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Water accounting for water management at the river basin scale in India: approaches and gaps

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Abstract

The main objective of this research paper is to assess the extent to which the concept of water accounting has been applied for water management at the river basin scale in India. For this, the study first assesses the importance given to the use of water accounting for water management in India's national water policy. It then analyses the evolution of water accounting approaches in India through a systematic review of the past research studies on the theme. Further, it looks at their contribution to decision-making concerning allocation of water resources and resolving conflicts over water sharing. Finally, it identifies the existing gaps in the methodologies for water accounting so far used in India.

Keywords: Systematic review; Water accounting; Water allocation; Water conflicts; Water policy

Highlights

- This review paper assesses the extent of water accounting (WA) application in India.
- For the purpose, a systematic review approach was followed to identify published work on WA in India.
- The main assessment is on the use of WA for water management at the basin scale.
- It identifies the existing gaps in the approach to WA in India.

Introduction

Water accounting is a tool to assist policymakers in making informed decisions on linking water availability and use, allocating water resources, investing in water infrastructure, improving water use efficiency, understanding the impacts of water management on users, and, making available a

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standardised information system (UN, 2012). In general terms, water accounts present a snapshot on total inflows in the basin, consumptive water use across sectors and quantum (and quality) of water returned to the systems, covering both surface water and groundwater (Molden, 1997). Usually, water accounts present information relating to the physical volumes of water – these are sometimes referred to as 'water balances'[1] (e.g., European Commission, 2015), although some approaches also consider water quality (pollutants added or removed from the water) and the economic aspects of water supply and use (Lange *et al*., 2007; Vardon *et al*., 2007; UN, 2012).

India has 20 major river basins which together provide, on average, about 1,914 billion[2] cubic metres (BCM) of annual replenishable water resources (Central Water Commission, 2017). Considering a total population of 1.3 billion, the annual per capita availability in the country is less than 1,500 cubic metres (cu m). The water availability is substantially higher in river basins having their sources in the Himalayas than those having their headwaters in the Indian peninsula (except for Godavari river basin). For instance, the annual per capita water availability in the Ganga–Brahmaputra–Meghna river basin system (fed by the Himalayas) is more than 20,000 cu m, whereas in the Cauvery river basin (in peninsular India) it is less than 550 cu m (Government of India, 2018). This is mainly because the average precipitation in the Himalayan river catchments is higher and climate is less arid or temperate in large areas in comparison to the catchments in peninsular India. Further, water demand for irrigation in the basins fed by Himalayas is lower compared to the peninsular river basins due to the poor availability of land in per capita terms (Kumar *et al*., 2012). Since per capita water availability is much lower than water demands in the peninsular river basins, there are transboundary (inter-state) conflicts when it comes to water sharing between the riparian states of such basins. Krishna and Cauvery are two such basins that regularly experience conflicts over water sharing during lean seasons and low rainfall years.

Over a period of time, water resources in most of the river basins in India have come under severe stress due to growing pressure from irrigation, domestic and industrial sectors. As per the available estimates of the National Commission for Integrated Water Resources Development in 1999, by 2050 overall water demand in the country will increase by 67% of the 2010 level (Government of India, 1999). Even now, significant parts of central and peninsular India experience water scarcity during average rainfall years.

The existing policies and regulations have done little to address the water management challenges that exist at the basin scale. Ineffective legislation to tackle groundwater over-use in agriculture (Saleth & Dinar, 2000; Bassi, 2014), lack of well-defined water rights (Narain, 1998; Kumar, 2000; Bassi, 2018), inadequate water pricing for irrigation (Kumar, 2010) and urban water supplies (Kumar, 2010, 2014b; Bassi & Kumar, 2012), and policy of providing free or highly subsidised electricity for agricultural use (Saleth, 1997; Kumar, 2005; Bassi, 2014) has made it even more difficult to manage the demand for water. As a result, conflicts over water sharing between riparian states have also increased.

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[1] Water balance provides an estimate on the water availability, water requirement, and water supply for a given year that helps in determining whether the basin is in water surplus or is in deficit. The water budget is prepared for allocating the available water resources for potential future uses. Water account includes both the physical (water abstraction, supply, use, return and deficit) and the economic aspects (cost of water abstraction, purification, distribution, wastewater treatment, etc.) of current uses, and sometimes adds explicit attention on water quality aspects.

[2] 1 billion equals 10^9.

Further, one of the major constraints to managing available water in the river basins is that none of the rivers have an operational river basin management plan. Even if such plans are developed in the future, presently, no institution exists for basin-wide implementation or enforcement of such plans. Moreover, as water is largely a state subject in India, upper riparian states often undertake development of water resources within their administrative jurisdiction without assessing the impacts of their action on water availability in the lower riparian states. It is more so in the case of groundwater due to two reasons: (1) the limited knowledge about the dynamics of interaction between groundwater and surface water in the basin context; and (2) poor monitoring of groundwater use which is through a large number of private wells (Kumar, 2010, 2014a).

One major hindrance to developing river basin management plans is the lack of reliable quantitative information on water availability and uses and how they interact at the level of river basin; for example, on the basin inflows (surface water and groundwater generated in the basin annually), actual consumptive use of water in different sectors and different regions and different seasons against the water supplied, change in the stock of water, irrigation return flows to aquifers and streams, wastewater outflows, and the amount of water that goes out of the basin. Only such information can provide clues on the type of interventions that can help improve water management in a basin. In this context, water accounts which are used to estimate both physical aspects of water (availability, abstraction, supply, uses, return, deficit and its quality) and economic aspects of water supply and uses (cost of abstraction, purification, distribution, wastewater treatment, etc.) can play an important role.

Globally, various tools and frameworks are developed for preparing river basin water accounts. Some of the important ones include the System of Environmental-Economic Accounting for Water (United Nations, 2012), Australian Water Accounting Standard (Commonwealth of Australia, 2012), Netherland's National Accounting Matrix including Water Accounts for River Basins (Brouwer *et al*., 2005), and China's Water Resources Accounting Framework (Zhu *et al*., 2004). Several countries are utilising one or other tools to prepare water accounts to support them in improving the water management at the basin scale. At the basic level, such as in the riparian countries sharing the Mekong basin, they are prepared to improve understanding of the overall water use and flow behaviour in a river basin (Kirby *et al*., 2006). At the more complex level, such as in Australia, Spain and South African countries, they are used for providing information to support better coordination on water development and management in co-riparian countries (Momblanch *et al*., 2014; Pedro-Monzonís *et al*., 2016), and making informed decisions on improving water allocation within and among the riparian countries (Lange *et al*., 2007; Commonwealth of Australia, 2012).

