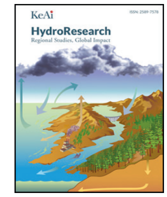
HydroResearch 3 (2020) 134–145

Contents lists available at ScienceDirect

HydroResearch

journal homepage: http://www.keaipublishing.com/en/journals/hydroresearch/



Exploring the relative water scarcity across the Indian million-plus urban agglomerations: An application of the Water Poverty Index

Aparna Sivaraman Prabha, Ashwin Ram, Zareena Begum Irfan *

Madras School of Economics, Gandhi Mandapam Road, Chennai 600025, Tamil Nadu, India

A R T I C L E I N F O

Article history:
Received 31 January 2020
Received in revised form 2 October 2020
Accepted 4 October 2020
Available online 13 October 2020

Keywords:
Water scarcity
Urban agglomerates
Domestic water security
Water management
Water Poverty Index

JEL classification:
Q25
Q53
C43
O13
E22

A B S T R A C T

Indian cities are rapidly expanding and with increase in migration the country is expected to witness unprecedented urbanization in the coming decade. In this context, it is important to take a holistic and realistic view of the challenges faced by Indian cities with respect to water so as to prepare and formulate policies that prompts for sustainable use of water resources and makes cities water resilient. This study evaluates the extent of water scarcity across forty-two million-plus Indian urban agglomerations incorporating Water Poverty Index (WPI). WPI combines the physical water availability with the people's capacity to access the resource, in order to assess the water scarcity. The purpose of the index is to offer a single composite value which plays a vital role in prioritizing the work related to water. The index captures the vulnerability or risk facing Indian cities to water scarcity based on five critical dimensions viz.; resource, capacity, access, use and environment.

1. Introduction

The growing population resulting in rapid depletion of valuable and scarce water resources calls, for immediate attention from all sections of the society including individuals, industries, civil society and government. Water is considered as an elixr of life, yet overexploitation of this life saving critical resources and the inefficient use of water across sectors resulting from bad policies has led to global water scarcity. According to World Economic Forum (2019), water crisis is one of the biggest challenges facing the century. There is a global consensus that the present global water crisis can purely be attributed to the mismanagement of the resources. India is no exception to this and is highly vulnerable to water stress (Schleifer, 2017). India's per capita water availability, a measure of water scarcity, continue to witness a significant decline due to the rapid socio-economic development and more importantly inefficient use of water. Apart from the population growth, climate change is further expected to exacerbate the problem. For instance, the per capita water availability has gone down from 1816 cubic meter in 2001 to 1588 cubic meter in 2011. Further, as of 2011, the country was dependent on neighboring nations for 30% of its water requirements to suffice the needs (Levy and Sidel, 2011). India for long has relied on supply driven approaches to water management and only in the last few years there is a gradual attention to demand side management. The water use efficiency across all the sectors in India is highly inefficient and with declining per capita water availability there is an urgent need to shift focus from supply side management to demand side management. This however calls for stronger political will, large scale governance reforms and institutional restructuring. Though agriculture is the largest user of freshwater resources accounting for over 85%, with increasing population growth and urbanization the domestic water demand is expected to double by the mid of the century (Amarasinghe et al., 2007). It was estimated that in 2010 total water withdrawal was 761 km^3 in India of which 91%, or 688 km^3, was used for irrigation. About 56 km^3 was for municipal and 17 km^3 for industrial use (FAO-UN, 2012).

Indian cities are not well prepared to handle this increasing demand with ageing and insufficient infrastructure. There is a huge body of literature (Ward and Michelsen, 2002; Lilienfeld and Asmild, 2007; Sharma et al., 2010; Fishman et al., 2015; Hans, 2016 and Sun et al., 2018) on water use in agriculture but there are very few but growing studies (Sampath et al., 2003; Shaban and Sharma, 2007; Singh and Turkiya, 2013; NITI Aayog, 2018) focusing on domestic water use. The domestic water supply and demand across Indian cities are characterized by high

* Corresponding author.
E-mail address: zareena@mse.ac.in (Z.B. Irfan).

https://doi.org/10.1016/j.hydres.2020.10.001

spatiotemporal inequality (IHDS, 2011). Hence there is an increasing interest to understand urban water management challenges.

There are several studies that have computed water security index at the global, national and regional level (Webb and Iskandarani, 1998; Grey and Sadoff, 2007; Cook and Bakker, 2012; Hao et al., 2012; Basu et al., 2015). However, there are relatively very few studies at the watershed or city level (Das and Safini, 2018; Jensen and Wu, 2018; Hoekstra et al., 2018; Singh et al., 2020). As water is very much local there is a greater need to understand water scarcity at the local level such as cities. India one of the fastest emerging nations is rapidly urbanizing and it is expected that by 2050 the urban population will be 1.7 billion from the present 1.35 billion in 2018 (World Bank, 2017). Cities in India face various environment related challenges and water scarcity is one such serious problem that warrants immediate attention with exponential population growth and climate change (United Nations, 2015). As cities in India are continuously expanding there will be increasing pressure on already stressed water resources. In this context, this paper takes a modest approach to understand water scarcity for forty two million plus urban agglomerations in India by creating a Water Poverty Index.

Water crisis is global in nature affecting both developed and developing countries and thus a plethora of literature (Lautze and Manthrithilake, 2012; Shao et al., 2013; Gain et al., 2016; Hoekstra et al., 2018) emerged examining water crisis across multiple dimensions and scales. A significant number of literature had used indices to understand water insecurity and therefore indices has become an important tool to assess water security. Water security is measured by the adequacy of water available by both quantity and quality for human, developmental and conservational needs. Generally studies on water security fall under either of the three categories viz.; descriptive, indexing and forecasting with the help of simulations (Sun et al., 2016). Majority of these studies emphasized on developing indicator based system for evaluating water scarcity using a diverse range of variables to create a composite index (Munda and Nardo, 2005). Water security indices offer a relative measure of achievements and drawbacks highlighting the hotspots and enabling policy formulation (Lawrence et al., 2002). Falkenmark index was the first attempt to measure the Available Water Resources (AWR) per capita using the renewable water available in the hydrological cycle per capita. However, the study included the floodwater which was uncalled for (Falkenmark, 1986). Since then over time, multiple other indices were developed to capture the water scarcity preceding the Water Poverty Index. Molle and Mollinga (2003) studied poverty-water nexus to assess the water scarcity. Water Poverty Index is a measure where people could be 'water poor' either due to unavailability of sufficient water in the neighborhood or 'income poor' where despite water is available it remains unaffordable. Thus understanding the multidimensional nature of the water scarcity along with the unequal distribution could be vital to allocate the resource efficiently.

The Water Poverty Index is an interdisciplinary measure which links household welfare with water availability. It indicates the degree to which water scarcity impacts human populations. Sullivan (2002) developed a Water Poverty Index to assess the vulnerability of households to water scarcity based on five critical dimension such as resources, access, capacity, use and environment. Lawrence et al. (2002) ranked 140 countries using the benchmark Sullivan Water Poverty Index and found that a majority of the developed and developing countries are at high risk to water scarcity.

Despite, the usefulness of WPI there exist mixed views on the practical use and applicability of the WPI. Komnenic et al. (2009) discusses how the Water Poverty Index (WPI) fails, as a composite index as WPI hides certain drivers of the water scarcity. Upon evaluating the WPI of Sava subbasin, the authors were of the view that the indicators of the WPI offer a good view but the index as whole fails to reflect the state of the resource due to the loss of information during the aggregation of the indicators. And, the WPI was observed to be largely correlated with two or more indicators; access and capacity which results in biased estimation. Also, the paper drew on the limitations from how the "water poor" was defined in the benchmark WPI. Low water access in impoverished areas cannot be described as water poor as lower access could also be due to the inability of the society to provide the resource and not merely reflecting households socio-economic conditions in acquiring the resource. A part of the above criticism is, however, uncalled for as the soundness of an index is determined by the available data, determination of weights and the validation of the composite index (OECD, 2008).

1.1. Re-examining the benchmark Water Poverty Index and Enhanced Water Poverty Index (e-WPI)

The benchmark WPI (Sullivan, 2002) aggregates the indicators by simple arithmetic aggregation using equal weights. It is essential to reconsider the existing benchmark aggregation as full compensability is implied amongst the various components wherein full compensability is not desirable as the goals are not equally legitimate (Munda and Nardo, 2005) Apart from that, the choice of weights determines the relative importance given to the variables and the weights could be either data dependent or judgment based. The conventional practice of judgment based weights leads to uncertainty. The variation in the data could be explained effectively by the data dependent option as the correlation between two or more indicators is corrected in this process (Garriga and Pérez Foguet, 2010).

As an alternative and to correct the limitations of the benchmark WPI, Garriga and Pérez Foguet (2011) developed an enhanced WPI (e – WPI) and assigned three different weighing approaches, (i) using explicit weights (ii) weights based on expert opinion (iii) and lastly statistical weights to determine the appropriate choice of weights and concludes that enhanced WPI calculated using the geometric aggregation is most appropriate. Table 1 shows the indicators used in e-WPI and the indicators used post PCA. Taking cognizance of these caveats in the benchmark WPI and the usefulness of e-WPI in this study we have developed a WPI based on both benchmark WPI and e-WPI to assess the relative extent of water scarcity across select million plus urban agglomerations.

