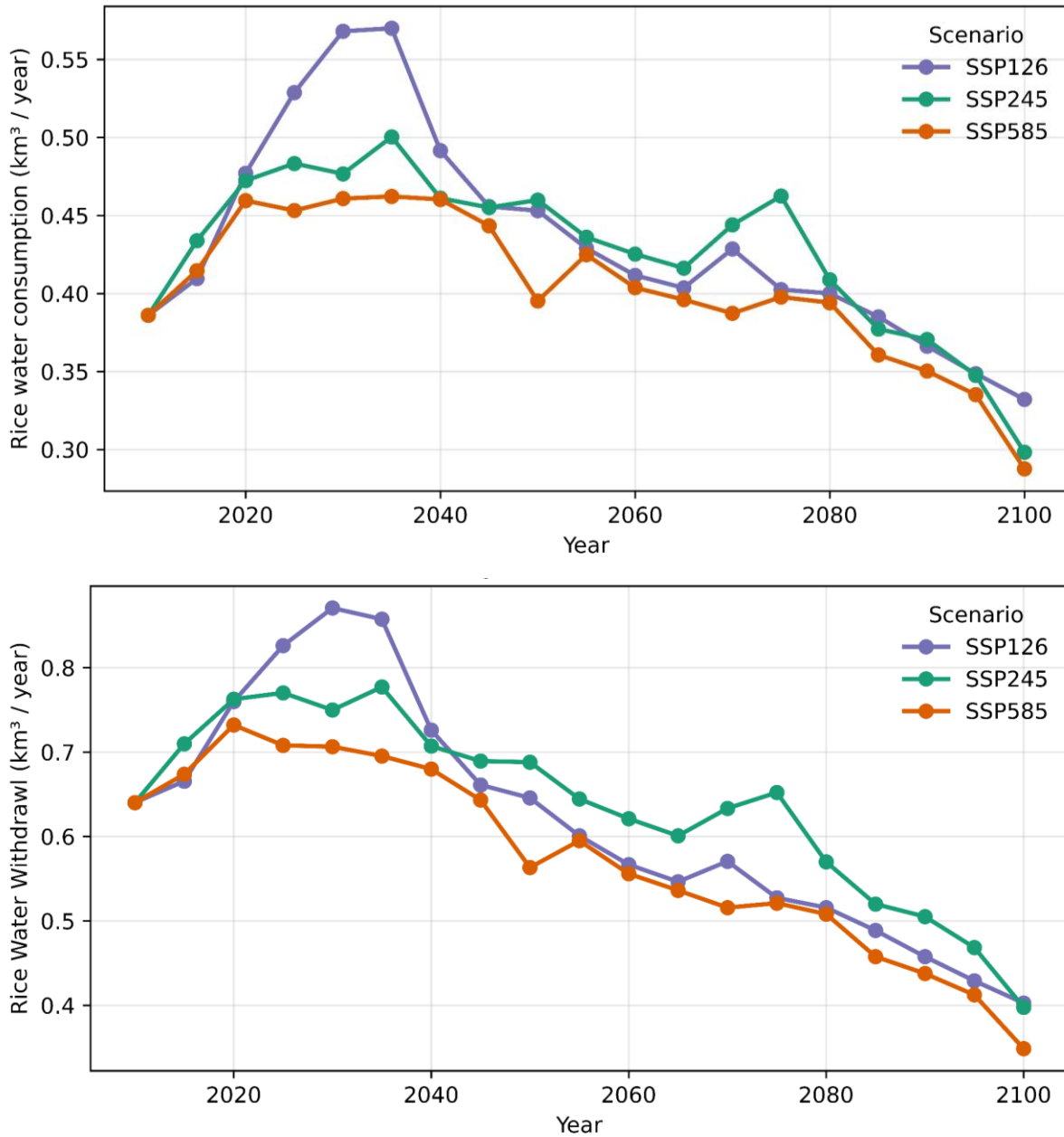


Figure 4 (a) Projected trends in irrigated rice water consumption and (b) irrigated rice water withdrawal in the Narmada basin under different socioeconomic pathways (SSP126, SSP245, and SSP585) from 2015 to 2100.

Figure 4 presents the projected long-term evolution of irrigated rice water consumption and withdrawal in the Narmada basin under three climate–socioeconomic scenarios (SSP126, SSP245, and SSP585) for the period 2015-2100. Figure 4(a) shows that rice water consumption increases across all scenarios during the early decades, peaking around the 2030s, followed by a

