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Global Sustainable Water Management: A Systematic Qualitative Review

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Abstract
Water quality and quantity decline due to anthropogenic factors and climate change, affecting 2.3 billion people in water-scarce areas, of whom 733 million reside in Asia, Africa, and Latin America. Therefore, this review paper examined sustainable global water management by focussing on four sustainable development goal (SDG #6) indicators, including water use efficiency in agriculture, integrated water management, transboundary water cooperation, and water user participation. The review covered articles from 2016 to 2023, using Scopus and Web of Science databases with specific selection criteria. A total of 216 sources were downloaded, and after data screening, 72 articles were analysed along with additional supplementary materials such as books, conference papers, and United Nations documents. The finding indicates emerging trends in sustainable water management for agriculture, including water-efficient technologies like alternate wetting and drying, drip irrigation, mulching, etc. However, careful implementation is required to address environmental concerns, prevent water pollution, minimise yield reductions, and ensure long-term sustainability. Moreover, integrated water resource management has faced challenges in practical implementation due to governance structures, economic circumstances, cooperation, and collaboration among stakeholders. While over 600 treaties aim to promote international water cooperation, only a few have been effective. In addition, out of 500 transboundary groundwater sources shared by countries, only six have dedicated treaties to govern their use. Thus, clearly defined rights, responsibilities, and sustainable management practises for each shared aquifer would foster the sustainability of these resources. Moreover, engaging communities through inclusive policies, dialogue, and empowerment is vital for sustainable water management. Investment in community education and capacity-building fosters transformative change and addresses global water management challenges, securing the future of precious water resources.

Keywords Sustainable water management · Integrated water resource management · Water-efficient agricultural technologies

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1 Introduction

Water is one of the most indispensable resources on the planet, yet, due to various anthropogenic factors and climate change, the quality and quantity of water are rapidly deteriorating. Alarming population growth, climate change, urbanisation, agricultural expansion, and industrialization are reducing water resources (Asif et al. 2023; Cook et al. 2022; Echeverria 2021). To make matters worse, there is at least a 50% chance that global warming will reach or exceed 1.5 °C soon (2021–2040) (IPCC 2022). As the world's population continues to grow rapidly, the demand for water resources is expected to increase. For instance, the global population is expected to reach 9.7 billion by 2050, which is anticipated to increase the demand for water (UN 2022). Currently, 2.3 billion people live in water-scarce locations, of which 733 million are from the global south, including Asia, Africa, and Latin America (UN Water 2021). Furthermore, two-thirds of the world's population (4.0 billion people) live in areas with acute water shortages at least one month of the year (Mekonnen and Hoekstra 2016).

The report by UN Water highlights that agriculture is the largest water consumer, accounting for 72% of water consumption (UN Water 2021). The Food and Agricultural Organisation (FAO 2023) also indicates that water usage is distributed, with 70% attributed to agriculture, 19% to industry, and 11% to municipal demand. To improve water use and mitigate water scarcity challenges, numerous efforts are underway worldwide. The United Nations announced the 17 Sustainable Development Goals (SDGs) agenda in 2015, with SDG 6 focusing on clean water and sanitation (UN Water 2023).

In 2015, the UN defined eight targets and 11 indicators for SDG 6 (UN Water 2021). The targets of SDG 6 form an interconnected framework for achieving comprehensive and sustainable water management. Safe drinking water (SDG 6.1.1) and safe sanitation and hygiene (SDG 6.2.1a) are foundational for ensuring water quality, complemented by handwashing facilities and water availability at households (SDG 6.2.1b) (UN Water 2018). Proper wastewater management (SDG 6.3.1a and SDG 6.3.1b) is crucial for maintaining ambient water quality (SDG 6.3.2) (UN Water 2021). Water use efficiency (SDG 6.4.1) optimises resource allocation and complements the evaluation of freshwater stress (SDG 6.4.2) (FAO and UN Water 2021). Integrated water management (SDG 6.5.1) is essential for harmonising water use, while transboundary water cooperation (SDG 6.5.2) emphasises international collaboration (Barua et al. 2019). Monitoring the changes in river basins (SDG 6.6.1) reflects overall water management impact, and rehabilitating water ecosystems (SDG 6.A.1) supports sustainability efforts (UN Water 2018). Engaging water users (SDG 6.B.1) fosters effective water management (Cook et al. 2022). Together, these targets address global water challenges holistically and promote sustainable water practises for present and future generations.

