



Assessing Water Stress in Punjab Through the Water Poverty Index: A Spatiotemporal Analysis

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Abstract: This paper examines the status of water stress and its pattern while identifying key areas for intervention to address the water scarcity challenges in Punjab, India. This study employed a micro-level approach to construct the modified water poverty index (MWPI) by using National Sample Survey (NSS) data from the 69th and 76th rounds. The key findings of the spatiotemporal analysis revealed that the state's overall water poverty status has deteriorated from 0.69 in 2012 to 0.66 in 2018. Descriptive data analysis highlights that deterioration in the index value of access, capacity, and environmental components is a matter of concern. Furthermore, the sub-component evidence reveals that dwindling access to safe water, longer collection times and distances, a growing burden of waterborne diseases, and the stagnant water surrounding drinking water sources due to inadequate water infrastructure highlight critical areas where the government needs to intervene with target policy initiatives that urgently and explicitly address these challenges and ensure the sustainable water resource management.

Key words: Water scarcity, water poverty index, national sample survey, spatiotemporal analysis, sustainable water resource management.

India, a vast and resource-rich country with extensive geographical diversity, holds significant potential for sustainable development. Among its various natural resources, water stands out as both unique and vital, given its critical role within ecosystems and its fundamental importance for sustaining life (Kumar *et al.*, 2005; Bhat *et al.*, 2014; Sheffield *et al.*, 2018). The issues of poverty and water scarcity are closely intertwined, posing persistent challenges worldwide due to increasing demand and limited freshwater availability (Cronin *et al.*, 2014; Maheswari and Chaithanya, 2014). Although approximately 70% of the Earth's surface is covered by water, about 97.5% is saltwater, leaving only 2.5% as freshwater-of which less than 1% is accessible as potable water (Mishra, 2023). Since both humans and ecosystems depend predominantly on freshwater resources, sustainable water management is essential for achieving global development goals, including UNESCO's Agenda 2030 (UNESCO, 2020a; Pandey *et al.*, 2024). Recognizing the critical importance of water, it has become a central focus of the Sustainable Development Goals (SDGs) and is now universally acknowledged as an essential human right (UNESCO, 2020b; IUCN, 2004).

Aside from health and economic issues, poor access to clean water goes far beyond health; it penetrates into daily life in deeply profound ways. When local water sources become dry, families, particularly women and children, spend hours each day walking long distances to collect water. This weighs them down by keeping them out of schools and engaging in work or learning skills, thereby leading to poverty traps and increasing social inequalities (Javed and Sarwar, 2016; Choudhuri and Desai, 2021). Water scarcity is no longer a far-fetched danger but an expanding disaster that hits millions of individuals (Shalamzari and Zhang, 2018; Pandey *et al.*, 2024). Population growth, industrial water demand, declining groundwater availability, erratic rainfalls, and poor waste management have all cumulatively contributed to make the situation worse (Joy *et al.*, 2014; Water Aid, 2018; Goswami and Ghosal, 2022; Pandey *et al.*, 2024). In India, inefficient water management contributed further to the issue, thereby making it one of the most pressing challenges of the twenty-first century (NITI Aayog, 2019; Pandey *et al.*, 2024). However, this dilemma goes beyond water to touch every aspect of life: health, education, food, gender, and economic security. Millions of lives will continue to suffer unless something is done about it.

Considering the impact of water scarcity on health, education, and livelihood, ongoing monitoring is necessary to assess water availability, utilization, and shifting concerns. Various indicators to measure water situation and inform sustainable solutions have been constructed by researchers in the past decades (Liu *et al.*, 2018; Pandey *et al.*, 2024). Among them, the most significant key indexes are the Falkenmark Water Stress Index, Social Water Stress Index, Water Resources Vulnerability Index, and Water Stress Index (Feitelson and Chenoweth, 2002; Shalamzari and Zhang, 2018; Pandey *et al.*, 2024). These studies mainly focus on the physical dimension of water scarcity; however, they fail to discuss socio-economic and environmental aspects (Shalamzari and Zhang, 2018; Pandey *et al.*, 2024). Although it was recognized later that water scarcity is a complex term in which the social, economic, and environmental factors are taken into account along with the physical factors of water supply (Goswami and Ghosal, 2022; Pandey *et*

al., 2024). Therefore, in this context, Sullivan's (2002) Water Poverty Index (WPI) has emerged as a comprehensive policy instrument for assessing water-related difficulties, combining both physical water shortage and social elements (Garriga and Foguet, 2010).

