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Implementation of multi-criteria decision-making methodology to rank the water security issues/challenges in the Indian context

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A B S T R A C T

Water security is a significant challenge in India due to its rapidly growing population, increasing demand for water, and frequent droughts and floods. The country has also been facing issues related to water pollution, inefficient water management practices, and limited access to safe drinking water. Ensuring water security in India requires a comprehensive approach that involves the integration of technology, policy, and community engagement to address the complex challenges associated with water management. This research paper identifies eight major challenges of water security in India, including population growth, climate change, water resource management, anthropogenic factors, technological factors, socio economic issues, geopolitical factors, and virtual water trade. Using the Analytical Hierarchy Process (AHP) method, this study ranks these challenges based on their relative importance. The findings suggest that population growth and climate change are the most critical challenges, followed by poor water resource management, anthropogenic factors, technological factors, socio economic issues, geopolitical factors, and virtual water trade. The study highlights the need for integrated and holistic approaches to address these challenges and ensure sustainable water management in India.

1. Introduction

Adequate amount of pure water is an essential ingredient for survival of livings, economy, ecological and social system of a nation. The quantity of freshwater on earth is 3.0 %. In this accessible quantity, 68.9% water is retained in the form of glaciers and ice caps. That is not a great usage of people. In addition, the short quantity and unpredictable distribution of remaining 29.9% drinkable groundwater render it prone to dispute (Cassardo & Jones, 2011). An emerging economy and population upsurge, such as in India, intensifies the issues of water security tremendously. Access to enough potable water for varied uses in a region leads to urbanization which in turn boosts water consumption proportionally. In the past century the global population expanded three times while demand for water climbed six times owing to industrialisation and increasing living standards. It is predicted that the demand of water would be 40-50% greater notably in the growing nations such as India and China by 2030. As shown in the report India's water supply would reach over 1.5 trillion m^3 by 2030 mostly as a result of population increase and domestic agriculture demand. The report also states that water supply in India in 2009 was 740 billion m^3 (McKinsey, 2009). When water supply falls below 1700 m^3 per person per year which is considered minimum need, the source of supply is considered stressed (Tindall et al., 2010). As per the report of World Water Demand and Supply, the quantity of water per person has decreased from more than 5000 m^3 per year in 1947 to less than 2000 m^3 per year in 1997 and by 2025 this number will further decrease 1500 m^3 annually which is far below the amount at which water stress is usually observed (WWAP, 2016). Water is an underlay of the economy of any country. Many sectors such as agriculture, arboriculture, fishery, power industries, construction, transportation and many more are highly reliant on water. Water is used in various ways by more than three out of every four jobs (Seckler, 1998). OECD report has alerted that consumption for water in India is anticipated to increase by over 70% by 2025, creating a massive imbalance between supply and demand and also severe groundwater degradation. This might have a substantial negative impact on economic growth. Increasing pumping cost, salty irrigation from over abstraction, crop losses are all repercussions of declining water levels (Cronin et al., 2014). Only 4% of available water resources on the entire earth is available in India for the 16% of the world population that is insufficient for growing demand of industry and agriculture creating supply demand mismatch (Government of India (GoI), 1999).

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The term “water security” was initially introduced by the World Water Forum in 2000 as a policy issue. Since then the ministerial declaration of the UN led to wide use of the term in global policy, development and Science agendas over the past 20 years. There have been numerous definitions of water security given by different organizations such as Global Water Partnership (GWP) (Chaves, 2014), UN water (ESCAP, 2013), UNESCO (Wouters, 2010), and OECD (OECD, 2013). However, the best fit definition for this study has been considered given by USAID is; *“Water security is adaptive capacity to safeguard the availability of, access to, and safe use of an adequate, reliable and resilient quantity and quality of water for health, livelihood, ecosystem and economies”.* Water security is a larger economical, ecological and geopolitical issue that affects more than just the water sector (GWP.org). Water must be managed sustainably by the population using river and groundwater as their main water source to sustain water consumption for human growth and preserve ecological benefits. The phrase “water security” tries to convey the intricate idea of comprehensive water management and the delicate balance between resource conservation and resource usage. Water security deserves to be done at municipal to country level (Government of India (GoI), 1999). It is the role of government and locals to implement the principle actions with the support of NGOs, fund providers, researchers, municipalities to execute top to down and bottom to top approaches to manage their places (Chaves, 2014).

