Integrated Water Resource Management and Climate Resilience: Sustainable Approaches to Address Water Scarcity in Developing Regions

Dr. Droupti Yadav[1*], Ankit Duhan[2], Dr. Biju Sidharthan[3], Dr. Mankamana Ram[4], Pragadeeshwaran Kannan[5]

[1*]Assistant Professor and Coordinator, Department of Environmental Science, School of Basic Sciences, CSJM University (Campus), Kanpur Nagar, U.P, India, Orcid Id: 1643-1651-1643-1651, Email Id: drdroupti.yadav@gmail.com

[2]Research Scholar, Department of Geography, Specialization in Geography, Panjab University, Chandigarh, Orcid Id: https://orcid.org/1643-1651-1643-1651, Email Id: ankit_d@pu.ac.in

[3]Scientist, Department of Plant Breeding and Genetics, College of Agriculture, Vellanikkara, Thrissur 680656, Kerala Agricultural University, Orcid Id: 1643-1651-1643-1651, Email Id: biju.s@kau.in

[4]Assistant Professor, Department of Economics, Faculty of Social Sciences, Specialization in Quantitative and Health Economics, Banaras Hindu University, Varanasi-221005, Orcid Id: https://orcid.org/1643-1651-1643-1651, Email Id: manokamana@bhu.ac.in

[5]Research scholar, Centre for Applied Geology, The Gandhigram Rural Institute (Deemed to be University), Gandhigram, Dindigul-624302, Tamil Nadu, India, Orcid Id: 1643-1651-1643-1651, Email Id: pragadeeshpragadeesh2204@gmail.com

HOW TO CITE:

Droupti Yadav, Ankit Duhan, Biju Sidharthan, Manokamna Ram, Pragadeeshwaran Kannan (2026).Integrated Water Resource Management and Climate Resilience: Sustainable Approaches to Address Water Scarcity in Developing Regions

International Journal of Special Education, 41(20s), 1643-1651

COPYRIGHT STATEMENT:

Copyright: © 2026 Authors. Open access publication under the terms and conditions of the Creative CommonsAttribution (CC BY) license (http://creativecommons. org/licenses/by/4.0/).

ABSTRACT:

Scarcity of water is a growing global issue caused by disparities in water resource distribution, increasing demand, unsustainable water use and climate change. Integrated Water Resource Management offers a way to link water risk analysis to sustainable and climate-resilient management. This study evaluates global patterns of water scarcity, examines the relationship between water stress and depletion, and identifies countries where future climate conditions may intensify existing risks. A quantitative secondary data analysis was conducted using Aqueduct 4.0 indicators, with basin-level data aggregated to the country level through area-weighted methods. Key variables included baseline water stress, depletion, variability indicators, drought risk, and projected stress under the 2050 business-as-usual scenario. The results reveal strong spatial inequality, with 47.17% of countries experiencing low stress and 14.62% facing extremely high stress. A clear positive relationship between water stress and depletion highlights the role of unsustainable extraction. Future projections indicate a general increase in water stress, with a subset of countries identified as high-risk due to both high baseline stress and significant projected increases. Sustainable water management therefore requires integrated, climate-informed, and region-specific strategies. Targeted interventions in high-risk regions should focus on demand management, groundwater regulation, adaptive allocation, and long-term resilience planning.

Keywords: Integrated Water Resource Management, water scarcity, climate resilience, water stress, climate change projections

Introduction

The impact of population growth, economic development and changing consumption patterns is putting increasing stress on water resources. Water is naturally unevenly distributed around the world, with stark disparities in availability and demand across different regions, which presents challenges for sustainable water management (Khilchevskyi & Karamushka, 2022). These disparities are exacerbated by the increasing dependence on groundwater, which is essential to ensuring water security but is often overexploited (Scanlon et al., 2023). Simultaneously, growing food demand has significantly increased water needs, especially in the agricultural sector, further exacerbating water scarcity (Islam & Karim, 2019). In addition, the spatial mismatch between water availability and human population has also resulted in the emergence of high water population density zones, where water demands far outpace local supplies (Nazari & Keshavarz, 2023). The impacts of climate change further complicate the situation by shifting and increasing rainfall variability, thereby impacting water availability and reliability. Precipitation changes have been found to aggravate agricultural water scarcity, especially in vulnerable areas (Liu et al., 2023). Together, these factors are part of a global water crisis, where both physical water scarcity and mismanagement are key challenges (Shemer et al., 2023).

