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ARTICLE

The Water Poverty Index: An application in the Indian context

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Abstract

For developing countries, the proportion of households covered by improved water resources is conventionally used to assess the water stress situation. However, in a developing country like India with a high population growth rate, water demand and supply are considerably mismatched. An agro-based economy with large variations in socio-economic conditions and changing rainfall patterns across the states imposes greater challenge on water resources. Therefore, there is a need to assess the water situation across the country in a holistic manner. This paper proposes application of the Water Poverty Index as a comprehensive policy tool to assess actual water-stress situation across 20 major states in India. This index covers important socio-economic parameters such as access, capacity, use and environment in addition to water resources of each state. The results and findings are expected to be of use to policymakers and implementing agencies. In view of policy formulation, a state performing well on a Water Poverty Index component can act as a benchmark for another state.

KEYWORDS

environment, India, socio-economic, water poverty index, water stress

1 | INTRODUCTION

Water stress is when the ecological as well as human demand of water cannot be met either due to insufficient availability of water or poor quality restricts its use. According to UNESCO (2019), more than 2 billion people reside in countries that experience high level of water stress. Further, regions which have been facing a high level of physical water stress[1] are mainly located in Africa and Asia.

A high level of water stress in these countries leaves a gap between water demand and water supply leading to either "Day Zero"[2] during the first year, or a drought situation in the subsequent years and a threat of a water crisis situation in the long term. Increasing population, economic growth, industrialization, urbanization, deteriorating water bodies due to sewage and industrial discharge and lag in implementing water treatment or re-cycling methods are further aggravating this situation. Therefore, it is crucial to assess the factors that lead to water stress in a country.

1.1 | A review of water stress indices

The timeline for selected water stress indicators is shown in Figure 1. The first water stress indicator proposed defines the fraction of total annual run-off available per person every year (Falkenmark, Lundqvist, & Widstrand, 1989).

Over subsequent years, an improvement over Falkenmark indicator was proposed by taking into consideration basic human requirements (Gleick, 1996). Meigh suggested an index which took into consideration total water utilization for various needs along with surface and groundwater resources (Meigh, McKenzie, & Sene, 1999). With different indexes and methods, it was clear that measurement of water stress involved several dimensions. In 2003, Sullivan proposed the Water Poverty Index (WPI) as a holistic tool which included assessment of water stress situations based on five components: resources, access, capacity, environment and use. Although, WPI requires multiple datasets for its construction, it is an improvement over previous indices since, it links the estimates of water availability with the socio-economic indicators.

Figure 2 gives an overview of the various national and international studies (2009–2018) which assessed WPI. There has been a greater proportion of studies published in Asia and Africa during this period.

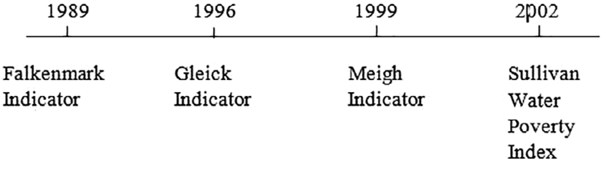

FIGURE 1 Timeline of a few water stress indicators. *Source*: Author's elaboration

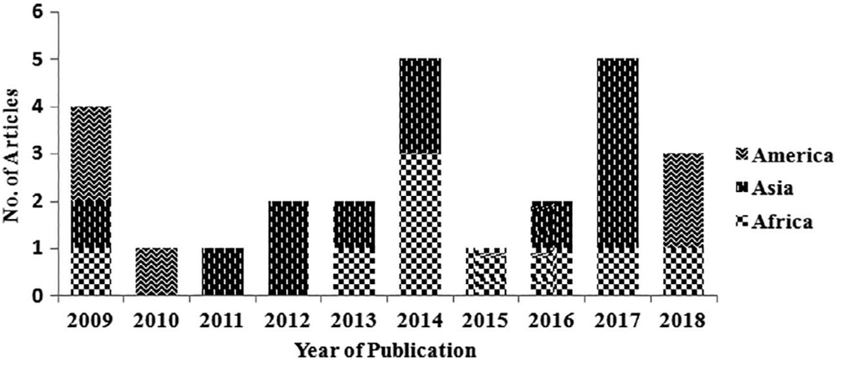

FIGURE 2 Number of studies reviewed employing WPI in Asia, Africa and America. *Source:* Author's elaboration

1.2 | Water stress in the Indian context

India is home to 18% of the world's population but has only 4% of its water resources.[3] Certain states are more agricultural intensive compared to others. This could possibly mean that irrigation demands differ in each state. To compound the problem further, the per capita availability of water has decreased drastically.

In India, the state governments have the authority to regulate and formulate water policies. Hence, an attempt has been made to take a closer look towards the water stress situation in multiple states of India. We examine various factors that play an important role in the availability and consumption of water. This study is the first attempt to consider the socio-economic indicators for water assessment in multiple states of India. A holistic overview of the water stress situation is expected to aid policy formulation at a state level.

1.3 | The water poverty index framework

The calculation of WPI requires information on five key components namely – resources, access, capacity, environment and use. The WPI framework (see Figure 3) has been adapted from the one proposed by Sullivan, Meigh, and Giacomello (2003). The part of the model describing relationships between the WPI components (resources, access, capacity, environment, use) and the indicators (R1…R3, A1…A5, C1, C2, E1….E3, U1….U3) represents the outer model. The components and WPI form a part of the inner model.

Sixteen indicators have been grouped into five components. Each key component has been assigned a score based on the respective indicators. Each indicator represents a different dimension for the corresponding WPI component.

