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Mapping Water Scarcity across Major States of India

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Water as a basic natural resource plays a critical role in any country's economic, ecological, and human development. Water is a state subject in India, and the provision of reliable, safe, and sustainable supply of water has emerged as a challenge due to geographical and institutional constraints. The water scarcity in 11 major states is evaluated through 20 variables that capture the multidimensional aspects of scarcity and the water poverty index. The results clearly indicate an alarming situation as these states face medium to severe scarcity. A sensitivity analysis indicates that the most critical variables impacting the water sector include socio-economic and environmental factors.

Water scarcity is the reality of our times and faced by people all around the globe. The rise in water scarcity and the frequent occurrence of water-related conflicts at the local, state, national, and international levels indicate an immediate need for a holistic approach to address the problem. The physical availability of water resources is essential for a healthy lifestyle, proper sanitation, and environmental needs. Water, as a basic natural resource, also plays a crucial role in any country's economic, ecological, and human development. The United Nations has recognised the access to safe and clean drinking water and sanitation as a basic human right, also enshrined as one of the 17 Sustainable Development Goals. Thus, water resource management plays a crucial role and has been considered the main challenge for emerging economies.

It is a matter of concern for India as nearly 600 million people face high to extreme water stress. Water quality at present is very poor, as India ranks 120 among 122 countries in the water quality index (NITI Aayog 2018). The challenges faced by the selected states in this analysis are different. Government policies and politics play a significant role in water management, as water is a state subject in India. The analysis of water scarcity can help study the role of economic development, political environment, and other factors affecting the water sector. Hence, it will be instructive to see how different states in India manage their water resources given their unique geopolitical challenges.

Measuring Water Scarcity

In recent times, performance indicators have been used extensively to evaluate relative achievement that can guide policymakers to the areas of improvement. It is vital to choose the right kind of indicators, as they have become an important policy tool to depict the socio-economic, political, ecological, and institutional state of a system. They help in highlighting the core feature of the system by summarising considerable information in a meaningful form. They act as a managerial tool giving directions to managerial policy and the allocation of resources.

There are several indicators pertaining to the water sector that have been developed and used worldwide. In the last three decades, the indices concerning water scarcity and stress have evolved from simple threshold indicators to multidimensional ones capturing environment, human water needs, and sustainable water use (Damkjaer and Taylor 2017). Many review articles (Damkjaer and Taylor 2017; Gleick and Cooley 2021; Xu and Wu 2019) highlight the evolution of water indicators considering various aspects of water scarcity. The major global challenge is to ensure a safe and adequate quantity of water for basic human use and maintain the ecosystems in which humans live. Therefore, many indices have been developed, expanding in two different directions: one, towards the socio-economic, ecosystem side, and two, towards a more physical measurement (per capita availability) (Doeffinger and Hall 2020).

The Water Poverty Index (WPI) is a holistic tool used worldwide to quantify water scarcity at different scales (Sullivan 2002). It is a multidimensional index with five components that try to capture the role of physical availability of water resources, access to clean water and proper sanitation, economic and human capacity factors, water demand by different sectors, and environmental water needs. The limitations of most multidimensional indicators include adaptability and scaling. However, the WPI has been used around the globe at various scales, given its ability to adapt to different scales and criteria (Jafari Shalamzari and Zhang 2018). The WPI presents an effective method for identifying variables that influence poverty, ranking the extent of water stress, and developing appropriate interventions in disadvantaged areas (Koirala et al 2020). It is also helpful in analysing the overall water sector performance at various scales—the lower the WPI, the better the water sector performance.

To the best of our knowledge, there is limited research on the application of the WPI as a comprehensive tool for mapping water scarcity in India. Specifically, studies that utilise the WPI to quantify water scarcity at the state and national levels are few in number. Some notable exceptions include Goel et al (2020) and Lawrence et al (2002). However, considering India's size and its geopolitical challenges, it is better to look at the state-level situation of water scarcity and water sector performance. This study aims to use the WPI as a tool to analyse and visually represent the status of water scarcity across states in India rather than contributing to the methodological advancement of the WPI.