gradual decline toward the end of the century. Under SSP126, rice water consumption rises from approximately $0.39 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to a peak of about $0.56\text{-}0.57 \text{ km}^3 \text{ yr}^{-1}$ in the early 2030s, before steadily decreasing to around $0.33\text{-}0.34 \text{ km}^3 \text{ yr}^{-1}$ by 2100, corresponding to an overall decline of roughly 40% from the peak level. SSP245 exhibits a more moderate peak, increasing from about $0.39 \text{ km}^3 \text{ yr}^{-1}$ to approximately $0.49\text{-}0.50 \text{ km}^3 \text{ yr}^{-1}$ during the 2030s, followed by a smoother decline to around $0.30\text{-}0.32 \text{ km}^3 \text{ yr}^{-1}$ by the end of the century (a reduction of $\sim 35\text{-}40\%$ from peak). In contrast, SSP585 consistently shows lower rice water consumption after mid-century, decreasing from approximately $0.39 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to about $0.29\text{-}0.30 \text{ km}^3 \text{ yr}^{-1}$ by 2100, representing a net reduction of roughly 25-30%. Similar declining trends are observed for rice water withdrawal (Figure 4(b)), with withdrawals peaking earlier than consumption and decreasing steadily after the 2030s across all scenarios. Under SSP126, rice water withdrawal increases from approximately $0.64 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to a peak of about $0.86\text{-}0.88 \text{ km}^3 \text{ yr}^{-1}$ in the early 2030s, before declining to around $0.40 \text{ km}^3 \text{ yr}^{-1}$ by 2100, representing a reduction of nearly 55% from the peak. SSP245 shows a more moderate but persistent decline, with withdrawals decreasing from around $0.64 \text{ km}^3 \text{ yr}^{-1}$ to approximately $0.40\text{-}0.42 \text{ km}^3 \text{ yr}^{-1}$ by the end of the century (a reduction of $\sim 35\text{-}40\%$). SSP585 exhibits the strongest reduction, with withdrawals falling from approximately $0.64 \text{ km}^3 \text{ yr}^{-1}$ to about $0.35 \text{ km}^3 \text{ yr}^{-1}$ by 2100, corresponding to a reduction of roughly 45%. The consistent reduction in withdrawals relative to consumption across all scenarios suggests improvements in irrigation efficiency and/or changes in rice cultivation practices over time. Overall, Figure 4 indicates that irrigated rice water use in the Narmada basin is projected to decline substantially over the century, with higher-emission scenarios leading to stronger reductions in both water consumption and withdrawal.

3.2 Water consumption and withdrawal by non-agricultural sectors in the Narmada basin

3.2.1. Domestic Water Consumption

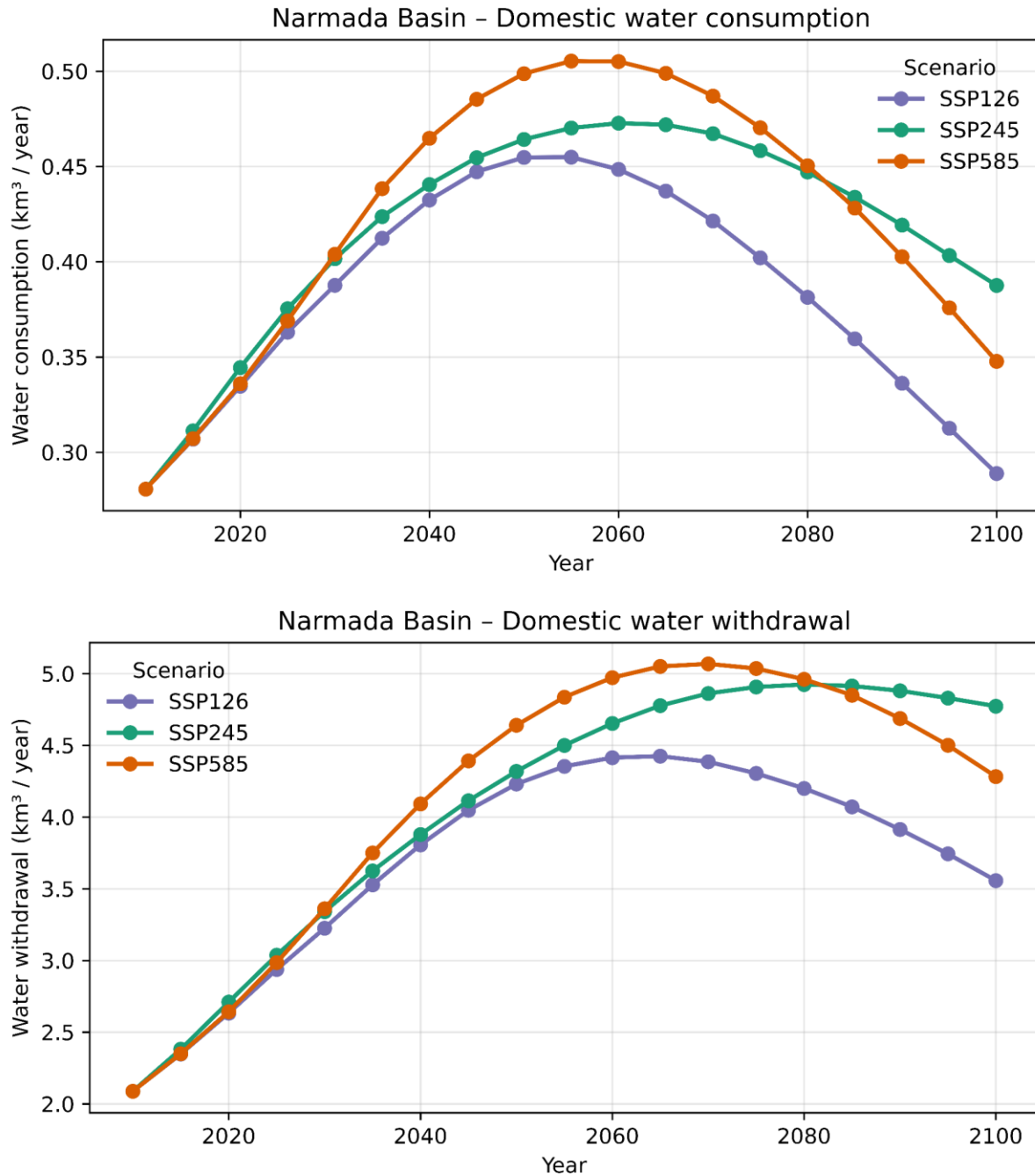


Figure 5 (a) Projected trends in domestic water consumption and (b) domestic water withdrawal in the Narmada basin under different socioeconomic pathways (SSP126, SSP245, and SSP585) from 2015 to 2100.