The main objective of this research is to assess the extent to which the concept of water accounting has been applied for water management at the river basin scale in India and identify the possible gaps in its approach. For this reason, the paper has three main tiers of analysis. The first is to assess the importance given to the use of water accounting for water management in national water policy. Second, is to analyse the evolution of water accounting approaches in India and the way such studies have addressed water management issues at the basin scale. The third is to assess the gaps in terms of the approach taken by such studies in promoting water allocation on an efficient and sustainable basis and addressing interstate or inter-user conflicts over water sharing.

After this Introduction, the section below describes the methodological approach used in our work. This is followed by a section that discusses the role of water accounting as highlighted in the India Water Policies, while the section after that provides a detailed account of the evolution of water accounting approaches in India by undertaking a comprehensive review of the past research studies. The next section discusses the gaps in terms of the usefulness of various water accounting approaches and their findings for water management at the river basin scale in India. The concluding section highlights the key findings of the paper and suggests the way forward in order to have an effective water accounting framework for India.

Methodology

As explained above, the research work aimed at: (i) exploring the policy support to water accounting in India's legislation; (ii) analysing the evolution of the approaches to water accounting applied to India by different scholars and institutions; and (iii) identifying gaps in the existing approaches to water accounting in relation to the support of water allocation and conflict management.

To understand the policy environment in India concerning the importance given to water accounting for addressing water management issues at the basin scale, National Water Policies of India were analysed. The first policy was adopted in 1987, was revised in 2002 and then again in 2012.

These policies were assessed in relation to their consideration of water accounting elements and approaches for improving water allocation (across water use sectors and riparian states) and promoting efficient use of water at the basin scale. Since one of the uses of water accounts is to provide information for better allocation of water resources among riparian states and hence inform disputes over water sharing between them, it is important to understand the governance mechanism in relation to the development and management of river basins in India. For this, Constitutional Provisions were analysed, especially with respect to managing inter-state water sharing and water-related conflicts.

A systematic review of existing scientific literature on the application of water accounting for water management in Indian river basins was undertaken in order to assess the methods adopted, the purpose of such studies and whether the findings were useful to address water management challenges at the basin scale. This process was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram proposed by Moher *et al*. (2009).

The use of a systematic review as a methodological approach increases the capability of researchers to find published studies on a given topic. Thus, the chosen approach is more efficient to identify various water accounting approaches in India than randomly taking online information or reaching out to the water management authorities or researchers individually, which usually has a low rate of response. All the papers cited and discussed in this article were identified through the systematic literature review. Since the review followed a systematic and standard approach to scan relevant scientific literature, the resulting analysis can lead to a more complete overview of existing approaches to water accounting in India.

For the systematic review, first of all, articles were identified using Clarivate Analytics 'Web of Science Core Collection' and Elsevier's 'ScienceDirect' search engines and other selected sources which included the International Water Management database and Hydrology and Earth System Sciences (HESS) discussions. The searches were run with the phrase 'Water Resource Accounting/ River Basin Water Accounting' for the articles published during the last 25 years (1995–2019). Overall, the search yielded 2,292 results. Following the screening and the eligibility process, 19 articles (including research reports and books) were considered for review, which were shortlisted based on their specificity to India, covering water accounting aspects at the basin or sub-basin scale, and after removal of papers that were common to the searches. Although the authors used two of the most established and commonly used engines for searching scientific articles, there is a possibility that some of the works might not have appeared as not all journals (but most of them) are indexed in these two engines. The procedure followed for the systematic review is presented in Figure 1.

To develop a more nuanced understanding of the acceptability of water accounting approach for making better policy decisions with respect to addressing inter-state water conflicts and efficient water allocation, the first author attended a brainstorming session 'Addressing the ever-increasing legal complexities in water development and management' at the India Water Week 2019. The session included the participation of officers from the central and state government water institutions and departments, public and private research organisations, prominent techno-legal experts on water, and representatives of the civil society organisations. During the session, the first author requested the session panelists to comment on the importance of water accounting for deciding on the water allocation between the riparian states sharing a river basin. Four of the nine panel members shared their views which were utilised to construct a narrative on inter-state water conflicts and the potential role of water accounting in addressing them through providing proper estimates on water availability and use and better allocation of water resources among the riparian states. These are discussed in the section 'Gaps in water accounting approaches for water management at the river basin scale'.

Water resources management and policy support for water accounting

As per Entry 17, List II, Seventh Schedule, Article 246 of the Indian Constitution, the 28 Indian states have full control over water resources within their jurisdiction (Government of India, 2015). However, the states' rights are subject to any law enforced by Parliament regarding the regulation and development of inter-state (transboundary) rivers (as per Entry 56, List I, Seventh Schedule, Article 246 and Article 262 of the Indian Constitution). In fact, Parliament can develop laws relating to inter-state rivers which can be enforced at the national level. River Boards Act, 1956 and the Inter-State River Water Disputes Act, 1956 are two such laws formulated at the national level. Thus, though water is primarily a state (provincial) subject, the central (national) government has a say when it comes to inter-state river basins.

The first National Water Policy of India was formulated in 1987 (Government of India, 1987a). Subsequently, it was revised in 2002 (Government of India, 2002) and then again in 2012 (Government of India, 2012). As per the constitutional rights granted to Indian states, they are free to formulate their own water policy but it has to be in sync with the overall aims and objectives as envisioned in the policy at the national level. Presently, at least 14 states in India have their own water policy. These include Andhra Pradesh (2008), Assam (2007), Goa (2000), Himachal Pradesh (2005, 2013), Karnataka (2002), Kerala (2008), Madhya Pradesh (2003), Maharashtra (2003), Meghalaya (2019), Odisha (2007), Punjab (1997, 2008), Rajasthan (1999, 2010), Tamil Nadu (1994) and Uttar Pradesh (1999)[3]. Since the National Water Policy is the overarching one, importance given to water accounting for water management in all the three versions of it has been analysed.

The National Water Policy 1987, without making any direct reference to the importance of water accounting, called for establishing a standardised national information system with a network of data banks and databases (Government of India, 1987a). This was to be achieved by integrating and

[3] Figures in parenthesis indicate the year in which the policy was adopted. Any subsequent figure within the same parenthesis indicates the year in which the policy was revised. State of Andhra Pradesh was bifurcated into Telangana and Andhra Pradesh in the year 2014.