The paper first discusses the need for a multidimensional water scarcity analysis at the state level in India. Then it details the methods, study area, and data used for the index calculation. Finally, results of this study are discussed and its policy implications are analysed.

Water Poverty Index

In this study, we have used the method initially developed by Lawrence et al (2002) and further refined by many researchers worldwide (Heidecke 2006; Sullivan et al 2006; Manandhar et al 2012; Jemmali and Sullivan 2014). The international WPI developed by Lawrence et al (2002) defines and compares the impact of water scarcity on the human population. It helps rank countries and communities on the basis of both socio-economic and physical factors associated with water scarcity. The WPI also helps concerned authorities with water management, monitoring the physical availability of resources and socio-economic factors impacting the access and use of those resources, and priorities for further improvement.

The WPI is an efficient, comprehensive tool for assessing water scarcity and water management at various micro and macro scales (Garriga and Foguet 2010). More precisely, the WPI is a decision-making tool to deal with issues like water availability, water use efficiency, productivity, and allocation (Ladi et al 2021). The widely used WPI consists of five components, namely resources, access, capacity, use, and environment (Lawrence et al 2002). Many researchers around the globe have implemented the WPI for evaluating the water scarcity situation by considering various subcomponents grouped under the main five components (Garriga and Foguet 2010; Githiora 2012; Jemmali 2017; Koirala et al 2020).

Lawrence et al (2002) have shown the correlation between the different components and comparison of the WPI with the HDI and the Falkenmark water stress indicator. Results show that a very weak correlation exists between the WPI and the Falkenmark water stress indicator, which means the WPI adds extra information to assess the progress towards sustainable water provision. The WPI has been used at different levels and scales to quantify water scarcity: (i) cross-country level (Cho et al 2010; Lawrence et al 2002; Jemmali and Sullivan 2014; Jemmali 2017); (ii) state and regional level (Heidecke 2006; Sullivan et al 2006; Goel et al 2020; Hawrami and Shareef 2020); (iii) basin and sub-basin level (Manandhar et al 2012; Koirala et al 2020; Van Ty et al 2010); and (iv) community level (Wilk and Jonsson 2013; Garriga and Foguet 2010; Prince et al 2021).

The selection of the subcomponents varies depending on such factors as scale and data availability and relevance. In this analysis, we have selected 20 different subcomponents based on a literature review of the application of the WPI at various scales and considering the data availability and relevance at the state level. These subcomponents and components of the WPI used in the analysis are discussed in detail as follows.

Resources (R): This component concerns the physical availability of water resources and other factors that affect water availability. In this study, four subcomponents are considered under the resource component of the WPI. The subcomponent R1 accounts for per capita total water availability (Jemmali 2017). R2 is a measure of long-term average precipitation, calculated by taking the mean of annual rainfall in the given state for 1985–2015 in millimetres (mm) (Jemmali 2017). R3 represents the average value of interannual variability (Jemmali 2017), whereas R4 accounts for the average value of seasonal (January–February, March–May, June–September, and October–December) variability for 1980–2015 (Garriga and Foguet 2010; Jemmali 2017). A higher value of the resources component is desirable, that is, abundant water resource with less variability, which means a high R1 and R2 and a low R3 and R4 values.

Access (A): This component captures the importance of access to improved drinking water and sanitation, recognising that water availability for growing food is as essential as for domestic and human consumption. For this component too, a higher value is desirable. Three subcomponents have been used to calculate this component. A1 is the percentage of the population with access to safe drinking water (Sullivan 2002; Garriga and Foguet 2010; Jemmali and Abu-Ghunmi 2016; Jemmali 2017). A2 is the percentage of the population with access to better sanitation (Sullivan 2002; Garriga and Foguet 2010; Jemmali and Abu-Ghunmi 2016; Jemmali 2017). A3 is the percentage of agricultural water-managed area equipped for irrigation (Lawrence et al 2002; Sullivan 2002). A3 is defined as the ratio of area equipped for irrigation to the total agricultural water managed area. It was approximated by calculating the ratio of net irrigated area to net area sown for the given state.