Table 1
Indicators used in E-WPI.
Source: Compiled by the authors using Garriga and Pérez Foguet (2010, 2011).

Dimension	Indicators in enhanced WPI	Indicators used after PCA[a]
Resource	R1: Water quantity sufficiency R2: Reliability of supply R3: Seasonal resource variability	R1 and R3
Access	A1: Access to safe water A2: Access to improved sanitation A3: One way distance to water source (km) A4: Waiting time (min) A5: Cost of water A6: Operational status of water source	A1, A2 and A6
Capacity	C1: Management system C2: Ownership over water source C3:Water association registered C4: Records kept C5: Financial control C6: Funds	C1, C2 and C3
Use	D1: Domestic water consumption rate D2:Conflict over water resources (human-human, human-livestock) D3: Use of local water treatment D4: Livestock water use	D1, D2 and D4
Environment	E1: Qualitative assessment of water quality E2: Protection of water sources E3: Number of pollution sources E4: Number of environmental impacts E5: Conflict over water resources (human-wildlife)	All except E3

[a] PCA: Principal Component Analysis.

2. Data and methodology

The primary objective of this study is to evaluate the relative extent of water scarcity across select million plus Indian urban agglomerations based on benchmark WPI. Sullivan (2002) enhanced WPI using secondary data sources such as the Indian Household Development Survey (IHDS 2, 2011), Indian Meteorological Department (2010) and the Central Ground Water Commission (2010).

According to Census of India (2011), there are 54 million plus urban agglomerations in India. Cities with a population of over one million qualify into this category. The IHDS data set is a survey of 41,544 households and these households are spread across 1503 villages and 971 urban neighborhoods. Districts contain both urban and rural areas; where districts with a largely urban and less rural area is called as urban-agglomerations. The IHDS-2 surveyed about 4817 urban households residing in the million-plus urban agglomerations of India. However, upon using the IHDS 2 and IMD data 12 out of 54 million plus urban agglomerations were missed as the data is lacking. Therefore, we have considered only 42 cities for which data is available. All the socioeconomic, demographic, household related variables are assessed from IHDS 2 while water related data were assessed from Indian Meteorological Department (IMD) and Central Ground Water Commission.

2.1. Water Poverty Index

The WPI covers five critical dimensions viz.; resource, access, capacity, use and environment. The following section briefly explains each of the dimension and the indicators used. It also highlights preliminary data for each of the sub dimensions.

2.1.1. Resource

Resource is broadly defined as the availability of freshwater in a particular country or region. To capture the resource component; Water availability which is normalized per capita (Net groundwater availability) and Water reliability as explained by the Variation in the annual rainfall from the Long Period Average are used. Sullivan WPI's resource evaluation of the supply per capita was used to measure the resource component.

$Resource = {}^{R_1+R_2}\!/_2$

R_1 = Net groundwater available per capita (normalized)
R_2 = Annual rainfall populated normalized with the long period average of 89 cm (normalized).

From the IHDS 2 data, it is also observed that a majority of the households across cities depend on both the surface and groundwater for their daily needs. Essentially, this implies that household fulfill their water demand by both surface and groundwater sources which apparently represent the physical availability of the resource. However, as the data on the volume of surface water availability was not available, only the groundwater data has been taken into consideration to calculate resource availability.

The variation in the amount of rainfall serves as a representative to measure water reliability as in India monsoon is crucial in meeting the water demand and rainfall is the predominant form of ground water recharge. Hence to account for the variability, the annual variation in all the forty-two urban agglomerations were considered from the IMD data set. In order to normalize the seasonal variability, the long period average of rainfall of 85 cm was used. Fig. 1 depicts the variation in average rainfall obtained by normalizing the annual average rainfall for top 10 and bottom 10 urban agglomerates considering the long period average rainfall.

2.1.2. Access

Access to a sufficient amount water is very essential for improved sanitation and hygiene. The e-WPI is used to capture the access component. The access component comprises of access to safe water as measured by the share of the population having access to the safe water supply inside the household premises and access to improved sanitation as indicated by the share of the population having access to improved sanitation inside the household premises

$Access = {}^{A_1+A_2}\!/_2$

A_1 = share of cumulative sanitation facilities inside the household at agglomorate level (normalized)

A_2 = share of cumulative piped water supply inside the household at agglomorate level (normalized).

Households in India depend on multiple sources to fulfill their water needs. It is observed from the pie-chart that piped water supply is a major source of water supply in the urban agglomerates where about 64% of the households have access to piped water supply inside their household premises and the reliability of public water supply is however very uncertain. On average, the public utilities supply water for about 6–8 h in the IHDS data (Fig. 2).

In India, the surface water is rightfully under the control of the state governments while groundwater is under private ownership. Hence, in the absence of efficient property rights, the volume of water which

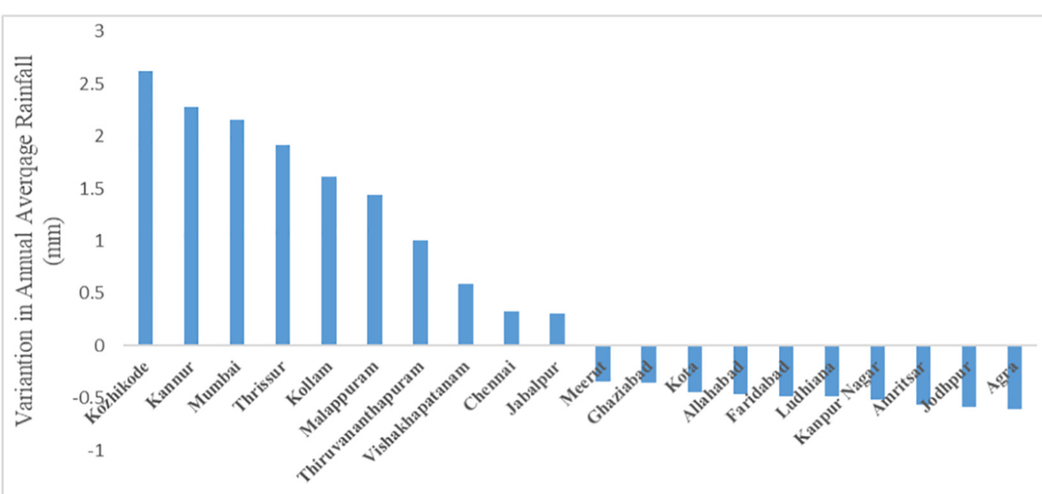


Fig. 1. Annual variation in rainfall in a subset of urban agglomerates.

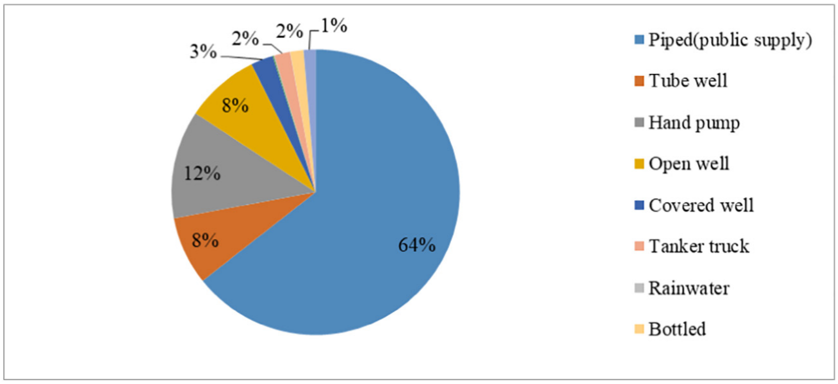


Fig. 2. Sources of water supply.

could be extracted is not clearly defined allowing the owners to extract at their own convenience, thus buying of water is minimal for domestic purposes. It is also evident from the above chart that; the contribution of tanker truck and bottled water as source of water supply is insignificant. Thus the sub-component "cost of water" was also not included in this study. Although informal markets exist to facilitate the buying and selling of water it is not very common and serves the purpose only during summer or times of critical water shortages or extended period of drought.

2.1.3. Capacity

Generally, capacity represents the physical infrastructure that supplies water but here capacity is defined as the ability of the person to demand for better water services and utilization. As water use across Indian cities are characterized by high spatiotemporal inequality, the present study is intended to understand the household capacity to avail water. This essentially implies that water supplied from utilities are not distributed equally where the rich and middle class enjoy the luxury of continuous water supply while the poor in most cases find it difficult to access reliable water supply. Moreover, though government monitors water generation and supply at watersheds level data on actual water consumption at the household level is largely lacking. Hence to assess the capacity component, economic capacity as described as poor and middle class/comfortable and the education level of the household head from IHDS is used. In order to evaluate the capacity component the WPI metric by Sullivan is used.

$$Capacity = {}^{C_1+C_2}/_{2}$$

C_1 = share of cumulative non − poor households at agglomorate level (normalized)
C_2 = share of cumulative household head educated above primary at agglomorate level (normalized).

Further, from Fig. 3 we observe a significant variation exists between consumption and income in the households at the agglomerate level. It is observed that the economic index present in the IHDS raw data acts a middle ground for both income and consumption. Hence, it was used to assess the economic capacity of the households. It is to be noted that the economic index was scaled by 200 units to compare with consumption and income (Table 2).