There is a considerable amount of literature on the causes and consequences of water scarcity globally and regionally. Studies have emphasised that water scarcity is not only a natural phenomenon but also a result of human actions such as land use, agricultural production and urbanisation. For example, differences in water use efficiency and allocation have been associated with regional variations in water footprints, especially in the agricultural sector (Wang et al., 2023). Meanwhile, climate-oriented research has highlighted that water availability in the future will be affected by the compounding effects of precipitation and evaporation, which will result in increased uncertainty in water systems (Konapala et al., 2020). In this regard, groundwater depletion has proven to be a major threat, with over-extraction diminishing ecosystem services and sustainability (Khorrami & Malekmohammadi, 2021). Integrated water management approaches have been recommended to address these issues. Integrated Water Resource Management (IWRM) has been envisaged as a mechanism to foster the coordinated development and management of water resources across sectors and scales (Benson et al., 2020). However, IWRM implementation is not consistent across jurisdictions, and the effectiveness of IWRM is limited by institutional, technical and socio-economic considerations (Nagata et al., 2022). Case studies have shown that effective water management involves developing localised strategies that link local and broader policy settings. A review of IWRM practices shows that although IWRM provides theoretical benefits, its effectiveness relies on governance and stakeholder participation (Dirwai et al., 2021). Recent evidence also shows that increasing frequency of hot and dry years can significantly worsen water scarcity conditions even in regions with stable or increasing precipitation, highlighting the complex influence of climate extremes on water availability (Coffel et al., 2019).

Although considerable progress has been made in developing knowledge on water scarcity and management, current research largely focuses on hydrological, climatic, or governance aspects separately. The linking of baseline water risk indicators with future climate change projections in an integrated manner is currently lacking. Additionally, while IWRM has been widely promoted as an overarching concept, empirical research that puts IWRM into practice by using quantitative, globally harmonized data is rare. This gap hampers the capacity to pinpoint areas where existing water stress will be exacerbated by climate change and to develop strategies accordingly.

This study seeks to examine global patterns of water stress and how they are likely to change under future climate change scenarios, given a consistent suite of water risk indicators. It aims to explore the nexus of water stress, depletion and variability, and to determine where future climate change will likely intensify water risks. In bridging empirical evidence with integrated water resource management principles, the study seeks to offer an empirical foundation for setting priorities and directing climate-resilient and sustainable water management strategies in developing areas.

2. Methodology

2.1 Research Design

This research is a quantitative, cross-sectional study using secondary data. The study was designed to explore the spatial distribution of water stress, inter-relationships between the key hydrological indicators and impacts under future climate scenarios. The approach combines retrospective and prospective analysis to provide a snapshot of present and potential future exposure to water stress. Aggregation of basin-scale indicators to the national scale translates hydrological risk indicators to policy-relevant scales, allowing interpretation in the context of integrated water resource management and climate resilience.

2.2 Data Source

The analysis used the Aqueduct 4.0 dataset that offers globally comparable indicators of water risk at high resolution (Kuzma et al., 2023). The dataset provides baseline indicators of water stress, depletion and variability, and future projections of water stress based on climate and socioeconomic scenarios. These are calculated using hydrological models and scoring systems, enabling the rankings of water risks across countries.

2.3 Variable Selection

We chose a range of indicators to capture the multiple dimensions of water risk and climate pressures. Water scarcity was represented by baseline water stress, which is the ratio between water demand and supply. Water depletion represents the level of over-extraction of renewable water resources. Annual variability and seasonal variability account for the variability of water supply over time, providing a measure of water system stability. Drought risk was included to capture the vulnerability to extreme water stress. For the future, projected water stress in 2050 under the business-as-usual scenario was used to indicate the future water scarcity.