Sustainable water management occurs within a complete framework that follows core principles and crucial components. The framework comprises governance, legislative and institutional framework, infrastructure, policies, technology, and financial resources (SIWI 2023; WB 2023). While the principles are good governance, equity, sustainability, participation or inclusiveness, accountability, effectiveness, coordination, and collaboration, the components encompass water conservation and efficiency, water quality management, wastewater treatment and reuse, ecosystem restoration and protection (Benson et al. 2020; Jimenez et al. 2020; UN Water 2021). The ultimate objective of SDG 6 is to secure the availability and sustainable management of water resources, ensuring the well-being of all life and preserving the planet's ecosystems for current and future generations (UN Water 2018).

Hence, while recognising the equal importance and vital contribution of all SDG 6, this review mainly focuses on four indicators that are also interdependent. For example, efficient water use in agriculture (SDG 6.4.1) is essential for supporting integrated water resource management (SDG 6.5.1), which is vital for effective cooperation in transboundary water management (SDG 6.5.2) and meaningful participation of water users (SDG 6.b.1) in achieving comprehensive and sustainable water management. The main goal of this review was to provide a general overview of the progress made and challenges encountered regarding the selected four indicators. It also serves as a baseline for future research papers focused on this area, including those by the authors of this paper. While many studies exist on SDG 6, only a few have addressed more than one indicator of this target. Thus, this study distinguishes itself by comprehensively examining the progress and challenges encountered in the context of the selected four indicators. However, it is essential to acknowledge the limitations of this review, which lie in its inability to consider all the indicators. Future studies may include all other indicators to provide a broader perspective.

2 Methodology

The present paper is a systematic, qualitative literature review wherein inclusion and exclusion criteria have been developed to meet the paper's objective. The selection process has prioritised articles focused on global, continental, comparative, or international issues between 2016 and 2023, with the primary goal being to assess the progress made on four indicators of SDG 6 since the announcement of sustainable development goals in 2015. Additionally, the review includes articles that delve into topics such as water use efficiency in agriculture, integrated water resource management, cooperation in transboundary water management, and water user participation, while being limited to those written in English. Country-specific experiences, wastewater treatment, the water-food-energy nexus, cities, and industrial and municipal water aspects have been excluded from the scope of this review (Fig. 1).

Considering the review's goal, the sources were searched on Scopus and the Web of Science. To locate the relevant material, Boolean literature searching methods such as water AND "sustainable management,“ water AND "agricultural technologies,“ "water AND "integrated management,“ water AND "transboundary cooperation, and "water AND user participation" with a time span of 2016–2023 were used. A total of 216 sources, comprising articles, books, and conference papers, were downloaded for review. Data screening and extraction were performed, and 72 articles were used for the final analysis. Additional supplementary materials included four conference papers, six books and book chapters, nine United Nations documents, and other credible organisation documents. In general, 92 records were used to produce this review paper. Figure 1 presents a summarised methodological package used in this review paper.