2.1.4. Use

The use dimension captures domestic water usage, treated water and no conflicts as its sub components. In the absence of data on domestic water usage, type of toilet is used as a proxy to assess the use component. As flushing water is considered as largest water intensive consumption behaviour of the household, the use of this variable is justified. Moreover, it is observed that in the majority of cities during summer and at times of acute water shortage domestic water use is characterized by conflicts over water usage. Therefore, share of households who are not involved in any conflict is also considered. Share of households who treat water before consumption is considered to assess the use component. The above factors were taken after careful evaluation of literature and considering the e-WPI.

$$Use = {}^{U_1+U_2+U_3}/_{3}$$

U_1 = share of cumulative no conflict reported over resources at agglomorate level (normalized)
U_2 = share of cumulative households where water is treated at agglomorate level (normalized)
U_3 = share of cumulative water used for toilet by households at agglomorate level (normalized).

From Fig. 4, we observe that collectively households in Pune, Ranchi, Varanasi, Dhanbad and Allahabad walk greater distances to fetch water

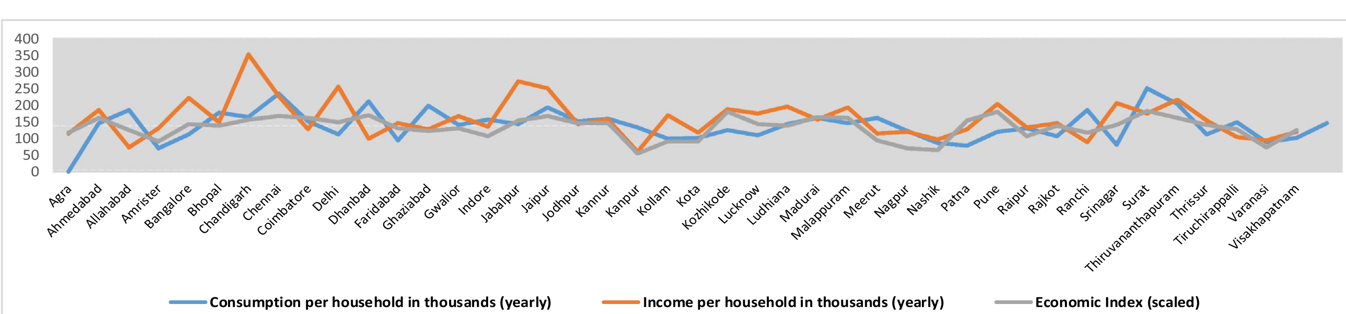


Fig. 3. Consumption, income and economic index.

Table 2
Water Poverty Index components.
Source: Compiled by the authors using the existing literature on WPI.

Dimension	Indicators	Variables name	Source
Resource	Water availability	Normalized Net Groundwater Per Capita Availability.	CGWC
	Water reliability	Variation in the annual rainfall from the Long Period Average.	IMD[b]
Access	Access to safe water	Share of the households having access to the safe water supply inside the household premises.	IHDS-2[a]
	Access to improved sanitation	Share of the households having access to improved sanitation inside the household premises.	
Capacity	Economic capacity	Share of the households who are not poor.	
	Education	Share of the households whose head of the household's had above primary education.	
Use	Domestic usage	Share of households who have semi-flush/flush latrine.	
	Treat water	Share of households who treat their water before consumption.	
	No conflicts	Share of households who do not involve any conflict over resources.	
Environment	Water quality	The volume of water free of pollutants like arsenic, heavy metals, fluorides, nitrates and iron.	CGWC[c]

[a] IHDS2: Indian Human Development Survey.
[b] IMD: Indian Meteorological Department.
[c] CGWC: Central Ground Water Commission.

on a regular day. Unfortunately, the indicator was absent for a large number of households, hence it could not be included in this study. Also, it was also observed that there existed a positive correlation between the distance to a water source and the type of toilet used by the household. For instance, the probability of using a flush toilet was relatively lower to pit latrine when the distance to the water source was larger. And it was also observed that the people walked larger distances when water was not sufficient particularly during summer.

2.1.5. Environment

Apart from availability, access, capacity and use, the quality of water is an important factor which impacts the lives of people. World Bank (2017) estimated that 21% of communicable diseases in India were linked to unsafe water and the lack of hygiene practices. Also, more than 500 children under the age of five die each day from diarrhea in India. As cities are close to industrial clusters and due to urbanization and population growth both surface and groundwater quality is seriously deteriorated. Release of effluents from industrial clusters and untreated domestic sewage are the major drivers of poor water quality. Apart from this urban runoff is also another significant factor affecting water quality (House et al., 1993; Dwight et al., 2002). India also ranks 121 amongst 122 nations on water quality (NITI Aayog, 2018). The data on surface water quality is very limited and lacking. Hence only groundwater quality is used to assess the environment dimension. The pollutants which were present in groundwater included arsenic, fluoride, iron and heavy metals like lead and cadmium. Based on their relative harm caused by the consumption the different pollutants were given different weights.

$$Environment = 1 + (-0.4E_1 - 0.3E_2 - 0.2E_3 - 0.05E_4 - 0.025E_5)$$

where E_1 is the arsenic, E_2 is heavy metals, E_3 is flouride, E_4 nitrate and E_5 is iron in the groundwater respectively.

3. Results & discussion

The following section discusses about the results of the index creation using arithmetic aggregation using equal weights, arithmetic aggregation using weights and multiplicative method. Cities are ranked across all the dimension on each of the sub components and as a single composite index. For discussion we have represented only the top and bottom five performers. See Appendix A for detailed ranking of all the forty two million plus urban agglomerations.

3.1. Resource

Resource is defined as the physical availability of freshwater resources. As indicated earlier, the resource component was assessed by its two sub-components the physical availability of the resource and seasonal variation of the resource. It is observed that despite the abundance of groundwater availability in areas like Ludhiana, Amritsar, Rajkot, and Vishakhapatnam it did not translate to high resource available per person due to high population to resource ratio, as of now. Apart from the population effect, the efficient allocation and management of the resource could also play a pivotal role in determining the sufficiency of a resource. Also, Chennai, Bangalore, Chandigarh, Dhanbad, and Ghaziabad were observed to be relatively water poor due to existence of a relative low resource base. The northern part of India is endowed with good amount of perennial rivers while southern part lack such natural water systems. As a result, cities in northern India face economic water scarcity while cities in south face both physical and economic water scarcity. Moreover, water cuts across administrative boundaries and as majority of states are also dependent on neighboring states for water there are many water disputes across states. The states in which bottom five cities are ranked face at least one water sharing dispute. It was observed that districts in Kerala received abundant rain in contrast

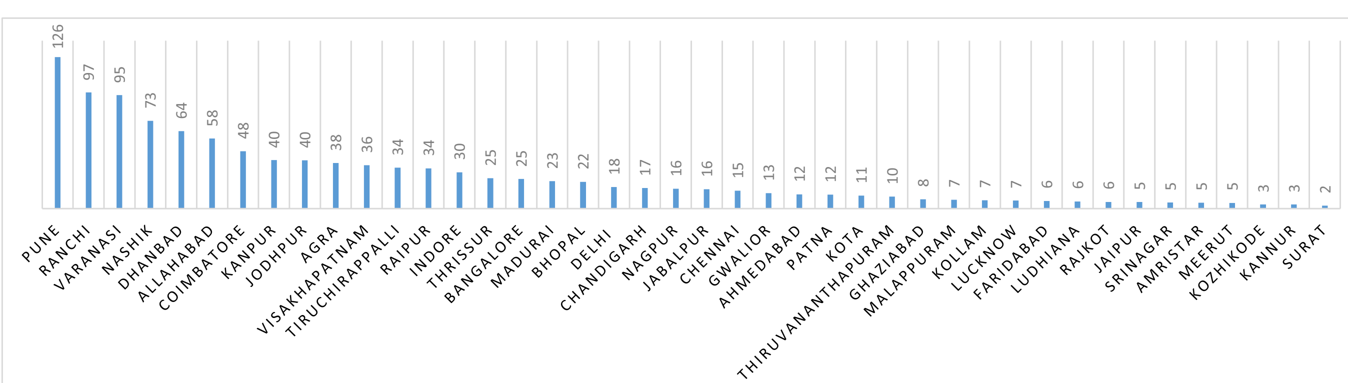


Fig. 4. Amount of time spent walking to collect water by households at urban agglomerate level per day.

Table 3
Arithmetic aggregation of the resource indicator using equal weights.
Source: Compiled by the authors using IMD and CGWC data.