Moreover, the WPI has been widely used in India in studies where the main focus was on water quality at the national, state, and district levels (Goel *et al.*, 2020; Pandey *et al.*, 2025; Chopra and Ramachandran, 2023; Prabha *et al.*, 2020). For instance, Goel *et al.* (2020) used the WPI to assess the water status of 20 major Indian states. The study focused on 2014 and identified Jharkhand and Rajasthan as states with the most water stress. Prabha *et al.* (2020) computed the WPI for India's metropolitan agglomerations with populations above 54 million in 2011 and found that 57% of households are water-poor. Pandey *et al.* (2025) analysed spatial and temporal patterns of water poverty in Rajasthan by computing the WPI between 2012 and 2018 and revealed that the state's water poverty status has improved over the given period. Despite its extensive use, studies employing the WPI remain limited in Punjab, a semi-arid state of India that is facing severe water crises.

Thus, in the above context, the present study is intended to construct the modified Water Poverty Index (MWPI) for Punjab at the state, regional, and district levels, giving a broad overview of water poverty. It further examines the MWPI trends, appraises interregional and interdistrict differences, and provides critical information about the spatial differences in water access and scarcity.

Punjab is one of the north Indian states, situated between longitudes 73°55' E to 76°50' E and latitudes 29°30' N to 32°32' N and extending an area of approximately 50,362 km² (CGWB, 2022). The state is divided into three distinct physiographic zones, including the Sub-mountainous zone, Central zone, and South-western zone by Punjab Agricultural University, based on some characteristics such as cropping pattern, soil quality, underground water, rainfall, soil texture, temperature, and humidity (Sidhu *et al.*, 2020). Geologically, the Punjab is an alluvial plain that slopes moderately from approximately 350 meters mean sea level in the northeast to around 180

meters in the southwest (Gosal, 2004). It shares an international border with Pakistan on the western side; however, Jammu and Kashmir also borders the state to the north, Haryana to the south and southeast, Rajasthan to the southwest, and Himachal Pradesh to the north (CGWB, 2023).

The state is predominantly an agrarian state and contributes approximately 18.91% of the nation's wheat and 12.6% of its rice to India's total food production (Sarkar and Das, 2014). Three perennial rivers, Sutlej, Beas, and Ravi, these surface water resources that are being fully utilized through a well-organized canal irrigation system. The available surface water resources of the State are unable to meet the demand of agriculture as such forcing farmers to rely heavily on groundwater for irrigation. As a result, 114 of the 150 Punjab blocks fall in the category of being over-exploited, yet the groundwater abstraction has increased up to 164%, which exceeds sustainable levels (CGWB, 2022). All these are compounded by the fact that Punjab has a diversified climate ranging from arid in the southwestern region to semi-humid in the north. Precipitation is from less than 300 mm in the southwest to as high as almost 1000 mm in the northeast, with an average of 579 mm, recorded in 2022 (CGWB, 2023).

Materials and Methods

Data Sources: This study utilized data on drinking water, sanitation, hygiene and housing conditions in Punjab from the nationally representative National Sample Survey (NSS) data specifically the 69th round (2012) and the 76th round (2018). The total number of households' data analyzed in the study were 2,124 (2012) and 2,361 (2018). Of the total, 1068 and 1223 households were in rural areas and 1056 and 1138 were in urban areas in the years 2012 and 2018, respectively. In 2012, only 20 districts existed in Punjab, which increased to 22 in 2018. Newly formed districts were Pathankot, which was earlier part of Gurdaspur, and Fazilka, separated from Ferozpur. However, to ensure consistency and facilitate a more effective comparison of data, the observations from these two districts were incorporated into their respective parent districts.

These are the most recent nationally representative datasets available, as no subsequent surveys or reports have been released after 2018. Hence, the 2018 round provides the latest official benchmark for assessing household-level access to water, sanitation, and hygiene facilities in India, and its comparison with 2012 helps to track progress and emerging challenges.