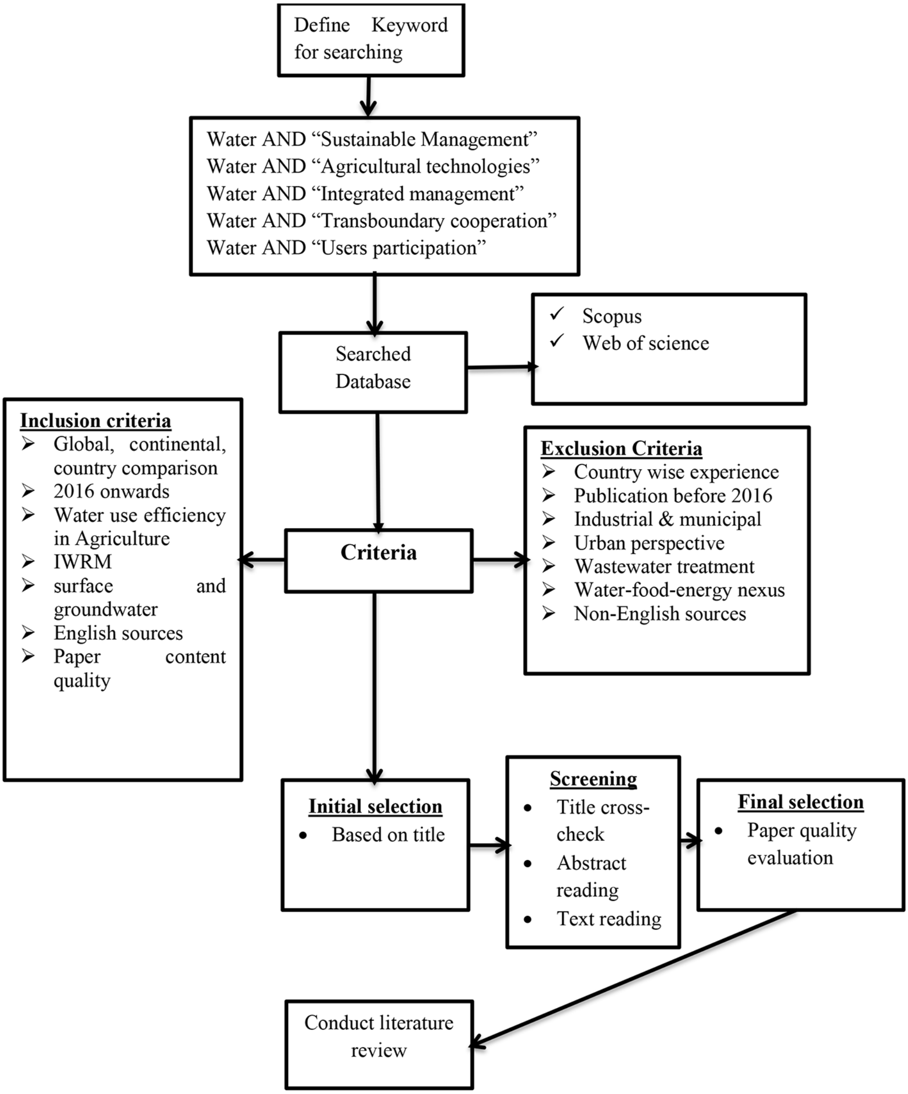

Fig. 1 Methodological framework for the literature review of sustainable water management

3 Discussion

Before delving into the main discussion, a brief explanation of the distinction between water governance and water management is essential. Water management entails human involvement in planning, implementing, and managing water resources, while water governance is the political, socio-economic, and administrative structure that potentially influences water utilization and management (HE and James 2021; SIWI 2023; WB 2023). Both are interconnected and complementary, with water management focusing on operational issues and water governance on mechanisms that facilitate these decisions. Central principles in water management and governance include cooperation, multi-level governance, transparency, accountability, policy harmonization, coordination, collaboration, participation, and education (Cai et al. 2021; Da Silva et al. 2020; Jimenez et al. 2020; Rowbottom et al. 2022). These principles ensure or delay the implementation of water management and governance.

3.1 Water-efficient Agricultural Technologies and Practices

Global efforts to minimise water use in agriculture include alternate wetting and drying, deficit irrigation, drip irrigation, micro irrigation, mulching, saturated soil culture, rainwater harvesting, and groundwater recharging (Srivastav et al. 2021; Zhao et al. 2020; Zhang et al. 2023). Advancements in science, earth observation, hydrological modelling, computer capabilities, and analytical approaches have opened new possibilities. The Internet of Things (IoT) and Block Chain, Light Detection and Ranging (LidAR), and Geographic Information System (GIS) are used for modelling and recording water and related issues (Ahmed et al. 2021; Ani and Gopalakirishnan 2020; Krishna et al. 2020; Wang et al. 2022b).

Alternate wetting and drying irrigation (AWD) is a promising and environmentally friendly method for water-efficient rice production (Ishfaq et al. 2020). Despite differences in air conditions, soil type, soil water content, dryness intensity, cropping season, crop types, and crop stage of growth, several studies have reported that AWD can save 20–70% of agricultural water use (Cheng et al. 2022; Ishfaq et al. 2020; Numery et al. 2021; Zhang et al. 2023). Without any balancing intervention, AWD can increase water use efficiency by 31%, but at a 6% yield loss, so limiting overall organic carbon effect sizes to less than 0.0003, pH above 0.015, and nitrate-nitrogen between 0.02 and 0.30 during AWD could boost rice yield by up to 4% (Zhang et al. 2023). Additionally, AWD can reduce water use in rice production when weeds are absent but can reduce yield when weeds are present (Dossou-yovo et al. 2022).

