

1 **Strategies for Enhancing Water Security in Iran's Agricultural Sector**
2 **under Climate Change**

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4 **Abstract**

5 The issue of climate change and its associated water security challenges has become a growing
6 concern for Iran, particularly in its agricultural sector. Increasing population, rising demand for
7 agricultural products, and the need for food security exacerbate these challenges. This study
8 highlights the risks posed by reduced precipitation, rising temperatures, and inefficient water
9 management practices, including heavy reliance on groundwater and outdated irrigation
10 systems. It emphasizes the urgent need for modern irrigation technologies, such as water
11 recycling (NEWater), and robust governance reforms to improve water use efficiency, analyzed
12 through the HES framework. The study concludes that adopting a comprehensive, long-term
13 strategy, incorporating technological innovations, localized water management practices, and
14 enhanced governance, can mitigate the impacts of climate change and ensure the sustainable
15 use of water resources in Iran's agricultural sector.

16 **Keywords:** Agriculture, Climate change, HES analysis, Iran, NEWater, Water security.

17 **1. Introduction**

18 It is undeniable that climate change and water security are fundamental global challenges for
19 sustainable development and human security. Water is essential for life and is a crucial aspect
20 of the goals and challenges of sustainable development. Moreover, climate change can
21 exacerbate water tensions and lead to a scarcity crisis, provoking both positive and negative
22 shifts globally (Zhou et al., 2021). Scholars, including Hosea (2022), have documented the
23 impact of these twin challenges on human security and development. In Iran, these challenges
24 are further intensified by multiple vulnerabilities, such as population growth, poverty,
25 governance deficiencies, and the effects of economic sanctions (Farzanegan & Habibpour,
26 2017; Pourezzat et al., 2018; Shahriyari, Amiri & Shahryari, 2018; Abdoli, 2020). Similarly,
27 Biswas and Tortajada's (2022) study on the estimated economic losses caused by climate-
28 related disasters shows that economic losses as a percentage of GDP are significantly higher
29 for low-income countries compared to high-income countries. This disparity may exacerbate
30 inequality both between rich and poor nations and within low- and middle-income countries

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31 (Biswas & Tortajada, 2022). Reports from Iran indicate that a 1% increase in the temperature
32 across the country's provinces could lead to a 0.12% decrease in GDP growth, contributing to
33 a climate-induced reduction in Iran's overall economic growth (Salehi Komroudi &
34 Abounoori, 2019).

35 **The escalating population growth in Iran presents significant challenges, particularly in**
36 **meeting the increasing demand for essential resources such as food, water, and energy.**
37 **With the population projected to reach 200 million by 2050, the strain on existing**
38 **resources will intensify, further complicating efforts to tackle climate change. As the**
39 **population grows, pressure on agricultural systems to produce more food increases,**
40 **leading to higher water consumption and energy use. In the context of climate change,**
41 **this demand becomes even more critical, as rising temperatures and decreasing**
42 **precipitation threaten the availability of these vital resources. Moreover, the relationship**
43 **between climate and agriculture is inherently bidirectional. Human activities,**
44 **particularly intensive agricultural practices, contribute to greenhouse gas emissions,**
45 **accelerating climate change. In turn, these climatic shifts exacerbate agricultural**
46 **vulnerabilities by increasing water requirements, reducing crop yields, and diminishing**
47 **overall productivity. This reciprocal relationship highlights the need for sustainable**
48 **solutions that address both climate change mitigation and adaptation in the agricultural**
49 **sector.**

50 The growing emphasis on sustainable pathways toward improving water security led Gray and
51 Sadoff (2007) to define water security as "the availability of an acceptable quantity and quality
52 of water that is essential to health, livelihoods, ecosystems, and production, and at the same
53 time the extent of the risks that water poses to people, the environment, and the economy."
54 This definition underscores that water is not only vital for human survival but also serves as
55 the economic foundation for millions of enterprises, farms, power plants, and industries, all of
56 which rely on dependable water quality and availability (Gunda et al., 2019).

57 In this regard, some researchers argue that the scope of social challenges in achieving and
58 maintaining sustainable water security is influenced by several factors, including: 1) the
59 hydrological environment, which is a natural heritage; 2) the socio-economic environment,
60 reflecting the economic structure and behavior of its actors, as well as the natural, cultural, and
61 political heritage; and 3) future environmental changes, notably climate change (Grey &
62 Sadoff, 2007). Consequently, addressing water security concerns requires not only
63 policymaking, comprehensive planning, technological innovations, and sectoral collaboration

64 but also consideration of their profound impacts on both natural and social environments. Even
65 if complete water security cannot be fully achieved, policy instruments should be expanded to
66 enhance water security. These tools may include governance strategies, institutional reforms,
67 market-based approaches, adaptive capacity-building, and information exchange (World Bank,
68 2015; OECD, 2013; United Nations University, 2013).

69 Given the interconnectedness of these vulnerabilities and the dynamic nature of the challenges
70 Iran faces, managing these concerns becomes increasingly complex. By consuming natural
71 resources, we generate more greenhouse gases, which contribute to global warming and further
72 climate change through various pathways. These issues increase the range of secondary
73 problems that can seriously affect food production, energy needs, usage patterns, and water
74 management.

75 This has often been a recurring issue, where solutions to one problem can create significant
76 challenges in other areas. As such, it is essential to ensure that solutions deemed effective for
77 addressing one major problem do not create issues in other contexts. Instead of focusing solely
78 on isolated problems, it is crucial to develop solutions that consider and evaluate the
79 interconnected challenges.

80 **This research fills a significant gap in the literature by exploring the interplay between**
81 **climate change and water security in Iran's agricultural sector—a topic that has received**
82 **limited scholarly attention. While existing studies often address climate change or water**
83 **security separately, this research uniquely examines their combined effects within the**
84 **context of Iran, focusing on the sector-specific challenges of agriculture. It identifies the**
85 **lack of localized strategies tailored to Iran's unique climatic, socio-economic, and**
86 **governance realities as a key research gap (Mansouri Daneshvar et al., 2019; Mirzaei et**
87 **al., 2019).**

88 **Additionally, the study highlights the underexplored potential of integrating recycled**
89 **water (NEWater) technologies into Iran's agricultural practices, drawing on**
90 **international examples such as those implemented in Singapore and Namibia (Tortajada**
91 **& van Rensburg, 2019). By doing so, it bridges the gap between global best practices and**
92 **local applicability. Furthermore, the research incorporates socio-economic and policy**
93 **dimensions, addressing gaps in the governance and planning frameworks that currently**
94 **hinder optimal water resource management in Iran (Jamali Jaghdani & Kvartiuk, 2021).**
95 **This comprehensive approach positions the study as a critical contribution to the**
96 **discourse on sustainable water management in arid and semi-arid regions.**

97 Climate change has had significant impacts on Iran, manifested in rising temperatures,
98 altered precipitation patterns, increased frequency of droughts, sudden floods, and
99 intensified dust storms. Over the past three decades, the average temperature in Iran has
100 increased by approximately 1°C per decade, with projections indicating a further rise of
101 2.6°C by the end of the century. This steady increase in temperature has accelerated
102 evaporation rates, exacerbating water shortages nationwide.