Figure 5 presents the projected long-term evolution of domestic (non-agricultural) water consumption and withdrawal in the Narmada basin under three climate-socioeconomic scenarios (SSP126, SSP245, and SSP585) for the period 2015-2100. Figure 5(a) shows that domestic water consumption increases steadily across all scenarios during the early to mid-century, reflecting population growth, urban expansion, and rising per-capita water demand. Under SSP126, domestic water consumption rises from approximately $0.28 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to a peak of about $0.45\text{-}0.46 \text{ km}^3 \text{ yr}^{-1}$ around the 2040s-2050s, before gradually declining to roughly $0.29 \text{ km}^3 \text{ yr}^{-1}$ by 2100, representing a reduction of about 35-40% from the peak. Under SSP245, consumption increases from around $0.29 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to approximately $0.47\text{-}0.48 \text{ km}^3 \text{ yr}^{-1}$ by the mid-century period, followed by a modest decline to about $0.39 \text{ km}^3 \text{ yr}^{-1}$ by 2100 (a reduction of ~15-20% from peak levels). In contrast, SSP585 shows the highest domestic water consumption throughout most of the century, increasing from about $0.28 \text{ km}^3 \text{ yr}^{-1}$ to a peak of nearly $0.50\text{-}0.51 \text{ km}^3 \text{ yr}^{-1}$ around the 2050s, before declining to approximately $0.35 \text{ km}^3 \text{ yr}^{-1}$ by the end of the century, corresponding to a reduction of roughly 30% from the peak. A similar temporal pattern is observed for domestic water withdrawal (Figure 5(b)), though with larger absolute magnitudes. Under SSP126, withdrawals increase from approximately $2.1 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to a maximum of about $4.3\text{-}4.4 \text{ km}^3 \text{ yr}^{-1}$ around mid-century, before declining to roughly $3.5\text{-}3.6 \text{ km}^3 \text{ yr}^{-1}$ by 2100 (a reduction of ~20% from the peak). SSP245 exhibits sustained growth in withdrawals from around $2.1 \text{ km}^3 \text{ yr}^{-1}$ to approximately $4.8\text{-}4.9 \text{ km}^3 \text{ yr}^{-1}$ by the 2070s, followed by a slight decrease to about $4.7 \text{ km}^3 \text{ yr}^{-1}$ toward the end of the century. SSP585 shows the highest withdrawal levels, increasing from approximately $2.1 \text{ km}^3 \text{ yr}^{-1}$ to a peak of about $5.0\text{-}5.1 \text{ km}^3 \text{ yr}^{-1}$ during the mid- to late-century period, before declining to roughly $4.3 \text{ km}^3 \text{ yr}^{-1}$ by 2100. The divergence between consumption and withdrawal trends across scenarios suggests potential improvements in water-use efficiency, supply-side management, and infrastructure development over time. Overall, Figure 5 indicates that domestic water use in the Narmada basin is strongly influenced by socioeconomic pathways, with higher-emission scenarios associated with higher mid-century demand and sustained pressure on water withdrawals despite partial declines toward the end of the century.