Deficit irrigation, introduced in the 1970s, conserves water resources and maintains productivity by reducing irrigation flows during the growing season (Yu et al. 2020). It increases wheat crop water use efficiency by 6.6% but reduces yield by 16.2% (Yu et al. 2020). In their study, Kogler and Soffker (2017) also found 20–40% irrigation water savings with yield decreases up to 10%. Cheng et al. (2021) discovered deficit irrigation performed well in clay loam soils with low bulk density and >200 mm precipitation, while Yu et al. (2020) found success in conditions with <200 mm precipitation and loamy or sandy soils using border or furrow irrigation. The inconsistency is due to varying crops, soils, precipitation, and irrigation methods. To prevent yield reduction, deficit irrigation must be >94.5% of total irrigation (Yu et al. 2020). Overall, deficit irrigation enhances water use efficiency and yield when considering method selection, timing, water, crop types, and season.

Drip irrigation reduces agricultural water use and enhances water productivity by delivering water and fertiliser directly to plant roots. This method improves water efficiency, increases yields, and ensures food security by minimising runoff and percolation losses (Greenland et al. 2018). Subsurface drip irrigation has shown a 6.42% yield increase and 5.39% water use efficiency improvement (Wang et al. 2022a). However, barriers like high costs and poor uniformity due to emission clogging hinder its widespread adoption (Greenland et al. 2018). Moreover, Zhang et al. (2022) found that film-mulching drip irrigation increased crop and water use efficiency by 20% and 30%, respectively. Mulching practises offer numerous benefits, improving soil quality and agricultural productivity. By minimising soil evaporation and preserving moisture, mulching conserves water resources and maintains favourable soil moisture levels for plant growth Kader et al. (2017). This reduces water loss and lowers crop water requirements. Additionally, mulching enhances soil water availability, making it more accessible for plant roots to uptake (El-beltagi et al. 2022). Furthermore, saturated soil culture, also known as hydroponics, is an agricultural technology that provides continuous irrigation, maintains steady water depth, and keeps the soil layer saturated (Ghulamahdi et al. 2023; Mallareddy et al. 2023). The saturated soil culture agricultural technology reduces water usage by up to 28% when compared to conventional flooded methods (Srivastav et al. 2021). Another study also found that using saturated soil culture agriculture technology decreased water inputs by 30–60% while reducing production by 4–9% (Mukherjee 2019).

Rainwater harvesting (RWH) involves collecting, storing, and conserving rainfall for agricultural and other uses, serving as supplemental irrigation during water scarcity (Velasco-Muñoz et al. 2019). It is widespread in countries like Japan, Singapore, the USA, and others (Yannopoulos et al. 2019). RWH systems can provide 12–100% of potable water in developing nations, addressing water shortages in countries like Bangladesh, India, Kenya, and South Africa (Musayev et al. 2018; Yannopoulos et al. 2019). Semi-arid regions use road runoff for irrigation, while Latin American countries use roof RWH for domestic consumption (Yannopoulos et al. 2019). Another significant water source for agriculture is groundwater recharge, where water from precipitation infiltrates the soil and percolates towards the water table (Hartmann 2022). Groundwater recharge, a vital process, contributes to the replenishment of groundwater reservoirs and sustains water availability for agriculture and other purposes (Hu et al. 2023). In general, water use efficiency in agriculture increased by 8% between 2015 and 2018 (UN Water 2021). Table 1 summarises water-efficient agricultural technologies, including their pros and cons.

In addition to the water-saving agricultural technologies, recent advances in computer technologies and modelling methods have significantly contributed to predicting, optimising, and monitoring equitable supply and distribution of water for sustainable agricultural practices (Srivastav et al. 2021). The Internet of Things (IoT) and Blockchain-based technologies also show potential for enhancing precision agriculture by incentivizing good water management practises (Pincheira et al. 2021; Velayudhan et al. 2022). IoT in water supply chain management addresses inadequate water monitoring and management (Ahmed et al. 2021). The benefits of blockchain operations outweigh the minimal increase in energy and storage use, with notable improvements in water management due to real-time data updates (Pincheira et al. 2021).

Wang et al. (2022b) emphasise the significance of conventional water resource management, particularly in steep-slope agricultural systems. However, time-efficient and cost-effective remedies necessitate the adoption of creative techniques and technologies like high-resolution remote sensing (e.g., LiDAR and drone) and GIS-based modelling (Wang et al. 2022b). In a study conducted on groundwater simulation in the USA using AnnAGNPS and MODFLOW models, (Momm et al. 2022) revealed that enhancing groundwater levels could be achieved by reducing irrigation rates by 20–40%, emphasising the significance of adopting water-efficient irrigation methods for ensuring sustainable groundwater resources. Additionally, AquaCrop modelling aids in predicting crop production and water use efficiency during cultivation (Srivastav et al. 2021).