Computation of Modified Water Poverty Index (MWPI): The Modified Water Poverty Index (MWPI) provides a composite evaluation of the water status of Punjab, computed annually for each district for the years 2012 and 2018, based on the aggregation of several water-related indicators. This indexing approach is an improvement over Garriga and Foguet (2010), Prabha *et al.* (2020), and Pandey *et al.* (2025), computed using the technique of the composite index approach developed by Iyengar and Sudharshan (1982). Previous studies restricted their analysis by assigning equal weights to each indicator and ignored the fact that not all indicators are equally important in assessing the overall phenomenon being measured.

Following the composite index methodology, MWPI extends the Water Poverty Index (WPI) to include new dimensions and indicators to enable region-specific water problems (Garriga and Foguet, 2010; Pandey *et al.*, 2025). While MWPI has five traditional elements-resource, access, secondary sources, capacity, and environment, MWPI reduces the structure to place four essential elements at the centre: resources, access, capacity, and environment. Moreover, nine indicators (Table 1) were chosen in this study based on data availability and literature, which were then grouped into four categories. Each indicator was given a weight based on the composite index approach and represents a distinct aspect of the corresponding MWPI component. A step-by-step procedure of computing the MWPI is detailed ahead.

Step 1: Different indicator variables, used to estimate the components, may have different scales. Thus, it is necessary to rescale all the variables on one scale using the normalization technique. Values of the variables are standardized in such a way that these range from 0 (extreme water poverty) to 1 (no water poverty).

Table 1. Components and Indicators for Construction of MWPI

Component	Indicators (Functional relationship with MWPI)	Values	Direction of relationship with WPI	Weight (2012)	Weight (2018)
Resource	R1: Water quantity sufficiency (Nadeem <i>et al.</i> , 2017)	1-Yes 0-No	(-ve)	0.035	0.025
	R2: Reliability of water source (Pandey <i>et al.</i> , 2025)	Frequency of supply of water	(-ve)	0.016	0.020
Access	A1: Access to safe water (Juran <i>et al.</i> , 2016)	1-Households have access to improved water 0-Otherwise	(-ve)	0.511	0.400
	A2: Access to sanitation (Garriga and Foguet, 2010)	1-Households have access to improved sanitation 0- Otherwise	(-ve)	0.045	0.199
	A3: Distance (Pandey <i>et al.</i> , 2025)	Distance travelled to reach a water source	(+ve)	0.068	0.014
	A4: Time spent to collect water (to andfro) (Pandey <i>et al.</i> , 2025)	In minutes (Excluding time taken for waiting at the source)	(+ve)	0.017	0.021
Capacity	C1: Income (Azqueta and Montoya, 2017)	Higher the income, lower the water poverty	(-ve)	0.078	0.050
	C2: Illness due to water (Azqueta and Montoya, 2017)	1-No 0-Yes	(-ve)	0.048	0.016
Environment	E1: Stagnant water surrounding the drinking water source (Garriga and Foguet, 2010)	1-No 0-Yes	(+ve)	0.182	0.255

When the observed values were related positively to poverty, the standardization was achieved by using the following equation 1:

$$X_{id} = \frac{\text{Actual value} - \text{Min value}}{\text{Max value} - \text{Min value}} \quad \dots 1$$

In case of negative relation of the observed values with poverty, the standardization was achieved by using the following equation 2:

$$X_{id} = \frac{\text{Max value} - \text{Actual value}}{\text{Max value} - \text{Min value}} \quad \dots 2$$

Step 2: Assign the weights to the standard values of the indicators using the following equation:

$$\bar{y}_d = \sum_{i=1}^m w_i x_{id} \quad \dots 3$$

where, w 's ($0 < w < 1$ and) were the weights determined by

$$w_i = \frac{k}{\sqrt{\text{var}(x_i)}} \quad \dots 4$$

$$k = \left[\sum_{i=1}^n \frac{1}{\text{var}(x_i)} \right]^{-1} \quad \dots 5$$

where k is the number of components.

Step 3: The unequal weights were obtained for each component, such as resources, access, capacity, and environment, and the respective weights were multiplied with the standardized values, and final indices were obtained.