3.2.2 Electricity

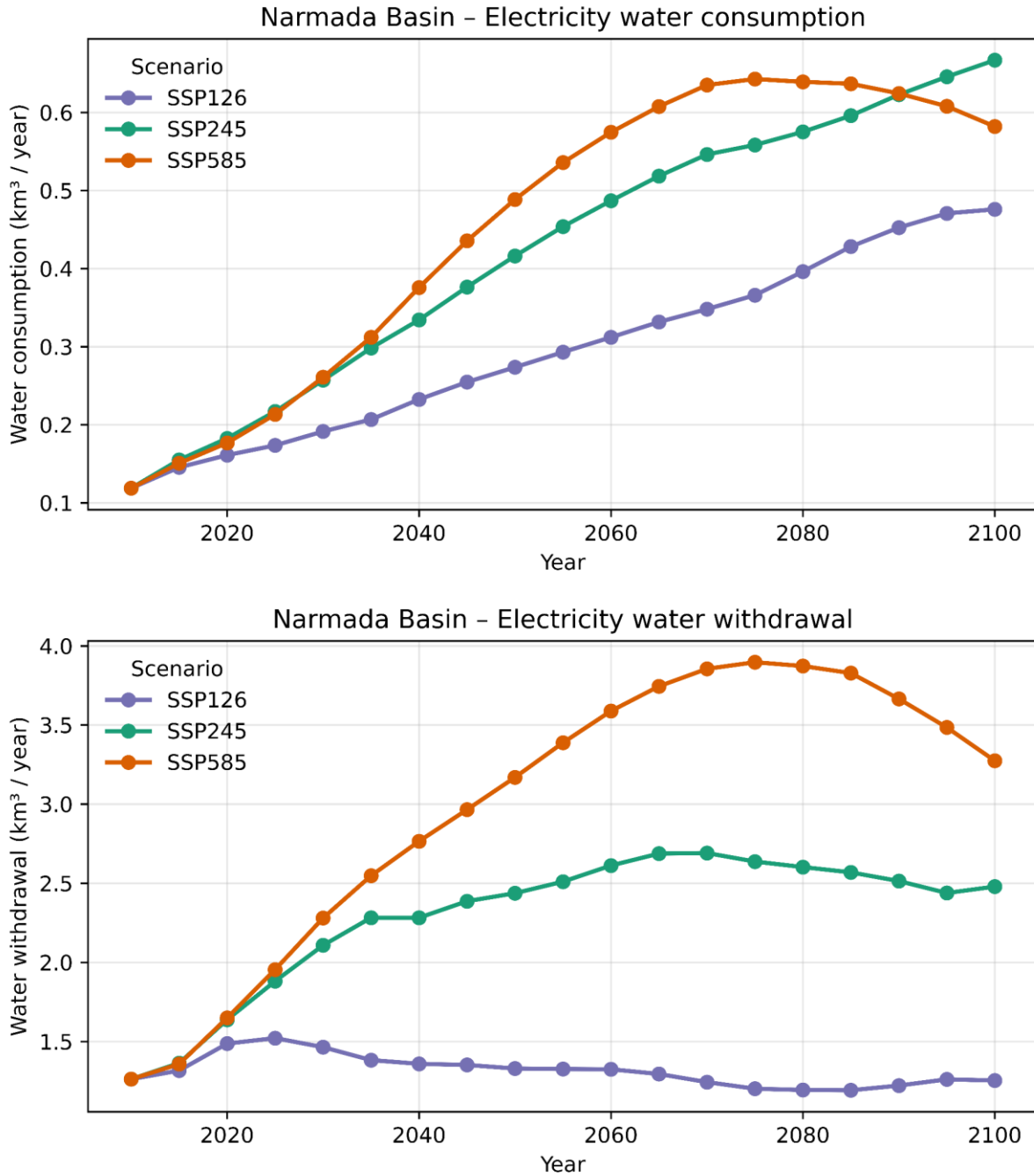


Figure 6 (a) Projected trends in electricity-sector water consumption and (b) electricity-sector water withdrawal in the Narmada basin under different socioeconomic pathways (SSP126, SSP245, and SSP585) from 2015 to 2100.

Figure 6 presents the projected long-term evolution of electricity-sector water consumption and withdrawal in the Narmada basin under three climate-socioeconomic scenarios (SSP126,

SSP245, and SSP585) for the period 2015-2100. Figure 6(a) shows that electricity water consumption increases across all scenarios throughout much of the century, reflecting growing electricity demand and expansion of power-generation capacity. Under SSP126, water consumption increases steadily from approximately $0.12 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to about $0.47\text{-}0.48 \text{ km}^3 \text{ yr}^{-1}$ by 2100, representing an almost fourfold increase over the century. Under SSP245, electricity water consumption rises more rapidly, increasing from around $0.12 \text{ km}^3 \text{ yr}^{-1}$ to approximately $0.65\text{-}0.67 \text{ km}^3 \text{ yr}^{-1}$ by the end of the century, corresponding to an increase of roughly 450% relative to 2015 levels. In contrast, SSP585 exhibits the highest mid-century consumption, increasing from approximately $0.12 \text{ km}^3 \text{ yr}^{-1}$ to a peak of about $0.64\text{-}0.66 \text{ km}^3 \text{ yr}^{-1}$ around the 2070s, followed by a modest decline to roughly $0.58\text{-}0.59 \text{ km}^3 \text{ yr}^{-1}$ by 2100. This late-century decline under SSP585 likely reflects structural shifts in the energy mix and improvements in cooling efficiency. Electricity water withdrawal shows a similar but more pronounced pattern (Figure 6(b)), with substantially larger absolute volumes. Under SSP126, withdrawals increase modestly from approximately $1.25 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to a peak of about $1.50\text{-}1.55 \text{ km}^3 \text{ yr}^{-1}$ in the early 2020s, before gradually declining to around $1.25\text{-}1.30 \text{ km}^3 \text{ yr}^{-1}$ by 2100, indicating relatively stable and efficient electricity water use under a low-emissions pathway. SSP245 displays sustained growth in withdrawals from about $1.25 \text{ km}^3 \text{ yr}^{-1}$ to approximately $2.6\text{-}2.7 \text{ km}^3 \text{ yr}^{-1}$ by the mid- to late-century period, followed by a slight decline toward $2.45\text{-}2.50 \text{ km}^3 \text{ yr}^{-1}$ by 2100. The highest withdrawals are observed under SSP585, where electricity and water withdrawals increase sharply from approximately $1.25 \text{ km}^3 \text{ yr}^{-1}$ to a peak of about $3.8\text{-}3.9 \text{ km}^3 \text{ yr}^{-1}$ around the 2070s, before declining to roughly $3.2\text{-}3.3 \text{ km}^3 \text{ yr}^{-1}$ by the end of the century. This represents a net increase of more than 150% relative to initial levels, despite the late-century reduction. The divergence between consumption and withdrawal trajectories, particularly under SSP245 and SSP585, suggests increasing adoption of water-efficient cooling technologies, shifts in power-generation portfolios, and improvements in thermal efficiency over time. Overall, Figure 6 highlights that electricity-sector water use in the Narmada basin is highly sensitive to future energy pathways, with higher-emission scenarios imposing substantially greater pressure on water withdrawals, especially during the mid- to late-century period.