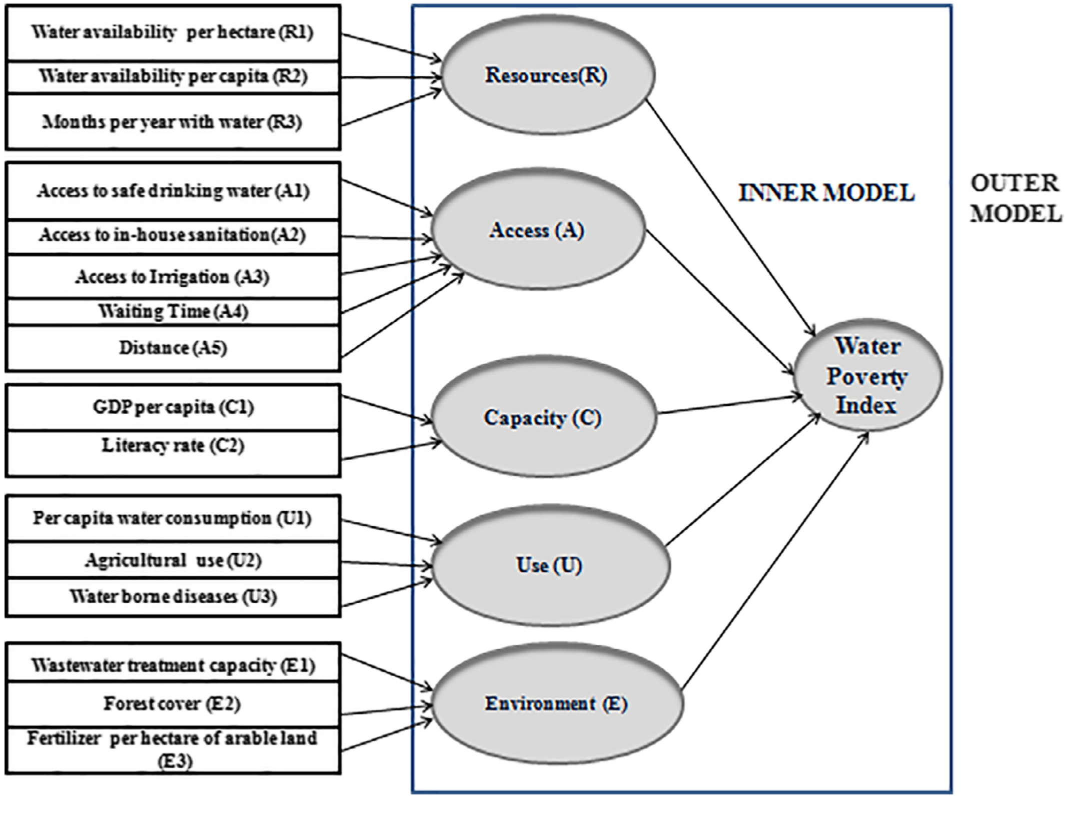

FIGURE 3 Theoretical model between various components and indicators. *Source*: Author's elaboration

1.3.1 | Resources

The indicators for this component assess the water resources from both qualitative and quantitative perspectives, taking into account reliability of supply and seasonal resource variability. Water availability per capita and water availability per hectare (Huang, Feng, Lu, Wen, & Deo, 2017) were taken as indicators for water availability. Months per year with water (Giné & Pérez-Foguet, 2009) was taken as an indicator for seasonal variability.

1.3.2 | Capacity

The indicators for this component refer to effectiveness of people's ability to manage water resources, particularly in the form of social and economic capacity. GDP per capita (Huang et al., 2017) is taken as an indicator of the economic capacity, whereas literacy rate (Anju, Vicky, & Sajil Kumar, 2017) is taken for social capacity.

1.3.3 | Access

The indicators for this component refer to accessing water for various needs. Water could be accessed for drinking or in-house sanitation and irrigation. It also combines physical access of water resources measured through distance and time to fetch this water. The percentage of households getting good quality drinking water (Zahra, Haider, Mahmood, & Ullah, 2012), population with access to in-house sanitation (Komnenic, Ahlers, & Van Der Zaag, 2009; Zahra et al., 2012), irrigated land as a proportion of arable land (Lawrence, Meigh, & Sullivan, 2002), average time taken in a day by household members to fetch drinking water from outside premises (Thakur, Neupane, & Mohanan, 2017) comprise the access component.

1.3.4 | Use

The indicators for this component refer to the utilization of water resources for agricultural, domestic or industrial use. The use component comprises agricultural water use (Zahra et al., 2012) and percentage of water borne diseases (Giné & Pérez-Foguet, 2008) apart from per capita water consumption as indicators. It was important to consider agricultural water use as an additional indicator apart from per capita water consumption, since a majority (80%) of the water in India is used for agriculture.

1.3.5 | Environment

The indicators for this component take into account sustainability of environment while accessing water for agriculture, industrial or domestic use. Forest cover was used as an indicator (Nadeem, Cheo, & Shaoan, 2018; Nair, 2003; OECD, 2008; Wurtz et al., 2019) since it promotes biodiversity and certain species of plants are negatively impacted by afforestation (Elmarsdóttir et al., 2008). Moreover, forest catchments are supposed to be of better water quality than urban and agricultural catchments (Brogna et al., 2018). The OECD (2008) indicators for environment suggest wastewater treatment rates as an indicator of freshwater quality, therefore, it has been used as an indicator in the model. The excessive use of fertilizers increases water pollution, which further degrades the water quality (Ganesh, Bajpai, & Malik, 2011). Thus, the indicator fertilizer per hectare of arable land (Giné & Pérez Foguet, 2015; Lawrence et al., 2002) has been used. It is worth noting that water quality as an aspect has been included in the environment component (Wurtz et al., 2019) indirectly through the indicators mentioned above.

2 | STUDY AREA

India is comprised of 28 states and nine union territories including the newly formed states and union territories. The hydrological details of the study area have been mentioned in Appendix A. As shown in Table A1, the water availability data (run-off) for some of the north eastern states and newly formed states is missing. Therefore, the scope of this paper is limited to water stress analysis of 20 states, namely, Odisha, Kerala, Bhar, Uttarakhand, Arunachal Pradesh, Punjab, Himachal Pradesh, Jammu and Kashmir, Rajasthan, Jharkhand, West Bengal, Andhra Pradesh, Assam, Chhattisgarh, Gujarat, Haryana, Karnataka, Madhya Pradesh, Tamil Nadu and Bihar.

The data on hydrological details and socio-economic characteristics of the study area have been given in Appendices A and B respectively. The months with rainfall (see Table A2) and socio-economic characteristics vary across the states. Kerala has the highest percentage of in-house sanitation whereas Odisha has the least (see Table B1). The decadal population growth rate is the highest for Arunachal Pradesh (see Table B2). Bihar is one of the most densely populated states with lowest per capita income and literacy rate (see Table B2). Kerala has historically been the state with the highest literacy rate (see Table B2). Himachal Pradesh has reported the highest percentage (5.6%) of reported cases of water borne diseases among all the states taken in the sample (see Table B3). Rajasthan is a desert region whereas Jammu Kashmir and Himachal Pradesh are hilly regions. Arunachal Pradesh has the highest forest cover whereas Haryana and Punjab the lowest (see Table B4).

2.1 | Data collection

As a first step of this cross-sectional study (2014), data was compiled from secondary sources for the indicators. Since this index was developed for assessment of water stress in low cost settings, it is advisable to calculate it using existing data wherever possible (Giné & Pérez-Foguet, 2010). The scope of this study is limited to the year 2014 due to poor data availability for most of the variables in the study for consecutive years. Water availability was calculated using both surface water and ground water.