103 Precipitation patterns have also undergone significant shifts. Around 67% of climate
104 stations in Iran report decreasing annual rainfall, with regions in the northern and
105 northwestern parts of the country experiencing declines of up to 15% in yearly
106 precipitation. Conversely, short-term, intense rainfall events have increased in arid and
107 semi-arid regions, leading to flash floods. Recent data reveals that 50% of monitored
108 stations have recorded an increase in 24-hour maximum precipitation, causing
109 devastating floods that affect urban infrastructure and agricultural productivity (Salehi
110 et al., 2020).

111 Droughts have become more frequent and prolonged, impacting over 90% of the country
112 to varying degrees. Between 2001 and 2022, Iran saw an unprecedented reduction in
113 groundwater reserves, losing approximately 130 billion cubic meters, primarily due to
114 unsustainable agricultural practices. This decline has placed additional strain on food
115 security and rural livelihoods (Barati et al., 2023). These reductions in precipitation,
116 groundwater, and renewable resources underscore the urgent need for targeted climate
117 adaptation strategies. Addressing these challenges will require a multidimensional
118 approach that integrates advanced water management practices, effective governance,
119 and community-level interventions.

120 This article explores the challenges of climate change and water security in Iran's agricultural
121 sector, aiming to identify optimal strategies for managing water consumption in the face of
122 escalating climate change and water insecurity. As climate change is expected to result in
123 decreased rainfall and increased temperatures in the coming years, implementing effective
124 water management strategies in agriculture is crucial. To achieve this, the article first
125 introduces the concept of water security, followed by an examination of its implications within
126 the context of climate change in Iran. It then highlights the significance and extent of water
127 consumption in Iran's agricultural sector. Finally, the article discusses key strategies for
128 enhancing water resource management in the country.

129

130 **2. Materials and Methods**

131 This research adopts a comprehensive and innovative methodology to address the
132 challenges of water security and climate change within Iran's agricultural sector. A
133 qualitative approach is utilized, combining systematic review, discourse analysis, scenario
134 modeling, and stakeholder analysis to provide a multidimensional perspective.

135 During the data collection phase, both primary and secondary data are gathered from
136 various sources. A systematic review of academic articles and reports is conducted to
137 understand the relationship between human-environment systems (HES) and water
138 security in the context of climate change. In total, 68 articles were reviewed and analyzed
139 to understand the interplay between human-environmental systems (HES) and water
140 security in the context of climate change, with 22 of these specifically exploring how
141 human activities, such as agricultural practices, groundwater extraction, and governance
142 frameworks, affect environmental feedback loops and the sustainability of water
143 resources. The review also emphasizes the role of advanced irrigation technologies,
144 governance reforms, and climate-resilient agricultural practices in improving water
145 security under changing climatic conditions. By synthesizing these perspectives, the study
146 establishes the HES framework as a conceptual foundation for exploring adaptive,
147 resilient, and context-specific water resource management strategies. Additionally, semi-
148 structured interviews are conducted with experts in agriculture, climate change, and
149 water policy to gather specialized insights and indigenous knowledge. Quantitative and
150 statistical data—including temperature fluctuations, precipitation patterns, and
151 agricultural water consumption—are sourced from national and international
152 organizations, providing a solid empirical foundation for the study.

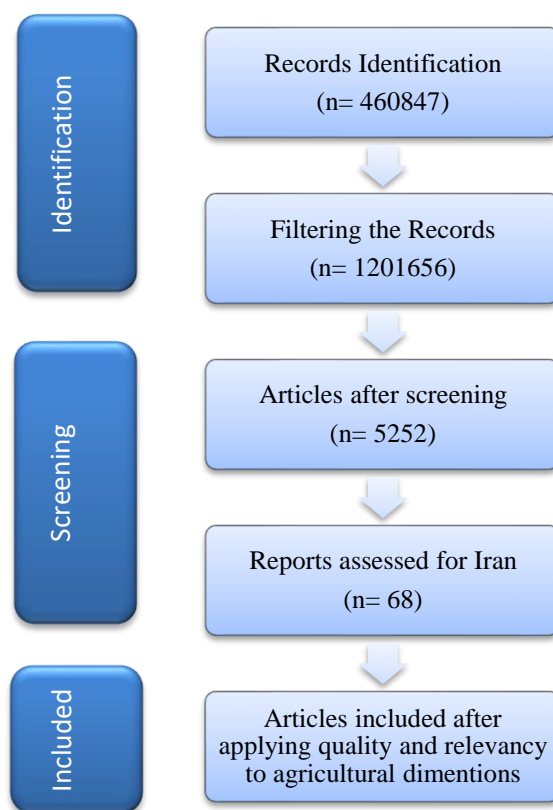
153 In the analysis phase, discourse analysis is applied to policy documents, academic
154 literature, and media reports, revealing patterns, contradictions, and thematic trends
155 related to water security and agriculture in Iran. Scenario modeling is employed to
156 simulate the impacts of climate change on water productivity and agricultural practices,
157 with projections for temperature increases and reduced precipitation. Moreover,
158 stakeholder network analysis examines the interactions and influence of key actors, such
159 as government agencies, farmers, and the private sector, to understand their roles in
160 water management.

161 The final stage of the research focuses on the development of practical and sustainable
162 solutions. A policy framework is proposed to optimize water resource management in

163 agriculture, emphasizing the adoption of advanced technologies, modern irrigation
164 systems, and water recycling methods such as NEWater. These solutions are validated
165 through expert consultations and feedback from key stakeholders. To enhance resilience,
166 adaptive decision-making tools are developed to assist policymakers in responding to
167 rapidly changing climatic conditions.

168 This research is innovative in several ways. First, it integrates multiple analytical methods
169 to offer a holistic understanding of the challenges. Second, it bridges global best practices,
170 such as NEWater technologies, with localized solutions tailored to Iran's specific context.
171 Third, it adopts a participatory approach by incorporating the perspectives and
172 interactions of various stakeholders. By addressing current challenges and proposing
173 forward-looking strategies, this study makes a significant contribution to the discourse
174 on sustainable water management in arid and semi-arid regions.