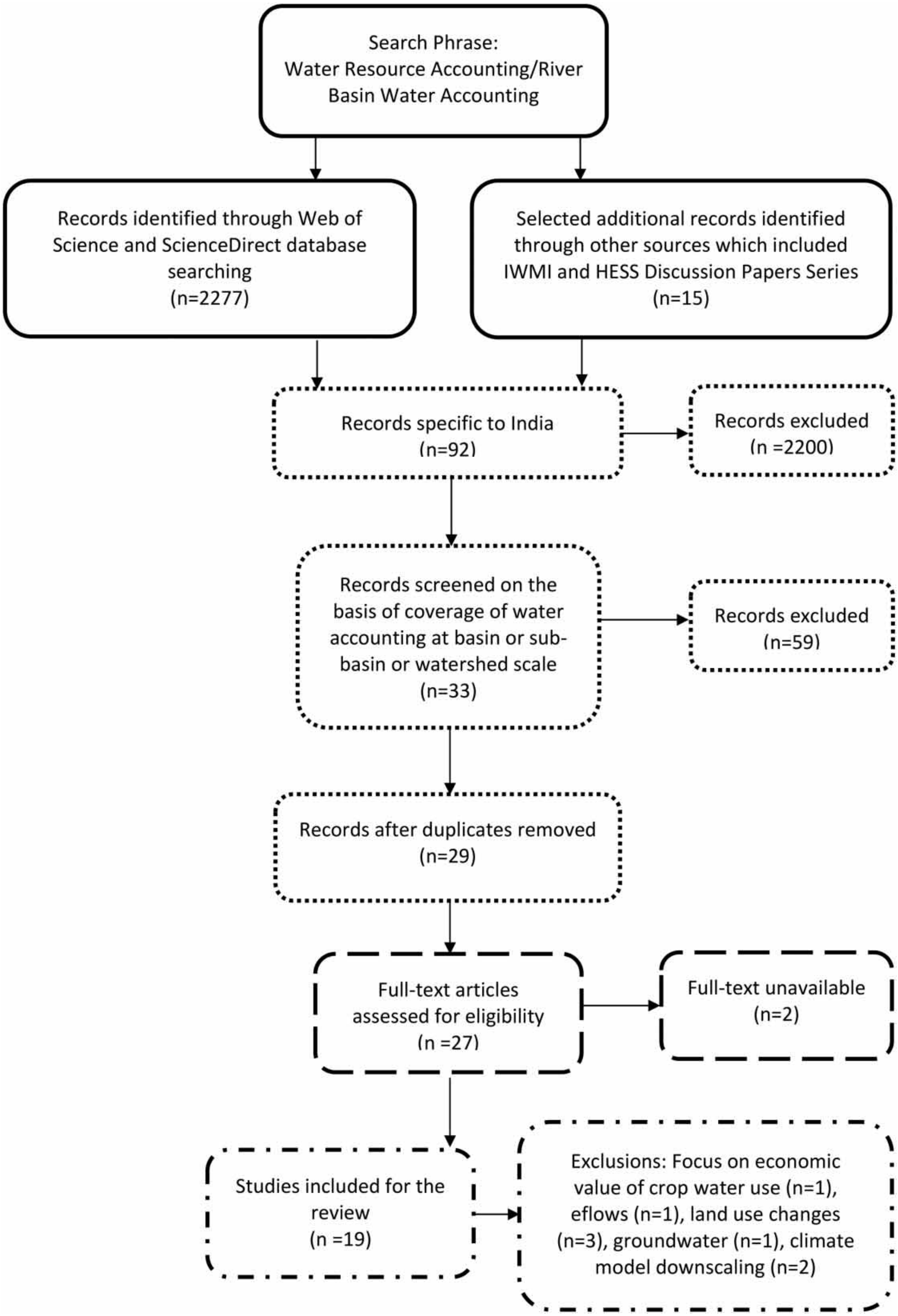

Fig. 1. Shortlisted articles following the systematic review process (based on Moher *et al.,* 2009). *Note*: Actions listed in boxes with solid lines indicate an identification process, in boxes with round dots screening process, in boxes with long dash eligibility process and in boxes with dash-dot final selection process.

strengthening the existing central and state level agencies and improving the quality of data sets and the processing capabilities. The 1987 policy highlighted that the information system should aim for proper data sets on water availability and actual water use (sector-wise consumptive use), and also include comprehensive and reasonably reliable projections of future water demand for diverse purposes. Further, the policy called for undertaking water resource planning for a hydrological unit such as a drainage basin or for a sub-basin with the help of organisations to be established for the same. To decide on the water allocation for various sectors, the first priority was given to drinking water, followed by (and in this order) irrigation, hydro-power, navigation, industrial and other uses. Thus, the policy was clear on the need for considering a proper hydrological unit, having a reliable information system on water availability and consumptive water uses, agencies for planning and management of river basins, and priorities of water allocation.

For the standardised national information system, the National Water Policy 2002 stressed the need for using the advances made in information technology to promote the exchange of data among various agencies (Government of India, 2002). The 2002 policy also pitched for planning and management of water resources at the basin or sub-basin level. For water allocation, the first priority remained drinking water, followed by irrigation, hydropower, ecology, agro-industries and non-agricultural industries and navigation and other uses. However, as was the case with the 1987 policy, the 2002 policy also did not make any direct reference to water accounting in relation to water planning and management.

The National Water Policy 2012, which is more comprehensive in terms of its approach to addressing the present water issues, clearly acknowledged the need for undertaking water balance and water accounting studies to improve water use efficiency at the basin scale (Government of India, 2012). For this, the establishment of institutional arrangements for each river basin to collect and synthesise data on a regular basis was proposed. Such data sets include rainfall, river flows, irrigated area (by crops and by source) and utilisation of surface water and groundwater for various uses. Also, the 2012 policy recommended publishing water accounts and water budgets every year for each river basin. Further, for evolving mechanisms to promote efficient use of water at the basin/sub-basin level, the policy proposed for the establishment of a proper institutional structure. In terms of water allocation, the policy provided first priority to safe water for drinking and sanitation, followed by allocation for other basic domestic needs (including for livestock), for achieving food security, for supporting sustenance agriculture and for minimum ecosystem needs. Thus, the 2012 policy made a clear shift towards addressing the social, economic and environmental water demands and suggested the use of water accounting and water balance to assess the sectoral allocation and promote efficient use of water (wherever necessary) to meet the growing water demand.

In summary, at the National Water Policy level, a trend can be observed from a water-quantity data set focus in 1987 to a broader consideration of improving water use efficiency and judicious allocation of water resources using the water accounting studies in 2012. In addition, with the inclusion of minimum ecosystem needs in 2012, the policies reflect an increasing complexity in the prioritisation of water allocation.