2.4 Data Processing and Aggregation

The data were prepared for consistent and reliable analysis. Negative or "filler" values were replaced with missing data. Data with missing geographic information were excluded to preserve spatial integrity. Given that the data are available at the sub-basin level, a spatial-weighted approach was used to aggregate data at the national level. This method accounts for the fact that larger areas contribute more to national totals, and thus maintains spatial representativeness.

2.5 Analytical Techniques

Both descriptive, relational and comparative methods are employed. Descriptive analysis was used to describe the distribution of indicators across the countries. Countries were grouped into water stress categories using established thresholds to allow comparison of water stress levels. Scatter plots were used to explore the association between water stress and water depletion. Analysis of future projections involved the comparison of baseline with projected values, and a change metric was calculated to measure the magnitude of the difference. The countries were also grouped according to the direction and magnitude of change to classify stability, improvement and degradation.

2.6 Identification of High-Risk Countries

To prioritize regions for action, countries were considered high-risk if they showed both high existing levels of water stress and substantial increases in future stress. Such a dual criterion identifies regions under both current and climate-induced stress. This subset identifies areas where integrated and adaptive water management approaches are needed.

3. Results

3.1 Global Distribution of Water Stress

Baseline water stress scores show a significant variation between countries. Figure 1 indicates that the distribution is highly skewed to the right with a high concentration of countries in the low-stress range and a clear tail leading to extreme stress values. This trend signifies that, there is while many countries experience relatively low pressure on water resources in many countries, there are a relatively few, yet high-intensity group of countries that are under acute scarcity conditions.

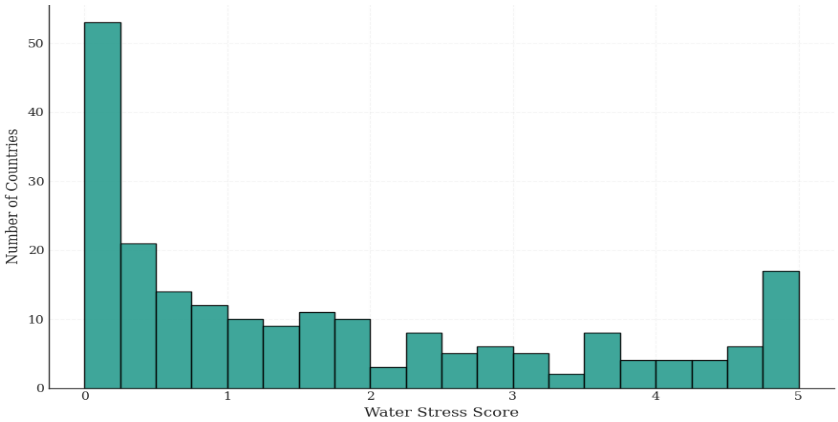

Figure 1. Distribution of Baseline Water Stress Scores

This variation is further measured using descriptive statistics. The average water stress level is 1.687, and the standard deviation is high (1.662), indicating a great variation among countries. It is important to note that the highest value is the upper limit of the Aqueduct scale (5.0), and the lowest one is near zero, which proves the inequality of the situation in the world in the context of water resources.

Table 1. Descriptive Statistics of Water Risk Indicators (n = 212 countries)

Statistic	Water Stress	Water Depletion	Interannual Variability	Seasonal Variability	Drought Risk
Count	212.000	212.000	212.000	212.000	184.000
Mean	1.687	1.459	1.951	1.386	2.561
Std Dev	1.662	1.555	0.872	0.639	0.732
Min	0.000	0.000	0.636	0.238	0.032
25th %	0.277	0.296	1.293	0.888	2.187
Median	1.076	0.863	1.705	1.311	2.623
75th %	2.923	2.267	2.392	1.759	3.066
Max	5.000	5.000	5.000	5.000	4.009

3.2 Classification of Water Stress Across Countries

The classification of the countries in terms of water stress levels shows how the water stress is unevenly distributed. As Figure 2 shows, almost half of the countries are in the category of low stress, with a decreasing number of countries in higher stress categories.

