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WATER ACCOUNTING AT THE RIVER BASIN SCALE: A SYSTEMATIC REVIEW OF GLOBAL PRACTICES

Ranjit A. Todkar[1], Subhash T. Kombde[2]
[1]Research Scholar, Department of Economics-Autonomous, Shivaji University Kolhapur, Maharashtra, India, ranjittodkar923@gmail.com
[2]Professor, Department of Economics-Autonomous, Shivaji University Kolhapur, Maharashtra, India, skombde@gmail.com

ABSTRACT
Water accounting has been increasingly used to examine how water is available, used, and depleted within river basins, particularly under conditions of rising scarcity and competing demands. Over the past two decades, a growing body of literature has been applying water accounting at the river basin scale, although approaches have differed widely in methods, data sources, and objectives. In this context, the present study has undertaken a systematic review of global river basin–scale water accounting practices. The review has followed a structured methodology guided by the PRISMA framework. Peer-reviewed journal articles published between 2000 and 2024 have been identified from Scopus and Web of Science databases, and 33 studies have been selected through a multi-stage screening process. These studies have been classified based on accounting frameworks, data sources, regional focus, and thematic orientation. The findings have indicated that water accounting has been used mainly as a diagnostic tool to clarify basin-level water availability and consumption. While recent studies have been increasingly using remote sensing- based methods and standardized frameworks, their integration with economic analysis and policy decision making has remained limited. Overall, the review has suggested that stronger institutional linkages are needed to enhance the practical relevance of water accounting in river basin management.
Keywords: Water accounting; River basin management; Systematic review; Basin-scale water use; Remote sensing; Environmental-economic accounting; Water governance

1. INTRODUCTION
Growing pressure on freshwater resources has been placing river basins at the center of water management debates across the world. Rising population, expansion of irrigated agriculture, rapid urban growth, and increasing climate variability have been intensifying competition for water within shared river systems. Because surface water, groundwater, ecosystems, and human uses are closely connected within a basin, decisions taken at this scale often shape the long-term availability and sustainability of water resources (Molden, 1997; FAO, 2012).

In response to these challenges, water accounting has been developing as a way of organizing information on water availability, use, depletion, and return flows in a structured and transparent manner. Unlike simple water balance exercises, water accounting seeks to provide consistent descriptions of how water moves through a river basin and how it is consumed by different sectors over time (Molden & Sakthivadivel, 1999). Such information has been increasingly used to support allocation decisions, irrigation planning, drought management, and policy evaluation at the basin level (FAO, 2016).

Over the past two decades, a wide range of water accounting approaches has been proposed and applied across different regions. Many studies have focused on physical water flows, often using hydrological models or satellite-based estimates of evapotranspiration to quantify water depletion within river basins (Karimi et al., 2013; Bastiaanssen et al., 2014). At the same time, other studies have been attempting to link water accounting with economic and institutional dimensions, examining water productivity, efficiency, and governance arrangements (Perry, 2007; Young & Loomis, 2014). More recently, standardized frameworks such as the System of Environmental Economic Accounting for Water and the FAO's Water Accounting Plus framework are increasingly being applied in several basins to improve comparability and policy relevance (United Nations, 2012; FAO, 2016).

Despite this growing body of work, the literature on river basin water accounting remains scattered. Studies differ widely in terms of objectives, spatial resolution, data sources, and analytical focus. Some applications have been designed mainly for diagnostic purposes, while others have been aiming to directly inform planning and allocation decisions. As a result, comparing outcomes across basins or drawing broader lessons from individual case studies has often proved difficult (Perry et al., 2017; Karimi et al., 2021).

Existing review papers have addressed selected aspects of water accounting, such as irrigation performance, remote sensing methods, or specific accounting frameworks. However, a systematic synthesis that brings together global practices of water accounting at the river basin scale remains limited. In particular, there has been little effort to examine how different approaches are being applied across diverse physical and institutional contexts and how they are being used in practice for basin management (Molden et al., 2010; Karimi et al., 2013).

Against this background, the present study has undertaken a systematic review of global water accounting practices at the river basin scale. By examining peer-reviewed studies from different regions and methodological traditions, the paper seeks to clarify how water accounting has been conceptualized, what methods and data have been used, and for what purposes these practices have been applied.