3.2.3 Livestock

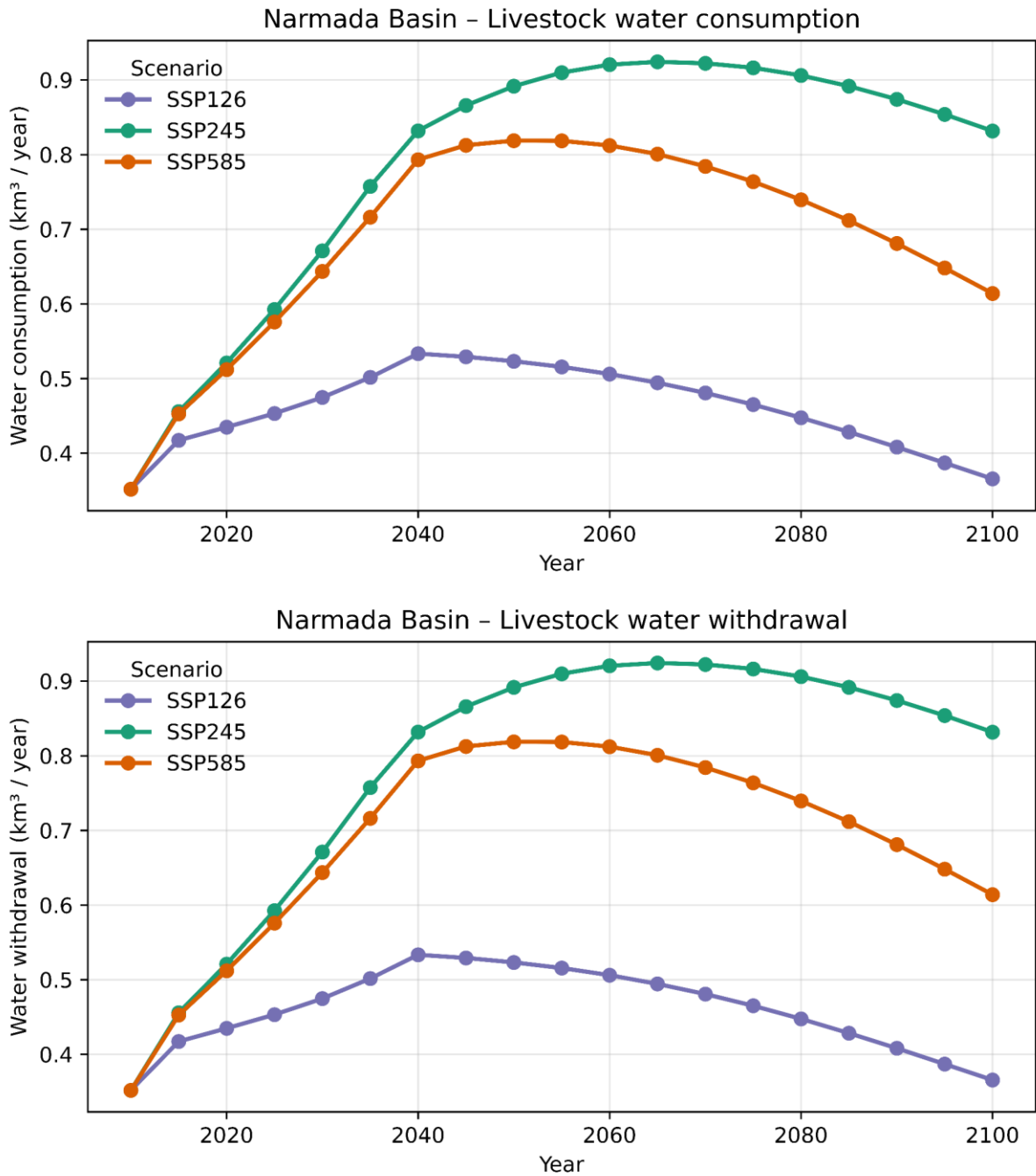


Figure 7 (a) Projected trends in livestock water consumption and (b) livestock water withdrawal in the Narmada basin under different socioeconomic pathways (SSP126, SSP245, and SSP585) from 2015 to 2100.

Figure 7 presents the projected long-term evolution of livestock water consumption and withdrawal in the Narmada basin under three climate–socioeconomic scenarios (SSP126, SSP245, and SSP585) for the period 2015–2100. Figure 7(a) shows that livestock water consumption increases across all scenarios during the early to mid-century, then gradually declines toward the end of the century. Under SSP126, livestock water consumption rises from approximately $0.35 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to a peak of about $0.53\text{-}0.54 \text{ km}^3 \text{ yr}^{-1}$ around the 2040s, before steadily declining to roughly $0.36\text{-}0.37 \text{ km}^3 \text{ yr}^{-1}$ by 2100, corresponding to a reduction of nearly 30% from peak levels. Under SSP245, consumption increases more sharply, rising from around $0.35 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to a maximum of approximately $0.92\text{-}0.93 \text{ km}^3 \text{ yr}^{-1}$ during the 2060s–2070s. Thereafter, consumption declines moderately to about $0.83\text{-}0.85 \text{ km}^3 \text{ yr}^{-1}$ by the end of the century, representing a reduction of roughly 10% from peak values. In contrast, SSP585 shows a rapid increase in livestock water consumption from approximately $0.35 \text{ km}^3 \text{ yr}^{-1}$ to about $0.81\text{-}0.82 \text{ km}^3 \text{ yr}^{-1}$ by the mid-century period, followed by a sustained decline to around $0.61\text{-}0.62 \text{ km}^3 \text{ yr}^{-1}$ by 2100, corresponding to a reduction of nearly 25% from the peak. A similar temporal pattern is observed for livestock water withdrawal (Figure 7(b)), with withdrawal values closely tracking consumption trends but at slightly higher magnitudes. Under SSP126, livestock water withdrawal increases from approximately $0.36 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to a peak of about $0.53\text{-}0.54 \text{ km}^3 \text{ yr}^{-1}$ in the 2040s, before declining to roughly $0.36\text{-}0.37 \text{ km}^3 \text{ yr}^{-1}$ by 2100. SSP245 exhibits the highest withdrawals across the century, increasing from around $0.36 \text{ km}^3 \text{ yr}^{-1}$ to approximately $0.92\text{-}0.93 \text{ km}^3 \text{ yr}^{-1}$ by the 2060s–2070s, followed by a modest decline toward $0.83\text{-}0.85 \text{ km}^3 \text{ yr}^{-1}$ by the end of the century. Under SSP585, withdrawals increase to a peak of about $0.81\text{-}0.82 \text{ km}^3 \text{ yr}^{-1}$ by mid-century and subsequently decline to approximately $0.61\text{-}0.62 \text{ km}^3 \text{ yr}^{-1}$ by 2100. The close alignment between livestock water consumption and withdrawal across all scenarios suggests relatively limited scope for efficiency gains compared to other sectors, with trends largely driven by changes in livestock population, production systems, and demand for animal-based products. Overall, Figure 7 indicates that livestock water use in the Narmada basin is strongly influenced by socioeconomic pathways, with higher-growth scenarios leading to substantially higher mid-century water demand, followed by stabilization or decline toward the end of the century.