Evolution of water accounting approaches in India

Various scholars and institutions have been working on proposing water accounting approaches for water management in India. An attempt to develop and formalise water accounting standards for tracking water depletion (actually consumed or lost to natural sinks such as to saline groundwater or made unusable due to poor quality) within water basins in India was made by Molden (1997). The focus was to analyse the productivity of applied water in irrigated agriculture to support the identification of opportunities for increasing water productivity and improving the rationale for the allocation of water among users. The water accounting framework by Molden (1997) was at three different levels, i.e., irrigation field, irrigation system and basin. The methodology suggested for each of these levels was based on the water balance approach which considers water inflows, water outflows and storage changes in the selected unit. However, the framework was applied to prepare water accounts only for the irrigation field and the irrigation system (of Bhakra) in a sub-basin of the Indus river and suggestions were made to identify opportunities for water savings and increasing water productivity for wheat and cotton crops. Thus, the methodology was not used for estimating water account at the river basin scale.

Batchelor *et al*. (2003) used Molden's (1997) approach to estimate the water account at the watershed scale in India to assess the status of water resources in the watersheds and identify resource management practices that should be promoted in such watersheds. The prepared water accounts were used to highlight the flaws in the design of watershed management projects, including the role of defective watershed management planning in increasing the upstream–downstream inequity in water availability. The underlying premise for their approach was to generate data and information on the current status of water resources and trends in water demand and water use using the water balance to successfully manage water. However, no comprehensive assessment of the consumptive use of water (actual usage) across sectors was made. Nevertheless, the study further advanced Molden's (1997) work on assessing water accounts at the irrigation system level to the watershed scale.

The first real attempt to prepare water accounting at the basin scale in India was made by Kumar & Singh (2001). Their approach involved assessment of the basin-wide annual water availability (annual surface water flows and renewable groundwater); quantification of the current uses of water within and outside the basin (domestic, agricultural, industrial and ecosystem uses); and examination of the implications of the current water diversions and use on the sustainability of hydrological systems (aquifers and surface water flows), environment and socio-economic development. For crop water use, their approach considered both blue and green crop water demands. For preparing the water account, mainly blue water (part of precipitation which is available as runoff and gross groundwater recharge including that from irrigation return flows) was considered. Based on the prepared water account for the Sabarmati river basin, Kumar & Singh (2001) suggested an integrated approach to water resources development and conjunctive use and management of both surface water and groundwater. One of the important outputs of their research was the development and demonstration of the methodology for estimating actual consumptive uses of water in different sectors.

Although not a perfect water account, Amarasinghe *et al.* (2004) attempted to prepare water balance for river basins in India. Their main objective was to highlight the variation in water supply and water demand across 19 major river basins in India and assess whether they are water-scarce (physical or economic terms) and are food (crop) surplus or deficit basins[4]. Further, Amarasinghe *et al.* (2004) used water balance to identify factors influencing future water supply and demand. These factors include spatial

[4] Physical scarcity of water is experienced when the annual renewable water resources are insufficient to meet water needs of all sectors, whereas in economic water scarcity, there are adequate water resources to meet the water needs, but inadequate economic, financial and skilled human resources to tap the water resources. A basin is considered food surplus if the total food production outstrips the demand and is food deficit if demand is more than the total food production (Amarasinghe *et al.*, 2004).

variation and growth of the population and domestic water demand; urbanisation and income-related changes in dietary preferences; growth in crop yield, cropping intensity and groundwater use; and growth in industrial and environmental water demand. The water balance prepared by Amarasinghe *et al.* (2004) used the Central Water Commission estimates (CWC, 2002) of basin-wise annual renewable water availability (prepared using mass balance concept) and National Planning Commission of India (Government of India, 1999) estimates for domestic sector and industrial withdrawals, which themselves were based on some assumptions. For instance, in the absence of water supply and actual water consumption data, the CWC assessment assumed that 15% of the water demand in the domestic and livestock sector is actually consumed. For industries, water consumption is fixed (arbitrarily) at 50% of the domestic demand. Thus, although their study provided water balance for river basins in India, it failed to reflect on the ground reality with regard to the actual water supply and water consumption in the basins. Following the methodology of Molden (1997), Venot *et al*. (2008) too prepared water accounting for the Krishna basin and used a water balance model for highlighting the downstream impact of water resources development in the upstream part of the basin. However, for the estimation of consumptive water use in domestic and industrial sectors, they did not consider actual return flows and based their estimates on considering an arbitrarily high water use efficiency of 70%. This would have resulted in an overestimation of the actual water use component.

By the mid-2000s, the use of hydrological models for estimating water accounts and water balance started to gain momentum. Such models made use of available data sets on water withdrawals or water supply with the public agencies and spatial data sets on climate, runoff, drainage, land use, etc., to predict the impact of climate variability and increased anthropogenic pressures (mainly water withdrawals) on the runoff availability. Some such studies were undertaken for the Krishna river basin (Bouwer *et al*., 2006; Bharati *et al*., 2009) and Ganges river basin (Cai & Sharma, 2010; Eastham *et al*., 2010; Sulser *et al*., 2010).

Kumar (2010) made a major improvement in preparing basin water accounting by considering both green (part of precipitation which is available as soil moisture for crop production) and blue water while analysing water accounts of Narmada river basin. The earlier approaches mainly focused on preparing water accounting for blue water. Kumar (2010) based on its findings argued that green water should be given sufficient importance while analysing the water account as large parts of river basins in India are under rainfed agriculture and thus contributing significantly to agricultural income and economy. Karimi *et al*. (2012) too prepared water accounting considering both green and blue water for the Indus river basin using primarily remote sensing-derived estimates of land use, land cover, rainfall, evaporation, transpiration, interception and biomass production (an approach called WA plus).

The assessments considering both green and blue water are important from the viewpoint of framing water allocation strategies as they help in determining the precise quantum of water that needs to be applied (blue water) in addition to the soil moisture (green water). Further, it provides decision-makers with options to frame policies for improving water productivity in both rainfed and irrigated agriculture.

Nevertheless, one of the major limitations of assessments using the remote sensing-derived estimates is the constraint in ground-truthing global and spatial (remote sensing) data sets for the basin area or region of assessment. However, the situation concerning hydrological data availability and their reliability has improved remarkably over the past 10–15 years in India. After the World Bank supported Hydrology Project (initiated in 1995), most of the historical data related to meteorology, hydrology, reservoir operations, water quality and groundwater are digitalised in many states through the establishment of Water Data Centres (WDC). Before digitalisation, the data sets are cleaned (to remove outliers) and checked for their integrity and consistency (to make them usable). Presently, nine states in India, including Andhra Pradesh, Chhattisgarh, Gujarat, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha and Tamil Nadu, have fully operational WDC. Nevertheless, data on consumptive use of water in various sectors remain an issue as presently they are not prepared at the national or state level.