The surface water was estimated by the state-wide run-off (Gupta, Chauhan, & Oza, 2016). The state-wide run-off is shown in Appendix A (see Table A1). It takes into account varying topography of the states and the precipitation for 35 years (1971–2005). The runoff has been adjusted with the rainfall variability data for the year 2014. If the rainfall was normal for a state in 2014, the adjustment factor was taken as zero. If rainfall is 'p' percent more than the normal rainfall, the runoff was calculated as runoff $\times$ $(1 + p/100)$ as an approximation technique.

The estimates which were used for missing run-off data are listed: Gangetic West Bengal for West Bengal; coastal Andhra Pradesh for Andhra Pradesh; Assam and Meghalaya (neighbouring state) for Assam; Delhi, Haryana and Chandigarh (neighbouring states) for Delhi; average of east and west Madhya Pradesh for Madhya Pradesh; Madhya Maharashtra for Maharashtra; Tamil Nadu & Pondicherry (neighbouring state) for Tamil Nadu; average of North Interior Karnataka, South Interior Karnataka and Coastal Karnataka for Karnataka.

The secondary data on reliability of water supply was unavailable in the Indian context. Therefore, it has not been included in the analysis.

As per the state-wide classification given by Indian Meteorological Department (IMD), each month for a state was classified to have excess, normal, deficient, scanty or no rainfall (see Table A3).

Following methods have been used to handle missing values:

1. In the absence of data values for 2014, the average of alternate years (2013, 2015) is used to estimate the missing indicator values for the year 2014.
2. In case of missing data values for previous years, the growth rate was used for estimating it.

3. For A4, data was not available for any of the previous years, so 2012 data was directly used. WS for Indian cities was only available from the year 2008. Due to the absence of data for the previous and subsequent years; WS statistics were multiplied by total population for the year 2014 to obtain water consumption statistics.

3 | METHODS

3.1 | Normalization

Since a number of different indicators were used for each component, it is important to bring them on one scale before calculating WPI. Therefore, each indicator (X_i) was assigned a score between 0 and 100. The variables which were not available as a percentage from the data source were normalized by a min-max approach:

$$X_{\mathbf{normalized}} = \frac{(X_i - X_{\mathbf{minimum}})}{(X_{\mathbf{maximum}} - X_{\mathbf{minimum}})}, \tag{1}$$

where $\mathbf{X}_{\text{maximum}}$ = Maximum value of respective component in the sample and $\mathbf{X}_{\text{minimum}}$ = Minimum value of respective component in the sample.

3.2 | Analysis – principal component analysis (PCA) followed by equal weight assignment

Several alternative methods could be explored at different scales for the construction of the WPI. Multivariate statistical techniques like PCA can also be used to determine the weights. However, in this study an equal weight assignment has been used. All indicators as well as the components are considered to have equal importance (Jemmali, 2017; Jemmali & Matoussi, 2013). Additionally, the results of the WPI study (Giné & Pérez-Foguet, 2010) confirm that results across different weighing schemes do not differ significantly.

As per the existing literature, WPI finds its application in different scales like river basin, community, etc. The balanced methodology of equal weight assignment is applied at large scales whereas the unbalanced methodology of unequal weights is applied at small scales (Li, Wan, & Jia, 2011). Further, an equal weight assignment methodology was used at the district level (Li et al., 2011), and hence can be applied at the state-level in this study:

$$\mathrm{R} = 0.33\,(\mathrm{R1} + \mathrm{R2} + \mathrm{R3}), \tag{2}$$

$$\mathrm{A} = 0.2\,(\mathrm{A1} + \mathrm{A2} + \mathrm{A3} + \mathrm{A4} + \mathrm{A5}), \tag{3}$$

$$\mathrm{C} = 0.33\,(\mathrm{C1} + \mathrm{C2} + \mathrm{C3}), \tag{4}$$

$$\mathrm{U} = 0.33\,(\mathrm{U1} + \mathrm{U2} + \mathrm{U3}), \tag{5}$$

$$\mathrm{E} = 0.33\,(\mathrm{E1} + \mathrm{E2} + \mathrm{E3}), \tag{6}$$

$$WPI = \frac{w_r R + w_{\mathbf{a}} A + w_{\mathbf{c}} C + w_{\mathbf{u}} U + w_{\mathbf{e}} E}{w_{\mathbf{r}} + w_{\mathbf{a}} + w_{\mathbf{c}} + w_{\mathbf{u}} + w_{\mathbf{e}}}, \tag{7}$$

Where w_r, w_a, w_c, w_u *and* w_e are the respective weights of the components. The weights are constrained to be equal, non-negative and also sum to unity (Thakur et al., 2017).

3.3 | Calculation of WPI

In absence of application of statistical technique for weight assignment, it is important to check the percentage variability in the WPI that could be explained by this model. Therefore, PCA was applied on all the indicators included in the outer model. PCA is an efficient way to transform a large set of correlated variables into a smaller set of uncorrelated variables, called principal components. If a set of *k* variables are highly correlated with each other, a few principal components can explain most of the variation in the original set of variables. Studies in the past have also used PCA in WPI assessment (Jemmali, 2017; Pérez-Foguet & Giné, 2011).

PCA was applied on all the indicators included in the outer model. The model clearly converged into five components (see Table 1). The "Total" column gives the eigenvalues. PC1 accounts for the highest variance (highest eigenvalue). The components named PC1, PC2, PC3, PC4 and PC5 explain 24.28%, 20.283%, 17.102%, 9.378%, 8.22% of variation in original data respectively. This approach showed that a set of 16 indicators could explain approximately 80% of overall variability in the WPI.

3.4 | Assignment of weights

A review of the studies which criticized the weight assignment techniques of various components used to construct WPI has been done (Giné & Pérez-Foguet, 2008). Further, the issue of aggregating correlated pieces of information with arbitrary weights in multi-dimensional indices has also been discussed (Molle & Mollinga, 2003). The usefulness of different methods has been assessed to calculate WPI followed by sensitivity analysis (Giné & Pérez-Foguet, 2010).

However, the solution to the water stress problem lies in identifying the scores of the components. Ranking of states with respect to the various components is critical for effective policy formulation, which is independent of the aggregation method used for index construction and hence the weight of components. The data problems and loss of crucial information in aggregation process is bound to happen.

4 | RESULTS

The WPI scores for various states are presented in Table 2. The component scores are presented in Table 3. Majority of the states in India are in the severe range of water stress. None of the states in the sample qualify for low water

TABLE 1 Eigen value analysis of various components

	Initial eigen-values		
Component	Total	% of variance	Cumulative %
PC1	4.128	24.28	24.28%
PC2	3.448	20.283	44.56%
PC3	2.907	17.102	61.67%
PC4	1.594	9.378	71.04%
PC5	1.397	8.220	79.26%

Source: Author's elaboration based on PCA output.