3.2.4. Manufacturing Industry

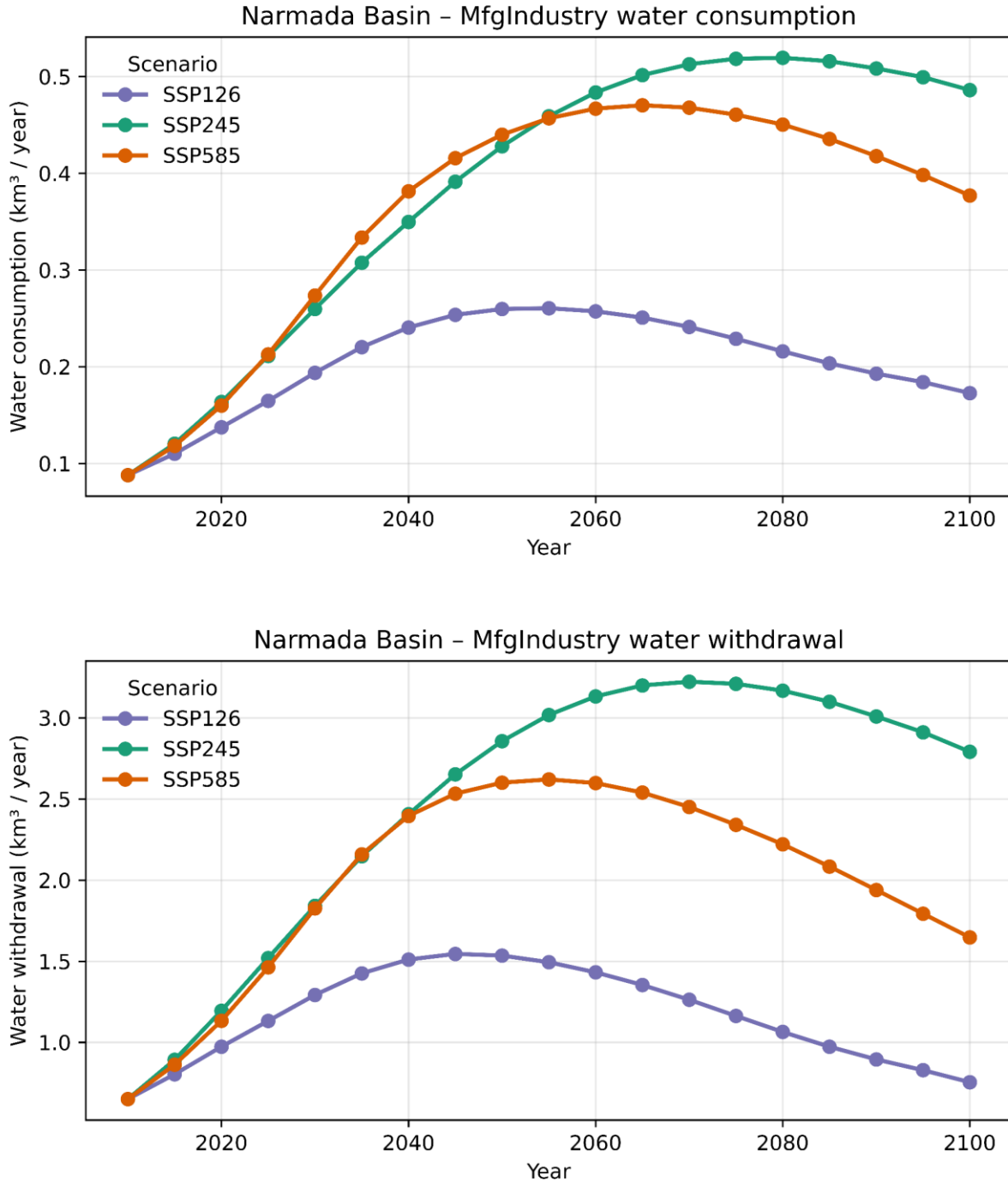


Figure 8 (a) Projected trends in manufacturing industry water consumption and (b) manufacturing industry water withdrawal in the Narmada basin under different socioeconomic pathways (SSP126, SSP245, and SSP585) from 2015 to 2100.

Figure 8 presents the projected long-term evolution of manufacturing industry water consumption and withdrawal in the Narmada basin under three climate-socioeconomic scenarios

