Entorno Geográfico | N° 31 | Enero – Junio 2026 | pp. 1-33 | ISSN (en línea): 2382-3518 | e20515157 | Universidad del Valle

DOI: 10.25100/eg.v0i31.15157
Espacio y Territorios

Analysis of Water Resources Support Capacity through an Integrated Modeling and Indicator-Based Framework: A Case Study of the Bakhtiari Watershed

Análisis de la capacidad de soporte de los recursos hídricos mediante un marco integrado de modelización y basado en indicadores: estudio de caso de la cuenca hidrográfica de Bakhtiari

Análise da capacidade de suporte dos recursos hídricos por meio de um modelo integrado baseado em indicadores: estudo de caso da bacia hidrográfica de Bakhtiari

Elham Ghasemi Ziyarani[1]
Shahid Beheshti University, Tehran, Iran. ghasemi-z@wrm.ir | 0009-0000-5295-3776

Maryam Ilanloo[2]
Islamic Azad University, Mahshahr, Iran. m.ilanloo6101@iau.ir | 0000-0001-7571-8808

How to cite? Ghasemi, E. & Ilanloo, M. (2026). Analysis of Water Resources Support Capacity through an Integrated Modeling and Indicator-Based Framework: A Case Study of the Bakhtiari Watershed. *Entorno Geográfico*, (31), e20515157. https://doi.org/10.25100/eg.v0i31.15157

Abstract

In recent years, growing environmental degradation worldwide has intensified the need to assess the impacts of human activities and to harmonize socio-economic development with sustainable ecosystems. Among the various approaches to evaluating human–environment interactions, the concept of water resources carrying capacity (adapted from the broader carrying capacity framework) has emerged as a valuable tool in water resource management.

---

[1] Ph.D. candidate in Environmental Science and Engineering (Land Use Planning) at Shahid Beheshti University. She holds a B.Sc. in Natural Resources Engineering (Environmental Science) from Islamic Azad University, North Tehran Branch, and an M.Sc. in Environmental Management Planning and Education from the University of Tehran.

[2] Ph.D. in Physical Geography from Islamic Azad University, Science and Research Branch. She holds an M.Sc. in Physical Geography from Islamic Azad University, Tehran Central Branch, and a B.Sc. in Physical Geography from Shahid Beheshti University.

Correspondencia: Maryam Ilanloo. Islamic Azad University, Mahshahr, Iran. Imam Khomeini Boulevard, Bandar-e Mahshahr, Khuzestan Province, Iran. Correo-e: m.ilanloo6101@iau.ir

This study introduces an integrated framework that combines simulation modeling, indicator-based assessment, and a pressure–support factor to evaluate water resources carrying capacity. The proposed method addresses two major shortcomings in existing studies: the insufficient consideration of environmental health status and the limited comparability among indicators. The framework was applied to the Bakhtiari watershed, Iran, for the period 2003–2023, divided into three intervals: 2003–2009, 2009–2017, and 2017–2023.

Assessments were conducted both annually and for each interval. Results show that water resource loading was within the carrying capacity only during the first period, while excessive loading occurred in the second and third periods. Both carrying capacity and environmental health declined markedly, reaching their lowest levels in the final period. Pressure–support analysis revealed increasing pressures on water resources alongside a continuous reduction in support capacity, largely driven by rapid economic development policies that overlooked sustainability.

The strong alignment between results and observed regional conditions highlights the framework's applicability for policy evaluation, scenario analysis, and forecasting. This approach provides a robust basis for assessing the socio-economic and environmental impacts of water resource management strategies in similar contexts.

Keywords: carrying capacity, environmental health, water resources, Bakhtiari watershed and Iran

Resumen

En los últimos años, el creciente deterioro ambiental a nivel mundial ha intensificado la necesidad de evaluar los impactos de las actividades humanas y de armonizar el desarrollo socioeconómico con ecosistemas sostenibles. Entre los diversos enfoques para evaluar las interacciones ser humano–medio ambiente, el concepto de capacidad de carga de los recursos hídricos (adaptado del marco más amplio de la capacidad de carga) ha surgido como una herramienta valiosa en la gestión del agua.

Este estudio presenta un marco integrado que combina modelización por simulación, evaluación basada en indicadores y un factor presión–soporte para evaluar la capacidad de carga de los recursos hídricos. El método propuesto aborda dos limitaciones importantes de estudios previos: la consideración insuficiente del estado de la salud ambiental y la comparabilidad limitada entre indicadores.

El marco se aplicó a la cuenca hidrográfica de Bakhtiari (Irán) para el período 2003–2023, dividido en tres intervalos: 2003–2009, 2009–2017 y 2017–2023. Las evaluaciones se realizaron tanto de forma anual como por intervalos.

Los resultados muestran que la carga sobre los recursos hídricos se mantuvo dentro de la capacidad de carga únicamente durante el primer período, mientras que se presentó una sobrecarga en el segundo y tercer períodos. Tanto la capacidad de carga como la salud ambiental disminuyeron de manera significativa, alcanzando sus niveles más bajos en el último período. El análisis presión–soporte reveló un aumento de las presiones sobre los recursos hídricos junto con una reducción continua de la capacidad de soporte, impulsada en gran medida por políticas de rápido desarrollo económico que descuidaron la sostenibilidad.

La fuerte concordancia entre los resultados y las condiciones regionales observadas destaca la aplicabilidad del marco para la evaluación de políticas, el análisis de escenarios y la prospectiva. Este enfoque proporciona una base sólida para evaluar los impactos socioeconómicos y ambientales de las estrategias de gestión de los recursos hídricos en contextos similares.

Palabras clave: capacidad de carga, salud ambiental, recursos hídricos, cuenca hidrográfica de Bakhtiari e Irán

Resumo

Nos últimos anos, a crescente degradação ambiental em escala mundial intensificou a necessidade de avaliar os impactos das atividades humanas e de harmonizar o desenvolvimento socioeconômico com ecossistemas sustentáveis. Entre as diversas abordagens para avaliar as interações entre sociedade e meio ambiente, o conceito de capacidade de suporte dos recursos hídricos (adaptado do marco mais amplo de capacidade de suporte) tem se destacado como uma ferramenta valiosa na gestão da água. Este estudo apresenta um marco integrado que combina modelagem por simulação, avaliação baseada em indicadores e um fator pressão–suporte para avaliar a capacidade de suporte dos recursos hídricos. O método proposto enfrenta duas limitações relevantes dos estudos existentes: a consideração insuficiente do estado da saúde ambiental e a limitada comparabilidade entre indicadores.

O marco foi aplicado à bacia hidrográfica de Bakhtiari (Irã) no período de 2003–2023, dividido em três intervalos: 2003–2009, 2009–2017 e 2017–2023. As avaliações foram realizadas tanto anualmente quanto por intervalos.

Os resultados mostram que a carga sobre os recursos hídricos esteve dentro da capacidade de suporte apenas no primeiro período, enquanto ocorreu sobrecarga no segundo e no terceiro períodos. Tanto a capacidade de suporte quanto a saúde ambiental diminuíram de forma significativa, atingindo seus níveis mais baixos no período final. A análise pressão–suporte revelou o aumento das pressões sobre os recursos hídricos juntamente com uma redução contínua da capacidade de suporte, impulsionada principalmente por políticas de rápido desenvolvimento econômico que negligenciaram a sustentabilidade.
A forte correspondência entre os resultados e as condições regionais observadas destaca a aplicabilidade do marco para avaliação de políticas, análise de cenários e projeções futuras. Essa abordagem fornece uma base robusta para avaliar os impactos socioeconômicos e ambientais das estratégias de gestão dos recursos hídricos em contextos semelhantes.

Palavras-chave: capacidade de suporte, saúde ambiental, recursos hídricos, bacia hidrográfica de Bakhtiari e Irã

Received: 11 August 2025 **Evaluated:** 22 september 2025
Accepted: 26 February 2025 **Published:** 5 March 2026

1. Introduction

Water is indispensable for human survival and socio-economic development (Yang et al., 2019). As a fundamental natural resource, it shapes ecological systems, sustains human existence, and drives economic growth (Yang & Yang, 2021). However, water scarcity poses a severe threat to food security, energy supply, and sustainable development (Yin et al., 2023). Challenges such as uneven distribution and overexploitation not only jeopardize environmental stability but also hinder global economic progress. Consequently, balancing water resource availability with socio-economic growth has become a critical area of research (Wang et al., 2024).

The concept of carrying capacity measures the ability of an environment to sustainably support human and other life forms (Djuwansyah, 2018; Li et al., 2023b). Within this framework, water resources carrying capacity (WRCC) has gained attention for its value in assessing sustainable water utilization. Previous WRCC studies have focused on conceptual definitions, methodological developments, and application case studies (Magri & Berezowska-Azzag, 2019). In the agricultural sector, agricultural water resources carrying capacity (AWRCC) is often predicted using system dynamics modeling (Barati et al., 2019; Mashaly & Fernald, 2020; Yan & Xu, 2022) or mathematical modeling (Zhang et al., 2018). While system dynamics models offer flexibility, they are sensitive to subjective parameter settings (Li et al., 2023a). Mathematical approaches —either predicting AWRCC directly from historical data (Luo et al., 2022; Li et al., 2023b) or via indicator-based modeling (Chi et al., 2018; Zhang et al., 2018; Xu et al., 2020)— often provide more robust and reproducible results.