Water security can be considered as the compris of five fundamental components. Those five components ensure water security for basic household needs, food production, environmental flows, risk management and independence, where risk management evaluates the level of protection provided by massive dam reservoirs against the impact of rainfall variability while independence determines the degree of safety and security of a nation's water resource from external changes. A five point scale is used to measure water security of an individual component in an area and summation of all results describe the overall water security out of 25 points for that area. High score denotes more secure access to water whereas low score denotes the reverse (Khan et al., 2020). The Asian Development Bank developed the framework of the national water security index that evaluates performance of five different spheres: household, economic, urban, environment and resilient elements of water security (Assefa et al., 2018). A common numerical scale has been evolved to represent the different indicators of different units. This scale varies from 1 to 5 and displays the interpretation of the different domestic water security index scores where a score less than 1.5 is considered poor and more than 4.5 is excellent (Onsomkrit, 2015).

A broad variety of water-related threats degrade human well-being and may lead to political unrest, violent conflict, mass relocation and migrations, and severe food crisis, which in turn can affect national, regional, and even global security. Political instability and violence are seldom driven by any one event, such as a water shortage. Instead, water emergencies should be recognised as contributing elements to instability. While water threats have plagued human civilizations for eons, today’s global population increase and economic growth with challenges from climate change generate a new urgency around an old issue. We identify water and security paths under three basic categories: reduced water supply or quality, rising water demand, and severe flood occurrences. Water risk is not only a consequence of hazards, such as major droughts and floods, it is also a function of a community’s governance ability and resilience in the midst of natural catastrophes. No one method is adequate to mitigate water risk. Instead, various methods will be required (Gleick & Iceland, 2018).

In the majority of the studies, just a few indications were used to evaluate domestic water security. However, such indicators present a limited view of the situation on water security. Thus, better indicators are necessary to study the water security status at the national level. The largest issue in measuring national water security is the absence of a well-organized framework (Assefa et al., 2018). Issues related to water are so interconnected that single insecurity may lead to different others. It is important to identify the core water security issues and rank them accordingly. Also, water is a crucial factor in government planning and making policies. Hence, having the severity ranking of different issues faced in achieving water security will be helpful in policy making for immediate problems and for long term future problems. It will also aid future research in this regard. According to best of the knowledge available to authors, the problem of ranking water security issues was not articulated before in any literature. In this study an effort has been made to create a framework cantered on the AHP technique that will benefit researchers and relevant authorities in creating effective solutions that address challenges in the best possible way. The various criteria for challenges related to water security are established through literature and inter interaction with different experts. The various criteria are allocated weight by independent experts and then aggregated weight has been calculated to obtain final ranking of criteria.

The remaining paper is organized into six sections. Section 2 deals with various possible criteria and their sub-criteria as the challenge for water security through literature review. Section 3 describes the methodology of AHP and aggregates the judgment of different decision makers. In the 4th section, the methodology has been applied to establish the ranking of criteria. Result and discussion and conclusion has been given in further two sections.

2. Challenges of water security

Uneven access to water across regions and seasons leads to shortages, supply uncertainty, and extreme events such as droughts and floods. Water supply organizations face significant challenges in maintaining sustainable delivery, particularly in arid areas where sources often dry up during summer months. Rapid population growth is intensifying demand while simultaneously reducing per capita water availability. Moreover, excessive rainfall on steep slopes and geologically young mountains contributes to flooding and sedimentation, which damage hydrological infrastructure and impose additional financial burdens on water supply systems. Water scarcity also fuels growing competition and conflict among sectors, further undermining water security (Jain, 2021).

To address these challenges, it is crucial to identify the key factors contributing to water insecurity using a Multi-Criteria Decision-Making (MCDM) approach. Accordingly, consultations were held with various policymakers, complemented by a comprehensive review of relevant research literature. This process led to the formulation of eight primary criteria, each encompassing multiple sub-criteria. These criteria and sub-criteria are examined in detail in the following section.

2.1 Population Growth

Concerns about declining water availability for food production, industry, and households have grown significantly alongside India's rapid population increase. As the population grows, so does the demand for water for drinking, sanitation, and agriculture. In 2022, India's population reached approximately 1.41 billion—a 0.68% increase from 2021 (World Bank). This rising demand for freshwater is driven primarily by population growth, migration, and shifting consumption patterns linked to economic development. India, as a developing nation, is expected to experience the most substantial increases in water demand, especially as its urban centers expand rapidly and wealth levels rise. Water needs for domestic use, sanitation, industry, and hydropower generation will grow substantially as more people migrate to cities. Additionally, urban and affluent populations adopting diets higher in meat and lower in grains will further increase demand for water-intensive products (NIC, 2012). An estimated population projection for the next ten years is illustrated in Fig.1 (Statista India).