175 A scoping review is seen as a method for synthesizing evidence-based research, focusing
176 on identifying research priorities and gaps to inform policy reviews and future studies
177 (Hosea & Khalema, 2020). This approach allows complex issues or under-examined
178 topics to be treated as specific projects (Gutierrez-Bucheli et al., 2022). The scoping
179 review led to the compilation of grey literature, studies, and available online reviews on
180 "climate change," "water security," and "Iranian agriculture," sourced from Scopus and
181 other scholarly search engines. Using these keywords, the search revealed 460,847 articles
182 related to climate change, of which 120,165 discussed both climate change and water. Of
183 these, only 5,252 articles addressed the intersection of water security and climate change.
184 When focusing specifically on Iran, just 68 articles covered both climate change and
185 water security in the Iranian context. Furthermore, 24 of these articles incorporated an
186 agricultural dimension in their discussion of climate change and water security in Iran
187 (See <https://www-scopus-com>). A purposive sampling technique was employed to ensure
188 the inclusion of high-quality, contextually relevant studies. Articles were selected based
189 on their geographical focus on Iran, methodological rigor, and relevance to the themes of
190 climate change, water security, and agricultural practices. Additionally, local studies and
191 reports were incorporated to capture region-specific insights and challenges.



192

193 **Figure 1.** Preferred Reporting Items for Systematic Reviews flow chart for the systematic
194 literature review.

195

196 3. Results

197 3.1. Climate change in Iran

198 Temperature and precipitation are two of the most critical climatic parameters influencing food
199 production in Iran. Among countries in West Asia, Iran is projected to experience a 2.6°C rise
200 in mean temperatures and a 35% decline in precipitation over the coming decades (Mansouri
201 Daneshvar et al., 2019). Evidence shows that Iran, like many other countries, has witnessed
202 rapid warming in recent decades. Alizadeh-Choobari et al. (2017), using meteorological data
203 from fifteen ground stations across Iran over a 63-year period (1951–2013), examined
204 minimum, maximum, and daily near-surface air temperatures. Their findings indicated that
205 annual minimum, maximum, and average near-surface air temperatures have all increased in
206 most regions of Iran. Thus, it can be concluded that Iran, like most countries, has been warming
207 rapidly over the past few decades. In particular, temperatures in many regions of Iran began to
208 show a significant shift in the 1980s or 1990s, with average temperatures rising by
209 approximately 1.2°C after these turning points (Alizadeh-Choobari & Najafi, 2017).

210 As a result of this warming, Iran has experienced a downward trend in annual precipitation.

211 The decrease in precipitation, coupled with rising temperatures, suggests that Iran has become

212 drier and more vulnerable to droughts in recent decades (Alizadeh-Choobari & Najafi, 2017).
213 Additionally, Bazrkar et al. (2015) predict an increase in monthly temperatures for Iran in the
214 coming years, based on the IPCC's SRES scenarios.

215 When considering precipitation, several critical parameters influence food production, such as
216 the quantity and variability of rainfall. In Iran, annual precipitation is declining at 67% of
217 climate stations, while 50% of the stations are experiencing an increase in the 24-hour
218 maximum precipitation (Salehi et al., 2020; Bazrkar et al., 2015). The decline in annual rainfall
219 is most prominent in northern and northwestern regions, while the increase in maximum 24-
220 hour rainfall is observed mainly in arid and semi-arid areas. Although regional variations in
221 annual precipitation are substantial, they are insufficient to compensate for the increasing 24-
222 hour rainfall events. These changing precipitation patterns began in the 1970s across most
223 climate stations, signaling the initial stages of climate change in Iran.

224 The decreasing annual precipitation could eventually lead to significant changes in Iran's water
225 supply, particularly increasing demand for agricultural and urban water in arid and semi-arid
226 regions. Conversely, the increasing intensity of 24-hour maximum rainfall poses a risk of
227 accelerating soil degradation, which could contribute to desertification in these already
228 vulnerable areas.

229 Recent studies highlight the growing prevalence of rainfall variability and climate change in
230 Iran, which has resulted in more frequent floods and droughts, the two most significant climate-
231 related challenges affecting food production (Vaghefi et al., 2019). Abeysekera et al. (2015)
232 observed substantial increases in rainfall variability in the dry zones during both cultivation
233 seasons. These changes lead to fluctuations in moisture conditions during the reproductive
234 stage of crops, impacting both the quantity and quality of crop yields. A recent study also
235 showed an increase in extreme rainfall during the cropping season, which can result in
236 excessive humidity during critical stages of crop development, ultimately affecting yield
237 quality and quantity (Abeysekera et al., 2015).

238 Extreme precipitation events have become critical factors in managing erosion and flood risks.
239 Maleksaeidi et al. (2021) note that over the past decade (2013–2017), extreme weather events
240 with varying impacts on crop production have become more frequent. Rice, a staple crop that
241 accounts for 15% of Iran's agricultural production, has been particularly affected. A
242 comparison between agricultural production data from 2011–2012 and 2018–2019 reveals a
243 troubling trend: agricultural production in Iran has stagnated, and the agricultural sector's share
244 of the GDP is expected to decrease significantly. The studies conducted in western Iran further

245 indicate water scarcity and low productivity, with environmental and climate-related disasters
246 identified as the major concerns of participants—two of which are directly linked to climate
247 change (Maleksaeidi et al., 2021).

248 According to the Iran Meteorological Organization, the average surface temperature in Iran has
249 risen by 1 to 1.5°C over the past 30 years, with an average increase of approximately 0.05°C
250 per year. Each 1°C increase in temperature results in a 5% to 7% rise in evapotranspiration.
251 Iran currently has around 106 billion m³ of renewable water, with 75% lost to
252 evapotranspiration, 17% as runoff, and 13% percolating into aquifers. However, only 30% of
253 this renewable water is accessible, amounting to around 31 billion m³. Over the next 50 years,
254 annual precipitation is projected to decline from approximately 357 billion m³ to 218 billion
255 m³. Groundwater and renewable water resources are expected to decrease significantly, from
256 45.7 billion m³ and 106 billion m³, respectively, to 8.64 billion m³ and 37.9 billion m³. This
257 disparity between the projected 38.9% decline in precipitation and the 81% and 64% reductions
258 in groundwater and renewable resources indicates a future intensification of water scarcity
259 (Barati et al., 2023; Cline, 2007; Mansouri Daneshvar et al., 2019; Babaeian et al., 2015).
260 Figure 2 illustrates the predicted climate change scenarios.