Capacity (C): This component attempts to capture different socio-economic factors that could affect the ability of users and utility providers to manage water resources effectively. A high capacity indicates high sensitivity and importance to socio-economic and infrastructure-related factors. We have considered six subcomponents. C1 is related to the per capita average income or net state domestic product (NSDP) (Sullivan 2002), which captures the capacity of people to pay for their expenditure. C2 concerns education, calculated using enrolment rate at the primary level, which plays a vital role in training people on the importance of safe water and sanitation practices (Wilk and Jonsson 2013). C3 is the unemployment rate, which captures water's importance as an employment enabler (Wilk and Jonsson 2013). C4 is related to the investment in the water sector and is calculated using the ratio of average expenditure on water and sanitation during 2007–12 and the given state's population (Githiora 2012; Jemmali 2017). More investment indicates a high priority by the government to safe water and sanitation. C5 is a measure of the under-five mortality rate, while C6 represents the average incidence of waterborne diseases (Sullivan 2002; Wilk and Jonsson 2013; Jemmali 2017).

Use (U): This component tries to capture water use across sectors. Water use varies significantly with economic development and is essential for daily human activities. A higher value of this component is desirable as it shows high water use efficiency in different sectors. Three subcomponents have been considered here, capturing water use in various competing sectors. U1 indicates domestic water scarcity, calculated as the difference between water required and water available for domestic water use annually. About 55 litres per capita per day (lpcd) and 135 lpcd were used as a standard water supply for rural and urban populations. The water available for domestic purposes was approximated using the criteria that the domestic sector accounts for 6% of per capita total water available. U2 and U3 capture water-use efficiency in the agricultural and industrial sectors, respectively (Sullivan 2002; Githiora 2012; Jemmali 2017). They are calculated as the share of water use by a specific sector adjusted by the sectoral share of the gross domestic product (GDP).

Environment (E): This component captures the importance of water for ecological use and other factors that impact the water supply and quality directly or indirectly. A high value of this component shows the importance given to environmental water needs. In this study, four subcomponents related to the environment have been considered. E1 captures forest area (as percentage of land area) (Lawrence et al 2002). E2 captures use of fertilisers in kilogram per hectare (kg/ha) of arable land (Jemmali 2017). E3 captures ground water quality index (Lawrence et al 2002; Jemmali 2017), expressed as an aggregated score of the number of districts in the state not affected by different groundwater pollutants. E4 is the river water health index (Lohani and Ait-Kadi 2013), calculated as an aggregated score of a number of different parameters such as dissolved oxygen in milligrams per litre (mg/l), potential of hydrogen (pH), conductivity in millisiemens per centimetre (mhos/cm), biological oxygen demand in milligrams per litre (mg/l), total coliform in most probable number per 100 milliliters (MPN/100ml) and fecal coliform (MPN/100ml) that are essential for the quality of river water. Except for E2, higher values of E1, E3, and E4 are desirable for a higher value of the environment component.

In this analysis, we have assigned equal weights to all the components to compute the final WPI. As suggested in the literature, equal weights is a popular approach while measuring the WPI as it avoids subjectivity, bias, and results in more acceptable and comparable indexes to stakeholders and policymakers (Manandhar et al 2012; Koirala et al 2020). The weights assigned to the above-listed five components are w_r, w_a, w_c, w_u, and w_e, respectively. Within each component, the subcomponents are averaged to get the component's aggregate value. Then, aggregation of the final WPI is done by a weighted average of its five components, considering equal weights to all the components as stated in equation 1.

$$\mathrm{WPI} = \frac{w_r R + w_a A + w_c C + w_u U + w_e E}{w_r + w_a + w_c + w_u + w_e} \ldots (1)$$