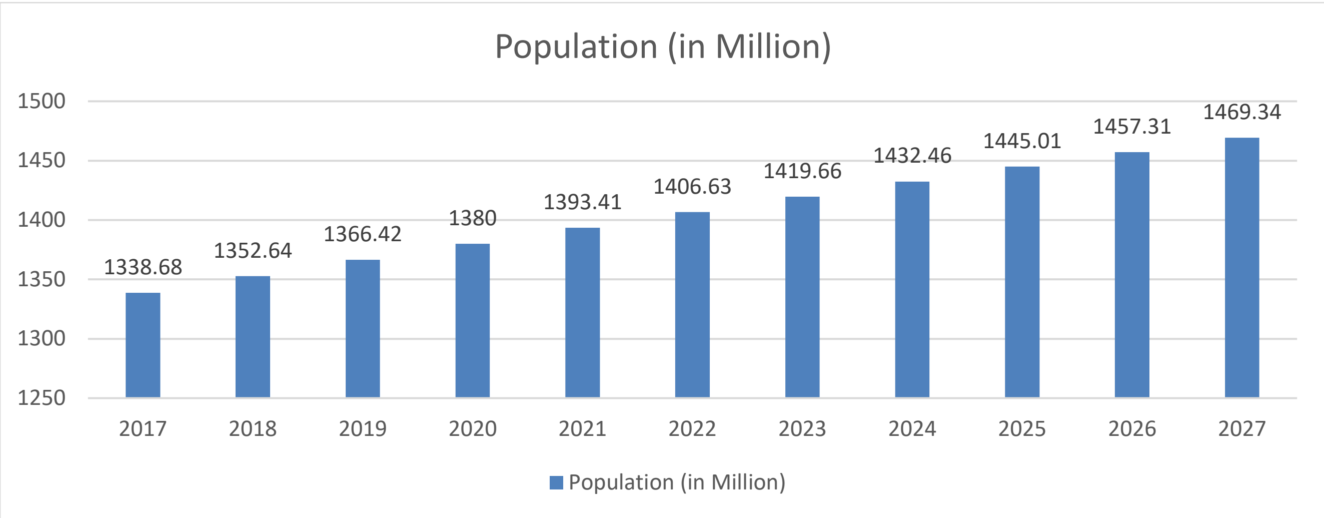

Fig. 1. Estimated total population of India from 2017 to 2027 (Source: https://www.statista.com/statistics/263766/total-population-of-india/)

2.2 Climate Change

The intensity, geographic and temporal variability of rainfall, evaporation rates, and temperatures across various agroclimatic zones and river basins are predicted to become increasingly complex and affected by climate change, which will have a significant negative impact on India's water resources. According to the 2010 INCCA report, major water resources in regions such as the Himalayas, Northeast, Western, and coastal areas of the country are expected to face substantial reductions in water yield by 2030 (Indian Network for Climate Change Assessment Report, 2010). Moreover, incidents such as floods, droughts, sea-level rise, and sedimentation are projected to become more frequent, adversely affecting water availability and quality, as well as human health (Asthana & Shukla, 2014). Climate change also influences rainfall patterns, soil moisture, glacier mass balance, river flows, and groundwater supplies. Consequently, floods and droughts are expected to occur more often and with greater severity (Kumar, 2018).

2.3 Socioeconomic Issues

Socioeconomic challenges encompass factors that influence the development and long-term management of water resources (Nkiaka, 2022). A society's ability to ensure water security is partly shaped by its socioeconomic context, which includes the economic structure, behavior of stakeholders, natural and cultural heritage, and government policies. Beyond risk and the actions of economic agents, this context also involves water infrastructure and institutions, as well as the broader macroeconomic framework and its resilience (Grey & Sadoff, 2007).