261 The implications of this decline in precipitation, coupled with rising temperatures, cannot be
262 overstated. Water insecurity is becoming increasingly probable (Patrick, 2021). Consequently,
263 the effects of climate change on food production and the agricultural sector at large are
264 emerging as critical policy and security issues.

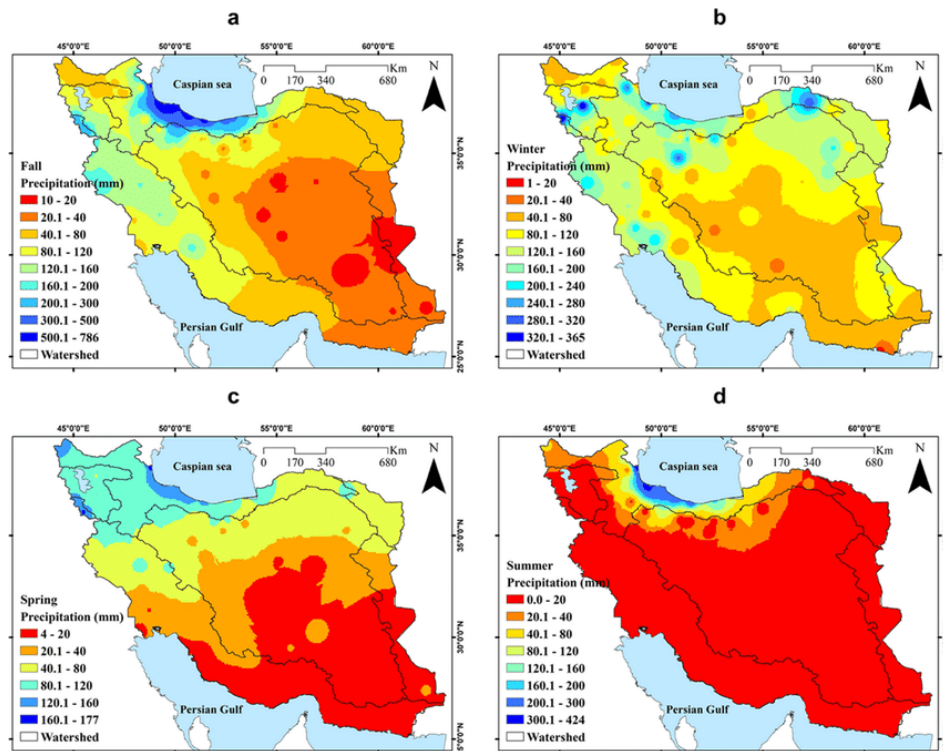


Figure 2. Long-term (2020 - 2050) mean precipitation in Iran (Behzadi et al., 2021).

3.2. Water Security in Iran

Water security is defined in various ways across cultural, academic, and practical contexts. At the Second World Water Forum in March 2000, held in The Hague, water security was characterized as the enhancement and protection of freshwater and coastal ecosystems, promoting sustainable development and political stability. It also involves ensuring safe and affordable water for all and protecting vulnerable populations from water-related hazards.

The Centre for Water Security defines water security as the ability of communities to maintain access to sufficient, quality water for human and ecosystem health, while efficiently protecting lives and property from water hazards (Centre for Water Security, 2014). Similarly, the United Nations (2013) emphasizes the importance of water security in ensuring sustainable livelihoods, promoting socio-economic development, preserving ecosystems, and ensuring stability. The UN's definition focuses on adequate water access to sustain livelihoods while safeguarding against pollution and water-related disasters.

Despite these varying definitions, they all aim to ensure access to safe and quality water for both social and economic needs. However, achieving consensus on water security at the transnational level remains challenging due to the lack of authoritative international legal frameworks and competing national interests. The diverse uses of water—along with the

285 significance of local context and cultural perspectives—further complicate this understanding.
286 Consequently, a comprehensive approach to defining and achieving water security is essential.
287 The Middle East, situated in an arid and semi-arid region, faces significant water security
288 challenges exacerbated by the effects of climate change (Sowers, Vengosh, & Weinthal, 2011;
289 Lelieveld et al., 2012; Osman et al., 2017; Mansouri Daneshvar et al., 2019; Nazemi et al.,
290 2020). Researchers have linked drought-induced water scarcity to political unrest and social
291 instability, particularly in Syria (Kelley et al., 2015; Almer et al., 2017), as well as in
292 Afghanistan and Iran (Dehgan, Palmer-Moloney, & Mirzaee, 2014). **Also, researchers**
293 **determined the water security indicators and the situation of water security in Iran and**
294 **their main watersheds (Zakeri et al., 2022).** Several studies have examined the complex
295 interplay between water scarcity, drought, and conflict in the region, highlighting the potential
296 for water shortages to escalate tensions and trigger conflicts (Gleick, 2014; Michel, 2017;
297 Czulda, 2022).

298 Iran faces severe water shortages and significant climate change impacts, which are further
299 exacerbated by challenges in water management and increasing consumption (Danaei et al.,
300 2019; Mirzaei et al., 2019; Gürsoy & Jacques, 2014). Poor management practices, including
301 excessive groundwater extraction, dam overflows, and inadequate wastewater treatment, have
302 brought Iran closer to the brink of "water bankruptcy" (Mirzaei et al., 2019). These challenges
303 threaten national security, as rising water stress may heighten the potential for conflicts
304 (Farinosi et al., 2018).

305 Iran's agricultural self-sufficiency projects, initiated as a response to economic sanctions,
306 present a dilemma for water security. While these projects are essential for ensuring food
307 independence, they place significant strain on the country's renewable water resources due to
308 excessive consumption driven by heavily subsidized water use (Jamali Jaghdani & Kvartiuk,
309 2021). Policymakers must find a balance between achieving agricultural independence and
310 maintaining sustainable water use. This balance will require reforms that promote advanced
311 agricultural technologies, reduce water consumption, and optimize crop production.

312 Historically, water in Iran has been used for agriculture, industry, and domestic purposes.
313 Biswas and Tortajada (2022) argue that ensuring water security requires addressing the long-
314 term needs of all these sectors. This article reviews the historical context of water consumption
315 in Iran, focusing particularly on agricultural use and the role of climate change in shaping water
316 security challenges.