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2. OBJECTIVES OF THE STUDY

The present study aims to systematically examine how water accounting has been applied at the river basin scale across different regions of the world. It seeks to identify the main conceptual frameworks and methodological approaches that have been used in basin-level water accounting and to examine the types of data and indicators that are commonly employed. At the same time, the study is intended to review the geographical spread and application contexts of these practices, with attention to the purposes for which water accounting has been used in planning, allocation, and management. By bringing together evidence from a wide range of studies, the review also aims to assess how water accounting has been supporting decision making at the basin level and where its practical limitations have been observed. Finally, the study intends to identify gaps in existing research and to highlight areas where further work is needed to improve the use of water accounting as a tool for river basin management.

3. METHODOLOGY OF THE REVIEW

The present study has adopted a systematic review methodology to examine global practices of water accounting at the river basin scale. The review process was designed to ensure transparency, consistency, and replicability, following the reporting logic of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. PRISMA was used as a guiding structure to document the identification, screening, eligibility assessment, and final inclusion of studies, while allowing flexibility appropriate to interdisciplinary water resources research.

3.1 Literature Search Strategy

The literature search was conducted using two major academic databases, Scopus and Web of Science, which provide comprehensive coverage of peer-reviewed journals in water resources, environmental science, and applied economics. The search covered studies published between 2000 and 2024, reflecting the period during which formal water accounting frameworks began to be developed and widely applied at the river basin scale. A combination of keywords related to water accounting and basin-level management was used, including water accounting, river basin, basin-scale water balance, environmental water accounting, and water management. Boolean operators were applied to refine the search and exclude unrelated fields. Only peer-reviewed journal articles and review papers published in English were considered. The initial database search returned 612 records.

3.2 Screening and Eligibility Assessment

The screening process was carried out in multiple stages in line with PRISMA recommendations. In the first stage, 112 duplicate records were identified and removed, resulting in 500 unique records. In the second stage, titles were screened to remove studies that were clearly outside the scope of the review, such as papers focusing solely on urban water supply, flood modelling, or engineering design without a basin-scale accounting perspective. This led to the exclusion of 278 records, leaving 222 studies for abstract screening.

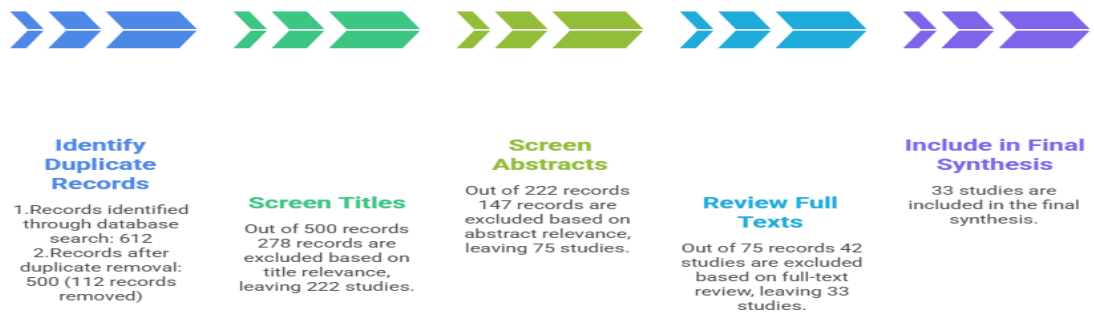
In the third stage, abstracts of the remaining studies were examined to assess their relevance to river basin water accounting. Studies were excluded at this stage if they focused only on plot-level irrigation performance, short-term hydrological simulations, or conceptual discussions without empirical application.

Following abstract screening, 147 records were excluded, and 75 studies were retained for full-text review. In the final stage, full texts of the selected studies were reviewed against the inclusion and exclusion criteria. Studies that did not apply water accounting explicitly at the river basin scale or lacked sufficient methodological detail were excluded. As a result, 42 studies were excluded at this stage, and 33 studies were included in the final synthesis.

3.3 Classification and Synthesis

The final set of studies was examined in detail and classified to support synthesis and comparison. Each study was grouped according to the type of water accounting framework used, the main data sources employed, the spatial scale of analysis, and the stated purpose of the accounting exercise. Based on this classification, the literature was organized into thematic categories such as physical water flow accounting, remote sensing-based accounting, economic and environmental accounting, and integrated basin management applications.