2.4 Water Resource Management

Water resource management is a critical issue in India due to its rapidly growing population, urbanization, and industrialization. Ensuring water security requires the implementation of efficient management policies and strategies. According to Vijay et al. (2019), water scarcity and poor water quality are two major challenges affecting water resource management in India. Dwivedi and Alappat (2018) highlight the need for improved water allocation and distribution systems, alongside more effective monitoring and enforcement of regulations. Additionally, Kumar et al. (2019) emphasize the importance of integrating traditional and modern water management practices to achieve sustainable water resource management. Together, these studies offer valuable insights into the challenges and potential solutions essential for securing India's water future.

2.5 Geopolitical Factors

Geopolitical issues pose a significant challenge to ensuring water security in India. The country hosts several transboundary rivers, making the distribution and management of water resources among different states and neighboring countries a complex matter. According to Singh (2018), water conflicts and disputes represent a major geopolitical challenge in India, highlighting the need for a more collaborative and cooperative approach to managing shared water resources. Additionally, Tiwari and Kumar (2018) emphasize the importance of international law and diplomacy in resolving water-related conflicts in the region. Furthermore, Singh and Kulkarni (2019) stress the necessity of effective water governance mechanisms to address geopolitical challenges related to water security in India. These geopolitical issues and the strategies to tackle them are critical considerations for securing India's water future.

2.6 Virtual Water Trade

Virtual water trade plays a critical role in ensuring water security in India. The country is one of the largest consumers of virtual water, importing substantial quantities of water-intensive goods from water-scarce regions. Kulkarni and Singh (2020) identify virtual water trade as a vital component of India's water security strategy and stress the need to promote sustainable practices in this area to address water scarcity. Joshi and Singh (2018) highlight how virtual water trade can alleviate water stress while improving farmers' livelihoods. Furthermore, Babu et al. (2021) emphasize the importance of developing efficient policies and strategies for virtual water trade to support sustainable water resource management. These issues must be carefully considered to secure India's water future.

2.7 Anthropogenic Factors

Anthropogenic factors such as terrorism, pollution, and war present significant challenges to ensuring water security in India. Singh et al. (2021) identify terrorist attacks targeting water resources as a major emerging threat, underscoring the need for enhanced security measures to protect water infrastructure. Singh and Sharma (2021) highlight the detrimental effects of pollution—particularly industrial pollution—on water quality and availability across the country. Additionally, Kumar and Sharma (2020) examine the impacts of war on regional water resources, with a focus on the India-Pakistan conflict. These human-induced challenges threaten India's water security and emphasize the urgent need for effective strategies to mitigate their effects.

2.8 Technological Factors

Despite the potential benefits of technology for ensuring water security in India, significant challenges and barriers remain. Sai et al. (2021) highlight the lack of adequate infrastructure and funding as major obstacles to adopting innovative water management technologies. Krishnani et al. (2021) identify the shortage of technical skills and expertise among water management professionals as a critical challenge in implementing these solutions. Furthermore, Kulkarni and Kulkarni (2021) emphasize the need for improved policy frameworks and regulations to facilitate the adoption of water management technologies.

3. Methodology

3.1 Fuzzy AHP Procedure

In 1965, Zadeh introduced fuzzy theory, which translates the managerial decision-making process into linguistic variables that are subsequently converted into numeric scales. Building on earlier fuzzy research, Bellman and Zadeh (1970) combined fuzzy theory with multi-criteria decision-making (MCDM) to address challenges related to accurately estimating the weights assigned to various criteria. The Analytical Hierarchy Process (AHP), while widely used, has limitations—particularly its difficulty in resolving ambiguity and uncertainty when mapping expert judgments to precise numerical values. This stems from the subjectivity inherent in paired comparisons, where experts may struggle to assign exact numbers (Chan & Kumar, 2007). Consequently, vagueness and uncertainty often dominate the decision-making process. Allowing decision-makers to specify interval ranges instead of single values increases their confidence in assessments (Deng, 1999). However, most mathematical and computational tools require exact values and thus fail to capture the qualitative and ambiguous aspects of decision-making.

These inconsistencies and uncertainties can be effectively managed using Fuzzy Set Theory (Bellman & Zadeh, 1970), which accommodates qualitative and incomplete information (Kulak et al., 2005). Fuzzy AHP, a hybrid approach combining the Analytical Hierarchy Process with Fuzzy Logic Theory, facilitates smarter and more efficient decision-making under uncertainty (Gani et al., 2021). The following section outlines the steps involved in applying Fuzzy AHP for weight evaluation (Saaty, 2008).