317 Water security is a multifaceted concept, encompassing a variety of indicators that
318 measure the availability, quality, efficiency, and sustainability of water resources. This
319 section explores the key water security indicators, their calculation methodologies, and
320 their implications for water management in Iran, as well as providing comparative
321 insights from both developing and developed countries.

322
323 **Key Indicators and Their Methodologies**

324 **1. Per Capita Water Availability:**

325 This indicator measures the total renewable freshwater resources divided by the
326 population. In Iran, per capita water availability has decreased from 7,000 cubic meters
327 in 1956 to less than 1,400 cubic meters in recent years, crossing the water stress threshold
328 of 1,700 cubic meters per capita (UNESCO, 2021). This sharp decline is attributed to
329 rapid population growth and overexploitation of water resources.

330
331 **2. Agricultural Water Use Efficiency**

332 Defined as the ratio of water effectively used by crops to the total water applied, this
333 indicator highlights irrigation inefficiencies. In Iran, irrigation efficiency averages 35%,
334 significantly lower than developed countries such as Australia and the United States,
335 where efficiencies range between 70–90% due to the adoption of modern technologies like
336 drip and precision irrigation (Mirzaei et al., 2019).

337
338 **3. Groundwater Depletion Rates**

339 Groundwater resources are crucial for Iran, accounting for over 50% of its agricultural
340 water supply. Between 2001 and 2021, Iran lost approximately 130 billion cubic meters
341 of groundwater due to unsustainable extraction (Nazari et al., 2020). By comparison,
342 developed countries have implemented strict regulations and monitoring systems to
343 control groundwater usage, reducing depletion rates significantly.

344
345 **4. Water Recycling and Reuse**

346 This indicator reflects the percentage of wastewater treated and reused for agricultural,
347 industrial, or domestic purposes. Iran recycles less than 10% of its wastewater, whereas
348 countries like Singapore have achieved recycling rates of over 30% through technologies
349 like NEWater, ensuring a sustainable water supply (Tortajada & van Rensburg, 2019).

350 Developing countries like Iran face significant challenges in achieving water security
351 compared to developed nations. The key differences lie in:

352 • **Technological Integration:** Developed countries widely adopt advanced
353 technologies such as precision irrigation, desalination, and water recycling. In contrast,
354 developing countries struggle with limited financial resources and access to such
355 innovations.

356 • **Policy and Governance:** Developed nations have established robust governance
357 frameworks to regulate water use and enforce sustainability practices, whereas
358 developing countries often face fragmented policies and weak enforcement mechanisms.

359 • **Climate Resilience:** Developed countries have invested in adaptive measures to
360 combat climate change impacts, while developing nations like Iran are more vulnerable
361 due to inadequate infrastructure and limited financial support.

362 These comparisons underscore the need for tailored approaches in addressing water
363 security. For Iran, improving irrigation efficiency and implementing wastewater
364 recycling programs can bridge the gap, while effective governance reforms can create an
365 enabling environment for sustainable water management.

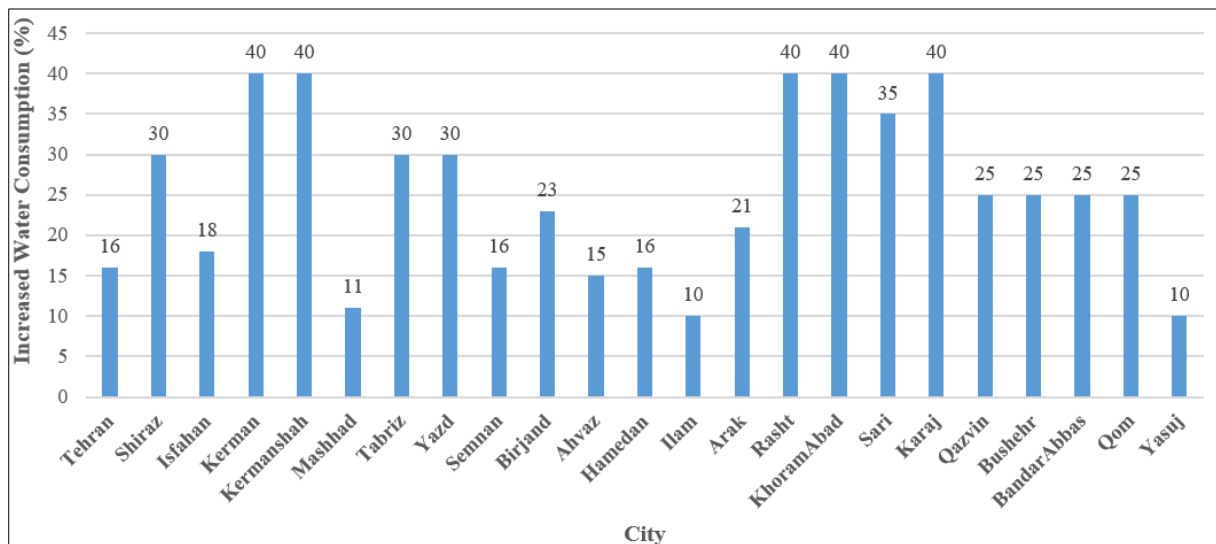
366 367 **3.3. Water consumption in Iran's agricultural sector**

368 Water consumption in Iran's agricultural sector is among the highest globally, accounting for
369 over 90% of the country's freshwater resources (Nazari et al., 2018). Rural households are
370 heavily dependent on agriculture, which remains largely traditional and is supported by
371 government subsidies for inexpensive water. Despite agriculture contributing only about 10%
372 of Iran's GDP, it remains the dominant user of water, far exceeding the global average for
373 renewable water resources. However, Iran's annual rainfall is less than one-third of the global
374 average, resulting in unsustainable groundwater extraction across all provinces (Golian et al.,
375 2021).

376 This growing groundwater depletion, often referred to as a sign of "water bankruptcy," poses
377 a significant threat to Iran's long-term food security (Mirzaei et al., 2019). Groundwater storage
378 has seen dramatic declines, with some regions losing up to -4,400 Mm³ between 2002 and
379 2017 (Safdari et al., 2022). The situation is exacerbated by increased agricultural water use,
380 which reached 103 billion cubic meters in 2021, far surpassing the national water consumption
381 estimate of 88.5 billion cubic meters (Yousefi et al., 2021).