TABLE 2 WPI scores calculated

Scores	State in ascending order of WPI Value
Severe (0–47.9)	Jharkhand
	Rajasthan
	Jammu and Kashmir
	Bihar
	Odisha
	Himachal Pradesh
	Assam
	Madhya Pradesh
	Arunachal Pradesh
	Chhattisgarh
	Andhra Pradesh
	Tamil Nadu
	Karnataka
	Uttarakhand
	Gujarat
	Kerala
	West Bengal
High (48.0–55.9)	Maharashtra
	Haryana
	Punjab

Source: Author's elaboration of states inspired by (Guppy, 2014).

stress category. Hence, it is clear that this situation will impose a greater challenge on the water scenario of the country in the coming years. Punjab, Haryana and Maharashtra are the least water stressed in the sample. The five states with the lowest WPI scores are Jharkhand, Rajasthan, Jammu and Kashmir, Bihar and Odisha.

4.1 | Resources (R)

None of the states qualify for the "high" category in resources. The worst affected among these is Uttarakhand which ranks the lowest in resources. The states falling in the 'severe' WPI range, having a high population growth rate and seasonal variability of rainfall will impose a greater challenge on water resources. The per capita annual water availability (Cronin, Prakash, Priya, & Coates, 2014) has already seen a drastic fall in India. Repeated droughts have a frequent occurrence in the states where monsoon rainfall was less than the mean rainfall (Gautam & Bana, 2014).

4.2 | Capacity (C)

None of the states are in the "very low" category in the capacity component. However, Bihar and Jharkhand lag behind other states. Furthermore, population increase will impose a greater challenge to provide in-house access to sanitation for all and will ultimately influence the access component. Additionally, with increase in the economic capacity in form of GDP per capita, standard of living would improve. This will result in an increase in water consumption for various purposes.

4.3 | Access (A)

India being an agro-based economy poses a greater challenge for access to irrigation in the coming years. With respect to accessibility most of the states are either in one of the medium or low categories. The accessibility of drinking water in terms of distance and time to fetch is a matter of serious concern, especially in the rural areas (see Appendix B, Table B1). Several trips are made to water sources daily which imposes a huge opportunity cost in the rural areas.

4.4 | Environment (E)

None of the states are in “high” category in the environment component. The environment component will play a crucial role in long term sustainability and improvement of WPI scores in the future. States have experienced both increase and decrease in forest cover in the past (see Appendix B, Table B4). With reference to the sewerage treatment, years of practice of discharging untreated sewerage into the rivers has polluted the rivers drastically.

4.5 | Use (U)

Uttarakhand, Jharkhand and Himachal Pradesh have the lowest scores in the “use” category. In India, majority of water is used for irrigation. With the high seasonal variation in the rainfall, a high volume of groundwater is being extracted which is ultimately leading to groundwater depletion. With respect to usage of contaminated drinking water, life-threatening diseases like typhoid, diarrhoea and viral hepatitis are prevalent.

5 | DISCUSSION

The study found that the majority of the states in India are water stressed. Some recent studies have also found that more than or equal to 50% of the major states in India performed below average with respect to SDG 6 (Khalid, Sharma, & Dubey, 2019). A summary of few states from different regions of India is as follows:

- *Northern India*: Jammu and Kashmir and Rajasthan are extremely water stressed and need attention on a priority basis.
- *Central India*: Bihar and Jharkhand need policy prioritization mainly with respect to the socio-economic components.
- *Eastern India*: Assam is under severe water stress, whereas Arunachal Pradesh is under medium-low water stress. However, West Bengal appears to have a better WPI score than above mentioned states.
- *Southern India*: Most of the coastal states still look to be in a better situation compared to the rest of India. This is possibly due to higher rainfall and comparatively less population in the coastal areas. However, Andhra Pradesh needs attention on access, use and environment components and Karnataka on use component. The rainfall statistics were good for Karnataka for the year 2014, hence it ranked medium with respect to resources despite low water availability statistics (see Appendix A, Table A2).

However, Punjab, Haryana and Maharashtra look to be the better performers in terms of WPI (see Table 2). However, Assam and Punjab look to be the top two performers in resources component (see Table 3). It is interesting to note that states like Chhattisgarh, Assam and Bihar which rank in one of the medium categories of resources, could still rank severe in WPI, that is, are water-stressed. This is a clear indication that other components like access, capacity, use and environment have an important role in water stress situation of a state.

TABLE 3 Component scores calculated by equal weight assignment method

Scores	Resources	Access	Use	Capacity	Environment
(75–85) Very High				Gujarat	
				Uttarakhand	
				Tamil Nadu	
				Kerala	
				Maharashtra	
				Haryana	
(65–75) High				Karnataka	
				Punjab	
				Himachal Pradesh	
(55–65) Medium High	Assam	Haryana		Andhra Pradesh	
	Punjab			West Bengal	
				Arunachal Pradesh	
(45–55) Medium	Karnataka	Chhattisgarh	Assam	Madhya Pradesh	Haryana
	Bihar	Himachal Pradesh	Madhya Pradesh	Odisha	Punjab
	West Bengal	Kerala		Assam	
	Chhattisgarh	Madhya Pradesh		Chhattisgarh	
		Tamil Nadu		Rajasthan	
		Uttarakhand		Jammu and Kashmir	
		West Bengal			
		Punjab			
(35–45) Medium Low	Haryana	Jammu and Kashmir	West Bengal	Jharkhand	Bihar
	Maharashtra	Odisha	Gujarat		Arunachal Pradesh
	Kerala	Arunachal Pradesh	Maharashtra		Assam
	Madhya Pradesh	Jharkhand	Andhra Pradesh		Tamil Nadu
	Arunachal Pradesh	Rajasthan			Madhya Pradesh
		Maharashtra			Andhra Pradesh
		Andhra Pradesh			Chhattisgarh
		Bihar			Karnataka
		Karnataka			Uttarakhand
		Gujarat			Gujarat
					Kerala
					Maharashtra
					West Bengal
(25–35) Low	Gujarat	Assam	Jammu and Kashmir	Bihar	Jharkhand
	Rajasthan		Punjab		Rajasthan
	Andhra Pradesh		Haryana		Jammu and Kashmir
	Jharkhand		Tamil Nadu		Himachal Pradesh

(Continues)

TABLE 3 (Continued)

Scores	Resources	Access	Use	Capacity	Environment
	Odisha		Rajasthan Odisha Karnataka Kerala Arunachal Pradesh Chhattisgarh Bihar		Odisha
(15–25) Very Low	Himachal Pradesh Tamil Nadu Jammu and Kashmir Uttarakhand		Himachal Pradesh Jharkhand Uttarakhand		

Note: Classification is based on normalized scores for the year 2014, inspired by water poverty intensity scale (Thakur et al., 2017).
Source: Author's elaboration.