Step 1: Create a pairwise comparison matrix based on the expert's recommendations.

Assume that the evaluation system contains 'N' elements. The pairwise comparison of elements '*i*' and '*j*' yields a square 'NxN' matrix 'M_1'. Each member e_{ij} in the matrix denotes the relative importance of element '*i*' in relation to element '*j*'. When $i = j$, $e_{ij} = 1$ and $e_{ji} = 1/$ v for 'M_1'. For pairwise comparison of system elements, Saaty's 1 to 9 scale (Saaty, 2008) is used, as indicated in Table 1.

Table 1

Numeric Value allocation for pair wise comparisons of matrix elements

Verbal judgment of relative importance between elements '*i*' and '*j*'	Numerical rating
Equal importance	1
Moderate importance of one element over other	3
Strong importance	5
Very strong importance	7
Extremely strong importance	9
	2, 4, 6 and 8 are intermediate values

Step 2: Create a fuzzy pairwise comparison matrix for expert assessments. In this context, see Tables 2 and 3.

Table 2

Linguistic variables, numerical crisp values, and fuzzy number

Linguistic Variable	Numerical Crisp values	Fuzzy Number		
		l	***m***	***u***
Equal importance	1	1	1	1
Moderate importance of one element over other	3	2	3	4
Strong importance	5	4	5	6
Very strong importance	7	6	7	8
Extremely strong importance	9	9	9	9
Intermediate values	2	1	2	3
	4	3	4	5
	6	5	6	7
	8	7	8	9

Table 3

Linguistic variables, Numerical Crisp values and Reciprocal Fuzzy Number (RFN)

Linguistic Variable	Numerical Crisp values	RFN		
		l	***m***	***u***
Equal importance	1	1	1	1
Moderate importance of one element over other	1/3	1/2	1/3	1/4
Strong importance	1/5	1/4	1/5	1/6
Very strong importance	1/7	1/6	1/7	1/8
Extremely strong importance	1/9	1/9	1/9	1/9
Intermediate values	1/2	1/1	1/2	1/3
	1/4	1/3	1/4	1/5
	1/6	1/5	1/6	1/7
	1/8	1/7	1/8	1/9

The fuzzy pairwise comparison matrix is shown in expression (1)

$$\widetilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ 1/\tilde{x}_{12} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{x}_{1n} & 1/\tilde{x}_{2n} & \cdots & \tilde{x}_{nn} \end{bmatrix} \tag{1}$$

where all the diagonal elements in the above matrix are 1, i.e., $\tilde{x}_{ij} = (1,1,1)$ for $i = j$

Step 3: Using the fuzzy geometric mean method, estimate the weight.

Calculate the weights of criteria using the geometric mean approach established by Buckley (1985), by following the stages developed by Kordi (2008), in which the weights in a pairwise comparison matrix of alternatives are derived by expression (2). The fuzzy weight is determined by expression (3).

$$r_i = \prod_{j=1}^{n} (a_{ij})^{1/n} \tag{2}$$

in which a_{ij}, where (i, j =1,…n) are the comparison ratios in the pairwise matrix and 'n' is the number of alternatives.

$$w_i = \frac{r_i}{\sum_j r_j} \tag{3}$$

Step 4: Conduct a consistency check.

To ensure that expert judgments/opinions are consistent in nature, the consistency of each fuzzy pairwise comparison matrices must be checked. It is accomplished by de-fuzzing the fuzzy pairwise comparison matrix by assigning a crisp numerical value in place of the fuzzy numbers. The defuzzification in this work is performed through the use of the value graded mean integration approach (Khan et al., 2018).

Let a TFN is given by T = (l, m, u), then the corresponding de-fuzzified crisp number is obtained by expression (4)

$$T_{crisp} = \frac{l+m+u}{3} \tag{4}$$

Followed by this, the pairwise matrix is normalized by dividing each element of a column by the sum of all the elements of the same column as given by expression (5).

$$\tilde{x}_{ij} = \frac{x_{ij}}{\sum_{j=1}^{n} x_{ij}} \quad \forall i, j \quad x_{ij} \in X \tag{5}$$

where n is the number of criteria selected for the comparison.