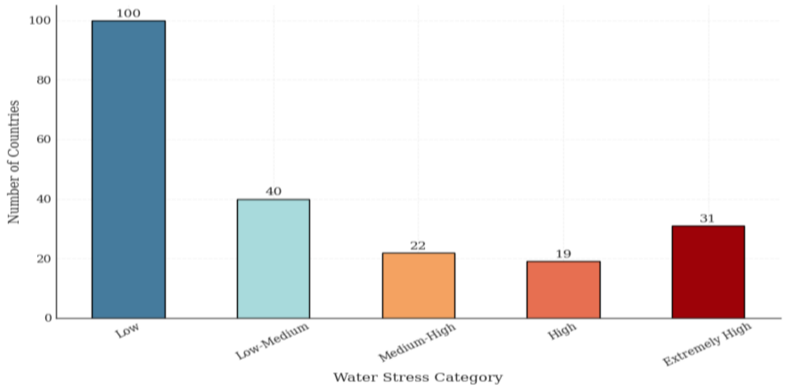

Figure 2. Distribution of Countries by Water Stress Category

Table 2 provides a more detailed breakdown. The number of countries in the low stress category is about 47.17%, with the extremely high stress category being 14.62%. Together, high and very high stress groups comprise almost a quarter of all nations, which highlights the non-trivial magnitude of severe water scarcity on the world level.

Table 2. Distribution of Countries by Water Stress Category

Water Stress Category	Number of Countries	Percentage (%)
Low	100	47.17
Low-Medium	40	18.87
Medium-High	22	10.38
High	19	8.96
Extremely High	31	14.62

3.3 Relationship Between Water Stress and Water Depletion

The water stress-water depletion interaction gives an insight into the drivers of scarcity. As Figure 3 indicates, the two variables show a distinct positive relationship with the countries that have a higher stress level, also showing a higher depletion score.

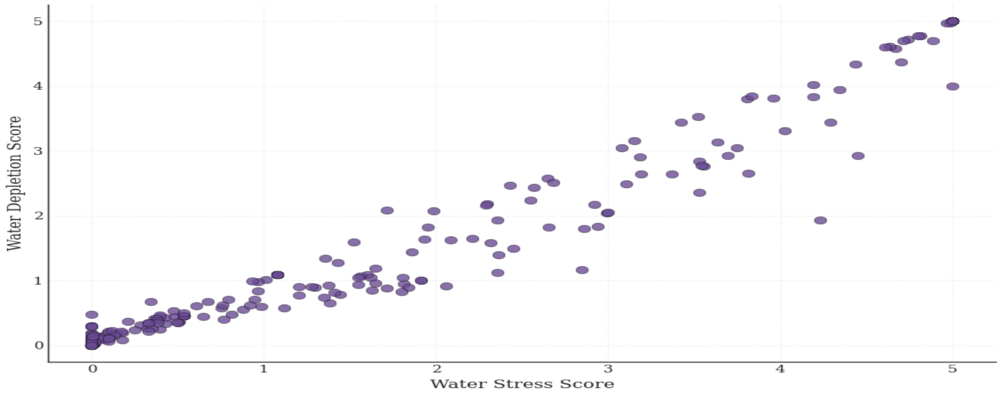

Figure 3. Relationship Between Water Stress and Water Depletion

The fact that the observations cluster on an upward trend implies that water scarcity is tightly linked with the extraction of the available resources. This shows that human-induced forces, especially unsustainable use of water, are significant factors in increasing water stress beyond natural hydrological limits.

3.4 Future Water Stress Under Climate Change Scenarios

Water stress projected for 2050 in the business-as-usual scenario indicates a clear shift towards greater stress levels. Figure 4 shows that the majority of observations are above the diagonal reference line, which implies that the level of stress in the future is higher than the present level of stress in most countries.