WRCC assessments have been conducted at various spatial scales, including urban (Wang et al., 2019), regional (Wang et al., 2020), and basin levels (Chen et al., 2020). The Bakhtiari watershed in Iran, though rich in natural resources, is ecologically fragile. Extensive water transfers to central Iran, combined with agricultural expansion, recurrent droughts, and water diversions since the 2010s, have drastically reduced runoff and degraded the Bakhtiari River ecosystem.

International studies have also provided valuable approaches and experiences in the field of assessing and managing water resource carrying capacity that can help enrich the analytical perspectives in this study. In Europe, research conducted in the Ebro River Basin in Spain has shown how reduced precipitation and increased water use can affect water resource availability in semi-arid regions, highlighting the importance of using integrated models. Also, the assessment of water levels in the Sakarya River Basin in Turkey using models such as WEAP is an example of designing sustainable strategies in the face of climate change and agricultural development (Yaykiran et al., 2019). In Latin America, research conducted in Bolivia emphasizes the role of indigenous knowledge and traditional practices of local communities in managing water resources in coastal and mountainous areas (Brugnach & Özerol, 2019). In Africa, a large-scale study of the northern and western regions of the continent over the period 1980–2100 shows how vulnerability to drought is exacerbated by socio-economic factors and highlights the need for climate-adapted planning (Henchiri et al., 2024).

In North America, the use of SWAT to analyze water availability in the Trinity and Niches River basins in Texas is an example of the use of advanced hydrological simulation tools to assess past and future scenarios (Sohoulande, 2019). In Australia, studies on managing the interaction between saltwater intrusion and groundwater resources in affected basins have shown that integrated approaches can be effective in simultaneously addressing water quality and quantity issues (Lyra et al., 2022).

This study introduces a novel WRCC assessment framework that integrates simulation modeling, indicator-based evaluation, and a pressure–support factor to capture both human impacts and environmental health. Unlike single-method approaches, this framework allows for indicator interchangeability and a more holistic evaluation of water resource sustainability. Applied to the Bakhtiari watershed over a 20-year period (2003–2023), the framework enables detailed temporal analyses, scenario assessments, and future condition forecasting. The findings aim to inform policy-making and guide sustainable water management in similarly vulnerable basins worldwide.

2. Materials and methods

2.1. Study Area

The Bakhtiari River watershed, a third-order basin within the Dez River basin (Figure 1), forms part of the Persian Gulf and Oman Sea watershed system. Major urban centers in the basin include Dezful, Andimeshk, and Shush. The Bakhtiari River is the second-largest tributary of the Dez River, joining the Sezar River about 40 km south of its confluence with the Sorkhab River.

The river originates on the southern slopes of the Oshtorankuh Mountains as the Darreh-Dayi River, flowing northwest to southeast. After merging with the Golestan River —rising from the high plateau south of Aligudarz— the course turns southward, running parallel to the Vahregan River, which flows in the opposite direction. Downstream, the Bakhtiari receives several small tributaries before turning westward, where it is locally called the Zalaki River. It then meets a major northern tributary before converging with the Sezar River, after which it continues as the Dez River.

The basin's climate is predominantly warm semi-arid. Average annual precipitation is 670.5 mm, with 33.4% of the area receiving less than 500 mm and 15.4% exceeding 1,000 mm. Annual temperatures range from 7.6°C to 24.4°C. Snowfall contributes about 21.4% of the total annual precipitation (Honarbakhsh et al., 2019).

3. Methodology

This study adopts an integrated approach that combines simulation modeling with an indicator-based evaluation to assess the water resources carrying capacity (WRCC) of the Bakhtiari watershed. The methodology comprises six main stages:

3.1. System Analysis and Simulation

The water resources system—particularly the agricultural sector—was analyzed to identify key components and interactions. Agricultural water use and hydrological processes were simulated using the Soil and Water Assessment Tool (SWAT). Population data, as well as industrial, domestic, and service sector water demands, were incorporated. Inter-basin water transfers were also estimated to provide a comprehensive account of total water use.

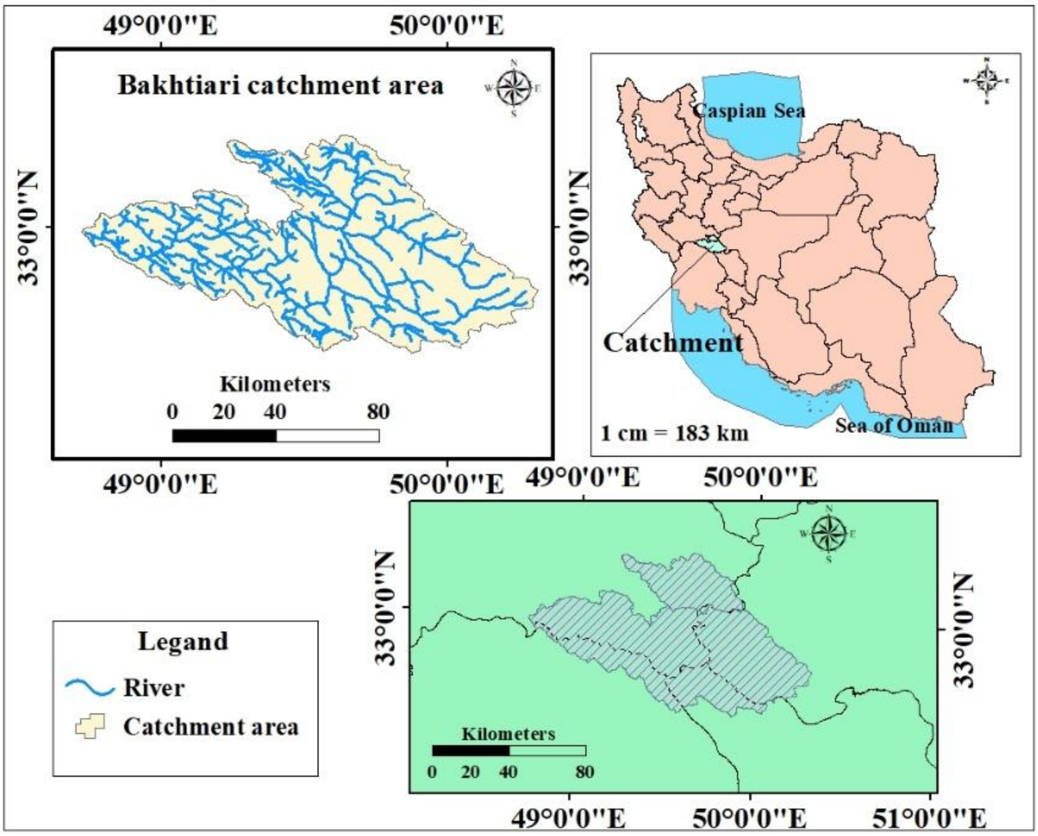

Figure 1. Location of the study area

Source: Elaborated by the authors

3.2. Indicator Development and Aggregation

Evaluation indicators were selected following the Pressure–Support–Status (PSS) framework. Indicator weights were determined using established weighting methods. Cumulative indices were then calculated for each subsystem, and a composite index representing the overall WRCC was developed.

3.3. Trend Analysis and Validation

Temporal trends of both individual and cumulative indicators were analyzed. These trends were validated against observed basin conditions, using hydrological indices to ensure consistency between model outputs and real-world environmental changes.

3.4. Final Assessment

A final WRCC evaluation was conducted, prioritizing environmental health and sustainability considerations in interpreting the results.

3.5. System Status Reporting

The status of the watershed system throughout the study period was reported according to established evaluation standards. Pressure–Support relationship patterns were analyzed to provide a comprehensive interpretation of system dynamics.

3.6. System Status Evaluation

The first step in assessing the water resources carrying capacity (WRCC) was to evaluate the current status of the Bakhtiari watershed, with a primary focus on the agricultural sector. This evaluation was based on outputs from the conceptual SWAT model developed by Delavar et al. (2022), whose calibration and validation results are summarized in Tables 1–2.

Using SWAT outputs, key parameters were calculated for the period 2003–2022, including actual agricultural water consumption (evapotranspiration), crop yields, cultivated area, groundwater recharge, and runoff per unit area.

Gross agricultural income was estimated using annual crop prices, adjusted for inflation via the Consumer Price Index (CPI) to ensure comparability across years. Price changes were evaluated using the Laspeyres index, which measures variations in the prices of goods and services relative to a base year by multiplying base-year consumption quantities by current prices to obtain real expenditure values.