The average value of the preference matrix for a criterion is used to generate a preference vector. The Eigenvectors w_i, which indicate the weight of each criterion, are evaluated and are shown below.

$$w_i = \frac{\sum_{j=1}^{n} x_{ij}}{n} \tag{6}$$

Here, $\sum_{j=1}^{n} x_{ij}$ represents the sum of all the elements in row i of the normalized pairwise matrix. The largest eigenvalue λ_{max} is evaluated by expression (7).

$$\lambda_{\max} = \sum_{i=1}^{n} \left\{ \left(\sum_{j=1}^{n} x_{ij} \right) \times w_i \right\} \tag{7}$$

The Consistency Index (CI) is evaluated by using expression (8) and Consistency Ratio (CR) as given by equation (9). Table 4, presents the random index RI for up to 10 criteria and it is used for the calculation of CR.

$$CI = \frac{\lambda \max - n}{n-1} \tag{8}$$

$$CR = \frac{CI}{RI} \tag{9}$$

Table 4
Random index values

Matrix	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

When the CR is 0.10, it shows that the matrix's consistency is acceptable; otherwise, the pairwise comparison must be repeated until an acceptable CR of 0.10 is achieved.

3.2 Expert judgments

For pairwise comparisons, the interdependence between components was assessed using expert judgment from relevant domains. Industry experts involved had extensive experience in production, planning, control, and maintenance activities within their organizations, with experience ranging from 6 to 20 years and positions spanning from Technical Manager to R&D roles. The academic experts were professors and researchers specializing particularly in electric vehicles and operations research. Data for the Fuzzy-AHP analysis were collected through multiple online interview sessions scheduled at the convenience of the experts. Their feedback was documented using a questionnaire specifically designed for this study. The judgments of five experts from diverse fields were utilized for the analysis; details of six experts from various domains are presented in Table 5.

Table 5
Experts Overview

S. No.	Background	Designation	Experience	Expertise
1	Academic	Professor	28	Water quality and climate change
2	Academic	Ass. Professor	8	Water Resource Management
3	Industry	Technical Manager	13	Circular Supply Chain
4	Industry	R&D	11	Water Security related frameworks
5	Industry	Lead Planner	9	Planning and execution

4. Application of Methodology

This section presents the application of the proposed methodology to identify and evaluate the challenges involved in establishing water security in India. To assess these challenges, a team of professionals—including academicians, industry experts, and representatives from relevant Non-Governmental Organizations (NGOs)—was assembled. The following procedures outline the steps undertaken to implement this methodological approach.

4.1 Assessing weightages of barriers

The first step is to determine the weight assigned to each challenge related to ensuring water security in India. This is achieved by following the Fuzzy AHP (FAHP) procedure outlined in Section 3.1. A fuzzy pairwise comparison matrix of the challenges is constructed using Saaty's 1–9 scale, based on the input from the expert team detailed in Table 5. Subsequently, a defuzzified matrix is derived to calculate the normalized weights of each criterion. The defuzzified matrix is presented in Table 6.

Table 5
Fuzzy Pairwise Comparison Matrix

	CH_1			CH_2			CH_3			CH_4			CH_5			CH_6			CH_7			CH_8		
CH_1	1	1	1	1	2	3	2	3	4	4	5	6	5	6	7	6	7	8	7	8	9	7	8	9
CH_2	1/3	1/2	1	1	1	1	1	2	3	2	3	4	2	3	4	4	5	6	6	7	8	7	8	9
CH_3	1/4	1/3	1/2	1/3	1/2	1	1	1	1	1	2	3	2	3	4	3	4	5	4	5	6	6	7	8
CH_4	1/6	1/5	1/4	1/4	1/3	1/2	1/3	1/2	1	1	1	1	1	2	3	2	3	4	4	5	6	5	6	7
CH_5	1/7	1/6	1/5	1/4	1/3	1/2	1/4	1/3	1/2	1/3	1/2	1	1	1	1	1	2	3	3	4	5	4	5	6
CH_6	1/8	1/7	1/6	1/6	1/5	1/4	1/5	1/4	1/3	1/4	1/3	1/2	1/3	1/2	1	1	1	1	1	2	3	2	3	4
CH_7	1/9	1/8	1/7	1/8	1/7	1/6	1/6	1/5	1/4	1/6	1/5	1/4	1/5	1/4	1/3	1/3	1/2	1	1	1	1	2	3	4
CH_8	1/9	1/8	1/7	1/9	1/8	1/7	1/8	1/7	1/6	1/7	1/6	1/5	1/6	1/5	1/4	1/4	1/3	1/2	1/4	1/3	1/2	1	1	1