With the improvement in availability and accessibility of long-term actual data sets on the climatic parameters (rainfall, evaporation, etc.), streamflow and sediments, the results from hydrological modelling have improved. Some such works have been undertaken in the Narmada river basin (James *et al.*, 2015) and the Yamuna river basin (Himanshu *et al.*, 2017). Nevertheless, the spatial data on land use and land changes accessed from the open-source global platforms, which is required by most of the hydrological models, are continued to be used with constraints of ground-truthing them. Of late, attempts have been made to prepare water accounts by actual assessment of the total inflows (pristine flows and groundwater recharge) and the consumptive water demand across the water use sectors in some basins including Warna (sub-basin of Krishna) (Kumar *et al.*, 2019), Luni (Kumar *et al.*, 2019) and for a city in Ganga basin (Bassi *et al.*, 2019). For these, data sets on the observed volume of streamflows, water releases from the canals, amount of water lifted from the rivers, storage changes in the reservoir, evaporation from the water bodies surface, the wastewater return flows to the surface water bodies, and the estimated actual water use across sectors (domestic, irrigation and industrial) were utilised.

To sum up, the basic premise for the development of water accounting approaches for India in the past and their application is to improve water use efficiency whether at the irrigation field, irrigation system, watershed, sub-basin or basin levels (Molden, 1997; Kumar & Singh, 2001; Cai & Sharma, 2010). Some other studies have used water accounts to highlight the intra-basin variation in water availability and demand (Batchelor *et al.*, 2003; Amarasinghe *et al.*, 2004; Kumar *et al.*, 2019). In terms of advancements in the methodological approach over the years, equal importance has been given to both green and blue water (Kumar, 2010) and there has been increasing use of satellite-derived data sets for preparing water accounts at the river basin scale (Eastham *et al.*, 2010; Sulser *et al.*, 2010; Karimi *et al.*, 2012).

Gaps in water accounting approaches for water management at the river basin scale

No common framework for water accounting

For water professionals to begin discussing management interventions for improving basin-wide management of water, analysing basin water accounts is the first step – to know how much of the available water gets consumed in various sectors, and the quality of the water used and also available for reuse. From the review of the existing studies on water accounting for river basins in India, we observe that no common framework is followed for preparing water accounts. For instance, in certain cases, water accounts considering only blue water have been prepared, and in some others, both green and blue water has been considered. The former approach is usually followed as it is difficult to estimate or obtain data on the usage of soil moisture, especially for the natural vegetation (Kumar *et al.*, 2019). Ideally, it is important to account for both blue and green water to manage the growing water demand for food. Specifically for green water, Kumar (2010) has emphasised that it needs to be recognised as an important component of the hydrological system and that it contributes significantly to water economy.

One such framework which is based on the principles of integrated water resources management (IWRM)[5] was prepared and adopted by the United Nations (UN) in 2007 with the objective of standardising concepts and methods in water accounting (United Nations, 2012). The framework, 'System of Environmental-Economic Accounting for Water (SEEA-Water)' is composed of five sub-accounts. The first is the physical flow account which records the water abstraction for various social and economic activities, water flows within the economy and the return flows (including pollutants) to the environment. The second is the physical asset account that captures the storage changes by measuring the water stock at the beginning and the end of the accounting period, and records the changes in the stocks that occur during the period. The third is the economic account which pertains to flows related to water products and information on the costs associated with water use, water supply and water-related financing. The fourth is the quality account that describes the stock of water in terms of its quality but without having indicators to explain the reasons for the changes in quality. The fifth account is on the valuation of water resources. For the first three accounts, there is considerable practical experience with most of the countries and an agreement over the concepts, definitions and classifications related to water, whereas the fourth and the fifth accounts are more experimental and for which not enough experience exists at the country level.

The SEEA-Water enables the organisation of the hydrological and economic information in a coherent and consistent manner and allows for the analysis of the contribution of water to the economy and of the impact of the economy on water resources. By 2017, at least 25 countries have either compiled and/or published water accounts using the SEEA-Water framework (or its adapted version) and 46 others are planning to compile them in the near future (United Nations, 2018). However, the use of SEEA-Water is still not planned in India, presumably due to lack of data sets pertaining to consumptive water uses in various sectors and the economic valuation aspects. Still, it is possible to prepare the physical flow and assets account for the river basins in India as the required data sets are available.

Reliability of data sets

There is a growing tendency to use remote sensing-derived global data sets which are available at a much coarser scale for preparing water accounts (Cai & Sharma, 2010; Eastham *et al*., 2010; Sulser *et al*., 2010; Karimi *et al*., 2012). While the approach may be useful for the average conditions in a river basin, it fails to capture the regional variation in water availability, demand and use within the basin. For instance, rainfall itself varies from less than 100 mm to more than 1,500 mm in the Indus basin (Karimi *et al*., 2012). Therefore, it is important to capture these regional variations while preparing the water accounts as it would help in framing proper regional water allocation strategies within a river basin. With the ongoing innovations in remote sensing technology, it is expected that in the near future the spatial data will be more useful for water resources management, especially in the regions with poor monitoring infrastructure (McCabe *et al*., 2017; Sheffield *et al*., 2018).

Various national level agencies in India have made significant advancements in data collection, their validation, and monitoring, especially on climatic parameters, streamflow, groundwater, reservoir storage and water quality. Central Water Commission (CWC), a technical agency for assessment of

[5] The IWRM promotes the coordinated development and management of water, land and related resources in order to maximise economic and social welfare in an equitable manner, without compromising the sustainability of vital ecosystems (United Nations, 2012).

surface water resources under the Ministry of Jal Shakti (MoJS), Government of India (GoI), is maintaining 938 hydro-meteorological monitoring sites across river basins in India (CWC, 2018). As per the World Meteorological Organisation criteria (WMO), depending upon the terrain, a streamflow station is necessary for every 1,000 sq. km in mountainous areas and 20,000 sq. km in arid areas (World Meteorological Organisation, 2008). Overall, for river basins in India, each stream gauging station installed by the CWC covers about 3,276 sq. km (Table 1). Thus, the density of streamflow monitoring stations in some of the basins having mostly semi-arid and arid conditions, such as WFR of Kutchh and Saurashtra, and Krishna, is substantially better than the WMO norms.