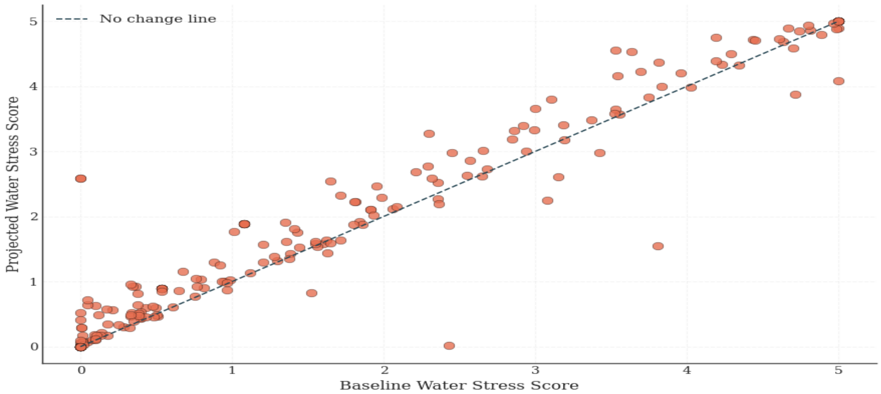

Figure 4. Baseline compared with Projected Water Stress by 2050

The fact that high-stress countries remain on the right side of the distribution curve indicates that the current weaknesses will probably become more pronounced instead of being reduced. The trend is indicative of the compound effects of climate variability and demand pressure on already stressed systems.

3.5 Projected Changes in Water Stress

The distribution of projected changes in water stress further shows a general tendency towards a worsening trend. As illustrated in Figure 5, the distribution is concentrated a notch higher than zero, with more countries registering an increase and a few registering a decrease in the levels of stress.

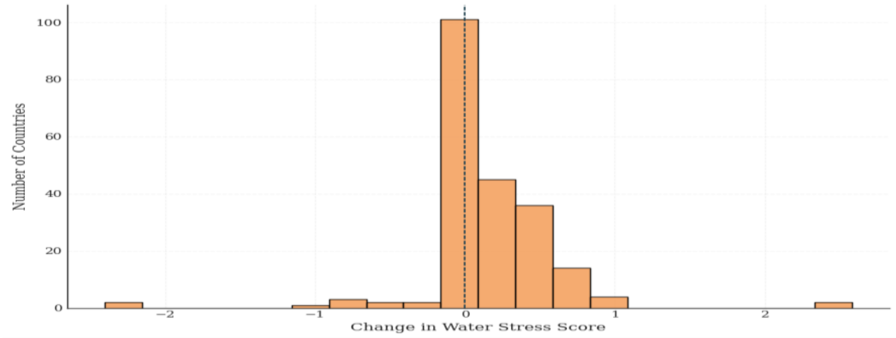

Figure 5. Projected Change in Water Stress by 2050

The fact that there is a long right tail suggests that although most countries are likely to experience moderate changes, a group of countries is expected to experience significant increases in water stress. This heterogeneity points out how climate impacts are unevenly distributed in the regions.

3.6 Identification of High-Risk Priority Countries

There is a group of nations that becomes especially vulnerable in terms of both the level of stress and its future growth. These are high-risk nations that have a baseline stress score of over 3 and a major positive change by 2050. Figure 6 depicts the scale of estimated growth.