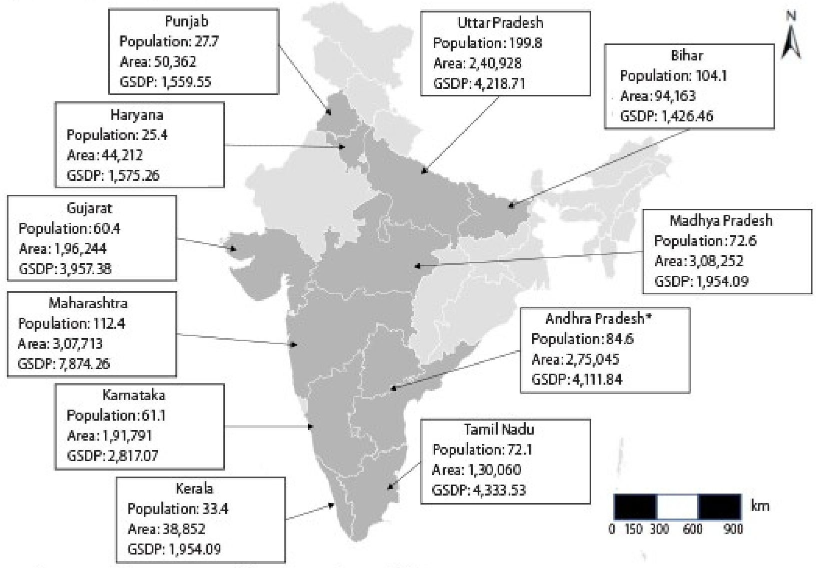
The final WPI score for comparing the water sector performance of various states in this study is calculated by multiplying the WPI score, given in equation 1, by 100. Thus, the final WPI score varies in the range of 0 to 100. Where 100 and 0 indicate the best (low level of scarcity) and worst (high level of scarcity) performance measure.

Although the WPI has been used worldwide, like any other index, it too has its limitations and criticisms (Jemmali 2017; Rijsberman 2006). The main criticism is related to the aggregation method, indicators, and weight selection criteria used for calculating the final WPI (Molle and Mollinga 2003). To make the WPI more robust and reliable, various weight selection criteria along with statistical techniques can be incorporated for future assessments at various scales.

Study Area and Data Sources

India is the second-most populous country globally with more than one-sixth of the world's population. With a total area of 32,87,469 square kilometres, India is the seventh largest country in the world. Our study area comprises 11 major states of India, namely Andhra Pradesh (AP),[1] Bihar, Haryana, Gujarat, Karnataka, Kerala, Maharashtra, Madhya Pradesh (MP), Punjab, Tamil Nadu (TN), and Uttar Pradesh (UP). The selection of these states was made based on the GDP contribution, agricultural production, and urbanisation. Selected states account for 70% of the total population and cover 57% of the geographical area of India. These states also contribute close to 69% of the total GDP of India. The description of the population, area, and state GDP of the selected states is depicted in Figure 1.

Figure 1: Population, Area, and GSDP of Selected Indian States



Population is in million, area in square kilometres, and GSDP in ₹ billion.

The 20 subcomponents classified under-five components were used to calculate the final WPI at the state level. For each component of the WPI, a number of different indicators were used; thus, it is critical to convert them to a single scale for evaluating the final WPI score (Gómez-Limón and Sanchez-Fernandez 2010; Talukder et al 2017). To overcome the problem of different units, we have used the min–max approach for normalising data as it is widely used by researchers for the WPI calculation at different scales (Githiora 2012; Goel et al 2020; Koirala et al 2020; Lawrence et al 2002; Manandhar et al 2012).[2]

Normalisation of positive factors (that is, factors for which higher values are better) was done using the following formula:

$$Z_i^* = \frac{Z_i - Z_{min}}{Z_{max} - Z_{min}} \quad \dots (2)$$

Similarly, for negative factors (that is, factors for which lower values are better), normalisation was done as follows:

$$Z_i^* = \frac{Z_{max} - Z_i}{Z_{max} - Z_{min}} \quad \dots (3)$$

where Z_i is the current value of factor Z for the state i, and Z_{max} and Z_{min} are the highest and lowest values of that factor, respectively. After normalisation, the values were distributed between 0 and 1, with the best-performing state at 1 and the worst-performing state at 0. The descriptive statistics, along with the preferable or desirable value of these 20 subcomponents is given in Table 1.