Results and Discussion

Water Poverty in Punjab: The overall MWPI score for Punjab, India, for all 20 districts was 0.69 in 2012 and 0.66 in 2018, indicating the condition in the state worsened in terms of water status. However, for determining which zone was more affected, the state was separated into three physiographic zones. A detailed component-wise analysis has been conducted as shown by Fig. 1. The first resource component captures both the quantity of water that is physically available to meet demand and the consistency or dependability of the water source. It indicates a widespread reduction in

the availability of resources in all zones from 2012 to 2018. However, in the sub-mountainous zone, the resource index value reduced from 0.70 to 0.65; in the central plain zone from 0.69 to 0.66, and in the southwestern zone from 0.68 to 0.67, as represented by the radar diagrams, where the contraction of the orange lines (2018) compared to the blue lines (2012) indicates about decline. However, in terms of access, which refers to the ability of people of a particular country or region to obtain water to satisfy their needs and also incur the cost in terms of time and distance covered to collect water. The sub-mountainous zone showed no change in its index score, remaining constant at 0.95. While the central plain zone experienced a decline from 0.97 to 0.95, in contrast, the southwestern zone showed improvement, with the score increasing from 0.95 in 2012 to 0.97 in 2018.

Further, the third component, capacity that shows how well people or households can use and manage water resources according to their financial situation and health. It takes into account the frequency of water-related illnesses as a measure of vulnerability and adaptive capacity, and income as a stand-in

for economic resilience. A similar change was observed in the capacity component across two regions, likewise in the access component. In the sub-mountainous zone, the capacity score decreased from 0.34 to 0.23, and in the central plain zone from 0.30 to 0.27. However, the score increased from 0.29 to 0.32 in the southwest zone.

Additionally, the environmental aspect analyzes ecological and sanitary conditions of water sources that may affect the quality of water and public health. Stagnant water near drinking water sources is specifically an indicator of unsanitary conditions and potential for water contamination, which further undermines water safety and sustainability of access to water in general and conditions for transmission of waterborne diseases. However, the most significant decline was recorded in the environmental component, particularly in the sub-mountainous zone from 0.06 to 0.01 and southwestern zones from 0.02 to 0.01. However, the central plain zone remains constant at 0.02.

Despite an overall decline in the MWPI score between the specified time frames, it is crucial to highlight that the decline was not uniform across all index components, with

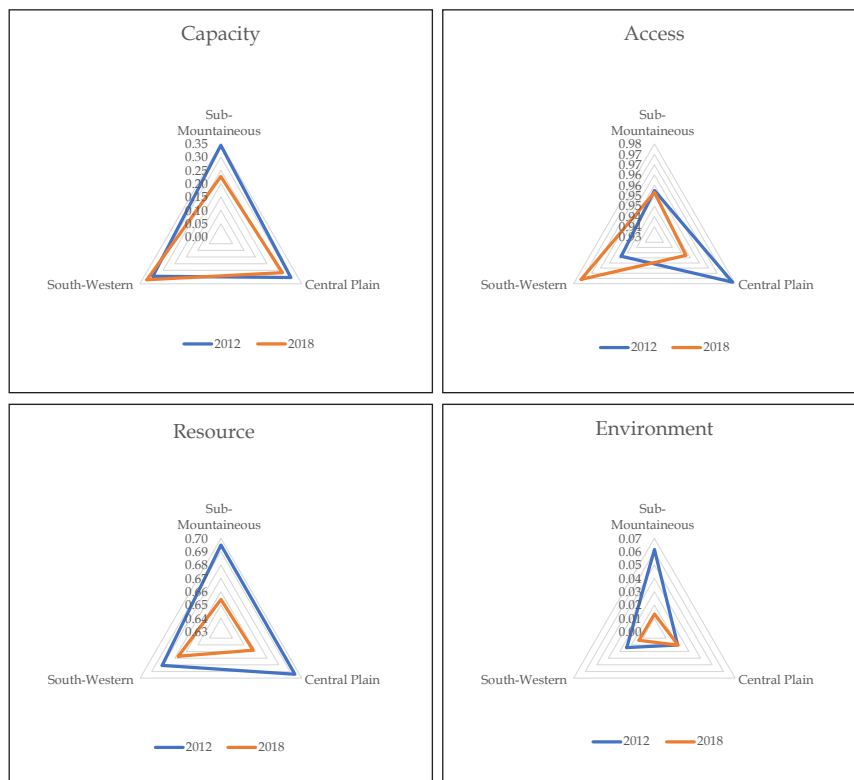


Fig 1. Zone-wise pentagram of components of modified water poverty index (MWPI)

Table 2. Zone-wise Index Values of Sub-components of Resource, Access, Capacity, Environment for 2012 and 2018