Infographic 1: PRISMA Screening Process for River Basin Water Accounting Studies



Summary tables were then prepared to present these classifications and to identify patterns, gaps, and emerging practices across regions.

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Table 1
Methodological Framework of the Systematic Review

Review Component	Description
Databases used	Scopus, Web of Science
Time period covered	2000-2024
Document types	Peer-reviewed journal articles and review papers
Language	English
Key search terms	Water accounting; river basin; basin-scale water balance; environmental water accounting; water management
Inclusion criteria	Studies applying water accounting at river basin scale with empirical analysis
Exclusion criteria	Studies limited to plot, project, or urban scale; purely conceptual papers
Screening process	Title and abstract screening followed by full-text review
Classification approach	Thematic grouping by framework, data source, and application purpose

4. SYSTEMATIC REVIEW OF GLOBAL WATER ACCOUNTING PRACTICES

The 33 studies included in the final review show that water accounting at the river basin scale has been practiced using a limited number of core frameworks, but applied in varied ways depending on regional context, data availability, and management objectives. While terminology differs across studies, most applications attempt to quantify water availability, use, depletion, and productivity within a defined basin boundary. Over time, the literature has gradually shifted from simple balance-based approaches toward more structured and standardized accounting systems.

4.1 Water Accounting Methods Practiced at the River Basin Scale

A close examination of the reviewed studies indicates four dominant accounting approaches. The earliest group of studies relies on conventional water balance methods, where inflows, outflows, and changes in storage are estimated using hydrological records. Examples include basin studies by Molden (1997), Perry (2007), and Ahmad et al. (2009), where accounting was primarily used to diagnose water availability and sectoral use.

A second and increasingly prominent group of studies applies remote sensing–based water accounting, particularly to estimate evapotranspiration and consumptive use. Karimi et al. (2013), Bastiaanssen et al. (2014), and Rebelo et al. (2017) demonstrate how satellite data can be used to generate spatially explicit basin accounts, especially in data-scarce regions.

A third group uses formalized accounting frameworks, most notably Water Accounting Plus (WA+) and SEEA-Water. WA+ has been applied in river basins such as the Indus, Nile, and Awash (Karimi et al., 2013; FAO, 2016; Droogers et al., 2017), focusing on depletion, availability, and productivity sheets. SEEA-Water applications, such as those discussed by United Nations (2012), Vardon et al. (2012), and Godfrey and Chalmers (2012), integrate physical water accounts with economic and institutional statistics.A smaller but growing set of studies adopts integrated basin accounting approaches, linking physical water flows with governance, allocation rules, or environmental objectives. Studies by Perry et al. (2017), Wheeler et al. (2020), and Grafton et al. (2018) fall into this category, emphasizing decision support rather than accounting alone.

Table 2
Water Accounting Methods and Key Studies Reviewed

Accounting Method	Key Authors (Year)	River Basin / Region	Main Focus
Conventional water balance	Molden (1997); Perry (2007); Ahmad et al. (2009)	Indus, Murray Darling	Availability and sectoral use
Remote sensing–based accounting	Karimi et al. (2013); Bastiaanssen et al. (2014); Rebelo et al. (2017)	Indus, Nile, Volta	Depletion and evapotranspiration
WA+ framework	Karimi et al. (2013); Droogers et al. (2017); FAO (2016)	Indus, Awash, Jordan	Basin diagnostics and productivity
SEEA-Water	UN (2012); Vardon et al. (2012); Godfrey & Chalmers (2012)	Australia, Europe	Physicaleconomic integration
Integrated basin accounting	Perry et al. (2017); Grafton et al. (2018); Wheeler et al. (2020)	Murray Darling	Allocation and governance

4.2 Regional Distribution of the Reviewed Studies

The reviewed literature is geographically uneven. Of the 33 studies, a large proportion focuses on water-stressed regions, particularly South Asia, the Middle East, and parts of Africa. This reflects the practical demand for accounting tools in basins facing allocation conflicts and scarcity. Fewer studies are found in humid regions, where accounting has been used mainly for environmental flow assessment or planning.