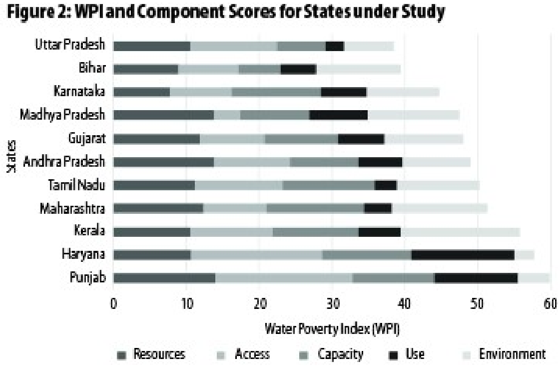
Table 1: Descriptive Statistics of 20 Subcomponents

Subcomponent	Max	Min	Average	Median	Desirable Value
Resources					
R1: Total availability of water resources (cubic metres)	937.5	287.3	616.6	713.9	High
R2: Long-term average precipitation (mm per year)	2,810	511	1,116	918.5	High
R3: Interannual variability (mm)	1,273	143.7	323.4	222.3	Low
R4: Seasonal variability (mm)	734.7	169.5	350.5	326.6	Low
Access					
A1: Percentage of population with access to safe drinking water	99.1	78	93.5	94.5	High
A2: Percentage of population with access to better sanitation	97.7	23.1	57.3	52.4	High
A3: Percentage of agricultural water managed area equipped for irrigation	99.1	18.7	54.3	52.4	High
Capacity					
C1: Per capita NSDP (₹)	64,218	14,362	45,255	47,834	High
C2: Enrolment rate: primary level	93.7	77.7	86.2	86.4	High
C3: Unemployment rate	6.7	1	2.7	2.2	Low
C4: Per capita expenditure on water and sanitation (₹)	0.016	0.001	0.005	0.004	High
C5: Under-five mortality rate	73	13	43	43	Low
C6: Average incidence of waterborne diseases (%)	32	1.13	13.8	13.3	Low
Use					
U1: Domestic water scarcity (lpcd)	108.62	0	58.96	50.83	Low
U2: Water-use efficiency in agriculture	2.2	0.14	0.69	0.4	High
U3: Water-use efficiency in industry	57.7	5.5	18.7	14.4	High
Environment					
E1: Forest area (%)	46.1	3.5	16.5	15.5	High
E2: Fertiliser consumption (kg/ha)	250.2	84.8	156.9	164.6	Low
E3: Groundwater quality index (%)	70.4	34.8	56.9	60.2	High
E4: River health index (%)	97.8	44.9	71.9	70.1	High

Results and Discussion

After normalisation, the first step was to calculate the individual aggregate score of five components for all the 11 states. The component's aggregate value is defined as the average value of its subcomponents, and the final WPI score is calculated using equation 1. The final WPI score thus varies in the range of 0 to 100. The state-level comparison for the WPI and its respective components are depicted in Figure 2 (p 50).

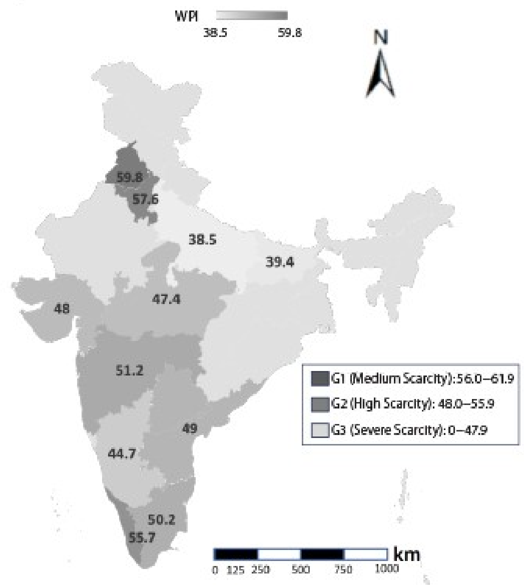
Figure 2: WPI and Component Scores for States under Study



In this analysis, the final WPI score ranges from 59.80 to 38.51 for states under study. Based on the classification of the final WPI score given by Guppy (2014), these states can be classified in three groups. The first group (G1) comprises states having a medium water scarcity (56–61.9), specifically Punjab (WPI=59.80) and Haryana (WPI=57.64). These are the only states performing relatively well and the least water-stressed. The second group (G2) has states with high water scarcity (48–55.9) and comprise Kerala (WPI=55.71), Maharashtra (WPI=51.25), TN (WPI=50.16), AP (WPI=49), and Gujarat (WPI=48.01). The third group (G3) has states with severe water scarcity (0–48.0) comprising MP (WPI=47.45), Karnataka (WPI=44.67), Bihar

(WPI=39.41), and UP (WPI=38.91). The final WPI score of these states is depicted in Figure 3.