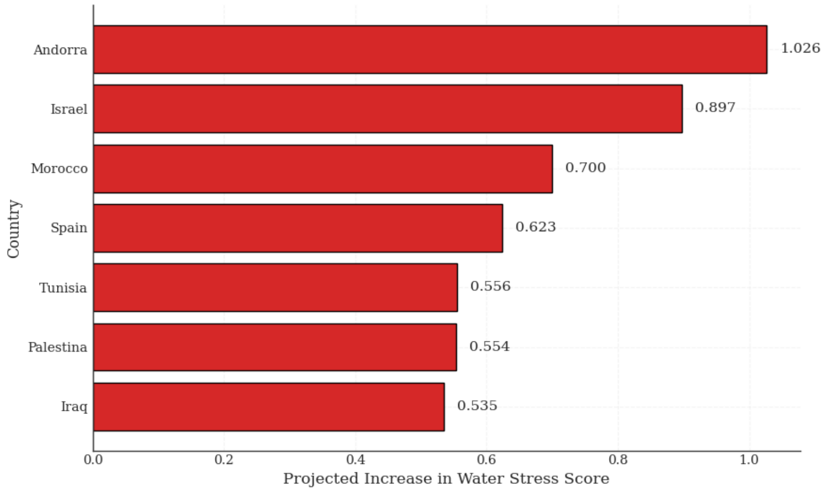

Figure 6. High-Risk Priority Countries by Projected Water Stress Increase

The detailed list of priority countries is given in Table 3. They are Andorra, Israel, Morocco, Spain, Tunisia, Palestine, and Iraq, with high levels of baseline stress and high projected increases.

Table 3. High-Risk Priority Countries Under Climate Change (2050, BAU Scenario)

Country	**Baseline Stress**	**Future Stress (2050)**	**Change**	**Category**
Andorra	3.530	4.556	1.026	High

Israel	3.635	4.532	0.897	High
Morocco	3.102	3.802	0.700	High
Spain	3.541	4.164	0.623	High
Tunisia	4.193	4.748	0.556	Extremely High
Palestine	3.811	4.364	0.554	High
Iraq	3.696	4.231	0.535	High

These nations are mainly found in arid and semi-arid areas, especially in the Mediterranean and the Middle East. They are important intervention targets since they are exposed to high baseline stress and intensification due to climatic factors.

4. Discussion

The findings show that the level of water stress is very uneven among the countries, with almost half of the countries in the low-stress category, and a sizeable minority of the countries are in the high-stress or extremely high-stress category. This uneven distribution shows that water scarcity is not uniform globally but a risk that is concentrated spatially and influenced by the variations in the hydrological availability, intensity of demand, and pressure on resources. Such a broad range in water stress scores further indicates that national water systems are being run on very different degrees of constraint, with significant implications in terms of designing sustainable responses to water management. Probably one of the most significant findings is the strong positive correlation between water stress and water depletion. The nations that are more stressed tend to have higher depletion scores as well, so scarcity is directly connected with the extent of extracting water resources compared to the amount of renewable water resources. The implication of this trend is that the problem of water scarcity is not merely a question of insufficient natural resources but also one of high rates of exploitation and pressure on the management. Water depletion in this regard is one of the main ways in which scarcity is exacerbated, especially where withdrawals are more than the capacity of water systems to replenish. The climate resilience aspect of the analysis is further enhanced by the future projection results. As can be observed in the comparison of the baseline and projected 2050 water stress, most countries will be facing more severe conditions due to the business-as-usual scenario. Even though there are countries that are stable or show an average improvement, there is an overall shift in the distribution of the projected change towards rising stress. This implies that the climate-related pressures will tend to reinforce the existing patterns of scarcity as opposed to evenly redistributing risk. High-risk priority cases are especially important as they are the countries with already high baseline stress that have already been combined with further projected cases and are thus of great importance when it comes to targeted intervention.

The result that the future water stress will probably increase in the most susceptible areas is in line with vulnerability-based evaluations that reveal that high-end climate change can significantly modify the global water availability, as well as vulnerability to scarcity (Koutroulis et al., 2019). The identified concentration of highly-stressed nations is also consistent with the recent findings that water stress develops unevenly in regions and is influenced by unequal patterns of consumption and redistribution of resources (Qu et al., 2025). The estimated increase of water stress conditions in the future is also aligned with the literature on adaptation to water scarcity and climate change, which highlights that water systems faced with increasing demand and climate uncertainty need to be planned, but not managed in reaction (Mehrazar et al., 2020). The same has been observed regarding future water scarcities due to the synergies between demographic increase and climate change, with long-term adaptation required to mitigate the vulnerability (Brown et al., 2019).