5.1 | State-wide analysis

The states have been divided into five categories on the basis of GDP per capita.

5.1.1 | Category A states: Bihar, Jharkhand, Assam (GDP per capita less than INR 50,000)

Jharkhand is the worst performer in WPI among the sample states. It has the second lowest score in capacity and use parameters. Lowest per capita income, low literacy rates and high population growth rates (see Appendix B, Table B2) are major contributors to the weak socio-economic status of Bihar and Jharkhand apart from low waste-water treatment capacity (see Figure 6). This situation is further aggravated by scanty rainfall and low groundwater availability in Jharkhand. Excess rainfall in Bihar elevated its rank in resources during the year; however, the state still needs to considerably improve its forest cover (see Appendix B, Table B4).

Assam—the state in the lowest category of per capita income, also ranks 'low' in access component. A water rich state is unable to utilize its water resources to its full potential due to poor water access for drinking and irrigation (see Appendix B, Table B1). The state ranks high in terms of water availability per hectare and water availability per capita (see Figures 4, 5) but ranks in one of the low categories of access and environment (see Table 3). This ultimately leads to a low ranking in WPI.

5.1.2 | Category B states: Jammu and Kashmir, Rajasthan, Madhya Pradesh, Chhattisgarh, Odisha, West Bengal (GDP per capita between INR 50,000–INR 75,000)

Jammu and Kashmir, Rajasthan, Odisha need attention on environment and use components. Jammu and Kashmir and Rajasthan have poor forest cover statistics. In fact, the amount of sewerage produced in Odisha, Rajasthan,

TABLE 4 Components of WPI and indicators selected at state level

Component	Indicator	Indicator definition	Indicator calculation	Source
Resources (R)	Water availability	Water availability per hectare (R1%)	Water availability/Total area (A)	Run-off (1971–2005): (Gupta et al., 2016)A: Ministry of Statistics and Programme Implementation (MoSPI);
		Water availability per capita (R1%)	Water availability/Total population (P)	P: Census of India (2011),
	Seasonal variation	Months per year with normal or excess rainfall (R3%)	The statistics for each month have been provided where each month is marked with categories like normal, excess, deficient or scanty rainfall	Kaur and Purohit (2016)
Access (A)	Drinking	Access to safe drinking water (A1%)	Number per 1000 households getting good quality of drinking water – average of rural and urban statistics computed	NSSO (2013)
	Sanitation	Access to in-house sanitation (A2%)	Population having in-house access to sanitation	Department of Drinking Water & Sanitation (2014).
	Irrigation	Access to irrigation (A3%)	Gross area under irrigation/Net sown area	Ministry of Agriculture and Farmers Welfare (MoAFW) 2013–14
	Time	Waiting time (Data was normalized to obtain A4)	Average waiting time (in minutes) taken in a day by household members to fetch drinking water from outside the premises	NSSO (2013)
	Distance	Distance (Data was normalized to obtain A5)	Distance household members have to travel distance source of drinking water per 1,000 members (less than 0.2 km)	
Capacity (C)	Economic capacity	GDP per capita (C1%)	GSDP (G)/Total population (P)	G: CSO (2019) P: Census of India (2011)
	Social capacity	Literacy rate - 7 years and above (C2%)	Data available as percentage	NSSO (2015)
Use (U)	Total water use	Total water consumption (Data was normalized to obtain U1)	Per capita water supply (WS) * Total population (P)	WS: CPCB (2009–10) P: Census of India (2011)
	Agricultural use	Agricultural use (U2%)	Annual groundwater draft (irrigation)/Net groundwater availability	CGWB (2017–18)
	Domestic Use	Water borne diseases (U3%)	Number of cases registered for water borne diseases/Total population(P)	Lok Sabha Unstarred Question No. 5492, 2017, Ministry of Health and Family Welfare.

(Continues)

TABLE 4 (Continued)

Component	Indicator	Indicator definition	Indicator calculation	Source
Environment (E)	Water quality	Wastewater treatment capacity (E1%)	For urban areas: Wastewater treatment capacity = Sewerage generation/Installed treatment capacity	MoEF, 2016
	Bio-diversity	Forest cover (E2%)	Average: Forest cover (2013), Forest cover (2015)	FSI (2013), FSI (2015)
	Pollution	Fertilizer per hectare of arable land (E3%)	Total N, P, K fertilizer (NPK)/Total agricultural land (AL)	NPK, AL: Ministry of Agriculture (2015)

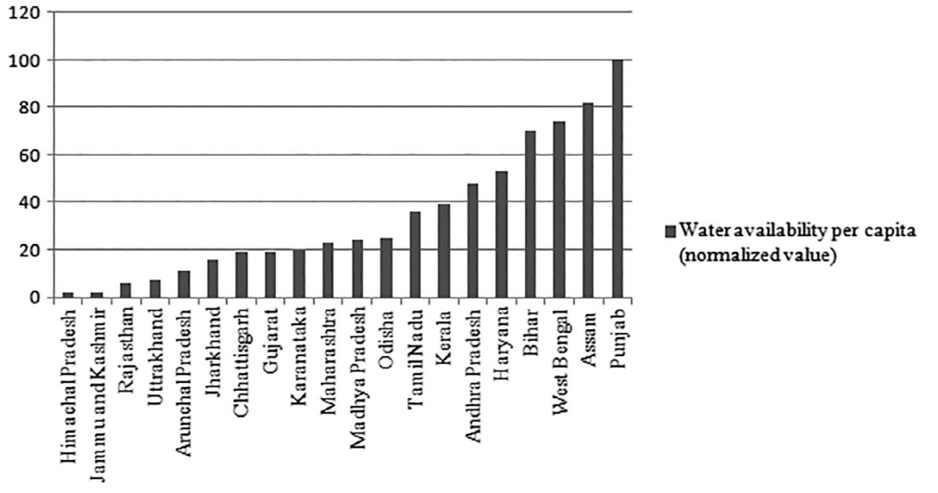

FIGURE 4 R1; *Source*: Author's elaboration (based on normalized scores for the year 2014)