382 Although the agricultural sector's share of total water consumption has been gradually
 383 decreasing, the absolute demand continues to rise. This trend, which began in earnest
 384 around 2013, is evident in Figure 3, which shows that despite attempts to curb overall
 385 consumption, agricultural water demand remains on an upward trajectory. With 90% of
 386 Iran's freshwater allocated to agriculture and an irrigation efficiency of only 35%, Iran
 387 lags behind developed countries, where irrigation systems typically achieve efficiencies
 388 between 70% and 90%. This inefficiency is a major challenge for Iran, especially when
 389 compared to international standards (Nazari et al., 2018; FAO, 2016). Currently, only 2.4
 390 million hectares of Iran's total 16.5 million hectares of agricultural land benefit from
 391 modern irrigation systems.

392 The inefficiency of Iran's irrigation practices underscores the urgent need for modernization in
 393 agricultural water management. Critics, including Mirchi et al. (2010), Madani (2010), and
 394 Islam & Madani (2017), point to significant failures in Iran's water management systems,
 395 which lack comprehensive planning that accounts for the ecological context of water use.
 396 Improved water management practices could allow Iran to achieve similar agricultural outputs
 397 with far less water consumption. Without substantial improvements, Iran faces a future where
 398 water scarcity—exacerbated by climate change and poor management—could severely affect
 399 its agricultural productivity and overall socio-economic stability.



400
 401 **Figure 3.** Increased water consumption in Iran in different states (Iran's energy balance, 2020).

402 3.4. NEWater; Continuous return of water to the recycling cycle

403 Technological advances illustrate that optimal water management can effectively mitigate
 404 water scarcity by recycling this vital resource (Tortajada & van Rensburg, 2019). Through

405 efficient collection, treatment, and reuse of wastewater, treated water can be cycled back into
406 consumption, including drinking water, without limitations on quality or quantity. NEWater
407 refers to high-grade reclaimed water produced through advanced purification processes,
408 including microfiltration, reverse osmosis, and ultraviolet disinfection. This technology,
409 pioneered in Singapore, recycles wastewater into potable water, significantly reducing
410 dependency on traditional freshwater sources. **In the context of this study, NEWater serves
411 as a potential model for addressing water scarcity in Iran through wastewater recycling.
412 Successful examples of this practice exist worldwide, one notable case being Windhoek,
413 Namibia, where innovative management of domestic wastewater has resolved long-
414 standing drinking water issues over the past 50 years. Despite Namibia's arid conditions,
415 its citizens have reported no health problems from using recycled drinking water
416 (Tortajada & van Rensburg, 2019).**

417 While Namibia may not be well-known in Iran, its leadership in recycled water use offers
418 valuable lessons. Singapore is another exemplary case, with over 30% of its water demand met
419 through recycled sources. Countries like Japan, Germany, and California have also adopted
420 similar strategies (Voulvoulis, 2018; Smith, 2017). Despite these successes, public acceptance
421 of recycled water, especially NEWater, which is perceived as superior to regular tap water,
422 remains a challenge due to psychological barriers (Bai et al., 2020; Tortajada & Buurman,
423 2017). This reluctance has generated significant opposition, ultimately causing the U.S.
424 government to halt major recycled water initiatives (Hartley, 2003).

425 In Iran, the total municipal wastewater generated is 6.5 billion cubic meters annually, with only
426 42% treated and recycled, raising environmental and public health concerns. The conventional
427 activated sludge process dominates this treatment, and operational costs average \$0.20 per
428 cubic meter (FAO, 2017). With total water withdrawal in Iran estimated at 93.3 billion cubic
429 meters per year, treating wastewater could fulfill 6% of the nation's water needs.

430 Reducing water consumption positively impacts the environment by lowering energy use and
431 greenhouse gas emissions, which is particularly crucial in the context of climate change. While
432 it is challenging to quantify the precise effects of a 6% reduction in water usage, it is evident
433 that this strategy is vital for ensuring sustainable water supplies and mitigating climate impacts
434 in Iran.

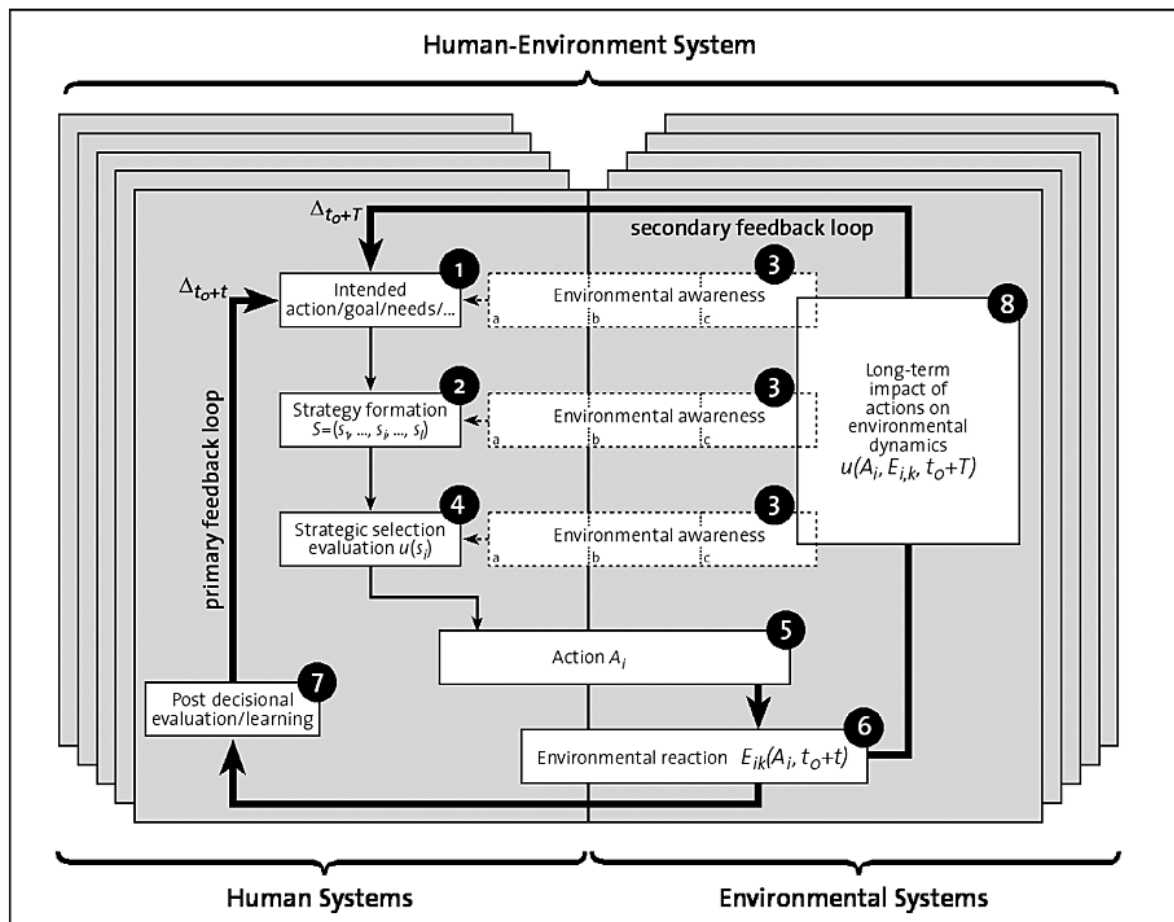
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437