Component	2012			2018		
	Sub-Mountainous Zone	Central Plain Zone	South-Western Zone	Sub-Mountainous Zone	Central Plain Zone	South-Western Zone
R1: Water insufficiency (%)	53.4	63.1	67.3	64.0	83.1	63.5
R2: Water frequency (index value)	0.69	0.47	0.50	0.80	0.62	0.53
A1: Access to Safe Water Sources (%)	98.6	99.8	99.0	99.3	98.7	99.6
A2: Access to Improved Sanitation (%)	66.0	85.9	74.5	97.1	96.5	97.0
A3: Distance Travelled to Reach Water Source (index value)	0.86	0.93	0.82	0.59	0.76	0.95
A4: Time Spent to Collect Water (index value)	1.00	0.70	0.73	0.24	0.16	0.50
C1: Income (index value)	0.31	0.24	0.26	0.30	0.34	0.30
C2: Water-related illness (%)	40.1	39.0	35.5	0.00	9.90	39.7
E1: Presence of stagnant water around the source of drinking water (%)	6.20	2.00	2.40	1.30	2.10	1.30

Source: Author's Calculations

some suffering more than others. Therefore, sub-component-wise analysis has been conducted. Table 2 highlights the indicators of the resource component. As evident, from 2012 to 2018, the percentage of households experiencing water insufficiency has increased in the sub-mountainous and central-plain regions. However, the water frequency has shown improvement across all zones during the given time frame. The seeming paradox is due to a variety of region-specific reasons. Punjab's central plain and sub-mountain regions have suffered intense loss of groundwater following extensive irrigation, especially of water-intensive crops like paddy (CGWB, 2018; Rodell *et al.*, 2009). Shallow and tube wells became unreliable as groundwater levels dropped, especially in the Kandi (sub-mountainous) regions, which have little potential for recharge. In parallel, the regularity of water delivery through piped systems was enhanced by policy interventions and infrastructure investments made under initiatives such as the Punjab Rural Water Supply and Sanitation Project, which increased the frequency of supplies (World Bank, 2014). However, increases in these directions did not necessarily equate to satisfactory water quantity at the household level owing to issues of distributional challenges (Prakash, 2005).

For the access component, the proportion of safe water-access households improved to some degree for all areas except the central plain (Table 2). In 2012, almost 99.8% of the households had access to safe water; in 2018,

the rate fell to 98.7%. The drop is attributed to declining groundwater quality and loss because of intensive agriculture, as noted by Rodell *et al.* (2009) and CGWB (2018), who reported rising contamination and over-exploitation in the central districts of Punjab. In addition, as evident from Table 2, the distance traveled and time taken to fetch water increased across all the regions except the southwestern zone. This is a sign of an emerging trend of increasing spatial inequality in water access, supported by the studies of Prakash (2005), who emphasized how social and geographic factors determine rural households' proximity to reliable water sources. Even in the southwest, where most improvement took place, waiting lists for water supplies increased in each area, reflecting growing strain on water supplies. This observation aligns with Chaudhuri and Desai (2021), who emphasized that even where water infrastructure is in place, escalating demand and limited supply capacity can result in longer waiting times and reduced service quality. Positively, access to improved sanitation facilities showed a consistent increase across all zones during the same period (Table 2), reflecting the influence of national programs such as the Swachh Bharat Mission. As noted by UNICEF (2019), this initiative significantly enhanced rural sanitation infrastructure, with Punjab emerging as one of the better-performing states in terms of implementation effectiveness.

Table 3. District-wise modified water poverty index (MWPI) score (average)

District	MWPI (2012)	MWPI (2018)
Gurdaspur	0.68	0.64
Amritsar	0.72	0.66
Kapurthala	0.71	0.68
Jalandhar	0.69	0.64
Hoshiarpur	0.68	0.64
Nawanshahr	0.69	0.66
Rupnagar	0.72	0.67
Fatehgarh Sahib	0.69	0.66
Ludhiana	0.70	0.66
Moga	0.69	0.65
Firozpur	0.68	0.67
Muktsar	0.68	0.68
Faridkot	0.68	0.67
Bathinda	0.68	0.66
Mansa	0.69	0.65
Sangrur	0.69	0.62
Patiala	0.69	0.67
S.A.S. Nagar (Mohali)	0.70	0.66
Barnala	0.69	0.67
Tarn Taran	0.68	0.68
Average	0.69	0.66