Table 1 Summary of Water Saving Agricultural Technologies

Irrigation Technique	Regions	Soil Type	Crop Type	Season	Application Conditions	Benefits	Drawbacks	Reference
Alternate Wetting & Drying	Tropical & Subtropical Regions	Loamy Clay Sandy	Rice (Paddy)	Wet and Dry Seasons	Controlled paddies water levels	Save water up to 20-70% when required condition fulfilled, Reduce methane emissions by more than 60%	Labour-intensive, require precise management	(Cheng et al. 2022; Ishfaq et al. 2020; Runkle et al. 2019)
Deficit Irrigation	Arid and Semi-Arid Region	Sandy clay loamy	Various Crops (e.g., maize, wheat, cotto, vegetable, fruit, etc.)	Dry Seasons	Controlled reduction in water supply	Water-saving (6–40%) stress adaptation in plants	Reduce yield up to 16%, crop water stress	(Cheng et al. 2021; Khapte et al. 2019; Kogler and Soffker 2017; Yu et al. 2020)
Drip Irrigation	worldwide	Sandy, Loamy, Clay, Silt	Various Crops (e.g., Vegetables, Fruits, tree and vine, Grains)	All Seasons	Precise water delivery to the root zone, Targeted irrigation	Water-efficient (increase water efficiency and yields by more than 5% under necessary preconditions) reduced water extravagance	Cost of installation and maintenance potential clogging of emitters	(Greenland et al. 2018; Wang et al. 2022a)
Mulching	Worldwide	Numerous	Various Crops (e.g., Vegetables, Fruits, Grains)	All Seasons	Soil moisture conservation, Weed control	Save water up to 30% Temperature moderation, less evaporation	Material cost, Degradation over time due to plastic and other wastes	(Elbeltagi et al. 2022; Kader et al. 2017; Zhang et al. 2022)

Table 1 (continued)

Irrigation Technique	Regions	Soil Type	Crop Type	Season	Application Conditions	Benefits	Drawbacks	Reference
Saturated Soil Culture	Tropical & Subtropical Regions	Loamy or Sandy	Rice (Paddy)	Wet Season	Soil saturation with a shallow water table and a controlled water level	High water availability, reduced leaching Decease water input by over 28%	Limited applicability to rice cultivation. Reduce yield 4–9%	(Mallareddy et al. 2023; Srivastav et al. 2021)
Rainwater Harvesting	Worldwide (mostly in dry, water-scarce locations)			Rainy season	Collection of rainwater for irrigation use during dry season	Sustainable and alternative water source	Rainfall fluctuation, storage limitations, Contamination	(Musayev et al. 2018; Velasco-Muñoz et al. 2019; Yannopoulos et al. 2019)
Groundwater Recharging	Worldwide, especially in the arid and semi-arid regions			wet or rainy seasons	Aquifer or well recharge, controlled water percolation	Groundwater replenishment for water sustainability	Complex hydrogeological conditions	(Hartmann 2022; Hu et al. 2023)

Moreover, the Water Erosion Prediction Project (WEPP) computer model predicts soil loss turbulence on hill slopes and in small watersheds across various land uses and environmental conditions (Mcgehee et al. 2023). The Integrated Excess Nitrogen Load Model (IENLM) estimates excess nitrogen load from agricultural activities (Feng et al. 2022), while the Soil and Water Assessment Tool (SWAT) measures watershed management and emission leakage into river basins (Ren et al. 2022). These technologies, among others, play a crucial role in evaluating and predicting water efficiency in agriculture for sustainable water management.

Despite the potential for sustainable water management in agriculture, there are drawbacks resulting from efforts to advance crop-water use efficiency in this sector. For example, excess nutrients from agriculture cause acidification and salinisation in European waters, with 60% of water bodies failing to meet good ecological status targets (Nikolaidis et al. 2022). Plastic mulching leads to soil contamination due to its toxic behaviour, while rubber mulching can damage crop plants if proper precautions are not taken (El-beltagi et al. 2022). The use of chemical fertilisers increases crop yields but can result in water body pollution through agricultural runoff (Srivastav et al. 2021). Additionally, the leaching of arsenic, nitrate, and pesticides from agriculture poses water pollution risks (Carrijo et al. 2022; Syafiuddin et al. 2020). Moreover, Ren et al. (2022) found the corn-soybean rotation system accounts for 83% nitrogen, 88% phosphorus inputs, and 64% and 46% nitrogen and phosphorus removals in the US Corn Belt. In Central Asia, irrigation runoff washes an average of 25% nitrogen, 5% phosphates, and 4% pesticides into water bodies (Feng et al. 2022). Therefore, proper precautions must be taken to avoid agricultural water pollution.