To complement the productivity assessment, caloric values per unit of crop yield were derived from the 2022 Agricultural Yearbook, enabling a more comprehensive evaluation of agricultural output in both economic and nutritional terms.

Table 1. Standards for assessing the carrying capacity of water resources

indicator	Grades	Standards	levels	indicator	Grades	Standards	levels
HSI	I	[0.8 - 1]	Healthy	WECCI	I	[0.8 - 1]	Excellent carrying
	II	[0.64 - 0.8]	Sub-healthy		II	[0.6 – 0.8]	Good carrying
	Ш	[0.48 - 0.64]	Normal		Ш	[0.4 – 0.6]	General
	IV	[0.32 - 0.48]	Critical		IV	[0.2 – 0.4]	Poor carrying
	V	[0.16 - 0.32]	Poor		V	[0 – 0.2]	Very poor carrying
	VI	[0 - 0.16]	Extremely poor				

Source: Du & Wang (2021)

Table 2. Types of system states in different pressure-support connection modes

Quadrant	A	B	C	D
Coupling state	High-High	High-Low	Low-Low	Low-High
Type	Advanced	Unsustainable	Weak	Potential

Source: Du and Wang (2021)

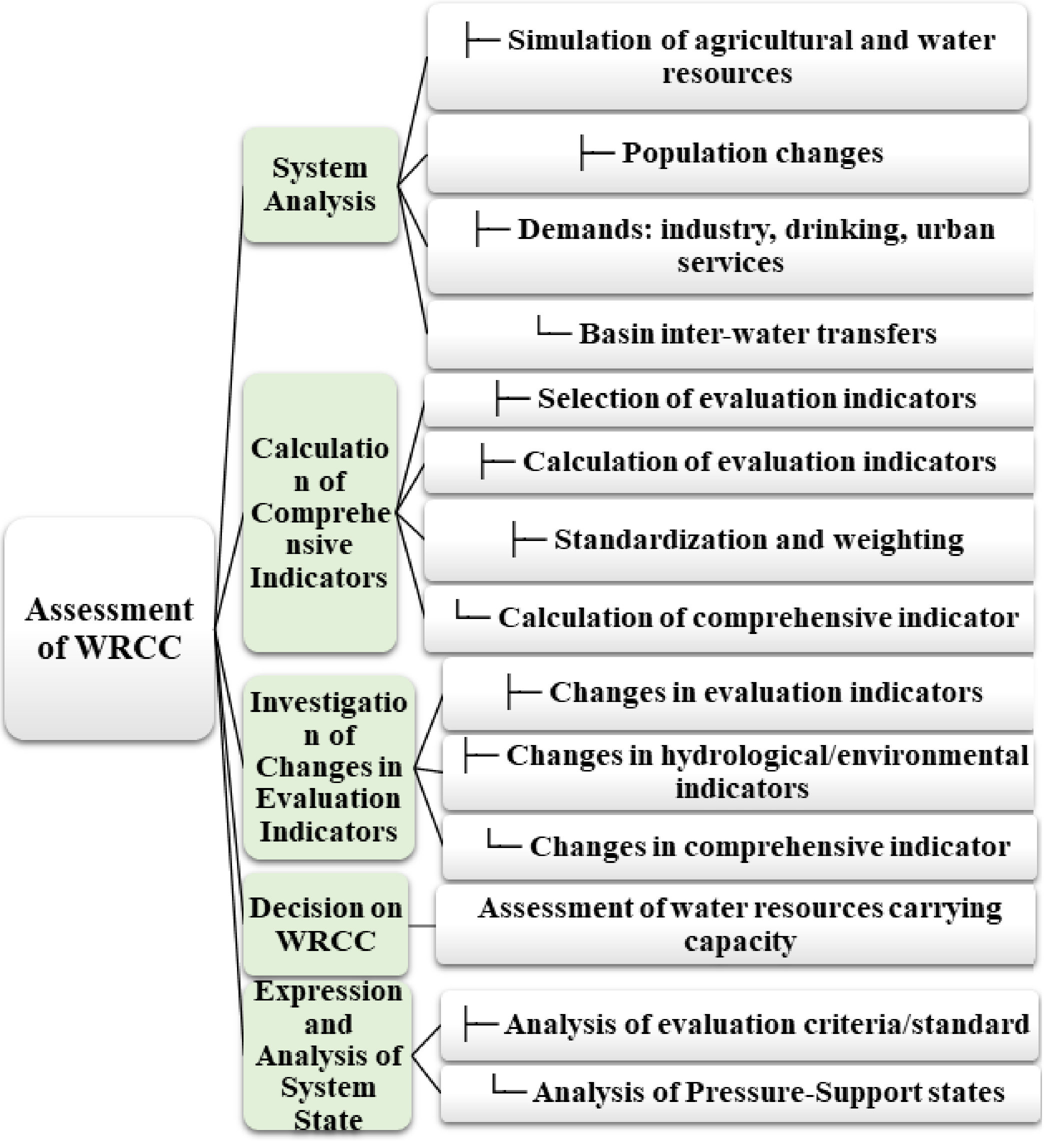

Figure 2. Research flowchart

Source: Elaborated by the authors

4. Result and discussion

4.1. Changes in Assessment, Cumulative, and Hydrological Indicators

Water resources carrying capacity (WRCC) indicators were evaluated using the Pressure–Support–State (PSS) framework. Because this study focuses on water quantity, only relevant indicators were considered:

- Pressure indicators: population density (persons/km²), income per unit area (Rial/km²), and caloric production per unit area.

- Support indicators: agricultural water consumption (evapotranspiration, mm), river runoff per unit area (mm/km^2), annual precipitation (mm), and groundwater recharge (mm).

- State indicators: per capita water resources (m^3/person) and inflow to the Dez River (m^3/s).

Hydrological simulations were performed using the calibrated SWAT model developed for the Bakhtiari watershed. Calibration and validation results for discharge at four hydrometric stations (2000–2023) are presented in Table 3. Model performance was evaluated using the Nash–Sutcliffe efficiency (NS), coefficient of determination (R^2), d-factor, and p-factor, which collectively measure accuracy and uncertainty.

During validation, NS values ranged from 0.42 (Barez) to 0.71 (Zafar Abad), indicating moderate to good agreement between simulated and observed discharges. R^2 values varied from 0.52 to 0.86, reflecting a reasonable correlation across stations. The d-factor ranged from 0.44 to 0.64, and the p-factor from 0.33 to 0.66, showing that a substantial proportion of observed data fell within the model's uncertainty bounds.

During calibration, model performance improved, with NS values between 0.63 and 0.75, and higher R^2 values (0.81–0.90), indicating stronger explanatory power. The d-factor varied from 0.20 to 0.75, while the p-factor values were generally lower (0.04–0.07), reflecting narrower uncertainty intervals around simulated discharges.

Overall, the SWAT model demonstrated robust performance in simulating streamflow in the Bakhtiari watershed. The slightly higher accuracy during calibration compared to validation is consistent with expectations and confirms the model's suitability for WRCC assessment in this region

Table 3. Results of calibration and validation of discharge at existing stations in the Bakhtiari watershed

Station name	Period	Calibration Period				Validation Period			
		p-factor	d-factor	R2	NS	p-factor	d-factor	R2	NS

Keshkan Bridge	2000-2023	0.04	0.2	0.83	0.65	0.33	0.55	0.81	0.61
Barez	2000-2023	0.06	0.65	0.81	0.63	0.52	0.64	0.62	0.42
Zafar Abad	2000-2023	0.07	0.75	0.84	0.73	0.57	0.44	0.52	0.71
Ghaleh Eslam	2000-2023	0.06	0.45	0.90	0.75	0.66	0.61	0.86	0.69

Source: Elaborated by authors

Table 4 summarizes the coefficient of determination (R^2) and Nash–Sutcliffe efficiency (NS) for evapotranspiration and yield simulations of six major crops in the Bakhtiari watershed: potato, barley, oil seeds, watermelon, rice, and peaches. For evapotranspiration, the model achieved strong correlations ($R^2 > 0.90$) for rice (0.98), watermelon (0.96), potato (0.92), and peaches (0.91), with slightly lower performance for oil seeds (0.70) and barley (0.47). NS values followed a similar pattern, showing excellent agreement for rice (0.98), potato (0.92), and peaches (0.91), but lower performance for watermelon (0.36) despite its high R^2, suggesting potential biases in error distribution. For crop yield, the model performed well for rice ($R^2 = 0.92$, NS = 0.92) and barley ($R^2 = 0.79$, NS = 0.70). Potato and oil seeds achieved moderate correlations ($R^2 = 0.63$ and 0.68, respectively), although NS for oil seeds was notably low (0.29). Watermelon and peaches showed weaker performance, with R^2 values of 0.50 and 0.60, and NS values of 0.53 and 0.61, respectively.