Source: Author's Calculations

The capacity component shows a mixed pattern, with family income levels increasing throughout most zones, except for a modest fall in the sub-mountainous area. However, even after such a development, income levels are relatively low, as is evident from low index scores (Table 3). This indicates that although there is economic progress, this is not yet enough to offset wider structural and institutional issues, as indicated by studies such as Nelson *et al.* (2013) and Sharma *et al.* (2015), which do acknowledge that income growth will not necessarily lead to increased water management capacity or resilience. This is especially the case in the sub-mountainous region, where widespread underdevelopment in various sectors viz, restricted access to infrastructure, education, health, and off-farm employment, remains the constraining factor on levels of income and capability, as testified by the Punjab Development Report (2005). Simultaneously, water scarcity and diminishing availability of safe water in the central plain region facilitated growth in waterborne diseases in these regions. Low intake of water has been

reported to be linked with adverse health effects such as decreased physical and gastrointestinal function (Popkin *et al.*, 2010). In addition, in the central-plain zone, a decrease in households' access to safe water may also have increased the incidence of water-related illness.

The environmental component shows an improvement in all zones except the central plain zone, where the percentage of stagnant water surrounding drinking water sources grew slightly from 2.00% in 2012 to 2.10% in 2018, an almost negligible change. In support, studies mentioned that extensive agricultural lands are facing growing environmental stress from intensive land use Liu *et al.* (2020) unplanned rural habitation, and overburdened sanitation infrastructure (Kumar, 2025), which often lags behind rapid settlement expansion. However, the sub-mountainous and south-western areas, in turn, registered lower levels of stagnant water as a result of improved sanitation and water regulation. These success stories are underpinned by the National Annual Rural Sanitation Survey (NARSS, 2018–19) and Ministry of Jal Shakti (2019) findings, which record extensive Open Defecation Free (ODF) coverage alongside extensive rural Punjab solid-liquid waste management infrastructure. Furthermore, Singh *et al.* (2020) note that improved residue management practices in the southwestern region have further enhanced environmental conditions by reducing surface runoff and preventing water stagnation around drinking sources.

Nevertheless, a detailed analysis of component-specific trends reveals escalating risks. Between 2012 and 2018, the sub-mountainous zone experienced a decline in all four components, indicating about exacerbation of the challenges of water security and socioeconomic situations. Correspondingly, the availability, access, and capacity indicators of the central plain zone have also declined, reflecting increasing strain on water and sanitation facilities. Meanwhile, the resource availability and environmental conditions of the southwestern zone also decreased, reflecting the need for special interventions to ensure water safety and reduce contamination hazards.

District-Level MWPI Score: Figure 2, highlights the final results for all MWPI

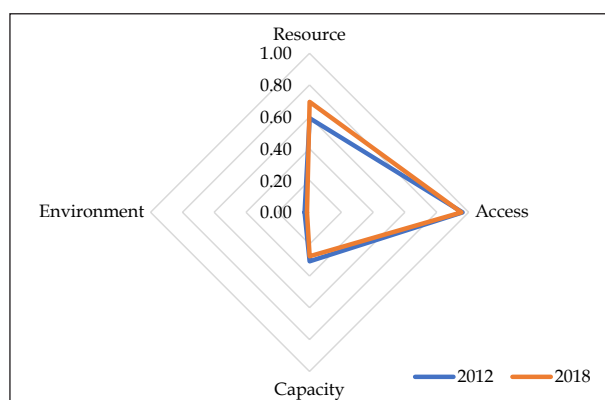


Fig. 2. Component-wise scores of modified water poverty index (MWPI).

components, represented as a radar diagram. The central point of the diagram is denoted as “0.” As we go farther from the origin, the magnitude of the depicted quantity rises. The outer layer represents the highest possible score of “1” that each component can achieve. As illustrated in Figure 2, the environment component had the lowest MWPI score among all four components, dropping from 0.03 in 2012 to 0.02 in 2018, indicating a significant deterioration in water safety conditions. The capacity component followed closely, falling from 0.31 to 0.28, indicating deteriorating socioeconomic resilience to water-related constraints. In comparison, the resource component’s MWPI score increased from 0.59 in 2012 to 0.69 in 2018. It reflects that water availability was improved while accessibility and adaptive capacity declined from 0.96 to 0.95 within the same years. All other factors except the resource component have deteriorated with time, of which environmental considerations have deteriorated the most, followed by the capacity component. These changes emphasize the need for targeted actions to improve water security and community resilience.