Water stress and depletion are identified with groundwater sustainability literature, which identifies that groundwater depletion and contamination may jeopardize the long-term sustainability of the water systems (Jia et al., 2019). The studies of groundwater in the region also indicate that climate change, change in land-use, and population increase may become contributing factors in increasing the rate at which groundwater is depleted, particularly in the region that relies on already scarce water resources (Ojeda Olivares et al., 2019). The policy implication of these findings is supported by the recent research on integrated water resources management, which suggests that

IWRM presents a workable platform for organizing water distribution, infrastructure, institutions, and sustainability objectives (Grigg, 2024). Climate-sensitive planning is also important, as reflected in the projections of green water scarcity, whereby in warming conditions, the risks may be greater in the rainfed agricultural system, and vulnerabilities in the water-dependent economies, which are more vulnerable (Rosa and He, 2025).

The results have a number of implications for integrated water resource management and climate resilience. The disproportion of water stress indicates that single policies cannot work, so risk-based approaches ought to be regional. The close association between water stress and water depletion highlights the importance of controlling withdrawals, efficiency enhancement and demand-side management. The predictions of the future show that the situation is going to get worse in the high-stress areas, and there is a need to integrate climatic scenarios in long-term planning. Adaptive measures like better storage, groundwater management and coordinated allocation among the sectors are necessary. Identification of priority countries further helps in targeted interventions with emphasis being laid on vulnerability reduction by integrated and sustainable water management strategies.

There are certain limiting aspects to mention. The research employs one dataset, thus being consistent, but fails to reflect local governance, socioeconomic status, and actual IWRM application. The analysis is done on a country level and thus may conceal regional differences within countries. Moreover, a single future scenario (2050 BAU) is applied, which may not be representative of other potential results. Subnational analysis, a variety of scenarios and other variables should be incorporated in future research to offer a more comprehensive picture. The analysis might be reinforced by further studies that consider the socioeconomic vulnerability, quality of governance, agricultural dependence, and adaptive capacity indicators. Integration of hydrological risk data alongside institutional and development variables would help to directly evaluate IWRM performance and resilience ability. To investigate the effects of management interventions on water stress outcomes in the future, other tools that could be used include causal modeling, spatial econometric models or basin-level case studies.

5. Conclusion

Water scarcity is not a uniform global condition but a concentrated and intensifying risk shaped by both resource limitations and unsustainable use. These findings indicate that extraction pressures are closely linked with high water stress and depletion, highlighting the pivotal role of extraction pressures in fueling scarcity beyond natural limits. Projections also suggest that climate change is going to increase the level of vulnerability that already exists, and some of the already stressed countries are going to be worsened by the year 2050. These results support the necessity to move towards integrated and progressive water management. IWRM does not appear as an abstract model but rather as a needed methodology to integrate supply, demand, and climate adjustment in the face of highly restricted systems. Such responses need to focus on region-specific actions, manage withdrawals, and incorporate climate projections into long-term planning. A more sustainable approach to water management will require less systemic vulnerability than merely increasing supply. Data-driven decision-making and institutional coordination are crucial to increase the resilience and sustainability of water security in high-risk areas under increasing climatic and socio-economic pressures.

References

Benson, D., Gain, A. K., & Giupponi, C. (2020). Moving beyond water centricity? Conceptualizing integrated water resources management for implementing sustainable development goals. Sustainability Science, 15(2), 1643-1651.

Brown, T. C., Mahat, V., & Ramirez, J. A. (2019). Adaptation to future water shortages in the United States caused by population growth and climate change. Earth's Future, 7(3), 1643-1651.

Coffel, E. D., Keith, B., Lesk, C., Horton, R. M., Bower, E., Lee, J., & Mankin, J. S. (2019). Future hot and dry years worsen Nile Basin water scarcity despite projected precipitation increases. Earth's Future, 7(8), 1643-1651.

Dirwai, T. L., Kanda, E. K., Senzanje, A., & Busari, T. I. (2021). Water resource management: IWRM strategies for improved water management. A systematic review of case studies of East, West and Southern Africa. PloS one, 16(5), e0236903.