Overall, the model reliably simulated evapotranspiration and yield for most crops, particularly rice and barley, which consistently demonstrated high accuracy. Lower performance for watermelon and oil seeds indicates areas where further calibration, refinement of crop parameters, or improved observational data could enhance model reliability.

Table 4. Values of R2 and NS indices of evapotranspiration and crop yield in the Bakhtiari watershed

Crops		peaches	Rice	watermelon	Oil seeds	Barley	Potato
Evapotranspiration	R^2	0.91	0.98	0.96	0.7	0.47	0.92
	NS	0.91	0.98	0.36	0.69	0.62	0.92
Yield	R^2	0.60	0.92	0.50	0.68	0.79	0.63
	NS	0.61	0.92	0.53	0.29	0.70	0.45

Source: Elaborated by authors

Figure 3 illustrates the standardized values (0–1 scale) of four pressure indicators—population density, evaporation, income per unit area, and calories per unit area—between 2003 and 2023.

Population density shows a steady, nearly linear increase from near-zero in 2003 to the maximum value of 1.00 in 2023, reflecting sustained demographic growth, likely driven by natural population increase and migration. This consistent upward trend signals increasing and persistent pressure on water resources. Evaporation exhibits pronounced interannual variability, with peaks in 2007 (1.02) and 2015 (0.97) likely linked to higher agricultural water demand or elevated atmospheric losses due to warmer, drier conditions. Sharp declines in 2005 (0.18) and 2011 (0.14) may correspond to cooler or wetter years. Income per unit area fluctuates substantially, reaching a maximum in 2021 (0.99) and showing highs in 2014–2017, potentially due to favorable economic or agricultural conditions.

Minimal levels in 2011 (0.00) and 2007 (0.24) may reflect drought impacts, reduced productivity, or economic downturns. Calories per unit area also vary considerably, with peaks in 2004 (0.93), 2008 (1.00), and 2015 (0.91), suggesting years of high agricultural output. Notable drops in 2006 (0.52), 2012 (0.70), and especially 2018 (0.00) point to possible harvest failures or reduced cultivated areas. Overall, population density demonstrates a predictable upward trend, while evaporation, income, and caloric output are more volatile, shaped by climatic fluctuations, agricultural practices, and socio-economic changes. This contrast underscores the persistent nature of demographic pressure compared to the variable pressures imposed by environmental and economic conditions

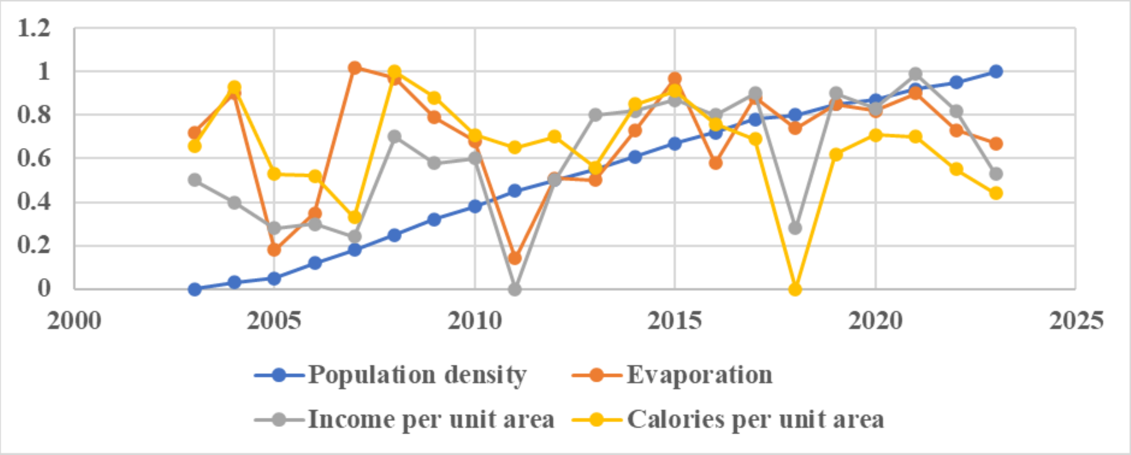

Figure 3. Pressure index values in the period 2003 to 2023

Source: Elaborated by the authors

Figure 4 presents the standardized values (0–1 scale) of four supportive indicators—river runoff per unit area, groundwater recharge, precipitation, and per capita water resources—over 2003–2023. River runoff per unit area remains mostly moderate (0.2–0.7) but shows two exceptional peaks in 2005 (0.9) and 2019 (1.4), likely linked to above-average precipitation events. Minimum values (0.2–0.3) occur in 2011, 2012, 2016, 2021, and 2023, consistent with drought years. Groundwater recharge is generally low (0.1–0.5), reflecting limited aquifer replenishment. The 2019 peak (0.9) coincides with high precipitation and runoff, while minima (0.1) occur in dry years such as 2006, 2016, and 2023, indicating its strong dependence on episodic rainfall. Precipitation varies between 0.6 and 0.9 in most years, with major spikes in 2005 (1.0) and 2019 (1.7) corresponding to runoff and recharge peaks.

Lower precipitation in 2016 (0.4) and 2023 (0.7) aligns with reduced hydrological support. Per capita water resources exhibit more gradual shifts, remaining stable (0.7–0.9) until 2013, then rising to a maximum in 2019 (1.6), before declining in 2020 (1.2) and stabilizing slightly lower (1.4–1.5) in 2021–2023. These trends reflect the combined effects of hydrological variability and population growth.

Overall, the supportive indicators demonstrate a clear synchronization during extreme wet years (2005, 2019) and simultaneous declines in drought years (2006, 2011–2012, 2016, 2023). These patterns highlight the need for integrated surface–groundwater management to buffer the watershed against climatic variability

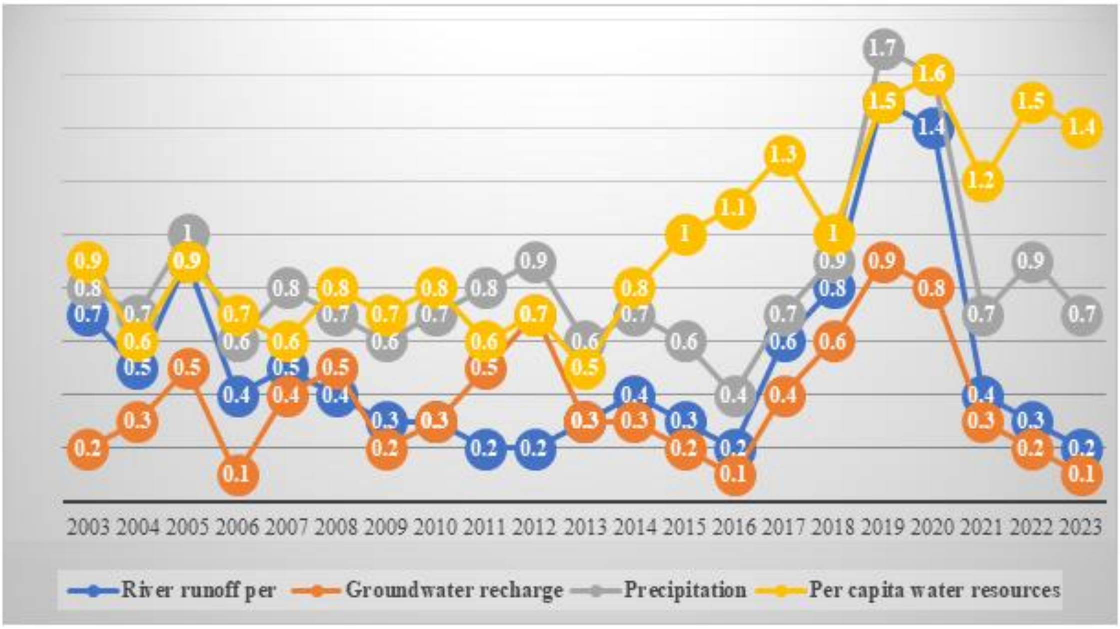

Figure 4. Support index values in the period 2003 to 2023

Source: Elaborated by the authors

Figure 5 presents the standardized inflow values to the Dez River (on a 0–1 scale) exhibit distinct hydrological patterns across three periods within 2003–2023.

Period 1 (2003–2009):

Inflow variability was moderate, ranging from a low of 0.40 in 2006 to a high of 0.90 in 2005, with an average around 0.62. This indicates generally favorable conditions, punctuated by high-flow years (2005, 2007) likely driven by above-average precipitation. Short-term drought effects are evident in lower values such as 2004 (0.50) and 2006 (0.40).

Period 2 (2009–2017):

This period experienced greater fluctuations and a slight decline in mean inflow. Peak inflow occurred in 2012 (0.80), whereas 2016 recorded the lowest value (0.30), reflecting severe low-flow conditions. Favorable years like 2011 (0.71) were offset by multiple years of moderate to low inflows, indicating increased hydrological variability possibly influenced by climatic and anthropogenic pressures.