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Table 3
Regional Distribution of Reviewed River Basin Water Accounting Studies

Region	Number of Studies	Representative Authors
South Asia	9	Molden (1997); Karimi et al. (2013); Ahmad et al. (2009)
Middle East & North Africa	8	Droogers et al. (2017); Bastiaanssen et al. (2014)
Sub-Saharan Africa	6	Rebelo et al. (2017); FAO (2016)
Australia	5	Vardon et al. (2012); Wheeler et al. (2020)
Europe & North America	5	Perry et al. (2017); Grafton et al. (2018)
Total	**33**	

4.3 Thematic Classification of Water Accounting Studies

Beyond differences in geographical coverage and methodological tools, the reviewed literature shows clear variation in the thematic focus of river basin water accounting studies.

Table 4
Thematic Classification of River Basin Water Accounting Studies

Theme	Main Focus Area	Number of Studies	Representative Studies
Diagnostic basin accounting	Water availability, inflows, outflows, and depletion	8	Molden (1997); Perry (2007); Ahmad et al. (2009)
Irrigation and water productivity	Efficiency, crop water use, productivity indicators	9	Karimi et al. (2013); Bastiaanssen et al. (2014); Droogers et al. (2017)
Environmental flows and ecosystems	Allocation for ecosystems and river health	6	Grafton et al. (2018); Wheeler et al. (2020)
Policy and allocation support	Basin planning, allocation rules, governance	5	Perry et al. (2017); FAO (2016)
Economic and institutional integration	Linking water accounts with economic data	5	Vardon et al. (2012); United Nations (2012)
Total		**33**	

While all studies aim to account for water at the basin scale, they differ in what they prioritize, ranging from basic diagnostic assessments to more policy-oriented applications.

Based on the stated objectives, analytical focus, and outputs of the reviewed papers, the 33 studies were grouped into five major thematic categories. This classification helps to clarify how water accounting has been used in practice and where emphasis has been placed in existing research.

The largest share of studies focuses on irrigation and water productivity, reflecting the importance of agriculture in basin-level water use. Diagnostic accounting studies also remain prominent, particularly in basins where basic information on water availability is limited. In contrast, fewer studies explicitly integrate economic or institutional dimensions, indicating that while water accounting methods have advanced technically, their use in broader economic and governance analysis remains relatively limited.

4.4 Synthesis

Taken together, the reviewed studies show that river basin water accounting has evolved from descriptive balance exercises into more structured tools aimed at supporting management and policy. However, applications remain shaped by data constraints and institutional capacity. While remote sensing has expanded the spatial scope of accounting, integration with economic decision making remains limited in many regions. This variation sets the basis for identifying common findings and research gaps, which are discussed in the next section.

5.FINDINGS

The expanded review of 33 river basin–scale water accounting studies reveals that water accounting has gradually evolved from a technical exercise into a broader analytical tool, although its use remains uneven across regions and policy contexts. At a global level, the findings suggest that while methodological capacity has improved significantly, the translation of water accounting results into sustained basin-level decision making remains limited.

One of the most consistent findings across regions is that water accounting has primarily been used to clarify physical water realities rather than to directly enforce allocation decisions. Early basin studies by Molden (1997) and Perry (2007) demonstrated that many perceived inefficiencies in irrigation systems disappear when water is viewed at the basin scale, as

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return flows are reused downstream. This insight has been repeatedly confirmed in later applications in South Asia and the Middle East, where accounting exercises revealed that increasing field-level efficiency does not always lead to basin-level water savings (Ahmad et al., 2009; Karimi et al., 2013). At a larger scale, this finding has challenged conventional policy approaches that focus narrowly on efficiency improvements without considering basin-wide hydrological linkages.

A second large-scale finding concerns the central role of consumptive use and depletion metrics. Across most reviewed studies, evapotranspiration emerges as the key variable for understanding real water use within basins. Remote sensing–based studies have shown that focusing on withdrawals or diversions alone can be misleading, particularly in basins with extensive irrigation reuse (Bastiaanssen et al., 2014; Rebelo et al., 2017). At continental scales, such as in African and Asian basins, satellite-based accounting has made it possible to compare depletion patterns across regions that lack consistent ground monitoring. However, several authors caution that uncertainty in remote sensing estimates can propagate through basin accounts if not carefully validated (Karimi et al., 2021).