Table 6
De-fuzzified matrix

	CH_1	CH_2	CH_3	CH_4	CH_5	CH_6	CH_7	CH_8
CH_1	1	2	3	5	6	7	8	8
CH_2	1/2	1	2	3	3	5	7	8
CH_3	1/3	1/2	1	2	3	4	5	7
CH_4	1/5	1/3	1/2	1	2	3	5	6
CH_5	1/6	1/3	1/3	½	1	2	4	5
CH_6	1/7	1/5	1/4	1/3	1/2	1	2	3
CH_7	1/8	1/7	1/5	1/5	1/4	1/2	1	3
CH_8	1/8	1/8	1/7	1/6	1/5	1/3	1/3	1

The normalized weights of the challenges were determined by following the FAHP procedures outlined in Section 3.1. These weights were then sorted and presented in Table 7. Additionally, the Consistency Ratio (CR) of the pairwise comparison matrix was calculated to assess the consistency of expert responses. Responses are considered consistent if the CR is less than 0.1. If the CR exceeds 0.1, the decision process is revised until an acceptable consistency ratio is achieved. In this case study, the CR value was 0.04—well below the 0.1 threshold—indicating a strong level of consistency in expert opinions.

Table 7
Normalized relative weights of water security challenges and ranking

S.no.	Water Security Issues	Notation	Weightage	Rank
1	Population Growth	CH_1	0.338	1
2	Climate Change	CH_2	0.217	2
3	Water Resource Management	CH_3	0.158	3
4	Anthropogenic Factors	CH_4	0.109	4
5	Technological Factors	CH_5	0.079	5
6	Socioeconomic Issues	CH_6	0.049	6
7	Geopolitical Factors	CH_7	0.030	7
8	Virtual Water Trade	CH_8	0.020	8

5. Results and Discussion

The fuzzy AHP analysis reveals that 'Population Growth Challenges' rank first, carrying a weightage of 33.8%, followed by 'Climate Change' as the second most significant challenge with 21.7% weightage. Issues related to socio-economics, geopolitics, and virtual water trade carry the least weightage. These results highlight the urgent need for government and relevant organizations to implement effective family planning and climate change policies. Additionally, the development of proper infrastructure and efficient water resource management is essential. The findings also suggest that government initiatives like 'Jal Shakti Abhiyan' have not been as effective as initially intended and require comprehensive restructuring. Increased research and development, along with greater public awareness, are necessary to address pollution and mitigate anthropogenic and technological challenges. Given the current extremely high water stress, India's water system will struggle to meet future demand as development accelerates.

6. Conclusion

This study identifies the key issues of water security in India through an extensive literature review and interactions with professionals, including academicians, industry experts, and representatives from Non-Governmental Organizations (NGOs). A statistical approach using Fuzzy AHP was employed to organize and rank the challenges associated with mitigating water stress. This research holds significant importance as it highlights India's efforts to address the widespread problem of water scarcity and its shift toward more sustainable solutions. The study not only identifies the barriers hindering progress but also quantifies the relative importance of each barrier based on expert opinions. Such categorization and prioritization can assist policymakers and relevant organizations in streamlining their strategies, enabling them to focus on mitigating the most critical challenges effectively.

The research also provides recommendations for overcoming major barriers. To tackle challenges related to climate change, the Government of India must increase investment in research and development aimed at evolving policies and planning that align with Sustainable Development Goal 6—'Clean Water and Sanitation'—while enhancing sustainability. Alongside these environmental challenges, anthropogenic factors such as terrorism, war, and civil unrest represent major concerns that cannot be overlooked.

Therefore, this study offers valuable insights for policymakers and authorities to develop more coherent, comprehensive, and effective strategies tailored to the Indian context of water security. However, there are limitations to this study, including the sample size and diversity of expert opinions, which may affect the generalizability of the results. The findings should be interpreted within a controlled framework, acknowledging possible deviations from ground realities. A more extensive literature review combined with detailed comparative analyses could offer avenues for further refinement.

Future research may explore additional Multi-Criteria Decision-Making (MCDM) methods such as Decision-Making Trial and Evaluation Laboratory (DEMATEL), Interpretative Structural Modelling (ISM), and Structural Equation Modelling (SEM). Since the global context is ever-evolving, some current challenges may diminish over time, continually opening new opportunities for research in this field.

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