Period 3 (2017–2023):

The final period is marked by pronounced extremes, with exceptional inflows in 2019 (1.50) and 2020 (1.40), likely due to intense rainfall or snowmelt. These peaks contrast with moderate values in 2018 (0.80) and low inflow in 2023 (0.50), highlighting an increasingly unstable hydrological regime influenced by climate variability and watershed changes.

Over the 21-year span, Dez River inflows demonstrate alternating wet and dry phases, with a trend toward greater variability in recent years. This underscores the need for adaptive water management strategies capable of mitigating the impacts of both droughts and floods.

Figure 5. Inflow rate to the Bakhtiari watershed in the period 2003 to 2023

Source: Elaborated by the authors

4.2. Weighting the Evaluation Indicators and Calculating the Cumulative Index

The entropy weighting method was applied to assign weights to the evaluation indicators and compute composite indices within each category. Table 5 summarizes the entropy-derived weights for the pressure and support indicators involved in assessing the water resources carrying capacity.

Among the pressure indicators, population density received the highest weight (3.8), reflecting its dominant influence on water resource pressure. This is followed closely by evaporation (3.5), which significantly affects water availability. Income per unit area (3.2) and calories per unit area (2.8) also contribute meaningfully, though to a lesser extent. In contrast, the support indicators carry notably lower weights. River runoff per unit area (0.7) has the greatest relative influence among these, while precipitation (0.55) also plays a significant supportive role. Groundwater recharge (0.21) and per capita water resources (0.18) have comparatively minor weights, indicating a relatively limited direct contribution to the watershed's supportive capacity.

This distribution of weights underscores a pronounced imbalance: the cumulative effect of pressure indicators substantially exceeds that of support indicators, highlighting the vulnerability of the Bakhtiari watershed's water resources system under current conditions.

Table 5. Weight of support and pressure indicators

pressure	Population density	Income per unit area	Calories per unit area	Evaporation
	3.8	3.2	2.8	3.5
support	River runoff per	Groundwater recharge	Precipitation	Per capita water resources
	0.7	0.21	0.55	0.18

Source: Elaborated by the authors

4.3. Index Aggregation and Comprehensive Evaluation

Figure 6 illustrates the temporal variations of the Support Index (SI), Health Status Index (HSI), and Pressure Index (PI) over the period 2003–2023.

During the initial years (2003–2005), all three indices showed relatively high values, with SI ranging from 0.7 to 0.9, HSI from 0.8 to 0.9, and PI from 0.7 to 0.9, indicating generally favorable hydrological and environmental conditions within the watershed.

From 2006 to 2010, a gradual decline was evident across all indices. SI decreased from 0.7 in 2006 to 0.5 in 2010, HSI dropped from 0.8 to 0.6, and PI declined slightly to 0.6. These trends reflect increasing pressures on water resources and emerging signs of ecosystem degradation.

Between 2011 and 2016, the indices remained at moderate-to-low levels, exhibiting some fluctuations. The lowest values during this period were observed in 2016, with SI at 0.4, HSI at 0.5, and PI at 0.4, indicating reduced support capacity, deteriorating health status, and sustained pressures on the system.

The period following 2017 saw a more pronounced downward trend, especially after 2019. By 2020, SI had decreased further to 0.4, HSI to 0.3, and PI to 0.2. The lowest values across the entire time series were recorded in 2023, with SI at 0.2, HSI at 0.3, and PI at 0.1. These figures signal a critical condition characterized by severely diminished support capacity and ecosystem health, alongside persistent and relatively high pressures.

Overall, these results demonstrate a clear long-term degradation trend across all indices, with the most significant declines occurring in the last decade. This trajectory highlights increasing stress on the Bakhtiari watershed's water resources, likely driven by a combination of climatic variability, overexploitation, and inadequate management strategies.

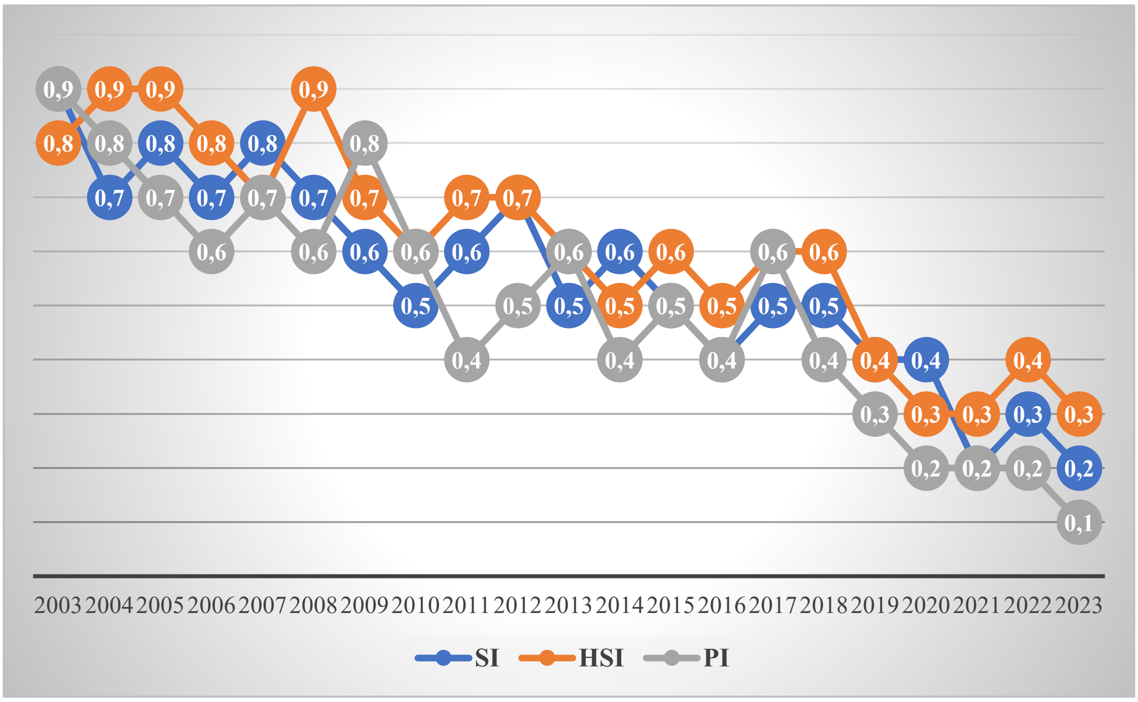

Figure 6. Changes in cumulative pressure, support, and status indicators over the period 2003 to 2023

Source: Elaborated by the authors

The balance between water demand and the capacity of water resources to meet this demand was evaluated through the Pressure-Support (PS) index in this study. Table 6 presents the average PS index values across the three examined periods.

The results show a marked increase in the PS ratio over time—from 2.6 in 2003–2009 to 5.6 in 2010–2017, and further rising to 6.8 in 2018–2023. This upward trend signifies escalating pressure on water resources relative to their support capacity, correlating with significant declines in both the water resources carrying capacity and the overall environmental health status during these periods.

Analysis of key hydrological and environmental parameters over the study period reveals notable differences between these intervals. Among these, precipitation—a critical factor affecting water resource support capacity—generally showed a declining trend. However, anomalously heavy rainfall events in 2019 and 2020 led to short-term increases in precipitation and inflow, temporarily boosting water availability in the region.

Table 6. Average changes in the degree of pressure-support index in the three periods studied

PS	2003-2009	2010-2017	2018-2023
	2.6	5.6	6.8

Source: Elaborated by the authors

Table 7 summarizes the average changes in the cumulative Pressure Index (PI), Support Index (SI), Health Status Index (HSI), and the comprehensive Water Resource Carrying Capacity Index (WECCI) across three distinct periods.

During 2003–2009, all indices reflected relatively strong conditions: SI at 0.9, HSI at 0.75, PI at 0.88, and WECCI at 0.84, indicating robust support capacity, favorable environmental health, and manageable pressure on water resources.

In the subsequent period (2010–2017), these values declined significantly. The SI dropped to 0.72, HSI plummeted to 0.31, PI decreased to 0.71, and WECCI fell to 0.58. This reflects a considerable reduction in the system's ability to support water demand and a marked deterioration in environmental health.

The most severe degradation occurred during 2018–2023, with SI declining further to 0.6, HSI to 0.21, PI to 0.41, and WECCI to 0.26. These results highlight increasing pressures and a severely compromised carrying capacity of the water resources system.

Overall, these trends reveal escalating stress on water resources and underscore the urgent need for improved management and conservation strategies to restore support capacity and safeguard ecosystem health.