Figure 3: WPI Score for States under Study



As suggested in the literature, information about the overall water sector performance is in the individual components and subcomponents rather than the final WPI score (Lawrence et al 2002). The final WPI is calculated as a composite index; thus, any change in the value of the main components can be reflected by the changed value of the final WPI score of the selected states. Hence, it will be interesting to analyse the role of these five components and their subcomponents on the final WPI.

The current aggregate value for the five components of the WPI and respective ranks of the selected states is presented in Table 2. It highlights the status quo along with the diverse challenges faced by the administration and policymakers of these states. The value of access is 0.18 for MP, showing a very poor situation of water infrastructure, whereas 0.94 value of access for Haryana shows the state government's focus on proper sanitation and clean water. Similarly, the low value of the environment component for Punjab (0.27) and Haryana (0.13) highlights the poor state of water quality and related issues. The aggregate values are very close in components like resources and capacity, while it is spread across the range for other components.

Table 2: WPI and Its Components Value (Rank) for States under Study

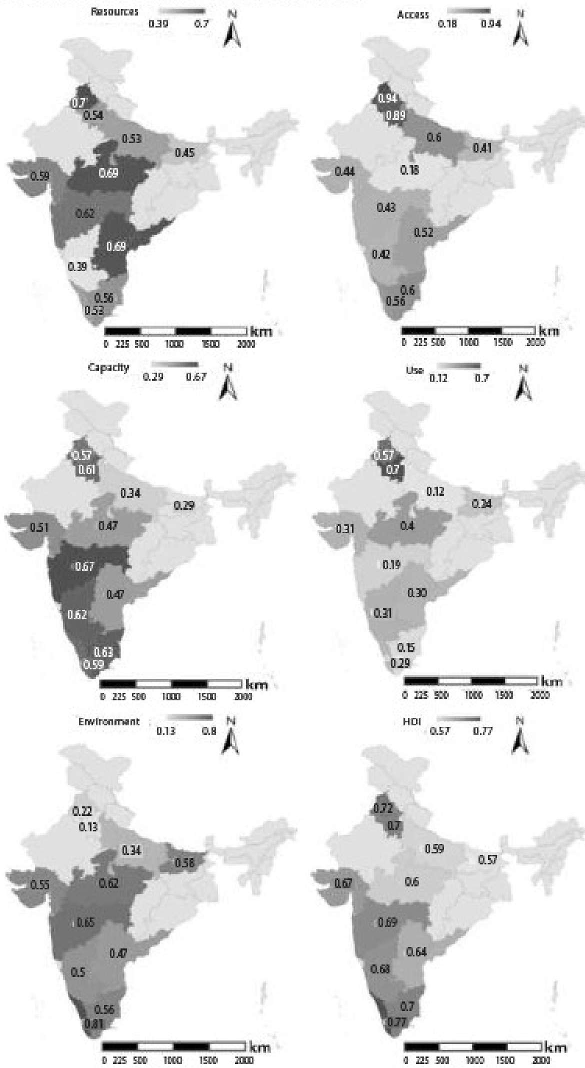
State	$R_{aggregate}$ (Rank)	$A_{aggregate}$ (Rank)	$C_{aggregate}$ (Rank)	$U_{aggregate}$ (Rank)	$E_{aggregate}$ (Rank)	WPI Score (Rank)
Punjab	0.7 (1)	0.94 (1)	0.57 (6)	0.57 (2)	0.27 (10)	59.80 (1)
Haryana	0.54 (7)	0.89 (2)	0.61 (4)	0.70 (1)	0.13 (11)	57.64 (2)
Kerala	0.53 (8)	0.56 (5)	0.59 (5)	0.29 (7)	0.81 (1)	55.71 (3)
Maharashtra	0.62 (4)	0.43 (8)	0.67 (1)	0.19 (9)	0.65 (2)	51.25 (4)
Tamil Nadu	0.56 (6)	0.60 (3)	0.63 (2)	0.15 (10)	0.56 (5)	50.16 (5)
Andhra Pradesh	0.69 (3)	0.52 (6)	0.47 (8)	0.30 (6)	0.47 (8)	49.00 (6)
Gujarat	0.59 (5)	0.44 (7)	0.51 (7)	0.31 (4)	0.54 (6)	48.01 (7)
Madhya Pradesh	0.69 (2)	0.18 (11)	0.47 (9)	0.40 (3)	0.62 (3)	47.45 (8)
Karnataka	0.39 (11)	0.42 (9)	0.62 (3)	0.31 (5)	0.50 (7)	44.67 (9)
Bihar	0.45 (10)	0.41 (10)	0.29 (11)	0.24 (8)	0.58 (4)	39.41 (10)
Uttar Pradesh	0.53 (9)	0.60 (4)	0.34 (10)	0.12 (11)	0.34 (9)	38.51 (11)