Similarly, Central Ground Water Board (CGWB), a technical agency for assessment of groundwater resources under MoJS, is monitoring 23,196 groundwater observation wells (Figure 2) (Central Ground Water Board, 2018); and, the Indian Meteorological Department (IMD) under the Ministry of Earth Sciences, GoI, maintains 1,351 automatic rain gauges and another 575 automatic weather stations across the country (Source: IMD, http://aws.imd.gov.in/). Again referring to the WMO criteria, a recording rainfall station (used for hourly measurement of rainfall as is done by automatic rain gauges) is recommended for 2,500 sq. km in mountainous areas and 100,000 sq. km in arid areas (WMO,

Table 1. Coverage of hydro-meteorological monitoring sites across river basins in India.

Sl. no.	Name of basin[a]	Basin drainage area (in 1,000 sq. km)	Average area covered per site monitoring streamflow (in sq. km)
1	West flowing rivers (WFR) from Tapi to Tadri	9.41	362
2	Sabarmati	21.67	1,667
3	Subernarekha	29.20	2,433
4	WFR from Tadri to Kanyakumari	34.25	1,370
5	Mahi	34.84	2,680
6	Minor rivers draining Myanmar and Bangladesh	36.20	7,240
7	East flowing rivers (EFR) between Mahanadi and Pennar	41.68	3,206
8	Brahmani-Baitarni	51.82	3,702
9	Pennar	55.21	6,902
10	WFR of Kutchh and Saurashtra	59.18	4,227
11	Tapi	65.15	5,429
12	EFR between Pennar and Kanyakumari	72.82	4,284
13	Cauvery	81.16	2,387
14	Narmada	98.80	3,800
15	Mahanadi	141.59	3,293
16	Krishna	258.95	6,022
17	Godavari	312.81	4,285
18	Indus (India part)	321.29	12,357
19	Ganga/Brahmaputra/Meghna/Barak (India part)	1,097.59	2,466
	Overall	**2,823.61**	**3,276**

Source: Authors' analysis based on data by CWC (2018).
[a]In total, India has 20 major river basins. One of them, i.e., Area of Inland Drainage in Rajasthan, is not considered as it has negligible water resources potential.

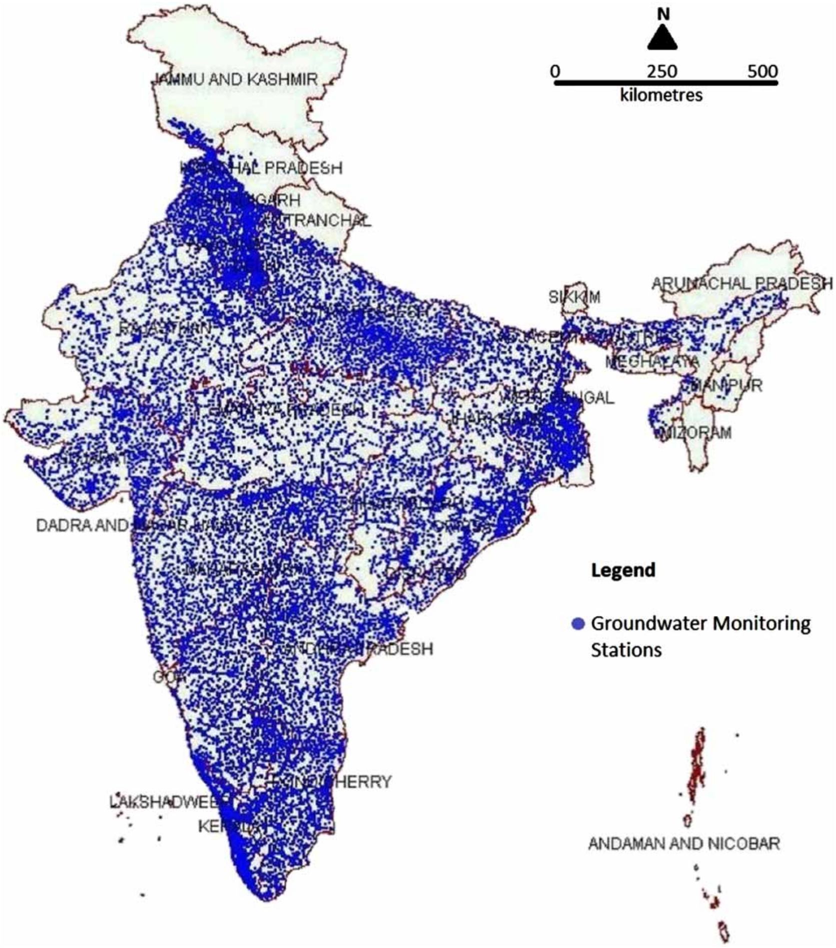

Fig. 2. Spread of CGWB monitored groundwater observations wells across India. *Source*: CGWB, (2018).

2008). Overall, in India, each automatic rain gauge installed by the IMD covers an area of about 2,090 sq. km. Further, various state agencies also maintain such data sets for the river basins within their jurisdiction. Thus, a large quantum of water resource data sets is available which can at least be used for preparing proper inflows and storage change components of the water accounts.

One of the major concerns that remains is the availability of reliable and long-term data sets on water quality and sector-wise (agriculture, industry and domestic) consumptive water use (Molden, 1997; Karimi *et al*., 2012, 2013). Also, often the same data set is collected by different government agencies and cannot be used for proper trend analysis. For instance, water quality data are collected and analysed by the Central Pollution Control Board (CPCB) and also by the CWC. However, the water quality parameters even for the same river or a water body are incomparable due to different monitoring locations and also the different purposes for which they are collected. While CPCB water quality monitoring stations are close to the drain outfall in the river, CWC monitoring stations are mostly in the stretch where there is less anthropogenic pressure on the river. Thus, sometimes it leads to confusion as data sets even for the same observed water quality parameter for a stretch of the river with the national and state agencies do not match.

Focus on the agriculture sector

Studies on water accounting in India have mostly focused on highlighting the inefficient use of water in agriculture and made suggestions for improving farm-level water use efficiency in agriculture as an option for water resources management. While it is true that agriculture is the major consumer of water and about 75% of the total water withdrawals are for agricultural use, with the growing economy and urbanisation, demand for water from the domestic sector and industries (including for power generation) is on the rise in India.

According to the National Commission for Integrated Water Resources Development (1999) estimates, overall water demand in India will increase from 710 BCM in 2010 to 1,180 BCM by 2050 (an increase of 67%). Among sectors, by 2050, water demand for power generation, inland navigation and maintaining aquatic ecosystems will increase three-fold, whereas for industries and domestic uses it will be more than double (Figure 3). Although the estimates on water demand are dated and need to be updated soon, it is important that the preparation of water accounts should take a holistic approach and should highlight the inefficiency in water use in sectors other than agriculture and identify and assess water re-use options at local or district scale so that effective resource management strategies can be drawn to address water stress across sectors.