The review also highlights that formal accounting frameworks have contributed to standardization but not necessarily to wider adoption. Frameworks such as WA+ and SEEA-Water have helped organize basin information in consistent formats and have made comparisons across basins more feasible (FAO, 2016; United Nations, 2012). Large-scale applications of WA+ in transboundary basins demonstrate its value as a diagnostic and communication tool, particularly in data-scarce environments (Droogers et al., 2017). At the same time, studies applying SEEA-Water show that linking physical water accounts with economic statistics remains institutionally demanding and is often limited to countries with strong statistical systems (Vardon et al., 2012; Godfrey & Chalmers, 2012). This suggests that scalability depends not only on methodological soundness but also on governance capacity.

Another important finding relates to the geographical concentration of water accounting practices. At the global scale, applications are heavily concentrated in basins facing scarcity, conflict, or rapid demand growth. South Asia, the Middle East, Sub-Saharan Africa, and Australia dominate the literature, while humid regions receive far less attention. This pattern indicates that water accounting is often adopted reactively, in response to visible stress, rather than as a routine planning instrument. Studies from Australia and parts of Europe show that when accounting is embedded within long-standing institutional arrangements, it is more likely to influence allocation and compliance (Wheeler et al., 2020; Grafton et al., 2018).

The thematic analysis further shows that economic integration remains the weakest component of basin-scale water accounting. Although many studies report indicators such as water productivity, relatively few explicitly connect water accounts with sectoral economic performance or welfare outcomes. Perry et al. (2017) argue that without such linkage, accounting exercises risk remaining descriptive and detached from policy trade-offs. Large-scale comparative studies highlight that basin managers often lack tools to translate accounting outputs into decisions involving agriculture, urban supply, and environmental flows simultaneously (Grafton et al., 2018). This gap becomes more pronounced at transboundary scales, where institutional fragmentation complicates economic coordination.

Finally, the review finds that policy uptake depends strongly on institutional embedding. Studies documenting long-term applications, such as those in the Murray–Darling Basin, show that water accounting has greater influence when it is tied to legal allocation rules, monitoring requirements, and enforcement mechanisms (Wheeler et al., 2020). In contrast, in many developing regions, accounting exercises remain project-based and externally driven, limiting their continuity and impact (FAO, 2016; Karimi et al., 2021). At a global scale, this suggests that technical advances alone are insufficient; sustained policy relevance requires alignment with governance structures and decision processes.

Taken together, these findings indicate that water accounting at the river basin scale has achieved substantial progress in measuring and describing water use, particularly through advances in remote sensing and standardized frameworks. However, its potential as a decision-support tool remains only partially realized. Bridging the gap between accounting outputs and basin-level economic and institutional decisions emerges as the central challenge for future research and practice.

6.CONCLUSIONS

This systematic review has examined global practices of water accounting at the river basin scale by synthesizing evidence from 33 peer-reviewed studies published over the past two decades. The review shows that water accounting has become an important tool for understanding how water is available, used, and depleted within river basins, particularly in regions facing increasing water stress. Across different contexts, water accounting has helped clarify basin-level water realities that are often overlooked when analysis is limited to local or project scales.

At a global level, the review finds that most water accounting applications continue to serve a diagnostic purpose. Studies consistently demonstrate the value of accounting in revealing patterns of consumptive use, return flows, and depletion, especially in irrigation-dominated basins. Advances in remote sensing have expanded the spatial coverage of water accounts and enabled analysis in data-scarce regions, making basin-scale assessment more feasible than in the past. Standardized frameworks such as WA+ and SEEA-Water have further contributed to organizing and presenting accounting results in a consistent manner.

At the same time, the review highlights clear limitations. Despite methodological progress, the integration of water accounting with economic analysis and policy decision making remains limited. Only a small share of studies explicitly links water accounts with allocation rules, economic outcomes, or institutional processes. As a result, many accounting exercises remain descriptive and are not systematically embedded in basin management systems. The uneven regional distribution of studies

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also suggests that water accounting is often adopted in response to crisis or scarcity rather than as a routine planning instrument. Overall, the findings indicate that water accounting at the river basin scale has matured technically but has not yet reached its full potential as a decision-support tool. Future efforts need to focus less on developing new accounting methods and more on strengthening institutional linkages, improving economic integration, and ensuring continuity of application. Doing so would allow water accounting to move beyond measurement and play a more effective role in supporting sustainable and equitable river basin management.

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