Table 7. Average changes in cumulative pressure, support, and status indices and comprehensive water resource carrying capacity index in three time periods

	SI	HSI	PI	WECCI
2003-2009	0.9	0.75	0.88	0.84
2010-2017	0.72	0.31	0.71	0.58

2018-2023	0.6	0.21	0.41	0.26

Source: Elaborated by the authors

4.4. Final Evaluation of Water Resources Carrying Capacity

The final assessment of the water resources carrying capacity was based on the decision-making framework illustrated in Figure 7. The evaluation outcomes for each of the three periods are summarized below:

Period 1 (2003–2009):

The Environmental Health Status Index (HSI), serving as the primary initial criterion, was 0.75—significantly above the critical threshold of 0.32. This allowed the evaluation to proceed to the second stage, where the comprehensive Water Resource Carrying Capacity Index (WECCI) was assessed. The WECCI value during this period was 0.84, also exceeding its permissible limit, leading to the final evaluation stage involving the Pressure-Support (PS) index. The PS index was 0.9, below the threshold value of 1.0. Consequently, the water resources carrying capacity during this period was classified as "Carrying", indicating a generally sustainable condition.

Period 2 (2010–2017):

The HSI sharply declined to 0.21, falling below the critical threshold of 0.32. Due to this, the water resources carrying capacity was classified as "Overload", indicating a stressed and unsustainable system.

Period 3 (2018–2023):

The HSI remained low at 0.31, still below the allowable threshold, resulting in the continuation of the "Overload" status for water resources carrying capacity.

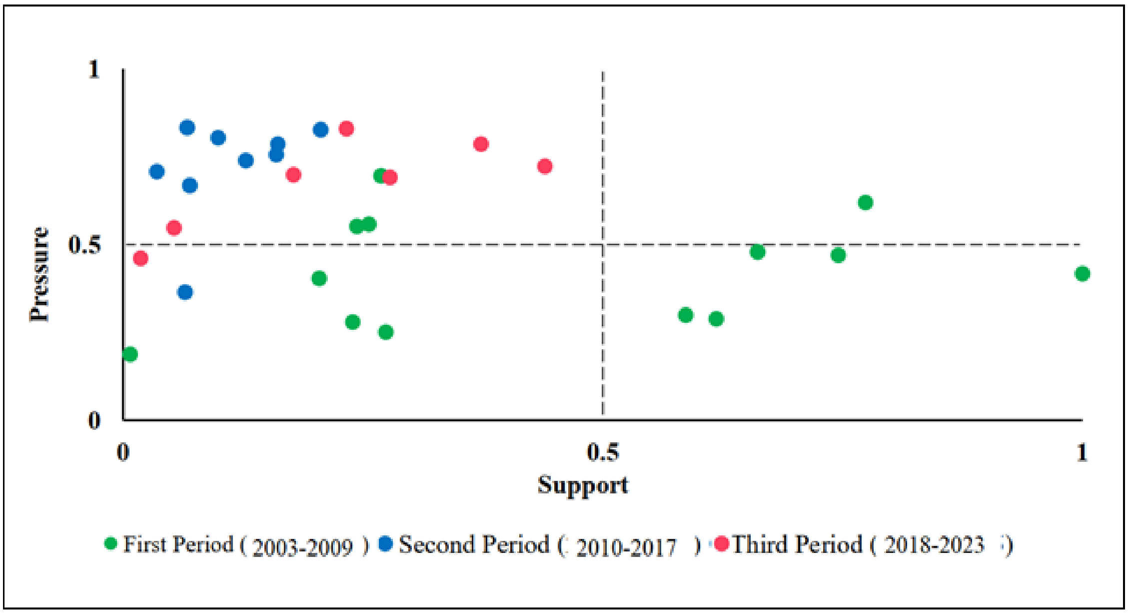

Figure 7. Pressure-Support Index Values in the period 2003-2023

Source: Elaborated by the authors

4.4.1. Analysis of the Pressure-Support (PS) Ratio

Period 1: The PS index showed variability across years but mostly remained within categories "C" and "D." This suggests fluctuating support capacity, with low support in some years balanced by higher support in others, and overall low pressure on water resources. The period is thus classified as state "C," where optimal management strategies should focus on strengthening the support subsystem, gradually advancing toward state "D," and ultimately achieving state "A."

Period 2: Most years fell under state "B," indicating a decline in support capacity compared to Period 1. This state reflects low support coupled with high pressure, signaling an urgent need for adaptive management, especially drought resilience and pressure mitigation. Unfortunately, implemented policies were inadequate or counterproductive, exacerbating pressure on water resources.

Period 3: This period also falls under state "B," though slightly improved due to better rainfall conditions. Nonetheless, ongoing water transfers to the Central Iranian Plateau increased the region's water stress, offsetting these gains.

4.5. Water Resource Carrying Capacity and Environmental Health Status

The annual status of water resources carrying capacity and environmental health, assessed according to the established evaluation standards, is depicted in Figures 8 and 9.

Environmental Health Status: Classified as Normal during the first period; declined to Poor in the second period; further deteriorated to Critical in the third period.

Water Resources Carrying Capacity: Rated as General Carrying in the first period; dropped to Poor Carrying status in both the second and third periods.

These results demonstrate a consistent decline in both environmental health and water resource carrying capacity, with a one-level drop during the second period, marking the lowest recorded condition in the study timeline.

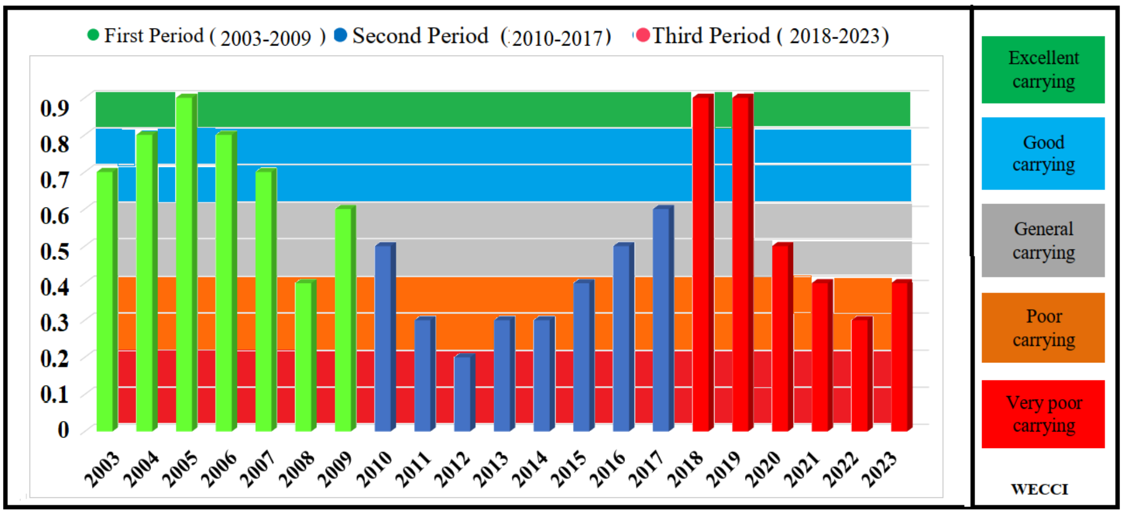

Figure 8. Changes in the Comprehensive Water Resources Carrying Capacity Index during the period (2003–2023)

Source: Elaborated by the authors

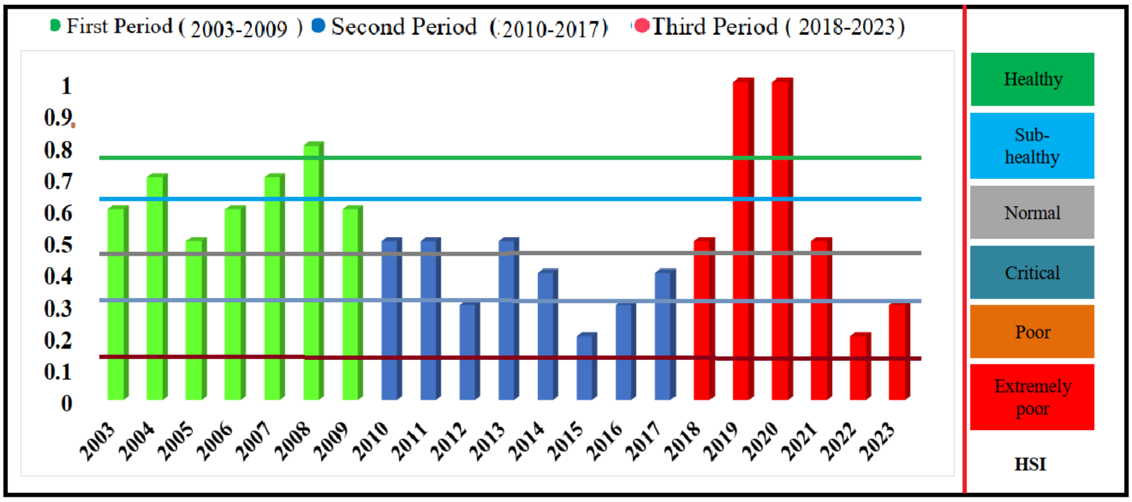

Figure 9. Changes in the Environmental Health Status Index

Source: Elaborated by the authors

4.6. Similarities and Differences with Other Studies

This study evaluates the carrying capacity of water resources and the environmental health status of the basin over the period 2003–2023, employing the DPSIR (Driver-Pressure-State-Impact-Response) framework, quantitative indicators, and Shannon entropy-weighting techniques. The results reveal a persistent imbalance between pressure and support factors, with population density and evaporation exerting the highest pressures, while support capacity—particularly groundwater recharge and per capita water resources—remains weak. Throughout the study period, the Support Index (SI), Health Status Index (HSI), and Pressure Index (PI) exhibited a clear downward trend, with the most severe deterioration occurring during the last decade. Extreme hydrological events, including high flows in 2019–2020 and drought years in 2016 and 2023, highlighted the system's vulnerability to climate change but failed to reverse the long-term decline in resilience.