Further, computing specific indicators using water accounts will be beneficial for deriving water use efficiency improvement strategies (UN, 2012). For instance, indicators such as estimate on water productivity (in agriculture and industries), the system losses (due to leakages, illegal water connections and faulty water meters), extent of water reuse, and water prices can influence water use efficiency substantially.

One concern that remains is the environmental flows requirement of river basins in India. The environmental flow assessment studies have been undertaken only for a few river stretches in selected basins, mainly for the Upper Ganga basin (O'Keeffe *et al.*, 2012; Tare *et al.*, 2017), and with limited scalability of the methodological approaches (Jain & Kumar, 2014). Although such assessments will

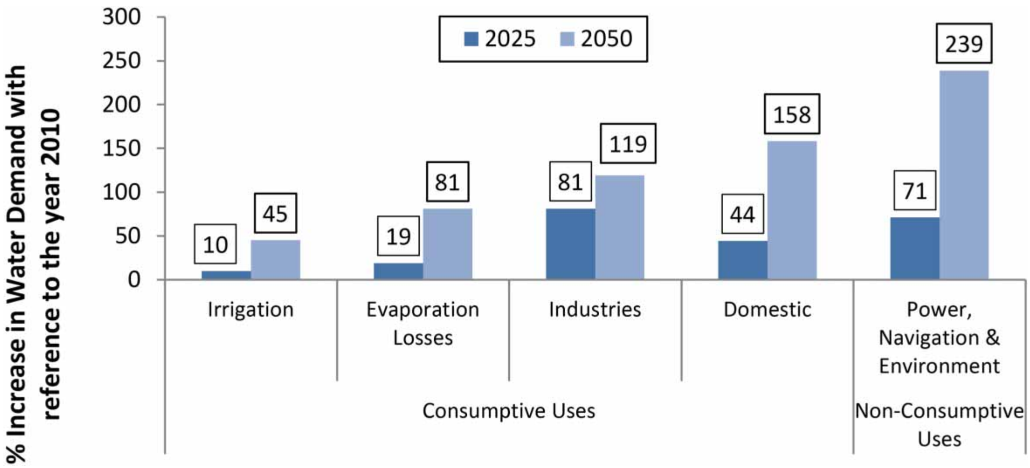

Fig. 3. Projected per cent increase in water demand in India by 2025 and 2050. *Source*: Authors' analysis using National Commission for Integrated Water Resources Development estimates (Government of India, 1999).

require substantial investments both in terms of resources and knowledge, they are needed to make water allocation (based on water accounts) sustainable in the future.

Improving water allocation

Overall, the per capita annual availability of water in India was less than 1,500 cu m in 2017. As per the Falkenmark Water Stress Indicator (Falkenmark *et al.*, 1989), at the national level, there is already water stress with per capita annual water availability below 1,700 cu m. Although per capita water availability remains high (above 2,000 cu m per annum) in some water-rich basins such as the Brahmaputra, Meghna, Narmada, and Brahmani and Baitarani, it is substantially low (below 1,000 cu m) in some other basins such as the Sabarmati, Pennar, Cauvery, Tapi, Mahi, Krishna and Subernekha (Figure 4).

The increase in water stress in some river basins (assuming same interannual water use per capita and per unit of agricultural and industrial production) is due to the combined effect of high temporal variability in rainfall and increasing quantum of production in these sectors. For instance, average annual streamflow at an upstream gauging site in the Krishna river basin is about 30,000 MCM. However, during wet years when the rainfall is above 1,400 mm it increases to more than 45,000 MCM, and during years of low rainfall (less than 850 mm) it falls below 6,000 MCM (Institute for Resource Analysis and Policy, 2016). With the population in the Krishna river basin expected to increase by about 20% by 2025 (in comparison to the year 2010), the per capita water availability will reduce substantially during years of low rainfall. For such basins, a systematic allocation of water considering the imbalances in supply and demand is very crucial. However, various reviewed studies on water accounting have not used their results to suggest a mechanism for the proper allocation of water resources for use in different sectors. One reason for this is the lack of

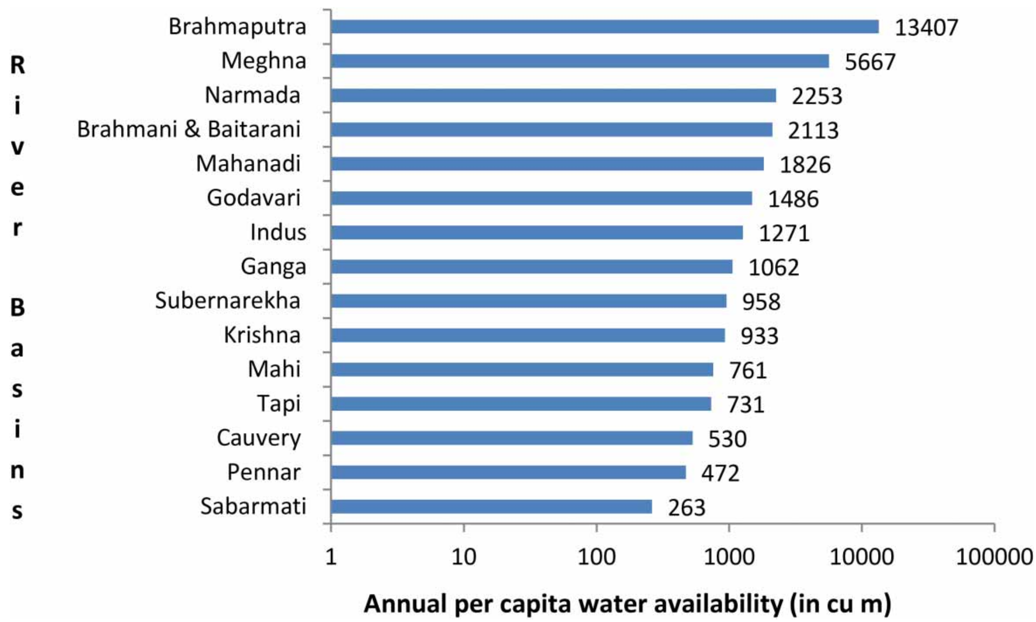

Fig. 4. Per capita water availability across different river basins in India. *Source*: Author's analysis based on data presented in the Government of India (GoI), (2018).

information on the average economic value of water use in different sectors, and the marginal returns that can be generated from reallocation of water between sectors.