Top five	R_1[a]	Top five	R_2[b]	Top five	Resource
Delhi	1.00	Kozhikode	1	Delhi	0.59
Ludhiana	0.29	Kannur	0.89	Kozhikode	0.53
Amritsar	0.24	Thrissur	0.78	Kannur	0.49
Vishakhapatnam	0.19	Kollam	0.69	Thrissur	0.44
Rajkot	0.19	Malappuram	0.63	Kollam	0.38
Bottom five	**R_1**	**Bottom five**	**R_2**	**Bottom five**	**Resource**
Chennai	0.00	Agra	0.00	Jodhpur	0.03
Bangalore	0.00	Jodhpur	0.01	Agra	0.04
Chandigarh	0.01	Amritsar	0.01	Faridabad	0.05
Dhanbad	0.02	Kanpur	0.03	Ghaziabad	0.05
Ghaziabad	0.03	Ludhiana	0.04	Kanpur	0.06

[a] R_1: Groundwater.
[b] R_2: Seasonal variation.

to other cities like Agra and Jodhpur in the seasonal variation component. Upon averaging the two sub-components using equal weights (Sullivan et al., 2003), it was found that Delhi emerged on top with 59% whereas Jodhpur ranks last with 3% resource wealth. Boken (2016), affirms in his study that depth of the groundwater table in Delhi increased in the period 2007–2010, which could be attributed to heavy monsoon in 2010. However as of 2020, Delhi is inching towards Day zero due to the overexploitation of its aquifers with the continual heavy influx of migrants. Table 3 ranks cities under both these sub-components and resource indicator.

Developing countries like India treat only about 35% of wastewater and the use of treated wastewater for non potable uses at the household is still largely lacking because of strong stigma associated with using treated wastewater. People are generally apprehensive of using treated wastewater because of hygiene and health concerns. However, at times of severe water scarcity wastewater is often considered as a potential resource which needs to be properly harnessed. The government should encourage the household to invest in on site wastewater treatment and should allocate funds in large scale wastewater treatment plants and make rainwater harvesting mandatory so as to tackle the resource shortage. As of 2015, the wastewater treatment potential of India was 22,963 million L/day which is only 37% of the wastewater generated per day (Central Pollution Control Board, 2015). However, not all sewage plants run at full potential and hence, increase in both sewage plants and efficiency of the existing plants is necessary to facilitate the resource needs.

3.2. Access

India has made a significant progress in improving access to piped water supply. According to Census of India (2011), 71% of the urban population and 29% of the rural population have access to piped water supply. However, this phenomenal success in increasing access alone did not suffice in improving the domestic water security situation as the supply from public utilities continue to be unreliable (Pattanayak et al., 2005; McKenzie and Ray, 2009). As water supply in India is largely under the control of government, with ageing infrastructure and in the absence of efficient revenue mobilization, public water utilities face enormous challenge in moving towards 24×7 water supply. As a result a majority of cities across India resort to rationing of water and on average supply water for 6–8 h and this partly fulfill household water needs and hence they resort to other water sources mostly private bore well. This has led to over exploitation of groundwater resources. About 85% of the drinking water needs are fulfilled by groundwater and majority of groundwater blocks in India are already under critical zone (CGWB, 2019).

The access component was also assessed by access to both water and sanitation inside the household premises. Huseo (2013) affirms that a significant increment in the number of sanitation facilies in states like Punjab, Haryana and Uttarakhand was observed in the Census of India (2011) from Census 2001. It could be attributed to Ludhiana being a forerunner in sanitation inside the household. It is observed that households in Kannur, Kozhikode and Jabalpur had better access to water inside their household premises whereas compared to households at Nashik and Kanpur respectively. The type of sanitation inside household premises included pit latrine, semi-flush and flush latrine. 18 out of 48 districts had 90% or more households with sanitation facilities inside their premises. Although the forerunners were cities from Northern India, it is also noted that most of 18 districts which had 90% or more households with sanitation facilities were urban agglomerations largely from the South of India. Therefore, in general, cities in southern India seems to fare relatively better in terms of sanitation facilities in comparison to cities in Northern India. Apart from socio economic development and effective public expenditure improved access to water services and sanitation facilities in south India might explain the highly conservative attitudes and beliefs people have on hygiene and sanitation. High level of literacy could also explain improved sanitation facilities. There is a greater need for bottom five cities to invest in improving access since access to sustainable and reliable water within household premises will have significant spillover effects on household productivity resulting in improved economic status and moreover the opportunity cost of collecting water from far off places is very high. It is to be noted that people particularly women and children in urban slums walk for about 44 min on an average to collect water (IHDS 2, 2011). Not only that improving access will also have positive externalities on public health as well. Access to adequate and reliable water supply of good quality has the potential to save significant economic costs. It is likely that campaigns like Swatch Bharat which has been advocating defecation free agglomerations could bear fruit in the coming years (Table 4).

Upon averaging the two access sub-components with equal weight (Sullivan et al., 2003), it was found that Srinagar, Kozhikode, and Malappuram emerged as the forerunners with better access while Nashik, Kanpur and Allahabad were lagging behind in terms of access.

3.3. Capacity

Capacity is to assess the capability of the household to access water resources. The sub-components of the capacity include the educational level of the head of the household and whether the household is poor or comfortable where the comfortable is a set of middle-class and the rich. Table 5 ranks both the sub-components and capacity indicator for top and bottom urban agglomerations.

Table 4
Arithmetic aggregation of the access indicator using equal weights.
Source: Compiled by the authors using IHDS data.

Top five	C_1[a]	Top five	C_2[b]	Top five	Access
Jabalpur	1	Ludhiana	0.97	Srinagar	0.96
Kannur	1	Srinagar	0.96	Kozhikode	0.95
Kozhikode	1	Patna	0.94	Malappuram	0.95
Chennai	0.99	Surat	0.92	Kannur	0.94
Thrissur	0.99	Malappuram	0.91	Patna	0.94
Bottom five	**C_1**	**Bottom five**	**C_2**	**Bottom five**	**Access**
Nashik	0.11	Kanpur	0.12	Nashik	0.13
Kanpur	0.19	Nashik	0.15	Kanpur	0.16
Allahabad	0.20	Allahabad	0.17	Allahabad	0.19
Varanasi	0.26	Ranchi	0.18	Dhanbad	0.27
Dhanbad	0.30	Dhanbad	0.24	Varanasi	0.31

[a] C_1: Share of water inside.
[b] C_2: Share of sanitation.

Table 5
Arithmetic aggregation of the capacity indicator using equal weights.
Source: Compiled by the authors using IHDS data.

Top five	E_1[a]	Top five	E_2[b]	Top five	Capacity
Surat	0.91	Kollam	1.00	Kozhikode	0.94
Kozhikode	0.89	Kozhikode	0.99	Surat	0.91
Pune	0.88	Thiruvananthapuram	0.99	Thiruvananthapuram	0.89
Dhanbad	0.84	Kannur	0.97	Malappuram	0.87
Jaipur	0.82	Malappuram	0.95	Pune	0.87
Bottom five	**E_1**	**Bottom five**	**E_2**	**Bottom five**	**Capacity**
Kanpur	0.27	Allahabad	0.53	Varanasi	0.46
Nashik	0.33	Varanasi	0.55	Nashik	0.51
Nagpur	0.36	Amritsar	0.58	Amritsar	0.51
Varanasi	0.37	Jodhpur	0.60	Kanpur	0.53
Amritsar	0.45	Dhanbad	0.62	Meerut	0.55

[a] E_1: Economic capacity.
[b] E_2: Share of household head education above primary.

The education of the household head was classified as below primary and above primary using the IHDS data. The share of household head with above primary education was used to evaluate the sub-component of capacity. Cities from Kerala were the forerunners and this is evident from the state being highly literate. In contrast, Allahabad and Varanasi relatively with low literacy level in comparison to other cities were poor performers. This implies that education level of household head is an important driver influencing the decision to demand for water services. Economic capacity of the household is also used to assess the capacity component and for this. The share of people with comfortable living index from IHDS was used, Improvements in education and economic status is expected to positively increase the advocacy for better water access and utilization. It was also found that urban agglomerations like Surat, Pune which fall amongst the top 10 richest cities in India had better economic capacity due to lower cost of living in comparison to other rich cities (Janaagraha, 2013). Kozhikode tops the capacity component, with relatively good economic status and literacy rates.

3.4. Use

The use is evaluated by the sub-components; the amount of water usage, conflict over resources and local treatment of the resource. As direct water consumption data is unavailable, the amount of water usage is assessed by the type of toilet used by the household. The household either had no toilet or used a pit latrine, semi-flush and flush latrine. The type of toilet was categorized into two types; one being no-toilet/pit latrine and the other being semi-flush/flush latrine. Pit latrine uses the lowest amount of water amongst the alternatives. Thus, it was clubbed along with the no-toilet scenario. The share of semi flush/flush latrine of households were calculated to evaluate the relative water usage. Urban agglomerations which were relatively resource abundant seemed to be using more water in contrast to resource-deprived ones.

At times of prolonged period of drought and critical water shortages it is observed that there is an increasing number of conflicts of over water usage. The share of number of conflicts over resources was used to capture the households perception of conflict over water in their societies. The local treatment of the resource was divided into two segments. The first segment included both never and rarely boiled and the other segment included usually and always boiled the water before consumption. The share of the later segment (usually/always) was used to evaluate the local treatment of the resource. Table 6 ranks both the sub-components and use indicator for top and bottom five Indian urban agglomerations.

According to the Census of India (2011), Kerala reports to having the least number of “no toilets” households in the state; evident with agglomerates from Kerala being forerunners in the domestic use component. From the Institute of Conflict Management (2017) map; it is observed that parts of Bihar witness conflicts; marked with Patna ranked as the urban agglomerate with relatively highest number of conflicts. Overall, the use component was assessed by averaging all the three sub-components discussed above. Thrissur, Kollam performed relatively better due to strong resource endowment, less conflict and better treatment of the resource in contrast to other cities such as Allahabad and Kanpur.