Comparative analysis across three distinct time periods indicated a transition from a naturally balanced environmental health state in the first period to an overburdened state with poor then critical environmental health in the subsequent periods. This degradation resulted from decreased support capacity, intensified water extraction, inter-basin water transfers, and unsustainable management policies. To halt further decline, urgent integrated strategies are needed, focusing on demand-side management, ecosystem restoration, and the incorporation of environmental thresholds into developmental planning. Without such measures, the basin risks irreversible losses in water resource sustainability and environmental health.

Similarities:

- Use of Hydrological and Environmental Health Indicators: Numerous contemporary studies employ similar indicators to evaluate water sustainability (Wang et al., 2019; Chen et al., 2020). These studies typically analyze long-term trends and emphasize the influence of population dynamics, climate variability, and management practices (Wang et al., 2019).

- Emphasis on Ecosystem Restoration and Sustainable Policies: Our findings align with research highlighting ecosystem restoration and sustainable policies as critical interventions (Li et al., 2023b; Zhou et al., 2020). Such studies stress the importance of integrated water resource management and innovative solutions to environmental challenges (Wang et al., 2022; ZamanZad-Ghavidel et al., 2020).

- Long-term Trend Analysis: Several investigations conduct extensive temporal analyses to identify water resource carrying capacity trends (Dang et al., 2023; Zhou et al., 2019), contributing to a nuanced understanding of factors like population growth, land use practices, and environmental policies over time (Wang et al., 2019).

Differences:

- Application of Specific Methodological Tools: This study uniquely applies systematic tools such as Shannon entropy weighting and the explicit calculation of pressure, support, and state indices, which are not universally used (Hu & Li, 2022; Wang et al., 2022). These tools allow for a quantitative and systematic analysis of the complex relationships affecting water resource carrying capacity (Li et al., 2023a).

- Detailed Temporal Scope and Extreme Event Data: The clear time frame (2003–2023) and detailed data on extreme years (2016, 2019–2020, 2023) provide unique insights into temporal trends and the impact of hydrological extremes on water resource capacity (Zhou et al., 2020; Kourtit et al., 2023; Pan et al., 2022).

- Focus on a Specific Regional Case Study: A distinctive aspect of this work is the incorporation of region-specific factors such as groundwater recharge rates and inter-basin water transfers, enabling a deeper understanding of local challenges and tailored solutions (Tan & Bi, 2018; Xu et al., 2022).

- Characterization of Environmental Health Transitions: This study provides a diagnostic framework capturing the transition of environmental health status from "normal" to "critical," offering comprehensive historical evaluation and targeted strategic development (Dang et al., 2023; Hu & Li, 2022; Zhang et al., 2021).

- Public Health-Related Conclusions: Some referenced studies explore the link between public health and water resources, emphasizing water quality's impact on human health and wellbeing (Pan et al., 2022; Patil et al., 2020; ZamanZad-Ghavidel et al., 2020), including risk assessment and mitigation strategies to protect public health.

- Overall, the comparative results contribute to a comprehensive understanding of both methodological robustness and system vulnerabilities, underscoring the urgent need for integrated, localized approaches in water resource management (Sun et al., 2018).

5. Conclusion

This study evaluated the carrying capacity of water resources and the environmental health status of the basin over the period 2003–2023, using the Pressure–Support–State framework, quantitative indicators, and entropy-based weighting. The results reveal a persistent imbalance between pressure and support factors, with population density and evaporation exerting the greatest pressures, while the support capacity—especially groundwater recharge and per capita water resources—remained weak and insufficient.

All three key indices—the Support Index (SI), Health Status Index (HSI), and Pressure Index (PI)—exhibited a clear downward trend, with the most severe deterioration occurring in the last decade. Hydrological extremes, such as the high inflows in 2019–2020 and drought years like 2016 and 2023, highlighted the basin's vulnerability to climatic variability but were insufficient to reverse the long-term decline in resilience.

Comparative analysis across three periods showed a transition from a "Carrying" state with Normal environmental health in the first period to an "Overload" state with Poor and then Critical environmental health in the second and third periods. This degradation was driven by reduced support capacity, intensified water extraction, inter-basin transfers, and unsustainable management policies.

The analysis further reveals that sustainable water resource management policies in the region have largely failed to reconcile rapid economic development with the finite support capacity of water resources. Rather than alleviating pressure, existing policies have intensified it, exacerbating the basin's deteriorating conditions.

To reverse this adverse trend, a comprehensive revision of water management policies is urgently required. Key priorities include:

Implementing effective measures to reduce pressure on water resources, such as demand-side management and efficient water use.

Enhancing the support capacity of the water resource system through ecosystem restoration and improved recharge techniques.

Integrating social and economic considerations with ecological sustainability to create adaptive and holistic management policies.

Only through such integrated and adaptive strategies can the overall carrying capacity of the basin's water resources be improved, securing long-term environmental health, water security, and sustainable development for the region.

6. Closing Statements

Contributions of each author:

Elham Ghasemi Ziyarani: conceptualization, investigation, data curation, formal analysis, writing – original draft, visualitazion and validation; Maryam Ilanloo: supervision, methodology, investigation, project administration and writing – review & editing.

Funding:

The authors declare that they did not receive funding for writing or publishing this article.

Conflict of Interest:

The authors declare no conflicts of interest in the writing or publication of this article.

Ethical Implications:

The authors have no ethical implications that should be declared in the writing or publication of this article.

Statement on the Use of Artificial Intelligence:

The authors declare that they did not use artificial intelligence.

7. Bibliographic references

Barati, A., Azadi, H. & Scheffran, J. (2019). A system dynamics model of smart groundwater governance. *Agricultural Water Management*, *221*, 502–518. https://doi.org/10.1016/j.agwat.2019.03.047

Brugnach, M. & Özerol, G. (2019). Knowledge Co-Production and Transdisciplinarity: Opening Pandora’s Box. *Water*, *11*(10), 1997. https://doi.org/10.3390/w11101997

Chen, D., Zhou, Q-G. & Yu, L. (2020). Response of resources and environment carrying capacity under the evolution of land use structure in Chongqing Section of the Three Gorges Reservoir Area. *Journal of Environmental Management*, *274*, 111169. https://doi.org/10.1016/j.jenvman.2020.111169

Chi, M., Zhang, D., Fan, G., Zhang,W. & Honglin, L. (2019). Prediction of water resource carrying capacity by the analytic hierarchy process-Shannon entropy discrimination method in a mining area. *Ecological Indicators*, *96*, 647–655. https://doi.org/10.1016/j.ecolind.2018.09.021

Dang, X., Zhao, X., Kang, Y., Liu, X., Song, J. & Zhang, Y. (2023). Analysis of Carrying Capacity and Obstacle Factors of Water Resources in Longnan City, China, Based on Driving–Pressure–State–Response and Technique for Order Preference by Similarity to an Ideal Solution Models. *Water*, *15*(14), 2517. https://doi.org/10.3390/w15142517

Delavar, M., Eini, M. R., Kuchak, V. S., Zaghiyan, M. R., Shahbazi, A., Nourmohammadi, F., & Motamedi, A. (2022). Model-based water accounting for integrated assessment of water resources systems at the basin scale. *Science of the Total Environment*, *830*, 154810. https://doi.org/10.1016/j.scitotenv.2022.154810

Djuwansyah, M. (2018). Environmental sustainability control by water resources carrying capacity concept: Application significance in Indonesia. *IOP Conference Series: Earth and Environmental Science*, 118, 012027. https://doi.org/10.1088/1755-1315/118/1/012027

Du, Y-W. & Wang, Y-C. (2021). Evaluation of marine ranching resources and environmental carrying capacity from the pressure-and-support perspective: A case study of Yantai. *Ecological Indicators*, *126*, 107688. https://doi.org/10.1016/j.ecolind.2021.107688

Henchiri, M., Zhang, J., Li, S., Essifi, B. & Wilson, K. (2024). Comprehensive assessment of drought vulnerability and resilience over North and West Africa during 1980–2100. *Agricultural Water Management*, *296*, 108804. https://doi.org/10.1016/j.agwat.2024.108804

Honarbakhsh, A., Niazi, A., Soltani, S. & Tahmasebi, P. (2019). Modeling the relationship between suspended sediments and hydrological and environmental characteristics of a basin (case study: basin of Dez Dam). *Quantitative Geomorphological Research*, *8*(1), 105–117. https://tinyurl.com/bd593jzk

Hu, A. & Li, Q. (2022). A pressure-state-response-support framework for assessing regional water environmental carrying status. *Frontiers in Environmental Science*, *10*, 1023180. https://doi.org/10.3389/fenvs.2022.1023180

Kourtit, K., Nijkamp, P. & Banica, A. (2023). An analysis of natural disasters' effects – A global comparative study of 'Blessing in Disguise'. *Socio-Economic Planning Sciences*, *88*, 101599. https://doi.org/10.1016/j.seps.2023.101599

Li, Q., Liu, Z., Yang, Y., Han, Y. & Wang, X. (2023a). Evaluation of water resources carrying capacity in Tarim River Basin under game theory combination weights.