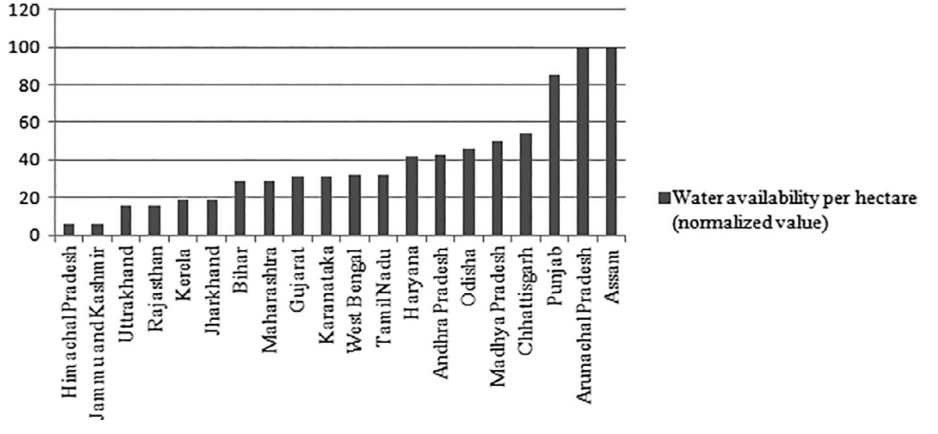

FIGURE 5 R2; *Source*: Author's elaboration (based on normalized scores for the year 2014)

Madhya Pradesh, Chhattisgarh and West Bengal need higher wastewater treatment capacity. Jammu Kashmir, Rajasthan, Madhya Pradesh, Chhattisgarh, West Bengal have very low consumption of NPK fertilizers compared to the agricultural land.

Chhattisgarh is yet another state like Bihar with a very high population but low literacy rate. Despite a water rich state, the distance to sources of drinking water is the highest for Chhattisgarh.

Poor access to safe drinking water is possibly responsible for high percentage of water-borne diseases in Jammu Kashmir. Poor access to in-house sanitation and distance to source of drinking water calls for a policy action in Odisha.

5.1.3 | Category C states: Himachal Pradesh, Punjab, Arunachal Pradesh, Karnataka, Andhra Pradesh (GDP per capita INR 75,000–INR 100,000)

Himachal Pradesh ranks “very low” in both resources and use parameters. The major concern areas for this state are the low groundwater availability and the highest percentage of water-borne diseases.

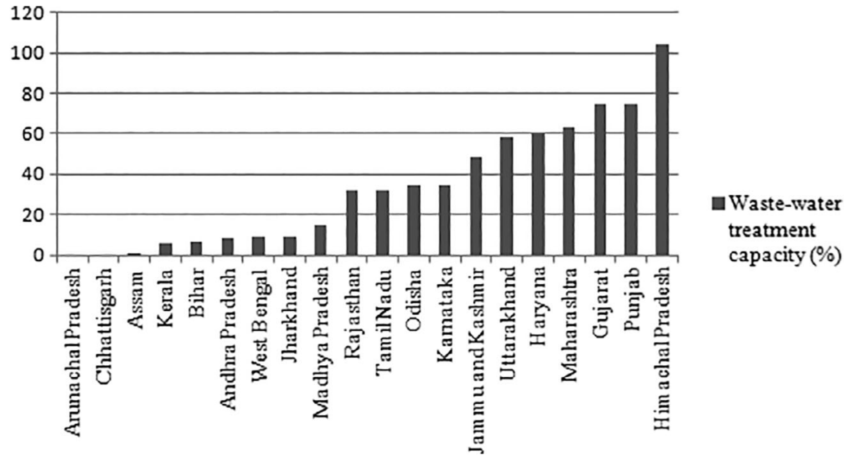

FIGURE 6 E2. *Source*: Author's elaboration based on waste-water treatment capacity till March'2015. Refer Appendix B (Table B4)

Andhra Pradesh and Karnataka have low per capita water supply. Further, Andhra Pradesh had less than normal rainfall during the year. Andhra Pradesh and Arunachal Pradesh need higher wastewater treatment capacity. In Karnataka, there is a low usage of NPK fertilizers as per the agricultural land. Although the second highest scorer in resources, Punjab has a low number of households who have access to sources of drinking water less than 0.2 km away.

5.1.4 | Category D states: Haryana and Uttarakhand (GDP per capita between INR 150,000–INR 200,000)

Both states have good waste-water treatment capacity. Uttarakhand needs attention on the use component scores. Both net groundwater availability and per capita water supply need attention in the state. Haryana has the lowest forest cover in the sample. For the sustainability of water resources, the state needs to focus on efficient use of water. Techniques like integrated water use management (Boutkan & Stikker, 2004; Ikhlayel & Nguyen, 2017), water reuse (Browning-Aiken, Ormerod, & Scott, 2011) and recycling of wastewater along with conservation of forest cover should also be encouraged. In Haryana, households face an issue of travelling more than 0.2 km to fetch drinking water.

5.1.5 | Category E states: Kerala, Tamil Nadu, Maharashtra, Gujarat (GDP per capita > INR 200,000)

The state of Gujarat ranks the highest in the capacity component and does not rank "low" in any of the components. According to Sustainable Development Goal (SDG) India Index Baseline Report'2018, Gujarat ranks among the achievers in SDG 6. Both Maharashtra and Gujarat have a good wastewater treatment capacity (see Figure 6), although Gujarat needs to focus on forest cover (see Appendix B, Table B4). Maharashtra has the highest groundwater availability and has better performance than most of the states with respect to socio-economic indicators.

Tamil Nadu has experienced droughts in the past which has been a concerning cause for a considerable number of farmer suicides (Mariappan & Zhou, 2019). The state has a need for prioritization of contingency plans to handle drought situations. The rainfall has been less than normal for Tamil Nadu in the year 2014 (see Appendix A, Table A2). Kerala needs intervention to improve the status of its groundwater availability, per capita water supply and waste-water treatment capacity (see Figure 6).

To rank high in WPI, each state needs to prioritize its policy with respect to the current status of the five index components. It is also important to understand that in a developing country like India unless policies related to improvement of socio-economic indicators are implemented, it will not be possible to drastically reduce the water stress of any state. Policy changes and priorities of government overtime will decide the course of progress of India towards SDG's (Khalid, Sharma, & Dubey, 2018).

6 | CONCLUSION

This paper assesses the water stress situation across 20 major states of India using WPI. The index focuses on four crucial socio-economic components pertaining to water: access, capacity, environment and use. From a policy perspective, the WPI will serve as a policy tool for integrating the national and sub-national water policy in India. This is expected to have a positive impact on the overall water stress situation and uniform socio-economic development in the country.

Punjab, Haryana and Maharashtra have performed better in WPI assessment compared to all other states due to overall performance across the components. The study found that the states of Jharkhand, Rajasthan, Jammu Kashmir, Bihar and Odisha are the five most water-stressed states in the country. This is mainly due to poor socio-economic conditions apart from water availability. One of the possible solutions to improve the water stress situation in a state is to look at its WPI component where it performed poorly and pay most attention to efficient utilization of its limited resource and manpower. Clear-cut policies targeting specific components will further help the cause. Further, a state scoring in one of the high categories of a particular WPI component could serve as a reference point or a benchmark for another state in terms of policy formulation.