3.2 Integrated Water Resource Management

Integrated water resource management (IWRM) has been a prominent water management approach since its acceptance in 1990, advocating for structural considerations of water demand and supply, cooperation, coordination, consensus building, and collaboration in both transboundary and intra-boundary water resource management (Apostolaki et al. 2019; HE and James 2021). Benson et al. (2020) proposed seven principles for effective IWRM implementation: integration, multi-level governance, community participation, economic valuation, gender mainstreaming, and ecosystems. Many nations have adopted IWRM to promote water diplomacy, cooperation, international water policy, strategy, and law (Nkiaka et al. 2021).

In 2017, global implementation of IWRM was at 49% (UN Water 2021). Bilalova et al. (2023) and Cai et al. (2021) found varying levels of implementation across regions, with Europe and Northern America at 67.4%, Australia and New Zealand at 72%, and other regions ranging from 34.1 to 54.8%. By mid-2020, global implementation had increased to 54%. Miranda and Reynard (2020) underlined that for the effective implementation of integrated water management, governments must make significant modifications to their legal and institutional frameworks. Moreover, integrated groundwater management is also gaining importance due to the rapid deterioration of surface water, with some countries facing overconsumption of groundwater.

Globally, agriculture accounts for 69% of groundwater abstraction, with 31% used for households and industries (United Nations 2022). Nationally, more than 90% of groundwater was extracted for irrigation purposes in Pakistan, Saudi Arabia, and Libya; over 80% in Bangladesh, Greece, India, and South Africa; and above 70% in Australia, the USA, and Argentina (Barnett et al. 2021; Cook et al. 2022; Syafiuddin et al. 2020; United Nations 2022). To ensure groundwater sustainability, cooperation and mutual interests among water users are crucial for managing aquifers (Echeverria 2021). Effective strategies should include systematic assessments involving stakeholders, improving understanding, acknowledging uncertainty, and considering societal needs (Elshall et al. 2020). Incentives for wise use of common pool resources such as water would be critical to ensuring the aquifer's long-term management (Echeverria 2021; Garrick et al. 2020).

To enhance aquifer sustainability, long-term groundwater development plans, reasonable pricing, quality preservation, and environmental impact assessments are crucial, especially for large-scale irrigation projects (Goya et al. 2020). Integrated modelling (Momm et al. 2022) and conjunctive water management, which combines surface and groundwater management, should be integrated into national policies (Syafiuddin et al. 2020). Campos et al. (2020) urge water-stressed countries, especially Arab countries, to improve their IWRM in order to better manage limited water resources by boosting cereal grain imports; however, this has its own pressure on the water resources of grain exporting countries and overall sustainable water management. Challenges facing IWRM implementation include lack of transparency, multi-level governance, funding shortages, institutional complexities, information gaps, an undefined integration scope, insufficient methods for participatory and integrated monitoring and evaluation, conflict, and instability, which can also hinder IWRM efforts (Cook et al. 2022; Gain et al. 2021; HE and James 2021; Hjorth and Madani 2023).

3.3 Transboundary Water Management Cooperation

Cooperation in transboundary water management involves establishing reliable relationships and reaping benefits for all parties involved. Over 310 transboundary rivers traverse more than 45% of the world's land area, passing through 153 countries (McCracken and Wolf 2019; UN Water 2021; Yan et al. 2022), leading to various treaties and agreements, bilateral and multilateral, to facilitate transboundary water cooperation. Examples include the Colorado and Rio Grande River Water Treaties between the US and Mexico (Rivera-torres et al. 2021), the Indus Water Treaty between India and Pakistan (Rai et al. 2017, 2022), the Ganga Water Treaty between India and Bangladesh, and the Mahakali Treaty between India and Nepal (Kryston et al. 2022; Saklani et al. 2020). Despite over 600 treaties signed for international water cooperation and sustainability, only a few have fully delivered on their promises (Kryston et al. 2022).