Table 7
Environment indicator.
Source: Compiled by the authors using CGWC data.

Top five	Environment	Bottom five	Environment
Chandigarh	1	Faridabad	0.03
Dhanbad	1	Amritsar	0.05
Lucknow	1	Gwalior	0.42
Srinagar	0.97	Jaipur	0.42
Pune	0.95	Delhi	0.45

3.5. Environment

The last component environment was evaluated by the groundwater quality of the area. Negative penalties were given to pollutant according to the level of impact they have on the consumption. Highest penalty was given to the presence of Arsenic in the groundwater which was followed by the presence of heavy metals, fluoride, nitrates, and iron. About 72% of the groundwater wells surveyed did not have any of the above-mentioned pollutants in their water. The presence of arsenic

Table 6
Arithmetic aggregation of the use indicator using equal weights.
Source: Compiled by the authors using IHDS data.

Top five	U_1[a]	Top five	U_2[b]	Top five	U_3[c]	Top five	Use
Kannur	1.00	Kochi	1.00	Rajkot	1.00	Kozhikode	0.94
Kozhikode	0.99	Kollam	0.92	Thiruvananthapuram	0.97	Thrissur	0.93
Indore	0.99	Srinagar	0.88	Thrissur	0.95	Kollam	0.88
Srinagar	0.97	Thrissur	0.87	Malappuram	0.94	Thiruvananthapuram	0.83
Bhopal	0.97	Thiruvananthapuram	0.84	Agra	0.94	Srinagar	0.79
Bottom five	**U_1**	**Top five**	**U_2**	**Bottom five**	**U_3**	**Bottom five**	**Use**
Nashik	0.06	Patna	0.00	Patna	0.01	Allahabad	0.09
Allahabad	0.11	Allahabad	0.01	Ghaziabad	0.09	Kanpur	0.12
Kanpur	0.12	Kanpur	0.02	Meerut	0.15	Visakhapatnam	0.24
Ranchi	0.16	Kota	0.02	Allahabad	0.16	Patna	0.32
Varanasi	0.25	Nashik	0.02	Jabalpur	0.24	Meerut	0.33

[a] E_1: Domestic use.
[b] E_2: Treat water.
[c] E_3: No conflict.

was observed only in four districts, of which Faridabad had all the other pollutants too. Table 7 ranks the environment indicator for a few urban agglomerations.

Literature affirms that Faridabad, Jaipur and Delhi had worst level of groundwater quality amongst all the million plus urban agglomerations due to heavy metal pollution. (Central Pollution Control Board, 2015) Surprisingly, only one-seventh of the districts had less than 50 percent groundwater being unfit for healthy consumption. Dhanbad emerged as the district with the presence of relatively best groundwater quality where the groundwater wells in the districts were free of all the pollutants aforementioned.

4. Water Poverty Index and aggregation methods

The subcomponents were aggregated by three approaches to form the Water Poverty Index for the forty-two urban agglomerations. The WPI is calculated using three approaches; namely additive with no weights, additive with weights and multiplicative. The weights for the additive aggregation were assigned based on factor loadings from factor analysis.

Both components and sub-components are averaged by addition respectively in the former two methodologies. The sub-components are aggregated by additive and components by multiplicative in the multiplicative in the multiplicative aggregation (Van der Vyver, 2013)

$$WPI_{additive} = \frac{Resource + Access + Capacity + Use + Environment}{5}$$

$$WPI_{multiplicative} = \sqrt[5]{Resource \times Access \times Capacity \times Use \times Environment}$$

$$WPI_{PCA} = \frac{a.Resource + b.Access + c.Capacity + d.Use + e.Environment}{5}$$

where a, b, c, d, and e are the factor loadings.

Fig. 5 show that all three multiplicative, additive and principal component are all highly correlated. Similarly, upon averaging the subcomponents of all three methodologies, it was observed that the results across all the methods remain same. Justifying the same, all the top 5 performing urban agglomerate are from the state of Kerala and despite the difference in the aggregation methods, Kozhikode's WPI is similar across the different methodologies. The vice-versa is observed in the case of Thiruvananthapuram. The low resource base translated to low multiplicative WPI in the case of Thiruvananthapuram affirms the fact that unlike the additive aggregation the multiplicative aggregation penalizes the differences in achievement by the different components. From Fig. 6, we observe that majority of the component's show similar values across the different methodology, the exception to this trend is Environment and Resource. The difference between the methodologies is discussed below the table. The rankings of the first five and last five urban agglomerations is found in Table 9.

The full compensability is implied from additive aggregation wherein it is not in the case of multiplicative aggregation. The difference in the scale is because the multiplicative index penalized the differences in achievement amongst the various components. Hence the scale of multiplicative values were lower than its counterparts. From existing literature (Garriga and Pérez Foguet, 2010), it is also affirmed that full compensability is not as desirable as a legitimate goal. Thus, the construction of the multiplicative aggregation is important to evaluate an appropriate index and hence for this reason is considered superior over the other methods. Studies affirm that there exist a strong positive correlation between the weighted geometric WPI and weighted arithmetic WPI (El-Gafy, 2018; Van der Vyver, 2013). Similarly, it can also be clearly seen from Table 8 that the correlation between the WPI rankings of the three approaches to be strong. On a whole, averaging the WPI values of the urban agglomerates; it was observed that $WPI_{additive}$,

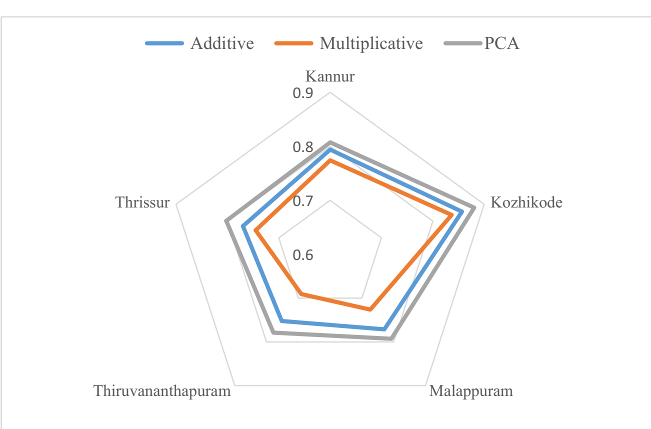


Fig. 5. Comparison of WPI values obtained by top 5 urban agglomerates using different aggregation methods.

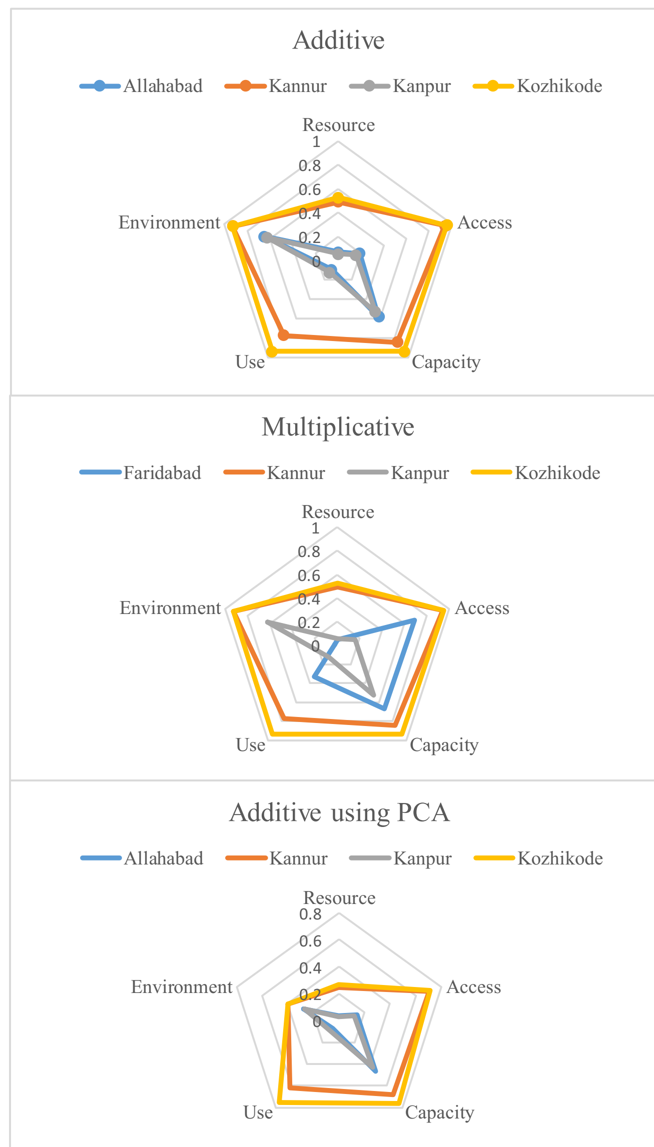


Fig. 6. Comparison of finest and poorest two agglomerates using different aggregation methodologies.

Table 8
Factor loadings.
Source: Compiled using IHDS data.