438 **3.5. Attention to the importance of the human-environmental system in increasing**
439 **water security against climate change**

440 Human-environmental systems (HES) are complex, paired systems that require specialized
441 methods and interdisciplinary approaches to understand and manage. Human-environmental
442 interactions represent the difference between harmful and beneficial interactions (Pahl-Wostl,
443 2015). Figure 4 shows the HES framework for water security. This framework and its relevant
444 principles are designed to facilitate research on and address complex human-environmental
445 issues. Typically, in the early stages of tackling a complex environmental problem, the issue
446 often appears unstructured and cannot always be clearly defined. The principles identified in
447 the HES framework (denoted by numbers) serve as key elements for understanding and
448 transforming the water security issue.

449 The framework adopts a hierarchical view of the human system. At each hierarchical level,
450 different regulatory mechanisms are in place concerning the environmental system.
451 Understanding these mechanisms helps identify intervening regulatory mechanisms. The
452 framework also focuses on the conceptualization of human behavior through goal setting,
453 strategy selection, action, and learning, with particular attention to immediate (primary) and
454 delayed (secondary) responses to the environmental system.

455 In this context, and according to the definition of water security, awareness of human and
456 environmental stimuli, along with the primary and secondary feedback loops between the
457 human and environmental systems, results from the interaction between ecosystem services,
458 such as the production and supply of water—and environmental hazards, such as floods and
459 droughts. These interactions ultimately influence the strategies adopted to ensure water security
460 in the basin (Scholdz, 2011)



461

462

463

464 The research findings provide a structured foundation that logically leads to the model
 465 presented in Figure 4, illustrating the interconnectedness of human-environmental systems
 466 (HES) and their relevance to water security in Iran's agricultural sector. The findings identify
 467 critical challenges such as the impacts of climate change, including rising temperatures and
 468 reduced precipitation, water insecurity, inefficient irrigation practices, and governance
 469 shortcomings. These challenges highlight the complexity of interactions between human and
 470 environmental factors, which is central to the HES model.

471 The study demonstrates how human activities, such as over-extraction of groundwater and
 472 reliance on traditional agricultural methods, exacerbate environmental stress. These
 473 interactions are captured in the HES model, which links human goals (e.g., achieving food
 474 security) with environmental constraints (e.g., water scarcity). Furthermore, the research
 475 underscores the need for holistic solutions, such as improving irrigation efficiency, adopting
 476 water recycling technologies like NEWater, and reforming governance structures. These

477 solutions align closely with the principles of the HES model, which emphasizes feedback loops
478 and regulatory mechanisms between human and environmental systems.

479 By proposing actionable strategies, such as better water management, technological adoption,
480 and farmer education, the findings align with the hierarchical structure and feedback-based
481 approach of the HES model. The review also highlights the critical role of the human-
482 environmental system (HES) in addressing water security challenges in the context of climate
483 change. Human activities, such as unsustainable irrigation practices and groundwater over-
484 extraction, have intensified environmental stressors, thereby reducing water availability.
485 Conversely, the implementation of advanced technologies (e.g., precision irrigation and water
486 recycling systems) demonstrates how human interventions can mitigate these impacts.

487 The reviewed studies highlight feedback loops within the HES framework, where climate
488 changes exacerbate agricultural water demand, and inefficient human responses further
489 degrade the environment. For instance, 75% of the analyzed articles identified groundwater
490 depletion as a direct consequence of unregulated extraction, while 60% emphasized the
491 potential of governance reforms to create adaptive water management systems. These findings
492 underscore the importance of integrating human-environmental systems into water resource
493 management strategies to enhance resilience against climate change.

494

495 **4. Discussion**

496 **This study examines the critical challenges of water security in Iran's agricultural sector,**
497 **particularly in the context of climate change. The findings highlight the significant risks**
498 **posed by rising temperatures, reduced precipitation, and inefficient water management**
499 **practices. Climate change exacerbates existing vulnerabilities in the agricultural sector,**
500 **including heavy reliance on groundwater and outdated irrigation methods, which**
501 **collectively account for over 90% of freshwater consumption in Iran.**

502 **The research emphasizes the urgent need for adopting modern irrigation systems to**
503 **address these inefficiencies, as Iran's current irrigation efficiency is only 35%, well below**
504 **global standards. Technological solutions, such as water recycling (e.g., NEWater) and**
505 **the expansion of greenhouse cultivation, offer promising strategies to reduce water**
506 **demand while maintaining agricultural productivity. However, implementing these**
507 **solutions requires robust governance reforms to regulate water usage, curb illegal**
508 **activities like unregulated well drilling, and optimize resource allocation.**

509 Additionally, the study stresses the importance of localized approaches to water resource
 510 management, considering Iran’s diverse regional climates and socio-economic conditions.
 511 Addressing these challenges necessitates collaborative efforts from policymakers,
 512 farmers, and the private sector to implement sustainable practices, enhance farmer
 513 education on advanced techniques, and foster innovation in agriculture.
 514 In conclusion, this research underscores the interconnected nature of climate change and
 515 water security challenges in Iran’s agricultural sector. By adopting a holistic approach,
 516 incorporating technological advancements, governance reforms, and sustainable
 517 practices, Iran can mitigate the impacts of climate change and ensure the long-term
 518 sustainability of its agricultural sector. These actions are essential for maintaining food
 519 security and preserving vital water resources for future generations. A conceptual
 520 summary of the research findings is presented in Table 1.

521
 522 **Table 1.** Comprehensive Summary of Research Findings.