In 2020, global implementation of cross-border water cooperation was 58%, with only Europe, North America, and Sub-Saharan Africa on track to achieve the goal of 100% implementation in 2030, while only 24 countries had accomplished this goal in 2020 (UN Water 2021). Penny et al. (2021) highlighted the successful water governance cooperation between France and Switzerland through the Genevese aquifer treaty signed in 1978, aiming to address diminishing water supplies. Despite over 500 transboundary groundwater sources shared by 150 countries, only six (Genovese, SASS, ITAS, Nubian, Disi, and Guarani) have a dedicated transboundary treaty to govern their use (Gallagher and Gergel 2017; McCracken and Meyer 2018; Penny et al. 2021).

The Guarani Aquifer, for instance, is one of the world's largest trans-boundary aquifers, shared by Brazil (68%), Argentina (21%), Paraguay (8%), and Uruguay (3%), and governed by a regional cooperation initiative funded by the Global Environmental Facility (Hirata et al. 2020). Furthermore, the water cooperation between Bangladesh and India on the Ganga River was also perceived as fruitful (Kryston et al. 2022). However, many rivers, lakes, and aquifers lack operational water cooperation arrangements, particularly in Latin America, North Africa, Western Asia, Central and Southern Asia, and Eastern and South-Eastern Asia (UN Water 2021). Mistrust, misinformation, unequal power dynamics, behavioural differences, and other factors have led to challenges in transboundary water management (Zareie et al. 2020). Additional obstacles include political disagreements, a lack of data sharing, language barriers, regional conflicts, competition, opportunism, weak stakeholder engagement, a lack of coordination, and cooperation (Al-saidi 2021; El-Nashar and Elyamany 2023; Nkiaka et al. 2021).

Therefore, expanding collaboration between countries is critical to improve transboundary water cooperation (Ma et al. 2020). Transparency, accountability, stakeholder engagement, and collaboration are essential for achieving transboundary water cooperation and sustainable water management (Jimenez et al. 2020; Vaio et al. 2021). To enhance collaborative working and facilitate joint decision-making, regular information exchange and the production of common knowledge and tools among relevant parties are necessary (Kull et al. 2021). Improving multi-level governance and partnerships involving actors from all sectors at the local, national, and international levels can help overcome challenges to sustainable water management (Cai et al. 2021; Vaio et al. 2021). In addition, trust and fairness play pivotal roles in transboundary water cooperation, given their sensitivity and dependence on the political context and interests of the water-sharing countries.

3.4 Community Participation

Community participation has become recognised as a viable solution for water resource management, with residents actively engaging in rural water management in Latin America to secure water access (Romano et al. 2021). Organised citizen and community participation can enhance water resource use, development, and decision-making procedures (Vaio et al. 2021). Despite being a buzzword among policymakers, scholars, and activists, community participation has seen limited success at the grassroots level, though national policies and laws are gradually acknowledging its value with increased participation rates (UN Water 2021). Broadening citizen participation and increasing their understanding of judicious water resource use can contribute to achieving water sustainability goals (Vaio et al. 2021).

Promising activities have been observed in the literature. For example, in Mexico, local communities actively participate in water decontamination, flood regulation, carbon detention, temperature control, and habitat provision, while South African organisations focus on water provision through women's training programmes and hiring for water protection and catchment species elimination (Kiss et al. 2021). Moreover, HE and James (2021) indicated successful participatory decision-making in the Colorado River Conservation Initiative involving seven US states. Gain et al. (2021) report extensive stakeholder participation in the "Room for the River" project in the Netherlands through participatory seminars. The Murray-Darling Basin in Australia is a recognised best practise example of participatory water management (Freak et al. 2022). In Brazil, participatory forums for basin governance have operated since 1996, involving civil society, private users, and government entities, promoting participatory water governance by limiting government representation to 50% (Mancilla García and Bodin 2019).

Thus, promoting community participation in sustainable water management includes involving diverse stakeholders, such as residents, farmers, NGOs, and indigenous groups, in decision-making processes (Ruiz-Villaverde and García-Rubio 2017). This can be achieved through participatory forums, public consultations, and community-based projects. Fostering inclusive policies and laws that recognise and value local contributions is crucial for enhancing community involvement. The depth of community participation focuses on empowering communities to contribute effectively to sustainable water management. Promoting community participation in sustainable water management involves providing information, resources, and capacity-building programmes, encouraging ownership of water initiatives, collaborating with experts and the government, implementing locally relevant solutions, improving community engagement, knowledge co-production, and disseminating research findings in a format easily accessible to the community (Obiero et al. 2022). Engaging in meaningful dialogues and partnerships with communities ensures long-term commitment and sustainability in water management.