Components	PCA weights
Resource	0.50
Access	0.75
Capacity	0.81
Use	0.80
Environment	0.43

$WPI_{multiplicative}$, WPI_{PCA} fell in range of 0.47–0.59. This is in line with Lawrence et al. (2002) study in which the WPI_{India} 0.53.

5. Conclusion

Water is an exhaustible resource and the present trend of increasing supply and overexploitation is highly unsustainable as the per capita water resources are declining at a faster rate. In the coming decade, India is expected to witness large scale migration and urbanization and is on the verge of a severe water crisis and hence there is an urgent need for renewed governance and institutional reforms to manage urban water. In this aspect, in order to drive policy formulation the present study has developed a Water Poverty Index to assess the relative degree of water scarcity across select million plus urban agglomerations based on limited secondary data.

The WPI developed in this study used five critical components which are crucial for understanding water security viz.; resource, access, capacity, use and environment. The dimensions and choice of indicators used in this study is based on extensive literature review and is based on the benchmark WPI and e WPI. As indices are subjected to loss of information and thus biasedness in reporting the data, to address this issue, we adopted different aggregation methods to calculate WPI so as to assess the relative water scarcity. A good balance between the five components often translates to high WPI. The results indicate there is no a single city in our analysis that topped all the dimension and this is the ultimate path towards which all the states and cities should move. However, achieving that is no easy a task and there needs strong political will, forward looking attitude and complete autonomy of institutions to achieve universal water security. Amongst all the components, urban agglomerates which topped the overall WPI performed poorly in the resource component and it is difficult to improve because it is beyond the control of government interventions as it is mostly dependent on rainfall and groundwater availability, all other components, particularly, the access, use and environment component needs greater government intervention.

Moreover, the number of sub-components within a particular component had a direct relation with the overall contribution of component in the index. The correlation between the WPI using all three approaches; additive using no weights, additive with weights and multiplicative and use component was relatively stronger in comparison to other components due to larger number of sub-components being used. Similarly, the correlation between the WPI and environment component was found to be the weakest amongst the five components as only one sub component was used.

It is to be highlighted that the effectiveness of the index is dependent on the ability of the index to retain maximum information regarding its indicators and sub-components or the ability of the index to minimize the loss of information pertaining to its subcomponent. In this regard, the study found that the multiplicative WPI reduced the spillover effects of high components unlike the additive WPI. Further, it is essential to note that the correlation between the indicators and index as a whole was least in the case of the multiplicative aggregation. It is important to educate and create awareness to the public on efficient water use through regular capacity building initiatives and training programmes. Apart from the state owned public utilities there are multiple agencies that are involved in urban water management that is actually complicating and escalating the problem. There is a greater need for proper coordination and consultations with all the departments to address the problem efficiently. As water is subjected to transboundary water conflicts, there is a greater need for decentralization and debureaucratization of urban water management.

Though this study has relied on almost nine year old data set which might have very little relevance now as there are high chances that the present on ground situation might be altogether different, we believe that this is first study of its kind to have developed a Water Poverty Index across cities in India using secondary data. We hope that the results of the present study will be of interest to policymakers and researchers to understand the vulnerability of cities to water scarcity. There is also scope for future research as when the new data on household and city level water related data is released such as census 2021 or IHDS 3, a similar index can be created and compared with the results of the present study. As with any other index experiments our index is also not robust and exhaustive and are subjected to certain limitations but however the results shed some light on the challenges faced by cities on various aspects of water and thus will serve the purpose of decision making process for policymakers. Despite all the limitations with respects to data availability and index creation, we hope that this study rekindles debate on the growing problem of urban water scarcity and enables future research on urban water security.

CRediT authorship contribution statement

Aparna Sivaraman Prabha: Writing - original draft, Formal analysis, Data curation, Investigation. **Ashwin Ram:** Writing - review & editing, Investigation. **Zareena Begum Irfan:** Conceptualization, Methodology, Supervision.

Table 9
Comparison of the rankings using different methodologies.
Source: Compiled by the authors using IHDS data.

Top five	WPI_1	Top five	WPI_2	Top five	WPI_3
Kannur	0.86	Kannur	0.88	Kozhikode	0.84
Kozhikode	0.79	Kozhikode	0.81	Kannur	0.77
Malappuram	0.77	Thrissur	0.80	Thrissur	0.74
Thrissur	0.77	Malappuram	0.79	Malappuram	0.73
Thiruvananthapuram	0.75	Thiruvananthapuram	0.78	Thiruvananthapuram	0.69
Bottom five	**WPI_1**	**Bottom five**	**WPI_2**	**Bottom five**	**WPI_3**
Kanpur	0.30	Kanpur	0.29	Faridabad	0.18
Allahabad	0.32	Allahabad	0.31	Kanpur	0.21
Varanasi	0.34	Varanasi	0.35	Allahabad	0.22
Faridabad	0.35	Nashik	0.35	Amritsar	0.25
Nashik	0.36	Faridabad	0.42	Varanasi	0.28

WPI_1: Additive with no weights. WPI_2: Additive with weights. WPI_3: Multiplicative with no weights.

Declaration of competing interest

The authors declare that they do not hold any kind of conflict of interest concerned with the submission of the present manuscript.

Acknowledgement

The authors are grateful to their parent institute, which provided them the infrastructural facility to conduct the research work.

Appendix A

Table 1a
WPI of the urban agglomerations compiled using various data sources.
Source: Compiled by the author using various data sources.

Urban agglomerations	Resource	Access	Capacity	Use	Environment	WPI
Agra	0.04	0.63	0.64	0.56	0.75	0.52
Ahmedabad	0.12	0.78	0.80	0.49	0.73	0.58
Allahabad	0.07	0.19	0.58	0.09	0.65	0.32
Amritsar	0.13	0.79	0.51	0.34	0.05	0.37
Bangalore	0.08	0.83	0.82	0.70	0.73	0.63
Bhopal	0.09	0.79	0.75	0.60	0.93	0.63
Chandigarh	0.12	0.87	0.86	0.75	1.00	0.72
Chennai	0.14	0.83	0.86	0.58	0.95	0.67
Coimbatore	0.08	0.50	0.75	0.50	0.75	0.52
Delhi	0.59	0.80	0.80	0.58	0.45	0.64
Dhanbad	0.08	0.27	0.73	0.40	1.00	0.49
Faridabad	0.05	0.69	0.67	0.33	0.03	0.35
Ghaziabad	0.05	0.74	0.72	0.34	0.65	0.50
Gwalior	0.13	0.84	0.74	0.42	0.43	0.51
Indore	0.12	0.77	0.68	0.61	0.93	0.62
Jabalpur	0.20	0.88	0.85	0.48	0.73	0.63
Jaipur	0.08	0.92	0.76	0.62	0.43	0.56
Jodhpur	0.03	0.48	0.65	0.39	0.73	0.45
Kannur	0.49	0.94	0.84	0.77	0.93	0.79
Kanpur	0.06	0.16	0.53	0.12	0.63	0.30
Kollam	0.38	0.69	0.73	0.88	0.63	0.66
Kota	0.09	0.77	0.61	0.43	0.73	0.53
Kozhikode	0.53	0.95	0.94	0.94	0.93	0.86
Lucknow	0.09	0.87	0.79	0.52	1.00	0.66
Ludhiana	0.17	0.91	0.78	0.60	0.45	0.58
Madurai	0.17	0.70	0.80	0.54	0.95	0.63
Malappuram	0.35	0.95	0.87	0.76	0.93	0.77
Meerut	0.12	0.84	0.55	0.33	0.55	0.48
Nagpur	0.18	0.65	0.60	0.60	0.75	0.56
Nashik	0.17	0.13	0.51	0.33	0.68	0.36
Patna	0.09	0.94	0.74	0.32	0.55	0.53
Pune	0.12	0.53	0.87	0.37	0.95	0.57
Raipur	0.17	0.62	0.67	0.33	0.75	0.51
Rajkot	0.21	0.82	0.72	0.64	0.80	0.64
Ranchi	0.08	0.31	0.66	0.37	0.73	0.43
Srinagar	0.08	0.96	0.78	0.79	0.98	0.72
Surat	0.15	0.93	0.91	0.63	0.75	0.67
Thiruvananthapuram	0.27	0.84	0.89	0.83	0.93	0.75
Thrissur	0.44	0.91	0.82	0.93	0.75	0.77
Trichy	0.14	0.33	0.68	0.36	0.73	0.45
Varanasi	0.07	0.31	0.46	0.36	0.50	0.34
Vishakhapatanam	0.28	0.45	0.65	0.24	0.73	0.47

Table 2a
Geometric WPI of the urban agglomerations compiled using various data sources.
Source: Compiled by the author using various data sources.