Punjab, with the highest WPI score (59.8), is ranked 10th and sixth in environment and capacity components. However, the effect of poor performance in these components is not reflected in the final WPI score and ranking of Punjab. The reason for this could be that the absolute value difference in the case of capacity is not that high to affect the overall WPI score, and the low value in the environment component is compensated by the higher values of remaining components. Similarly, although MP ranks second in the resource component with a normalised value of 0.69 and ranks third in both use and environment components but in the final WPI ranking, it ranks eighth (WPI=47.45). The reason for this could be the high absolute difference in the value of the access component for MP, which has a much lower value (0.18) compared to the highest value of 0.94.

Moreover, the final WPI score for the middle group states is very close. Hence, a slight increase or decrease makes too much difference in the ranking of these states. For Maharashtra, poor performance in access (0.43) and use (0.19) components resulted in fourth rank in the final WPI ranking despite the high value in the resource, capacity, and environment components. For Karnataka, the rank in capacity (third) and use (fifth) components is relatively better as compared to other components. However, the actual value of these components is not high enough to improve the state's overall WPI score. To get a high rank in the final WPI score, the WPI score of Karnataka should at least be greater than 47.45. In the case of the last two states, poor performance in all the five components resulted in a low ranking in the final WPI score. These low ranks and values indicate the water sector's ill situation, infrastructure issues related to water quality, and other socio-economic factors in these states.

The variation of WPI components, that is, resources, access, capacity, use, and environment along with the Human Development Index (HDI) in selected states is illustrated in Figure 4. From the analysis of the WPI components and the HDI, it is clear that the states with lower HDI are the states with the highest water scarcity (lower WPI score). There is a strong positive correlation between the HDI and the capacity component of the WPI. This is because the capacity component of the WPI and the HDI share common subcomponents. In this analysis, states like Gujarat, AP, MP, UP, and Bihar are those with lower capacity ranks and have lower HDI ranks. Lawrence et al (2002) have reported similar results with a strong positive correlation between the HDI and capacity components. The final WPI score for Punjab, Haryana, and Kerala is higher than the national average estimated by Lawrence et al (2002) (that is, WPI=53.2), whereas for all the other states under study, the WPI score is less than the national average.

Figure 4: WPI Components and HDI Variation for Selected States



Sensitivity Analysis

Sensitivity analysis was performed to evaluate the robustness of the WPI score and ranks of the selected states by changing the aggregate component's value by 10% and 30%. For each state, all the five components' values were increased one at a time, keeping the values of other components and states unchanged to analyse the effect of change in the value of one aggregate component's value on the final WPI score. The improved WPI score of the state under analysis was then used to rank it compared to other states' WPI scores. A component is termed effective only if it results in improved ranking for that state. The effectiveness of components can be derived by the improvement in the state's rank, that is, the more significant the rank improvement (indicated by asterisk), the highly effective is the component.