Grigg, N. S. (2024). Framework and function of integrated water resources management in support of sustainable development. Sustainability, 16(13), 5441.

Islam, S. M. F., & Karim, Z. (2019). World's demand for food and water: The consequences of climate change. In Desalination-challenges and opportunities. IntechOpen.

Jia, X., O'Connor, D., Hou, D., Jin, Y., Li, G., Zheng, C., ... & Luo, J. (2019). Groundwater depletion and contamination: Spatial distribution of groundwater resources sustainability in China. Science of the Total Environment, 672, 1643-1651.

Khilchevskyi, V., & Karamushka, V. (2022). Global water resources: distribution and demand. Clean water and sanitation, 1643-1651.

Khorrami, M., & Malekmohammadi, B. (2021). Effects of excessive water extraction on groundwater ecosystem services: Vulnerability assessments using biophysical approaches. Science of the Total Environment, 799, 149304.

Konapala, G., Mishra, A. K., Wada, Y., & Mann, M. E. (2020). Climate change will affect global water availability through compounding changes in seasonal precipitation and evaporation. Nature communications, 11(1), 3044.

Koutroulis, A. G., Papadimitriou, L. V., Grillakis, M. G., Tsanis, I. K., Warren, R., & Betts, R. A. (2019). Global water availability under high-end climate change: A vulnerability based assessment. Global and Planetary Change, 175, 1643-1651.

Kuzma, S., Bierkens, M. F., Lakshman, S., Luo, T., Saccoccia, L., Sutanudjaja, E. H., & Van Beek, R. (2023). Aqueduct 4.0: Updated decision-relevant global water risk indicators. Washington, DC, USA: World Resources Institute.

Liu, J., Fu, Z., & Liu, W. (2023). Impacts of precipitation variations on agricultural water scarcity under historical and future climate change. Journal of Hydrology, 617, 128999.

Mehrazar, A., Massah Bavani, A. R., Gohari, A., Mashal, M., & Rahimikhoob, H. (2020). Adaptation of water resources system to water scarcity and climate change in the suburb area of megacities. Water Resources Management, 34(12), 1643-1651.

Nagata, K., Shoji, I., Arima, T., Otsuka, T., Kato, K., Matsubayashi, M., & Omura, M. (2022). Practicality of integrated water resources management (IWRM) in different contexts. International Journal of Water Resources Development, 38(5), 1643-1651.

Nazari, B., & Keshavarz, M. (2023). Water population density: Global and regional analysis: B. Nazari, M. Keshavarz. Theoretical and Applied Climatology, 153(1), 1643-1651.

Ojeda Olivares, E. A., Sandoval Torres, S., Belmonte Jimenez, S. I., Campos Enriquez, J. O., Zignol, F., Reygadas, Y., & Tiefenbacher, J. P. (2019). Climate change, land use/land cover change, and population growth as drivers of groundwater depletion in the Central Valleys, Oaxaca, Mexico. Remote Sensing, 11(11), 1290.

Qu, J., Qin, C., Wang, H., Zhao, Y., He, F., Guan, Z., ... & Shi, L. (2025). Water stress evolution and redistribution pathways under global inequality in consumption. Water Research, 125112.

Rosa, L., & He, L. (2025). Global multi-model projections of green water scarcity risks in rainfed agriculture under 1.5° C and 3° C warming. Agricultural Water Management, 314, 109519.

Scanlon, B. R., Fakhreddine, S., Rateb, A., de Graaf, I., Famiglietti, J., Gleeson, T., ... & Zheng, C. (2023). Global water resources and the role of groundwater in a resilient water future. Nature Reviews Earth & Environment, 4(2), 1643-1651.

Shemer, H., Wald, S., & Semiat, R. (2023). Challenges and solutions for global water scarcity. Membranes, 13(6), 612.

Wang, Q., Zheng, G., Li, J., Huang, K., Yu, Y., & Qu, S. (2023). Imbalance in the city-level crop water footprint aggravated regional inequality in China. Science of the Total Environment, 867, 161577.