(SSP126, SSP245, and SSP585) for the period 2015-2100. Figure 8(a) shows that manufacturing water consumption increases rapidly across all scenarios during the early to mid-century, followed by stabilization or decline toward the end of the century. Under SSP126, water consumption rises from approximately $0.09 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to a peak of about $0.25\text{-}0.26 \text{ km}^3 \text{ yr}^{-1}$ around the 2050s, before gradually declining to roughly $0.17\text{-}0.18 \text{ km}^3 \text{ yr}^{-1}$ by 2100, representing a reduction of nearly 30% from peak levels. Under SSP245, manufacturing water consumption exhibits the strongest growth, increasing from around $0.09 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to a maximum of approximately $0.51\text{-}0.52 \text{ km}^3 \text{ yr}^{-1}$ during the 2070s-2080s. Thereafter, consumption declines slightly to about $0.48\text{-}0.49 \text{ km}^3 \text{ yr}^{-1}$ by 2100, corresponding to a modest reduction of roughly 5-8% from the peak. In contrast, SSP585 shows rapid early growth, with consumption increasing from approximately $0.09 \text{ km}^3 \text{ yr}^{-1}$ to about $0.46\text{-}0.47 \text{ km}^3 \text{ yr}^{-1}$ by the mid- to late-century period, followed by a more pronounced decline to around $0.37\text{-}0.38 \text{ km}^3 \text{ yr}^{-1}$ by 2100, representing a reduction of nearly 20% from peak levels. Manufacturing water withdrawal follows similar temporal patterns but with larger absolute magnitudes (Figure 8(b)). Under SSP126, withdrawals increase from approximately $0.65 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to a peak of about $1.50\text{-}1.55 \text{ km}^3 \text{ yr}^{-1}$ around the 2040s-2050s, before declining steadily to roughly $0.75\text{-}0.80 \text{ km}^3 \text{ yr}^{-1}$ by the end of the century, corresponding to a reduction of nearly 50% from peak withdrawal levels. SSP245 shows the highest withdrawals across all scenarios, increasing from around $0.65 \text{ km}^3 \text{ yr}^{-1}$ to approximately $3.20\text{-}3.25 \text{ km}^3 \text{ yr}^{-1}$ by the 2070s, followed by a moderate decline to about $2.75\text{-}2.85 \text{ km}^3 \text{ yr}^{-1}$ by 2100 (a reduction of ~10-15%). Under SSP585, manufacturing water withdrawal rises rapidly from approximately $0.65 \text{ km}^3 \text{ yr}^{-1}$ to a peak of about $2.55\text{-}2.60 \text{ km}^3 \text{ yr}^{-1}$ during the mid-century period, before declining to roughly $1.60\text{-}1.70 \text{ km}^3 \text{ yr}^{-1}$ by the end of the century, representing a reduction of nearly 35-40% from the peak. The divergence between consumption and withdrawal trends across scenarios indicates substantial potential for improvements in industrial water-use efficiency, recycling, and process optimization, particularly under SSP245 and SSP585. Overall, Figure 8 highlights that manufacturing industry water use in the Narmada basin is highly sensitive to socioeconomic development pathways, with higher-growth scenarios generating substantial mid-century pressure on water withdrawals, followed by partial decoupling of water use from industrial output toward the end of the century.

3.2.5 Mining

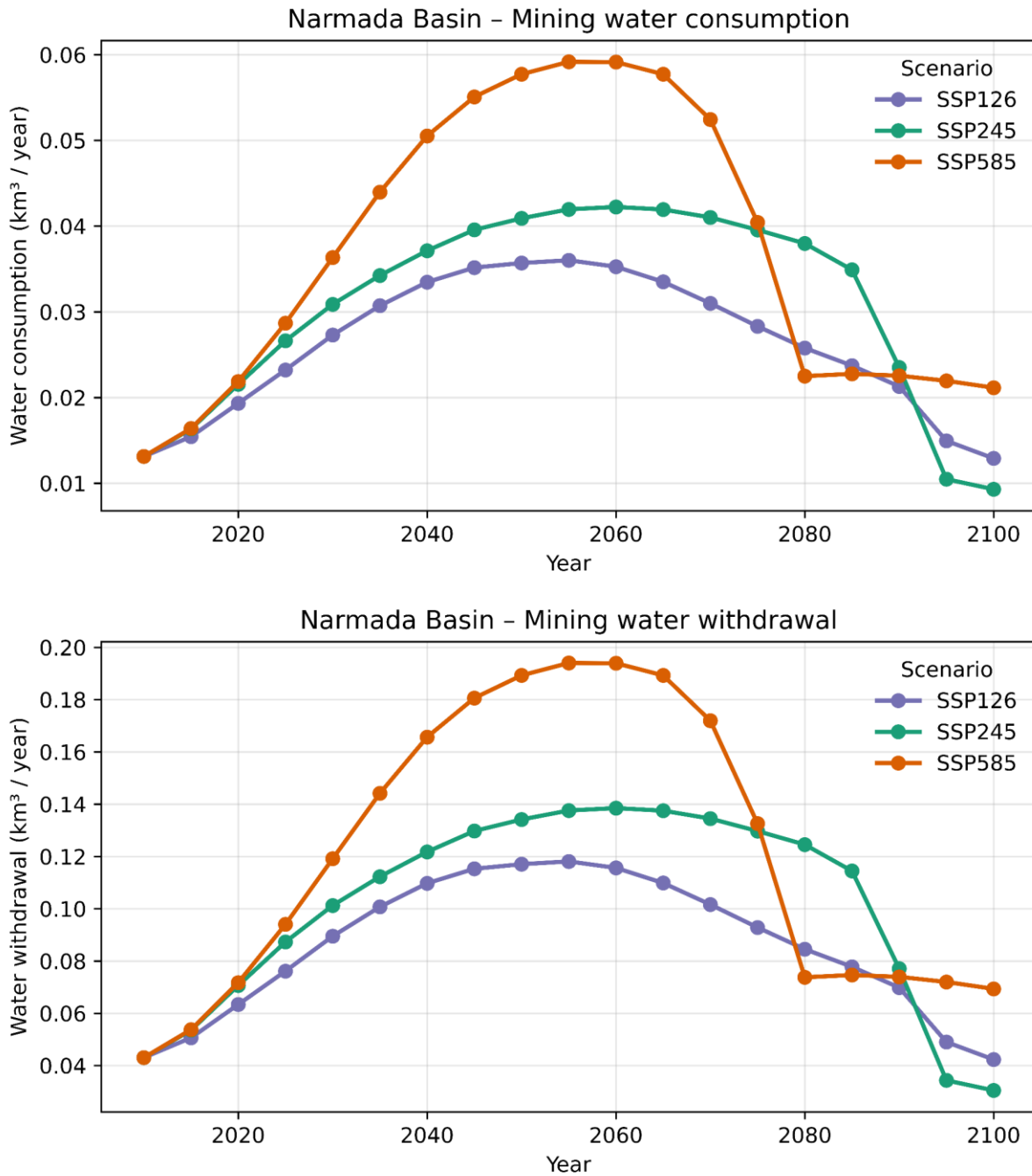


Figure 9 (a) Projected trends in mining water consumption and (b) mining water withdrawal in the Narmada basin under different socioeconomic pathways (SSP126, SSP245, and SSP585) from 2015 to 2100.