In Table 3 (p 52), columns WPI_R, WPI_A, WPI_C, WPI_U, and WPI_E show the improvement in ranks of different states when that particular component's value is increased by a given percentage. For instance, WPI_R shows the effectiveness of resource dimension. This analysis helps understand the importance of these components in achieving better WPI scores, and thus, resulted in improved ranking for the selected states.

Our analysis indicated that most of the states show no improvement in the ranking for the 10% increment in the aggregated components' value. However, states like Gujarat, MP, and TN exhibit a slight improvement (indicated by single asterisk) for this 10% increment for most components. In comparison, AP showed improvement in rank only for a 10% increment in the resources component.

With a 30% increment in the components' value, other than Punjab, Maharashtra, and Bihar, all other states showed improvement in their ranks in the range of one to four. Among all the states under study, MP showed the highest rank improvement, followed by Gujarat, and AP, respectively. For Karnataka, a 30% increase in capacity and environment component resulted in a rank improvement of two and one units, respectively. Of the five components of the WPI, resources, environment, and capacity emerge as the most effective components in this analysis.

The effect of increment is more pronounced in the middle group as they show the highest rank movement. This can be explained by the WPI score in Table 3, as the absolute values of the WPI for this group are very close to each other, and therefore a slight increment results in improvement in the rank for the states in the middle group. In the case of Maharashtra, although the absolute value of the WPI increases with the increment in individual component's value, this jump in the WPI score is not enough to surpass that of other states in the first group. Therefore, a 30% increment also resulted in no improvement in the rank for this state. The same is the case with states in the lower group, for instance Bihar and UP, whose slight improvement does not, however, result in a significant value change in the final WPI score to improve their respective rank.

As already mentioned, the information is in the components, and not in the final WPI. With this objective, we tried to determine the effect of the individual components and its implications for the states. As per our analysis, the significant components are resource, environment, and capacity, as they resulted in significant improvement of ranks of states. Out of these three components, we have control over only two components, that is, capacity and environment. Hence, all states need to start working towards improving their socio-economic factors, water quality, and investment in water and sanitation for better and sustainable water sector management.

In Conclusion

This paper is an attempt to map the water scarcity across major states of India. The WPI has been adopted as a holistic and interdisciplinary tool to access water scarcity at various levels. For a country like India, it is essential and critical to manage its scarce resources sustainably. This study tried to amplify the importance of multidimensional analysis of water scarcity in India, where challenges and constraints of water resource management change within states. It gives an overview of how well these states manage their water resources. This analysis can also be helpful for policymakers to decide and prioritise the area of improvement.

We have used 20 subcomponents under five components of the WPI to quantify the situation of water scarcity and the area of improvement for a particular state. The WPI score for the states under study ranges from 38.51 in the case of UP to 59.8 for Punjab. The states with low WPI scores should be given priority considering the performance of various components of the WPI.

Our results show the effect of different socio-economic, environmental, and other factors along with the physical availability of water on the overall water sector performance and water scarcity. Punjab, Haryana, and Kerala perform well in comparison with the other states. As per the results of this study, the most water-scarce states are Karnataka, Bihar, and UP. The primary cause of the poor performance of these states is the poor condition of their socio-economic components apart from the physical availability of water. One possible solution to improve the condition of water scarcity in India is to give priority to those components of the WPI on which the given state performs poorly.

In this study, a sensitivity analysis was also conducted to review the importance and effect of the WPI components on the overall WPI score. The following results indicate that the improvement in water scarcity in most states has resulted due to better performance in resource, capacity, and environment components of the WPI. The improvement in these components' values resulted in a high WPI score for the states, and an upward movement in ranking is also noticed for most states. Hence, policymakers should consider these factors while framing future water policies for better and sustainable water resources management.

Notes

1 Andhra Pradesh represents the data for both present-day Andhra Pradesh and Telangana.

2 The min-max approach is a method used to normalise data, bringing it to a common scale between a minimum and maximum value. In this approach, the minimum value in the dataset is assigned a normalised value of zero, and the maximum value is assigned a normalised value of one. The remaining values are scaled proportionally between zero and one based on their relative position within the minimum and maximum range. This technique is commonly used in data pre-processing and machine learning algorithms to improve model performance and consistency when dealing with variables of different magnitudes.

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