The final WPI score for all 20 districts of Punjab state was 0.69 in 2012 and 0.66 in 2018, indicating a deterioration in the water status of the state. Almost all the districts deteriorate their index score except Muktsar and Tarn Taran, which remain steady at a score of 0.68 throughout the given years of 2012 and 2018. Table 3 indicates the significant variations in the Modified Water Poverty Index (MWPI), with values ranging from 0.68 to 0.72 in the year 2012, indicating moderate water poverty levels. Additionally, the districts with the highest MWPI, such as Rupnagar (0.72), Amritsar

(0.72), and Kapurthala (0.71), were relatively less affected by water poverty. However, the districts such as Gurdaspur (0.68), Hoshiarpur (0.68), Muktsar (0.68), Faridkot (0.68), Bathinda (0.68), Firozpur (0.68), and Tarn Taran (0.68) had the lowest MWPI values, showing greater water stress. The overall value of the water poverty index of almost all the districts has decreased, indicating that the water crisis has increased in the state.

However, in 2018, the overall MWPI had fallen, with an average of 0.66, which indicated worsening water conditions in the majority of districts. Largest falls in MWPI were observed in Sangrur (0.62), Gurdaspur (0.64), Hoshiarpur (0.64), Jalandhar (0.64), Moga (0.65), Mansa (0.65), indicating worsening water poverty. These findings support the observations of the Jerath *et al.* (2014), which identifies central Punjab districts such as Sangrur and Moga as highly vulnerable due to groundwater over-extraction, paddy-wheat monoculture, and inefficient irrigation practices. In contrast, Muktsar (0.68), Tarn Taran (0.68), and Kapurthala (0.68) witnessed moderate stability in 2018. While Muktsar and Tarn Taran maintained a consistent score of 0.68 across both years of 2012 and 2018, this may be due to localized adaptive strategies; however, the score of Kapurthala declined from 0.71 to 0.68 in 2018. On average, though some districts showed comparatively stable levels, however majority of the districts show decline from 2012 to 2018, indicating an increasing water crisis among districts of Punjab.

Conclusions

This study revealed that the state’s water poverty situation deteriorated in 2018 as compared to 2012, and behind this decline, the key responsible components were access, capacity, and environment. While the resource component witnessed a slight improvement during the given years. Further, the zone-wise assessment of water poverty sheds light that the southwestern zone was the most water-poor in 2012; similarly, the sub-mountainous zone was most severely affected in 2018. Even though water poverty situations deteriorated in all zones throughout the given years, however, the sub-mountainous and central plain zones were significantly impacted; consequently, their index score declined in 2018. Moreover, the district-

wise water poverty analysis revealed that the most water-poor districts lie in the central plain and southwestern zone. Furthermore, among the 20 districts, excluding Mukatsar and Tarn Taran (with no change), the overall score of MWPI deteriorated in all other districts from 2012 to 2018. Additionally, Faridkot and Ferozpur experienced a very slight decline, suggesting relatively stable conditions as compared to other districts. The component-wise analysis revealed that the decline in the water status (decline in MWPI score) in these districts is primarily attributed to the deterioration of access to safe water, the increasing distance and time required for water collection, the rising burden of water-related diseases, and stagnant water surrounding the drinking water source. Additionally, the environment deteriorated in most of the districts out of all four components of MWPI during the given period.

Although the WPI serves as a potent policy instrument, however, its efficacy is accompanied by the method of weight assignment constraints. The outcomes are highly sensitive to the weights allocated to different indicators. However, when unequal weights are assigned, certain indicators may disproportionately influence the final WPI score, potentially overemphasizing or underrepresenting specific aspects of water poverty. Therefore, regular evaluation and refinement of weights, along with annual monitoring, are essential for accurate water stress assessment. Given the distinct characteristics of each district, it is advisable to formulate tailored policies targeting specific components to mitigate water poverty. Emphasis should be placed on strengthening water infrastructure, prioritising community-based water management approaches, and behavioral change. Moreover, given the multidimensional nature of water poverty, integrated water resources management could be an effective tool for addressing it. While acknowledging the state's efforts in water management, a lot still has to be done.

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