SEEW-Water framework of UN (2012) highlights that water accounting can play an important role in analysing the social and economic benefits of current water allocation and alternative allocations. For instance, the latest NWP 2012 of India suggests that water for productive uses, such as for commercial agriculture and industries (except for supporting sustenance agriculture and minimum eco-system needs), should be allocated and priced on economic principles to avoid its wastage and ensure its efficient utilisation. To achieve this, various water optimisation models[6] are available which can estimate the potential gains from reallocating water to the highest value users. The database required for such models can be derived from various output tables generated by the water accounts.

Addressing inter-state water conflicts

The studies on water accounting have been silent on their usefulness for addressing transboundary water conflict in India.

River Boards Act, 1956 and the Inter-State River Water Disputes Act, 1956 (amended in 1980 and in 2019) are the two legislations enacted by the Parliament of India to regulate, develop and manage transboundary rivers. However, to date, no single river board has been constituted due to the fact that establishing it requires a request being made by the state government to central government and such a request has never been made by any of the riparian states. The probable reason is that states want to keep full control of the water resources within their administrative jurisdiction and fear that any arbitration by the central government supported mechanism will adversely affect their existing water share.

Thus, most of the water planning and development for inter-state river basins is undertaken within administrative boundaries of the state rather than by considering the hydrological unit, i.e., the whole river basin. This approach has led to disputes among states as most river basins are shared by several states and water demand for meeting domestic, industrial, agricultural and environmental needs within each riparian state has gone up remarkably. The dispute over water sharing becomes more prominent during years of low rainfall when the overall water availability reduces.

To address water conflict, various tribunals have been formed by the national government using the powers bestowed upon it in the Inter-State River Water Disputes Act, 1956. However, such tribunals have taken a long time in settling water disputes, and whatever decision has been arrived at, it has been contested by states on one or other accounts (Table 2). The main resistance of the riparian states to the tribunal's decision is due to improper estimates on the basin water availability (mostly based on old data sets) and on the sectoral water demand in the basin leading to faulty water allocations. This, together with general centre-state conflicts and political issues (because of different political parties ruling the government at the centre and state), further compounds the problem (Richards & Singh, 2002). This is where preparing a proper water account using the latest data sets and sharing such account regularly between the riparian states in a transparent manner can play an important role, as it provides near-accurate estimates of basin-level water availability and water uses. Further, the know-how of water availability and its use will help states to plan sectoral water allocation within their territory in a proper manner.

[6] Such models estimate marginal values for water that are based on an optimum allocation of water and the corresponding reconfiguration of economic activity and prices (UN, 2012). The economic activity that generates highest marginal return is given priority in water allocation.

Table 2. Tribunals formed to address state-level transboundary water conflicts in major river basins of India.

Name of the tribunal	River basin	Riparian and beneficiary states and union territories	Year of formation	Most recent status
Godavari water disputes tribunal	Godavari	Maharashtra, Andhra Pradesh[a], Odisha, Madhya Pradesh[b], and Karnataka	1969	Decision on final water allocation was made in July 1980
Krishna water disputes tribunal-I	Krishna	Andhra Pradesh, Maharashtra, Odisha, Madhya Pradesh and Karnataka	1969	Decision on final water allocation was made in May 1976 with a condition that the decision of the tribunal can be reviewed after May 2001
Krishna water disputes tribunal-II		Andhra Pradesh, Maharashtra, Telangana and Karnataka	2004	The final decision of the tribunal (given in November 2013) has been delayed by the highest court of India (Supreme Court) after the formation of the state of Telangana in 2014. The new state has demanded to revisit the decision as it was not party to decisions taken by either of the Krishna basin tribunals
Narmada water disputes tribunal	Narmada	Madhya Pradesh, Gujarat, Maharashtra and Rajasthan	1969	Decision on final water allocation was made in December 1979
Ravi-Beas water disputes tribunal	Indus	Jammu and Kashmir, Himachal Pradesh, Punjab, Rajasthan, Haryana and Chandigarh	1986	Decision on final water allocations is yet to be made
Cauvery water disputes tribunal	Cauvery	Tamil Nadu, Karnataka, Kerala and Puducherry	1990	After a series of confrontations and appeals concerning water sharing among the riparian states, final decision on water allocation was made in February 2018 after Supreme Court's (India's highest court) intervention

Source: Based on Government of India (1979a, 1979b, 1987b); Sharma (2016) and The Supreme Court of India (2018).
[a] In 2014, a new state of Telangana was carved out from Andhra Pradesh.
[b] In 2000, a new state of Chhattisgarh was carved out from Madhya Pradesh.

Conclusion and policy implications

Based on the assessment of the Indian water policies and the provisions in the Indian constitution, it is clear that the 2012 National Water Policy has made a clear shift towards addressing the social, economic and environmental water demands and suggested use of water accounting and water balance to assess the sectoral allocation and promote efficient use of water (wherever necessary) to meet the growing water demand. However, the water allocation across sectors should also consider the economic valuation of the benefits generated from the use of the water (Kumar, 2010).

In this study, we carried out a systematic review of literature on water accounting for river basins in India. Out of the 2,292 results, those articles (including research reports and books) were considered for review that covered water accounting aspects at the basin, sub-basin or watershed scale in India. The review indicates that water accounting approaches have been evolving in India. With the availability of data sets and information from the increased number of hydro-meteorological gauging stations, the estimate on the resource availability component of the water account has improved. However, the problem remains with estimating consumptive water use across sectors.

Some other gaps were identified in the water accounting approach in terms of its suitability to address basin-level water management challenges in India. These include lack of standard methodologies for assessing water accounts, limited reliability of the water quality data sets produced from monitoring systems on the ground and satellite-derived data sets on water use, and emphasis on preparing water accounts for agriculture sector without considering the other sectors of water use.

With the advancement of water accounting concepts and methodologies for estimating them globally, India needs to move towards adopting a framework of its own and prepare water accounts for all major river basins. Such accounts need to be updated on a regular basis which can support decisions to allocate water efficiently and to address inter-state conflicts over sharing water more effectively.

Thus, water accounts can support planning for river basin management in India. However, for preparation of the basin scale water account on a regular basis and a management plan, formation of a basin-wide governance set-up having respect, engagement and trust of the riparian states is a necessity. Given the current conflict over water allocation among riparian states in several river basins, this will require a stepwise approach and mediation by the central water ministry or other appropriate institutions, for example, in the framework of projects carried out with international partners or funding agencies. Further, capacity building on using the existing tools developed globally to guide preparation of water accounts and for preparation of river basin management plans is desirable.

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Data availability statement

All relevant data are included in the paper or its Supplementary Information.

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