Ecological Indicators, *154*, 110609. https://doi.org/10.1016/j.ecolind.2023.110609

Li, W., Liu, S., Chang, W., Zhang, X., Li, C. & Qin, T. (2023b). Research Progress on the Evaluation of Water Resources Carrying Capacity. *Polish Journal of Environmental Studies*, *32*(3), 1975–1986. https://doi.org/10.15244/pjoes/160199

Lyra, A., Loukas, A., Sidiropoulos, P., Voudouris, K. & Mylopoulos, N. (2022). Integrated Modeling of Agronomic and Water Resources Management Scenarios in a Degraded Coastal Watershed (Almyros Basin, Magnesia, Greece). *Water*, *14*(7), 1086. https://doi.org/10.3390/w14071086

Luo, W., Shen, L., Zhang, L., Liao, X., Meng, C., & Jin, C. (2022). A load-carrier perspective method for evaluating land resources carrying capacity. *International Journal of Environmental Research and Public Health*, *19*(9), 5503. https://doi.org/10.3390/ijerph19095503

Magri, A. & Berezowska-Azzag, E. (2019). New tool for assessing urban water carrying capacity (WCC) in the planning of development programs in the region of Oran, Algeria. *Sustainable Cities and Society*, *48*, 101316. https://doi.org/10.1016/j.scs.2018.10.040

Mashaly, A. & Fernald, A. (2020). Identifying Capabilities and Potentials of System Dynamics in Hydrology and Water Resources as a Promising Modeling Approach for Water Management. *Water*, *12*(5), 1432. https://doi.org/10.3390/w12051432

Pan, D., Shao, Y., Song, Y., Huang, D., Liu, S., Zeng, X., Liang, J., Tan, H. & Qiu, X. (2022). Association between maternal per-and polyfluoroalkyl substance exposure and newborn telomere length: Effect modification by birth seasons. *Environment International*, *161*, 107125. https://doi.org/10.1016/j.envint.2022.107125

Patil, V., Pinto, S., Govindaraju, T., Hebbalu, V., Bhat, V. & Kannanur, L. (2020). Multivariate statistics and water quality index (WQI) approach for geochemical assessment of groundwater quality—a case study of Kanavi Halla Sub-Basin, Belagavi, India. *Environmental Geochemistry and Health*, *42*, 2667–2684. https://doi.org/10.1007/s10653-019-00500-6

Sohoulande, D. (2019). Streamflow Drought Interpreted Using SWAT Model Simulations of Past and Future Hydrologic Scenarios: Application to Neches and Trinity River Basins, Texas. *Journal of Hydrologic Engineering*, *24*(9), 05019024. https://doi.org/10.1061/(ASCE)HE.1943-5584.0001827

Sun, J., Yu, X., Xiao, Q., Song, J. & Sun, S. (2018). Utilization Characteristics and Sustainability Evaluation of Water Resources in China. *Water*, *10*(9), 1142. https://doi.org/10.3390/w10091142

Tan, F. & Bi, J. (2018). An inquiry into water transfer network of the Yangtze River Economic Belt in China. *Journal of Cleaner Production*, *176*, 288–297. https://doi.org/10.1016/j.jclepro.2017.12.129

Wang, X., Zhang, S., Gao, C. & Tang, X. (2024). Coupling coordination and driving mechanisms of water resources carrying capacity under the dynamic interaction of the water-social-economic-ecological environment system. *Science of The Total Environment*, *920*, 171011. https://doi.org/10.1016/j.scitotenv.2024.171011

Wang, X., Zhang, S., Tang, X. & Gao, C. (2022). Research on water resources environmental carrying capacity (WRECC) based on support-pressure coupling theory: a case study of the Guangdong-Hong Kong-Macao Greater Bay Area. *Journal of Environmental Management*, *320*, 115805. https://doi.org/10.1016/j.jenvman.2022.115805

Wang, J., Ren, Y., Shen, L., Liu, Z., Wu, Y. & Shi, F. (2020). A novel evaluation method for urban infrastructures carrying capacity. *Cities*, *105*, 102846. https://doi.org/10.1016/j.cities.2020.102846

Wang, X., Dong, Z., Xu, W., Luo, Y., Zhou, T. & Wang, W. (2019). Study on Spatial and Temporal Distribution Characteristics of Coordinated Development Degree among Regional Water Resources, Social Economy, and Ecological Environment Systems. *International Journal of Environmental Research and Public Health*, *16*(21), 4213. https://doi.org/10.3390/ijerph16214213

Xu, W., Zhou, C., Liu, B., Wang, D., Zhao, X., Yang, X., Zhu, X. & Lin, Z. (2022). Study on water resources carrying capacity in Zhuanglang River Basin. *Environmental Monitoring and Assessment*, *194*, 390. https://doi.org/10.1007/s10661-022-10027-6

Xu, Y., Ma, L. & Khan, N. (2020). Prediction and Maintenance of Water Resources Carrying Capacity in Mining Area—A Case Study in the Yu-Shen Mining Area. *Sustainability*, *12*(18), 7782. https://doi.org/10.3390/su12187782

Yang, S. & Yang, T. (2021). Exploration of the dynamic water resource carrying capacity of the Keriya River Basin on the southern margin of the Taklimakan Desert, China. *Regional Sustainability*, *2*(1), 73–82. https://doi.org/10.1016/j.regsus.2021.01.005

Yang, Z., Song, J., Cheng, D., Xia, J., Li, Q. & Ahamad, M. (2019). Comprehensive evaluation and scenario simulation for the water resources carrying capacity in Xi'an city, China. *Journal of Environmental Management*, *230*, 221–233. https://doi.org/10.1016/j.jenvman.2018.09.085

Yan, B. & Xu, Y. (2022). Evaluation and prediction of water resources carrying capacity in Jiangsu Province, China. *Water Policy*, *24*(2), 324–344. https://doi.org/10.2166/wp.2022.172

Yin, X., Huang, C. & Sun, K. (2023). Evaluation of water resources carrying capacity in Anhui Province based on association analysis model in the context of digital transformation. *Desalination and Water Treatment*, *299*, 239–247. https://doi.org/10.5004/dwt.2023.29682

Yaykiran, S., Cuceloglu, G. & Ekdal, A. (2019). Estimation of Water Budget Components of the Sakarya River Basin by Using the WEAP-PGM Model. *Water*, *11*(2), 271. https://doi.org/10.3390/w11020271

ZamanZad-Ghavidel, S., Bozorg-Haddad, O. & Goharian, E. (2020). Sustainability assessment of water resource systems using a novel hydro-socio-economic index (HSEI). *Environment, Development and Sustainability*, *23*, 1869–1916. https://doi.org/10.1007/s10668-020-00655-8

Zhang, N., Wang, Z., Zhang, L. & Yang, X. (2021). Assessment of Water Resources Carrying Risk and the Coping Behaviors of the Government and the Public. *International Journal of Environmental Research and Public Health*, *18*(14), 7693. https://doi.org/10.3390/ijerph18147693

Zhang, X-Y., Zuo, Q-T., & Yang, Q-X. (2018). Calculation of the water resources dynamic carrying capacity of Tarim River Basin under climate change. *Desalination and Water Treatment*, *119*, 243–252. https://doi.org/10.5004/dwt.2018.22056

Zhou, Y., Li, X., Gao, Y., He, M., Wang, M., Wang, Y., Zhao, L. & Li, Y. (2020). Carbon fluxes response of an artificial sand-binding vegetation system to rainfall variation during the growing season in the Tengger Desert. *Journal of Environmental Management*, *266*, 110556. https://doi.org/10.1016/j.jenvman.2020.110556

Zhou, X-Y., Zheng, B. & Khu, S-T. (2019). Validation of the hypothesis on carrying capacity limits using the water environment carrying capacity. *Science of The Total Environment*, *665*, 774–784. https://doi.org/10.1016/j.scitotenv.2019.02.146