Dimension	Findings	Implications
Climate Change Impact	- Mean temperature to rise by 2.6°C by 2100. - Precipitation decline of 35%, leading to intensified droughts and floods.	- Reduced water availability for agriculture. - Increased vulnerability of crops to extreme weather.
Water Usage in Agriculture	- 90% of water is consumed in agriculture. - Groundwater depletion at alarming rates (e.g., -4400 Mm ³ between 2002-2017).	- Threatens long-term food security. - Risks of desertification and land subsidence.
Irrigation Efficiency	- Current efficiency is ~35% vs. 70-90% in developed nations. - Only 2.4 million hectares use modern methods out of 16.5 million hectares of farmland.	- High water wastage. - Immediate need for adoption of advanced irrigation techniques.
Governance Challenges	- Lack of specific cultivation patterns aligned with National Agricultural Plans. - Weak enforcement of water usage laws and excessive subsidies.	- Unsustainable agricultural practices persist. - Potential for socio-economic conflicts.
Technological Gaps	- Recycling municipal wastewater only meets 6% of national water needs. - Low adoption of technologies like NEWater.	- Missed opportunities for sustainable water management.
Socio-Economic Factors	- Limited private sector investment due to government price controls. - Farmers lack knowledge in advanced agricultural methods.	- Stagnation in productivity and innovation. - Inefficiency in resource allocation.

523
 524 Also, some of the most important effective ways to improve water security in Iran's
 525 agricultural sector in the current water shortage situation can be introduced as follows:
 526 - Lack of a specific cultivation pattern in the country based on the National
 527 Agricultural Plan,
 528 - Quantitative and qualitative development of greenhouse cultivation,

- 529 - Transferring the growing season of some agricultural products from spring to
- 530 autumn and winter,
- 531 - Increase the use of modern irrigation systems and educate farmers in this regard,
- 532 - Repair of canals,
- 533 - Preventing the drilling of illegal wells
- 534 - Consolidation of agricultural lands in one area,
- 535 - Modification of the traditional pattern of agricultural water consumption,
- 536 - Prevent contamination of surface and groundwater resources,
- 537 - Attention to climate diversity in water resources management,
- 538 - Utilizing operational research in order to achieve the goal of reducing the level
- 539 and increasing agricultural production,
- 540 - Paying attention to the production of strategic products for the country's self-
- 541 sufficiency,
- 542 - Quantitative and qualitative development of conversion industries in the
- 543 agricultural sector,
- 544 - Improving the quality and nutritional value of products produced,
- 545 - Use of intelligent methods to store water in dry areas and
- 546 - Use of soilless or hydroponic cultivation methods.

547 This article underscores the critical importance of effective water resource management in
548 ensuring water security in Iran's agricultural sector. It emphasizes that improving water
549 management practices is directly linked to Iran's ability to secure adequate water for its
550 agricultural needs. The article also highlights the potential of strategies such as NEWater, a
551 water recycling initiative, to enhance water management in the agricultural sector.

552 Moreover, the article stresses the necessity for long-term planning and a sustained commitment
553 from government officials to prioritize water security within agriculture. While short-term and
554 medium-term solutions are essential, the article argues that long-term plans are crucial to
555 address water security effectively. This requires a shift from seeking immediate responses to
556 embracing a more sustained, strategic approach.

557 In addition to long-term planning, the article advocates for promoting a culture of optimal water
558 consumption within the agricultural sector. This includes improving the cultural infrastructure
559 around water usage and conducting national research to develop cultivation models better
560 suited to Iran's diverse climate conditions. By integrating these measures, along with

561 strengthening law enforcement, the article posits that water security in Iran's agricultural sector
562 can be achieved in the future.

563

564 **5. Conclusions**

565 Based on the research findings, several recommendations are put forward for future
566 studies aimed at tackling water security challenges in Iran's agricultural sector. Future
567 research should focus on regional water management, recognizing the varied climatic and
568 agricultural conditions across Iran. Comparative studies could help develop tailored
569 strategies for sustainable water use in different regions. Additionally, research into the
570 impact of modern irrigation technologies, such as drip and sprinkler systems, on water
571 efficiency and crop yields is essential. Field trials and case studies would provide valuable
572 insights into the feasibility and scalability of these methods. Integrating renewable energy
573 sources like solar and wind power into water recycling and desalination processes is
574 another critical area for investigation. This could improve the sustainability of water
575 management systems while reducing reliance on conventional energy. Furthermore,
576 future studies should include economic analyses of agricultural water subsidies to
577 evaluate their effects on water consumption, agricultural productivity, and farmer
578 incomes. This would provide a foundation for potential policy reforms aimed at
579 improving water use efficiency. Understanding farmers' attitudes toward adopting
580 advanced technologies and sustainable practices is equally important. Research could
581 assess the effectiveness of training programs and identify barriers to behavioral change.
582 Additionally, developing and testing climate-resilient crop varieties that require less
583 water and are better suited to Iran's changing climate is a promising area for innovation.
584 Longitudinal studies on the implementation of water recycling technologies, such as
585 NEWater, would provide insights into their environmental, economic, and health impacts
586 over time. Moreover, evaluating the effectiveness of existing water governance
587 frameworks and proposing integrated models involving local, regional, and national
588 stakeholders could strengthen policy and management systems. These recommendations
589 address the gaps identified in the study and offer valuable directions for advancing both
590 knowledge and practical solutions to ensure sustainable water security in Iran's
591 agricultural sector.

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749 راهبردهای افزایش امنیت آب در بخش کشاورزی ایران در شرایط تغییر اقلیم

750 مجید غلامی، بهاره حیدری، مریم افخمی، و محمدعلی کیانی

751 چکیده

752 موضوع تغییرات اقلیمی و چالش‌های امنیتی مرتبط با آن به نگرانی فزاینده‌ای برای ایران به‌ویژه در بخش کشاورزی
753 تبدیل شده است. افزایش جمعیت، افزایش تقاضا برای محصولات کشاورزی و نیاز به امنیت غذایی این چالش‌ها را تشدید
754 می‌کند. این مطالعه خطرات ناشی از کاهش بارندگی، افزایش دما، و شیوه‌های مدیریت ناکارآمد آب، از جمله وابستگی
755 شدید به آب‌های زیرزمینی و سیستم‌های آبیاری قدیمی را برجسته می‌کند. این بر نیاز فوری به فن‌آوری‌های آبیاری مدرن،
756 مانند بازیافت آب (NEWater)، و اصلاحات قوی حکمرانی برای بهبود کارایی مصرف آب، که از طریق چارچوب
757 HES تحلیل می‌شود، تأکید می‌کند. این مطالعه نتیجه‌گیری می‌کند که اتخاذ یک استراتژی جامع و بلندمدت، ترکیب
758 نوآوری‌های فن‌آوری، شیوه‌های مدیریت محلی آب و حکمرانی تقویت‌شده، می‌تواند اثرات تغییر اقلیم را کاهش داده و
759 استفاده پایدار از منابع آب را در بخش کشاورزی ایران تضمین کند.