The WPI is a powerful policy tool but few of its limitations cannot be ruled out. The results of WPI are sensitive to the number of indicators, aggregation method and weights of indicators. The WPI ranking of states may change if unequal weights are given to the respective indicators and their components. Additionally, different statistical techniques and aggregation functions could be used for the sensitivity analysis. It is important to check the WPI scores on an annual basis for monitoring the water stress situation on a state wide basis.

7 | FUTURE WORK

The future work could include longer term studies to analyse the water stress situation of India over a larger time span, say 5–10 years. Also, possibilities of addition of new and robust indicators to the WPI should be debated. For example, domestic and industrial water consumption may serve as two crucial indicators, since the share of these indicators is continuously increasing over time. An improvement in data quality and its frequency will further enhance the acceptability of the WPI.

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ENDNOTES

[1] Physical water stress is defined here as the ratio of total freshwater withdrawn annually by all major sectors, including environmental water requirements, to the total amount of renewable freshwater resources, expressed as a percentage (UN World Water Report, 2019).

[2] For details, please refer: https://www.wri.org/blog/2015/08/ranking-world-s-most-water-stressed-countries-2040

[3] For details, please refer: https://economictimes.indiatimes.com/news/economy/policy/to-avert-impending-crisis-india-must-respond-urgently-to-managing-water-resources-better/articleshow/64724673.cms

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APPENDIX A.

Data related to study area

TABLE A1 Hydrological details of the study area (1971–2005)

Name of the state	Run-off (mm)
Odisha	448.6
Kerala	855
Bihar	486.9
Uttarakhand	281.2
Arunachal Pradesh	667.5
Punjab	189.8
Himachal Pradesh	217.1
Jammu and Kashmir	57
West Rajasthan	49.7
East Rajasthan	227.3
Jharkhand	477.8
Gangetic West Bengal	538
Coastal Andhra Pradesh	265.9
Assam and Meghalaya	955.5
Chhattisgarh	440
Gujarat	194
Haryana, Chandigarh and Delhi	144.1
North Interior Karnataka	239.4
South Interior Karnataka	361.5
West Madhya Pradesh	372.0
East Madhya Pradesh	456.0
Madhya Maharashtra	433.6
Tamil Nadu and Pondicherry	182.9

Source: Modelling surface run-off and trend.
Analysis over India (Gupta et al., 2016).

TABLE A2 Percentage departures of sub-division wise monthly rainfall (2014)

State	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Odisha	−99%	−16%	−7%	−69%	59%	−57%	47%	7%	19%	0%	−92%	−81%
Kerala	−47%	−34%	−41%	−13%	5%	−30%	−7%	75%	22%	22%	−34%	26%
Bihar	28%	245%	−17%	−96%	103%	−32%	−23%	5%	−28%	−26%	−100%	−79%
Uttarakhand	−12%	85%	19%	13%	−19%	−63%	8%	−38%	−48%	−30%	−100%	108%
Arunachal Pradesh	−62%	4%	−55%	−69%	2%	−17%	−27%	67%	−8%	−81%	−56%	−73%
Punjab	−14%	−17%	20%	96%	32%	−54%	−59%	−75%	16%	−73%	−88%	6%
Himachal Pradesh	−32%	21%	4%	−15%	−1%	−43%	−30%	−41%	−38%	−57%	−82%	13%
Jammu and Kashmir	10%	−24%	41%	9%	−4%	−45%	−48%	−28%	294%	−17%	−40%	−95%
West Rajasthan	−73%	−52%	23%	101%	107%	−54%	−8%	−22%	105%	−90%	−92%	−100%
East Rajasthan	406%	104%	74%	152%	−22%	−62%	−13%	14%	37%	−81%	−100%	−65%
Jharkhand	−38%	174%	34%	−90%	124%	−29%	−4%	−8%	−27%	−40%	−100%	−82%
Gangetic West Bengal	−95%	100%	−33%	−96%	27%	−25%	−9%	−5%	−20%	−56%	−99%	−94%
Coastal Andhra Pradesh	−92%	−88%	−42%	−66%	32%	−66%	−12%	−9%	−19%	−17%	−54%	−37%
Assam and Meghalaya	−88%	−8%	−62%	−72%	3%	−17%	−33%	16%	29%	−78%	−89%	−96%
Chhattisgarh	−80%	163%	44%	17%	41%	−44%	12%	−12%	18%	20%	−69%	−89%
Gujarat Region	832%	−29%	−78%	248%	−75%	−91%	2%	−44%	71%	−85%	−85%	−100%
Haryana Chandigarh and Delhi	−27%	15%	111%	0%	45%	−44%	−56%	−80%	−17%	−40%	−96%	40%
Coastal Karnataka	−100%	−35%	−37%	13%	7%	−43%	1%	46%	16%	3%	−45%	103%
North Interior Karnataka	−100%	261%	462%	3%	71%	−52%	1%	70%	−38%	−28%	−8%	135%
South Interior Karnataka	−71%	−21%	109%	7%	40%	−25%	26%	58%	15%	4%	−59%	47%
West Madhya Pradesh	201%	575%	1%	−28%	−79%	−71%	16%	−32%	13%	−80%	−73%	105%
East Madhya Pradesh	60%	225%	42%	−8%	−64%	−31%	−19%	−37%	−30%	51%	−81%	24%
Madhya Maharashtra	182%	678%	802%	−16%	14%	−70%	15%	27%	−21%	−51%	45%	115%
Tamil Nadu and Pondicherry	−58%	−55%	−56%	−80%	106%	4%	−26%	35%	−15%	40%	−35%	−25%

Source: Rainfall statistics by Kaur and Purohit (2016).

TABLE A3 Scale for classification of months in each state

Category	Departures from normals
Excess	20% or more
Normal	−19% to +19%
Deficient	−20% to −59%
Scanty	−60% to −99%
No rain	−100%
No data	Data not available

Source: Kaur and Purohit (2016).

APPENDIX B.:

Data used for water poverty index calculations

The source of the data in the tables is given below and the year is mentioned in Table 4.