Moreover, community education is an essential component of sustainable water management. For instance, (Da Silva et al. 2020) found that education plays a crucial role in a community's capacity to understand and influence water resource management decisions, as evidenced in various indices such as the water sustainability index (WSI), the water poverty index (WPI), the Canadian water sustainability index (CWSI), and the West Java water sustainability index (WJWSI). Hence, a transparent and inclusive process would encourage community participation and consultation, as water-related decisions can have both positive and negative consequences for the whole population (Cook et al. 2022). Overall, community participation in all aspects of water management should be expanded to ensure the resource's long-term viability.

4 Conclusion and Future Perspectives

The 2030 agenda, with SDG 6, emphasises clean water and sanitation as fundamental pillars for sustainable development and global prosperity, aiming to ensure availability and sustainable water management. In alignment with this objective, the presented paper examined the progress and challenges encountered in four indicators of SDG 6. The paper discussed these four indicators separately to showcase the advancements made and the challenges faced with respect to each of them. By analysing each indicator independently, the paper provides a comprehensive overview of the current status and highlights specific areas that require attention and improvement.

4.1 Water use Efficiency in Agriculture

The use of advanced technologies and modelling tools, in conjunction with water-efficient practises like alternate wetting and drying, deficit irrigation, drip irrigation, mulching, and saturated soil culture, offers promising solutions to reduce agricultural water usage while maintaining productivity. However, the trade-off from most of these agricultural technologies through chemical fertiliser run-off can have a tremendous effect on the goal of SDG 6: clean water and sanitation. Therefore, proper management through capacity building for farmers at local levels is highly important. Although not specifically presented by most of the existing literature, large-scale agricultural projects like state farms and industrial farms in most developed and developing countries could take a lion's share of leaching agrochemical inputs into surface and groundwater, so a necessary precaution must be taken. In addition, plastic mulching in agriculture has environmental problems like plastic pollution and microplastic contamination, which can be avoided by using more sustainable alternatives such as biodegradable mulch films composed of plant-based polymers or compostable materials.

4.2 Integrated Water Resource Management

Integrated water resource management (IWRM) has gained popularity as a method of water management, emphasising cooperation and collaboration among different stakeholders. However, its practical implementation has faced several challenges, including a lack of transparency, multi-level governance, insufficient funding, complex institutional structures, and information gaps. The global average of IWRM implementation was around 54% in 2020. To improve IWRM, governments and water-stressed countries must address the identified bottlenecks, invest in better governance structures, increase funding, ensure transparency, and develop methodologies for participatory monitoring and assessment. By doing so, IWRM can contribute to sustainable water management and preserve water resources for future generations.

4.3 Cooperation for trans-boundary Water Management

Transboundary water cooperation is crucial for sustainable water management, but implementation varies globally. Progress has been made in Europe, North America, and Sub-Saharan Africa towards achieving transboundary water management goals. Challenges include mistrust, information gaps, power imbalances, conflicts, and weak stakeholder engagement. To ensure a sustainable future, prioritise enhanced collaboration, transparency, and stakeholder involvement. Regular information exchange and inclusive policies bridge gaps. Establish unwavering trust and fairness. Strengthen international partnerships for effective water management, mitigating water calamities, and fortifying water systems for generations to come.

4.4 Community Participation

Promoting community participation in sustainable water management is a vital step towards ensuring the long-term viability and sustainability of water resources. To achieve this goal, it is essential to prioritise and implement a directive proposal that emphasises inclusive policies, resource allocation, and stakeholder dialogues. By recognising and valuing local contributions, meaningful dialogues can be fostered, leading to more effective decision-making processes. To empower communities, investment in education, capacity-building, and the provision of resources is necessary. Engaging residents, farmers, NGOs, and indigenous groups in decision-making processes through participatory forums and public consultations is critical for transformative change. Only through decisive action can we secure the future of our precious water resources and promote sustainable water management.

Moreover, future research should prioritise investigating the role of indigenous knowledge in sustainable water management and its significance in addressing intergenerational equity issues, which have been largely underestimated in existing literature. Additionally, researchers should delve into the concept of rural-urban integrated sustainable water management, exploring the potential for public-private partnerships (PPP) in crisis-affected water sectors. Moreover, given the rapid growth of commercial bottled water supply, particularly in developing countries, there is a critical need to examine its impact on exacerbating water scarcity and seek ways to balance this trend for more sustainable water management.

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