Urban agglomerations	Resource	Access	Capacity	Use	Environment	WPI
Agra	0.04	0.63	0.64	0.56	0.75	0.38
Ahmedabad	0.12	0.78	0.80	0.49	0.73	0.48
Allahabad	0.07	0.19	0.58	0.09	0.65	0.22
Amritsar	0.13	0.79	0.51	0.34	0.05	0.25
Bangalore	0.08	0.83	0.82	0.70	0.73	0.49
Bhopal	0.09	0.79	0.75	0.60	0.93	0.50
Chandigarh	0.12	0.87	0.86	0.75	1.00	0.58
Chennai	0.14	0.83	0.86	0.58	0.95	0.56
Coimbatore	0.08	0.50	0.75	0.50	0.75	0.40
Delhi	0.59	0.80	0.80	0.58	0.45	0.63
Dhanbad	0.08	0.27	0.73	0.40	1.00	0.36
Faridabad	0.05	0.69	0.67	0.33	0.03	0.18
Ghaziabad	0.05	0.74	0.72	0.34	0.65	0.36
Gwalior	0.13	0.84	0.74	0.42	0.43	0.43
Indore	0.12	0.77	0.68	0.61	0.93	0.51

(continued on next page)

Table 2a (*continued*)

Urban agglomerations	Resource	Access	Capacity	Use	Environment	WPI
Jabalpur	0.20	0.88	0.85	0.48	0.73	0.55
Jaipur	0.08	0.92	0.76	0.62	0.43	0.43
Jodhpur	0.03	0.48	0.65	0.39	0.73	0.30
Kannur	0.49	0.94	0.84	0.77	0.93	0.77
Kanpur	0.06	0.16	0.53	0.12	0.63	0.21
Kollam	0.38	0.69	0.73	0.88	0.63	0.64
Kota	0.09	0.77	0.61	0.43	0.73	0.42
Kozhikode	0.53	0.95	0.94	0.94	0.93	0.84
Lucknow	0.09	0.87	0.79	0.52	1.00	0.50
Ludhiana	0.17	0.91	0.78	0.60	0.45	0.50
Madurai	0.17	0.70	0.80	0.54	0.95	0.55
Malappuram	0.35	0.95	0.87	0.76	0.93	0.73
Meerut	0.12	0.84	0.55	0.33	0.55	0.40
Nagpur	0.18	0.65	0.60	0.60	0.75	0.50
Nashik	0.17	0.13	0.51	0.33	0.68	0.30
Patna	0.09	0.94	0.74	0.32	0.55	0.41
Pune	0.12	0.53	0.87	0.37	0.95	0.46
Raipur	0.17	0.62	0.67	0.33	0.75	0.44
Rajkot	0.21	0.82	0.72	0.64	0.80	0.58
Ranchi	0.08	0.31	0.66	0.37	0.73	0.34
Srinagar	0.08	0.96	0.78	0.79	0.98	0.55
Surat	0.15	0.93	0.91	0.63	0.75	0.57
Thiruvananthapuram	0.27	0.84	0.89	0.83	0.93	0.69
Thrissur	0.44	0.91	0.82	0.93	0.75	0.74
Trichy	0.14	0.33	0.68	0.36	0.73	0.38
Varanasi	0.07	0.31	0.46	0.36	0.50	0.28
Vishakhapatanam	0.28	0.45	0.65	0.24	0.73	0.43

Table 3a
Weighted WPI of the urban agglomerations compiled using various data sources.
Source: Compiled by the author using various data sources.

Urban agglomerations	Resource	Access	Capacity	Use	Environment	PCA WPI
Agra	0.02	0.47	0.52	0.45	0.32	0.54
Ahmedabad	0.06	0.58	0.65	0.40	0.31	0.61
Allahabad	0.04	0.14	0.47	0.07	0.28	0.31
Amritsar	0.06	0.60	0.42	0.27	0.02	0.42
Bangalore	0.04	0.62	0.66	0.56	0.31	0.67
Bhopal	0.05	0.59	0.61	0.48	0.40	0.65
Chandigarh	0.06	0.65	0.70	0.60	0.43	0.74
Chennai	0.07	0.62	0.69	0.46	0.41	0.69
Coimbatore	0.04	0.38	0.61	0.40	0.32	0.53
Delhi	0.30	0.60	0.65	0.46	0.19	0.67
Dhanbad	0.04	0.20	0.59	0.32	0.43	0.48
Faridabad	0.02	0.52	0.55	0.26	0.01	0.42
Ghaziabad	0.03	0.55	0.58	0.28	0.28	0.53
Gwalior	0.07	0.63	0.60	0.33	0.18	0.55
Indore	0.06	0.58	0.55	0.48	0.40	0.63
Jabalpur	0.10	0.66	0.69	0.38	0.31	0.66
Jaipur	0.04	0.69	0.62	0.50	0.18	0.62
Jodhpur	0.01	0.36	0.53	0.31	0.31	0.46
Kannur	0.25	0.71	0.68	0.62	0.40	0.81
Kanpur	0.03	0.12	0.43	0.10	0.27	0.29
Kollam	0.19	0.52	0.59	0.70	0.27	0.69
Kota	0.04	0.58	0.50	0.35	0.31	0.54
Kozhikode	0.26	0.72	0.76	0.75	0.40	0.88
Lucknow	0.04	0.65	0.64	0.42	0.43	0.67
Ludhiana	0.08	0.68	0.63	0.48	0.19	0.63
Madurai	0.08	0.53	0.65	0.43	0.41	0.64
Malappuram	0.17	0.71	0.71	0.61	0.40	0.79
Meerut	0.06	0.63	0.44	0.26	0.24	0.50
Nagpur	0.09	0.49	0.48	0.48	0.32	0.57
Nashik	0.09	0.10	0.41	0.26	0.29	0.35
Patna	0.05	0.70	0.60	0.25	0.24	0.56
Pune	0.06	0.40	0.70	0.30	0.41	0.57
Raipur	0.08	0.46	0.54	0.26	0.32	0.51
Rajkot	0.11	0.61	0.58	0.51	0.34	0.66
Ranchi	0.04	0.23	0.54	0.30	0.31	0.43
Srinagar	0.04	0.72	0.63	0.63	0.42	0.75
Surat	0.08	0.69	0.73	0.50	0.32	0.71
Thiruvananthapuram	0.14	0.63	0.72	0.67	0.40	0.78
Thrissur	0.22	0.68	0.66	0.74	0.32	0.80
Trichy	0.07	0.25	0.55	0.29	0.31	0.45
Varanasi	0.04	0.23	0.37	0.29	0.22	0.35

Table 3a (*continued*)

Urban agglomerations	Resource	Access	Capacity	Use	Environment	PCA WPI
Vishakhapatanam	0.14	0.34	0.53	0.19	0.31	0.46

References

Amarasinghe, U.A., Shah, T., Turral, H., Anand, B.K., 2007. India's water supply and demand from 2025–2050: business-as-usual scenario and deviations. International Water Management Institute. Research Report 123 ISSN 1026-0862, ISBN 976-92-9090-687-2.

Basu, M., Hoshino, S., Hashimoto, S., 2015. Many issues, limited responses: coping with water insecurity in rural India. Water resources and rural development. 5, 47–63. https://doi.org/10.1016/j.wrr.2015.07.001.

Boken, V.K., 2016. Groundwater crisis of a mega city: a case study of New Delhi, India. Balanced Urban Development: Options and Strategies for Liveable Cities. Part V, Chapter 14. Water Science and Technology Library vol. 72. Springer Open. ISBN: 978-3-319-28110-0, pp. 211–219. https://doi.org/10.1007/978-3-319-28112-4.

Census of India, 2011. Provisional Population Totals. Office of the Registrar General and Census Commissioner, Government of India, New Delhi.

Central Ground Water Board (CGWB), 2010. http://cgwb.gov.in/.

Central Ground Water Board (CGWB), 2019. National Compilation on Dynamic Groundwater Resources of India. India, Government of.

Central Pollution Control Board, 2015. http://moef.gov.in/about-the-ministry/organisations-institutions/boards/central-pollution-control-board/.

Cook, C., Bakker, K., 2012. Water security: debating an emerging paradigm. Global Environment Change. 22 (1), 94–102. https://doi.org/10.1016/j.gloenvcha.2011.10.011.

Customized Rainfall Information System (CRIS), Hydromet Division, 2010. India Meteorological Department. http://hydro.imd.gov.in/hydrometweb/(S(khhjyz55bdnenx45gdhmci45))/DistrictRaifall.aspx.

Das, D., Safini, H., 2018. Water insecurity in urban India: looking through a gendered lens on everyday urban living. Environment and Urbanization ASIA 9 (2), 178–197. https://doi.org/10.1177/2F0975425318783550.

Dwight, R.H., Semenza, J.C., Baker, D.B., Olson, B.H., 2002. Association of urban runoff with coastal water quality in Orange County, California. Water Environment Research. 74 (1), 82–90. https://doi.org/10.2175/106143002X139776.

El-Gafy, I.K.E.D., 2018. The water poverty index as an assistant tool for drawing strategies of the Egyptian water sector. Ain Shams Engineering Journal. 9 (2), 173–186. https://doi.org/10.1016/j.asej.2015.09.008.

Falkenmark, M., 1986. Freshwater – time for a modified approach. Water Resources and Policy. 15 (4), 192–200. https://www.jstor.org/stable/4313251.

Fishman, R., Devineni, N., Raman, S., 2015. Can improved agricultural water use efficiency save India's groundwater? Environ. Res. Lett. https://doi.org/10.1088/1748-9326/10/8/084022.

Food and Agriculture Organization (FAO), 2012. Irrigation in southern and eastern Asia in figures, AQUASTAT Survey. FAO Water Reports No 37 ISSN: 1020-1203. http://www.fao.org/3/i2809e/i2809e.pdf.