TABLE B1 Data values used to calculate 'access' indicator for the states

State	A1 (Number per 1,000 households)		A2	A3 (in thousand hectares)		A4 (in minutes)		A5 (Number per 1,000 households)	
Name	Access to safe drinking water-rural	Access to safe drinking water-urban	Access to in-house sanitation	Gross area under Irrigation	Net sown area	Waiting time-rural	Waiting time-urban	Distance to source of drinking water (less than 0.2 km)-rural	Distance to source of drinking water (less than 0.2 km)-urban
Odisha	873	914	11.72%	1,505	4,495	13	15	608	221
Kerala	947	902	94.94%	468	2051	9	9	227	162
Bihar	801	850	21.60%	5,145	5,252	17	16	258	133
Uttarakhand	944	856	68.56%	544	701	18	15	291	124
Arunachal Pradesh	911	829	45.38%	57	225	12	3	282	18
Punjab	849	729	75.23%	7,732	4,145	10	10	101	61
Himachal Pradesh	945	887	88.04%	200	550	11	10	366	52
Jammu and Kashmir	780	656	25.21%	496	741	12	14	298	67
Rajasthan	806	871	29.61%	9,865	18,268	20	24	322	85
Jharkhand	899	839	28.71%	238	1,384	22	20	491	221
West Bengal	821	889	58.19%	5,661	5,234	13	16	547	384
Andhra Pradesh	880	932	35.84%	4,095	6,448	13	11	423	176
Assam	580	638	41.28%	375	2,820	7	6	160	55
Chhattisgarh	905	901	40.26%	1,751	4,686	13	14	636	349
Gujarat	941	831	54.42%	5,939	10,302	12	20	263	114
Haryana	924	771	77.83%	5,708	3,497	17	13	165	108
Karnataka	938	919	35.85%	4,112	9,923	17	18	541	146
Madhya Pradesh	908	885	27.53%	9,919	15,422	18	16	563	252
Maharashtra	941	926	49.68%	4,556	17,368	17	18	381	100
Tamil Nadu	865	884	46.41%	3,311	4,714	13	18	590	290

TABLE B2 Data values used to calculate for "capacity" indicator of the states

State	C1			C2
Name	GSDP in crores (at current prices[INR])	Population	Decadal population growth rate (2001–2011)	Literacy rate
Odisha	296,475	41,974,218	14%	75.50%
Kerala	465,041	33,406,061	4.9%	95.20%
Bihar	317,101	104,099,452	25.4%	67%
Uttarakhand	149,074	10,086,292	18.8%	85.10%
Arunachal Pradesh	14,581	1,383,727	26%	76.30%
Punjab	332,147	27,743,338	13.9%	79%
Himachal Pradesh	94,764	6,864,602	12.9%	85.10%
Jammu and Kashmir	95,619	12,541,302	23.6%	74.40%
Rajasthan	551,031	68,548,437	21.3%	67.60%
Jharkhand	188,567	32,988,134	22.4%	70.30%
West Bengal	676,848	91,276,115	13.8%	78.30%
Andhra Pradesh	464,272	49,386,799	9%	66.80%
Assam	177,745	31,205,576	17.1%	85.90%
Chhattisgarh	206,833	25,545,198	22.6%	73.10%
Gujarat	807,623	60,439,692	19.3%	79.90%
Haryana	399,268	25,351,462	19.9%	76.60%
Karnataka	816,666	61,095,297	15.6%	75.50%
Madhya Pradesh	439,483	72,626,809	20.3%	71.30%
Maharashtra	1,649,647	112,374,333	16%	83.80%
Tamil Nadu	968,530	72,147,030	15.6%	80.20%

TABLE B3 Data values to calculate 'use' indicator of the states (population and the growth rate are tabulated in Table B2)

State	U1 (in lpcd)	U2 (in bcm)		U3
Name	Per capita water supply	Annual groundwater draft(irrigation)	Net groundwater availability	Water-borne diseases
Odisha	247.59	4.14	16.69	1.97%
Kerala	190.28	1.18	5.66	1.20%
Bihar	218.23	10.36	28.49	0.76%
Uttarakhand	177.06	0.84	1.97	0.00%
Arunachal Pradesh	119.00[a]	0.002	3.99	1.18%
Punjab	290.24	34.05	23.39	0.72%
Himachal Pradesh	221.3	0.16	0.53	5.60%
Jammu and Kashmir	140.01	0.2	4.82	4.30%
Rajasthan	179.78	13.79	11.26	1.05%
Jharkhand	209.12	0.63	5.99	0.34%
West Bengal	187.88	10.84	26.56	2.09%

(Continues)

TABLE B3 (Continued)

State	U1 (in lpcd)	U2 (in bcm)		U3
Name	Per capita water supply	Annual groundwater draft(irrigation)	Net groundwater availability	Water-borne diseases
Andhra Pradesh	109.47	7.29	18.48	3.00%
Assam	301.66	4.06	28.9	0.28%
Chhattisgarh	174.18	3.76	11.9	0.54%
Gujarat	143.14	12.3	19.79	0.84%
Haryana	142.59	13.32	10.3	0.85%
Karnataka	148.19	8.76	14.83	1.42%
Madhya Pradesh	144.6	17.95	34.16	1.22%
Maharashtra	310.09	15.93	31.48	0.66%
Tamil Nadu	79.9	12.98	18.59	0.37%

Note: [a] The per capita water supply statistics for Arunachal Pradesh have been taken from by TERI (2018).

TABLE B4 Data values for "environment" indicator of the states

State	E1 (in MLD)		E2		E3 (in kg/ha)
Name	Sewerage generation	Installed treatment capacity	Forest cover (2013)	Forest cover (2015)	Total N,P,K fertilizer
Odisha	1,121	385.54	32.33%	32.34%	98.13
Kerala	2,552	152.97	46.12%	49.50%	121.03
Bihar	1879	124.55	7.74%	7.74%	164.87
Uttarakhand	566	330.1	45.82%	45.32%	143.8
Arunachal Pradesh	50	0	80.39%	80.30%	0
Punjab	1,664	1,245.45	3.52%	3.52%	216.73
Himachal Pradesh	110	114.72	26.37%	26.40%	52.74
Jammu and Kashmir	547	264.74	10.14%	10.34%	89.07
Rajasthan	2,736	865.92	4.70%	4.73%	49.69
Jharkhand	1,270	117.24	29.45%	29.45%	82.45
West Bengal	4,667	416.9	18.93%	18.96%	131.17
Andhra Pradesh	2,871	247.27	16.77%	15.25%	226.72
Assam	703	0.21	35.28%	35.22%	65.41
Chhattisgarh	951	0	41.14%	41.12%	100.22
Gujarat	4,119	3,062.92	7.48%	7.48%	119.52
Haryana	1,413	852.7	3.59%	3.58%	179.48
Karnataka	3,777	1,304.16	18.84%	18.99%	136.06
Madhya Pradesh	3,214	482.23	25.15%	25.13%	84.43
Maharashtra	8,143	5,160.36	16.45%	16.45%	127.07
Tamil Nadu	5,599	1,799.72	18.33%	20.26%	153.76