Figure 9 presents the projected long-term evolution of mining-sector water consumption and withdrawal in the Narmada basin under three climate-socioeconomic scenarios (SSP126,

SSP245, and SSP585) for the period 2015-2100. Figure 9(a) shows that mining water consumption increases during the early to mid-century across all scenarios, followed by a pronounced decline toward the end of the century. Under SSP126, mining water consumption rises from approximately $0.013 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to a peak of about $0.035\text{-}0.036 \text{ km}^3 \text{ yr}^{-1}$ around the 2050s, before declining steadily to roughly $0.013\text{-}0.014 \text{ km}^3 \text{ yr}^{-1}$ by 2100, corresponding to a reduction of nearly 60% from peak levels. Under SSP245, consumption increases from around $0.013 \text{ km}^3 \text{ yr}^{-1}$ to approximately $0.041\text{-}0.042 \text{ km}^3 \text{ yr}^{-1}$ by the mid-century period. Thereafter, consumption declines gradually until the 2070s, followed by a sharp reduction toward the end of the century, reaching approximately $0.009\text{-}0.010 \text{ km}^3 \text{ yr}^{-1}$ by 2100. This represents a reduction of nearly 75–80% from peak consumption levels. In contrast, SSP585 exhibits the highest mid-century mining water consumption, increasing from approximately $0.013 \text{ km}^3 \text{ yr}^{-1}$ to a peak of about $0.058\text{-}0.060 \text{ km}^3 \text{ yr}^{-1}$ during the 2050s-2060s. After this peak, consumption declines sharply, falling to roughly $0.021\text{-}0.022 \text{ km}^3 \text{ yr}^{-1}$ by 2100, corresponding to a reduction of about 60-65% from peak levels. Mining water withdrawal follows a similar but more pronounced pattern (Figure 9(b)), with larger absolute volumes. Under SSP126, withdrawals increase from approximately $0.045 \text{ km}^3 \text{ yr}^{-1}$ in 2015 to a peak of about $0.115\text{-}0.118 \text{ km}^3 \text{ yr}^{-1}$ around the 2050s, before declining to roughly $0.040\text{-}0.045 \text{ km}^3 \text{ yr}^{-1}$ by 2100, representing a reduction of nearly 65% from peak withdrawal levels. SSP245 shows a comparable trajectory, with withdrawals increasing from around $0.045 \text{ km}^3 \text{ yr}^{-1}$ to approximately $0.135\text{-}0.138 \text{ km}^3 \text{ yr}^{-1}$ by mid-century, followed by a sharp decline after the 2070s to about $0.030\text{-}0.035 \text{ km}^3 \text{ yr}^{-1}$ by the end of the century, corresponding to a reduction of nearly 75% from peak levels. The SSP585 scenario exhibits the highest withdrawal volumes, increasing from approximately $0.045 \text{ km}^3 \text{ yr}^{-1}$ to a peak of about $0.190\text{-}0.195 \text{ km}^3 \text{ yr}^{-1}$ during the 2050s-2060s, before declining steeply to roughly $0.068\text{-}0.072 \text{ km}^3 \text{ yr}^{-1}$ by 2100. This represents a reduction of nearly 65% from peak withdrawal levels. The sharp post-mid-century decline in both mining water consumption and withdrawal across SSP245 and SSP585 reflects strong structural shifts in extractive activities, resource depletion, and potential regulatory or technological constraints on mining operations. Overall, Figure 9 indicates that mining-sector water use in the Narmada basin is highly sensitive to socioeconomic pathways, with higher-growth scenarios generating substantial mid-century pressure on water resources, followed by pronounced long-term reductions toward the end of the century.

4. Conclusion

Projected water consumption and withdrawals across the Narmada Basin diverge considerably by sector and scenario. While agriculture remains the largest overall sector in terms of water usage, non-agricultural demands, particularly domestic supply, electricity generation, and manufacturing are seen to rise sharply under higher growth SSPs and exert more pressure around mid-century. In scenarios such as SSP585 and SSP245, many agricultural withdrawals fall towards the late century as socioeconomic changes and modeled efficiency gains take effect, even as electricity, domestic, and industrial withdrawals peak earlier. The result is a shifting pattern of stress, from being irrigation-dominated pressure today to multi-sector competition in the future.

These findings strengthen the case for integrated, scenario-aware basin planning that accounts for both climatic and socioeconomic trajectories. The modeled efficiency improvements and structural shifts also show that policy choices matter such as investments in irrigation modernization, urban water efficiency, lower water dependent industrial processes, and improved cooling technologies for power plants can materially change long-term outcomes. And the projections in the report should be used as decision support tools and not as single predictions but as a way to map plausible futures, prioritizing monitoring in hotspots, and steer targeted policy and investment actions.

5. References

- 1) Khan, Z., Thompson, I., Vernon, C. R., Graham, N. T., Wild, T. B., & Chen, M. (2023). Global monthly sectoral water use for 2010–2100 at 0.5° resolution across alternative futures. *Scientific Data*, 10(1). <https://doi.org/10.1038/s41597-023-02086-2>



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