Gain, A.K., Giupponi, C., Wada, Y., 2016. Measuring global water security towards sustainable development goals. Environment Research Letters. 11 (12). https://orcid.org/0000-0001-5358-9208.

Garriga, R.G., Pérez Foguet, A., 2010. Improved method to calculate a water poverty index at local scale. J. Environ. Eng. 136 (11). https://doi.org/10.1061/(ASCE)EE.1943-7870.0000255.

Garriga, R.G., Pérez Foguet, A., 2011. Application of revised Water Poverty Index to target the water poor. Water Sci. Technol. 63 (6), 1099–1110. https://doi.org/10.2166/wst.2011.347.

Grey, D., Sadoff, C.W., 2007. Sink or swim? Water security for growth and development. Water policy. 9, 545–571. https://doi.org/10.2166/wp.2007.021.

Handbook on Constructing Composite Indicators: Methodology and User Guide. Joint Research Centre, European Commission. OECD, pp. 1–162. http://www.oecd.org/sdd/42495745.pdf.

Hans, V.B., 2016. Water management in agriculture: issues and strategies in India. SSRN. 7, 578–588. https://doi.org/10.2139/ssrn.3072421.

Hao, T., Du, P., Gao, Y., 2012. Water environment security indicator system for urban water management. Frontiers of Environmental Science & Engineering. 6, 678–691. https://doi.org/10.1007/s11783-012-0450-7.

Hoekstra, A.Y., Buurman, J., Van Ginkel, K.C., 2018. Urban water security: a review. Environ. Res. Lett. 13 (5). https://orcid.org/0000-0002-4769-5239.

House, M.A., Ellis, J.B., Herricks, E.E., Hvitved-Jacobsen, T., Seager, J., Lijklema, L., Clifforde, I.T., 1993. Urban drainage-impacts on receiving water quality. Water Sci. Technol. 27 (12), 117–158.

Huseo, A., 2013. Toilet Coverage and Sanitation Performance in India By States (2001–2011). https://www.communityledtotalsanitation.org/resource/toilet-coverage-and-sanitation-performance-india-states-2001-2011-0.

Indian Human Development Survey Round 2, 2011. University of Maryland and National Council of Applied Economic Research (NCAER) New Delhi. https://ihds.umd.edu/.

Institute for Conflict Management, 2017. India: conflict map. https://satp.org/satporgtp/countries/india/database/conflictmapindia_2017.htm.

Janaagraha, 2013. Voice of India's Citizens Survey. https://economictimes.indiatimes.com/infrastructure/surat-pune-ahmedabad-indias-best-cities-to-live-in/slideshow/19396479.cms.

Jensen, O., Wu, H., 2018. Urban water security indicators: development and pilot. Environ Sci Policy 83, 33–45. https://doi.org/10.1016/j.envsci.2018.02.003.

Komnenic, V., Ahlers, R., Van Der Zaag, P., 2009. Assessing the usefulness of the water poverty index by applying it to a special case: can one be water poor with high levels of access? Physics and Chemistry of the Earth. Parts A/B/C 34 (4–5), 219–224. https://doi.org/10.1016/j.pce.2008.03.005.

Lautze, J., Manthrithilake, H., 2012. Water security: old concepts, new package, what value? Natural Resources Forum: A United Nations Sustainable Development Journal. 36 (2), 76–87. https://doi.org/10.1111/j.1477-8947.2012.01448.x.

Lawrence, P.R., Meigh, J., Sullivan, C., 2002. The Water Poverty Index: An International Comparison. Department of Economics, Keele University, Keele, Straffordshire, UK issn 1352-8955. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.536.2948&rep=rep1&type=pdf.

Levy, B.S., Sidel, V.W., 2011. Water rights and water fights: preventing and resolving conflicts before they boil over. American journal of public health association. 101, 778–780. https://doi.org/10.2105/AJPH.2010.194670.

Lilienfeld, A., Asmild, M., 2007. Estimation of excess water use in irrigated agriculture: a Data Envelopment Analysis approach. Agricultural Water Management. 94 (1) (3), 73–82. doi:https://doi.org/10.1016/j.agwat.2007.08.005.

McKenzie, D., Ray, I., 2009. Urban water supply in India: status, reform options and possible lessons. Water Policy 11 (4), 442–460. https://doi.org/10.2166/wp.2009.056.

Molle, F., Mollinga, P., 2003. Water poverty indicators: conceptual problems and policy issues. Water Policy 5 (6), 529–544. https://doi.org/10.2166/wp.2003.0034.

Munda, G., Nardo, M., 2005. Constructing Consistent Composite Indicators: The Issue of Weights. Institute for the Protection and Security of the Citizen. Joint Research Centre EUR 21834 EN. https://core.ac.uk/download/pdf/38619689.pdf.

NITI AAYOG, 2018. Composite Water Management Index (CWMI): A Tool for Water Management. Jal Shakti Ministry, GOI http://social.niti.gov.in/uploads/sample/water_index_report.pdf.

Pattanayak, S.K., Yang, J.C., Whittington, D., Bal Kumar, K.C., 2005. Coping with unreliable public water supplies: averting expenditures by households in Kathmandu, Nepal. Water Resour. Res. 41 (2). https://doi.org/10.1029/2003WR002443.

Sampath, A., Kedarnath, B., Ramanujam, C., Haidery, H., Rao, R., Arunachalam, R., Jeet, V., 2003. Water Privatization and Implications in India. Association for India's Development, Austin USA http://doccentre.org/docsweb/water/water_privatization.pdf.

Schleifer, L., 2017. 7 reasons we are facing a global water crisis. https://www.wri.org/blog/2017/08/7-reasons-were-facing-global-water-crisis.

Shaban, A., Sharma, R.N., 2007. Water consumption patterns in domestic households in major cities. Econ. Polit. Wkly. 42 (23), 2190–2197.

Shao, D.G., Yang, F.S., Liu, Y.L., Xiao, C., 2013. Urban water security index and its evaluation criterion. South-to-North Water Transfers and Water Science & Technology. 11, 122–126. http://en.cnki.com.cn/Article_en/CJFDTotal-NSBD201301026.htm.

Sharma, B.R., Rao, K.V., Vittal, K.P.R., Ramakrishna, Y.S., Amarasinghe, U., 2010. Estimating the potential of rain fed agriculture in India: prospects for water productivity improvements. Agric. Water Manag. 97 (1), 23–30. https://doi.org/10.1016/j.agwat.2009.08.002.

Singh, O., Turkiya, S., 2013. A survey of household domestic water consumption patterns in rural semi arid village. India. GeoJournal. 78, 777–790. https://doi.org/10.1007/s10708-012-9465-7.

Singh, S., Tanvir Hassan, S.M., Hassan, M., Bharti, N., 2020. Urbanisation and water insecurity in the Hindu Kush Himalaya: insights from Bangladesh, India, Nepal and Pakistan. Water Policy 22 (1), 9–32. https://doi.org/10.2166/wp.2019.215.

Sullivan, C., 2002. Calculating a water poverty index. World Dev. 30 (7), 1195–1210. https://doi.org/10.1016/S0305-750X(02)00035-9.

Sullivan, C.A., Meigh, J.R., Giacomello, A.M., 2003. The water poverty index: development and application at the community scale. Natural Resources Forum: A United Nations Sustainable Development Journal. 27 (3), 189–199. https://doi.org/10.1111/1477-8947.00054.

Sun, F., Staddon, C., Chen, M., 2016. Developing and applying water security metrics in China: experience and challenges. Curr. Opin. Environ. Sustain. 21, 29–36. https://doi.org/10.1016/j.cosust.2016.10.006.

Sun, S.K., Li, C., Wu, P.T., Zhao, X.N., Wang, Y.B., 2018. Evaluation of agricultural water demand under future climate change scenarios in the Loess Plateau of Northern Shaanxi. China. Ecological Indicators. 84, 811–819. https://doi.org/10.1016/j.ecolind.2017.09.048.

United Nations, 2015. World population prospects: key findings and advance tables. Economic and social affairs, population division. ESA/P/WP.241. https://population.un.org/wpp/Publications/Files/Key_Findings_WPP_2015.pdf.

Van der Vyver, C., 2013. Water poverty index calculation: additive or multiplicative function? Journal of South African Business Research. Article ID 615770. https://doi.org/10.5171/2013.615770.

Ward, F.A., Michelsen, A., 2002. The economic value of water in agriculture: concepts and policy applications. Water Policy 4 (5), 423–446. https://doi.org/10.1016/S1366-7017(02)00039-9.

Webb, P., Iskandarani, M., 1998. Water insecurity and the poor: issues and research needs. ZEF Discussion Papers on Development Policy. Policy No. 2 , p. 66 ISSN 1436-9931. https://www.zef.de/fileadmin/user_upload/zef_dp2-98.pdf.

World Bank Group, 2017. Waterlife: improving access to safe drinking water in india. http://documents.worldbank.org/curated/en/586371495104964514/pdf/115133-WP-P152203-PUBLIC-17-5-2017-12-28-1-WaterlifeCaseApril.pdf.

World Economic Forum, 2019. Global Risk Report. 14th edition. ISBN: 978-1-944835-15-16. http://www3.weforum.org/docs/WEF_Global_Risks_Report_2019.pdf.