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ARTICLE

Implications of the Concept of Glocalization for Science Education for Sustainability with a Specific View on Promoting Water Literacy

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Abstract
Challenges in global water use draw attention to narratives that raise awareness and influence policy but often fail to address specific local issues effectively. The idea of glocalization integrates global and local perspectives and recognizes the unique ecological knowledge of local and indigenous communities, which may differ from Western modern scientific views. This study provides a comprehensive analysis of the literature in education, specifically focusing on science education and its relationship to glocalization in the context of water education. It explores the relevance of glocalization in advancing education for sustainability in the case of teaching and learning about water use. It proposes a framework to operationalize education for sustainability by incorporating local water issues and their connection to global challenges. By repositioning the boundaries of global and local in the context of water education, the study aims to present a glocal perspective. The paper suggests a glocalization framework related to strategies for science education to promote a deeper understanding of the interconnectedness between global and local issues, as well as a Social-Ecological Systems (SES) conceptual framework that leads to water education for sustainability. Additionally, the study presents a framework for developing water educators through glocalization and sustainable professional development, incorporating components such as communities of practice, professional learning communities, action research, and external experts.

Keywords Science education · Education for sustainability · Sustainable development goals · Water education · Water literacy · Glocalization

1 Introduction

With the Agenda 2030, the United Nations in 2015 agreed on 17 Sustainable Development Goals (SDGs), encompassing a wide range of human values necessary for the peaceful coexistence of communities in a sustainable world (United Nations Department of Economic & Social Affairs, 2023). Water is one of the natural resources that the SDGs directly address. Water has a pivotal role in human life, e.g., in targets 6, "Clean water and sanitation," and 14, "Life below water." The importance of water lies in its central role in any

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socio-ecological environment. Any society needs to address potential risks and damages that can impact both water availability and quality. Consequently, maintaining water sustainability relies on sustaining the ability of the ecosystem to support the required quantity and quality of clean water for current life and future generations (Camata et al., 2022).

Effects of water scarcity and water contamination have been experienced in both industrialized and developing nations. It is crucial to surpass international and political limits to fulfill the global water requirements in a sustainable way that protects and conserves this common resource. Rockström et al. (2009) identified freshwater use as one of nine planetary boundaries, emphasizing that exceeding sustainable water withdrawal and consumption thresholds could destabilize the Earth's system. Over the past decades, public and private sector organizations, at national and international levels, have joined forces to tackle worldwide issues related to clean water availability and sanitation (Choffnes & Mack, 2009). Over the past quarter century, global water problems have continued to increase, affecting human health and good life, which is also a target in the Agenda 2030 with SDG 3 "Good health and well-being." The debate about water crises developed global narratives that increased public awareness and influenced policy but often did not adequately tackle specific local problems at the community level. In contrast to the global climate crisis affecting the whole planet, although with different impacts in various regions, water problems are mostly confined to specific regions and influenced by local natural and human-related factors (Shamsudduha, 2024). Despite diverse efforts by various stakeholders such as governments, international bodies, and local communities, water education is often overlooked, leading to fragmented and uncoordinated initiatives in addressing water issues (Etgen et al., 2019).

Water education is important for preparing a generation of experts, policymakers, and citizens who are knowledgeable in making water-related decisions across various fields. Water is a core component of many disciplines, such as geography, agriculture, economics, and public health. Therefore, an interdisciplinary approach to water education is necessary. In most countries, current teaching standards are still focused on specific disciplines. Despite teaching different subjects to guide water education across all educational levels comprehensively, it is crucial to develop a transdisciplinary understanding of water-related educational standards. These standards can offer guidelines for water-related curricula, teaching, and assessment. Water literacy has been identified as one of the needed standards for the future, defined as "the culmination of water-related knowledge, attitudes, and behavior" (McCarroll & Hamann, 2020). This definition is based on other definitions of water literacy, which also emphasize the importance of knowledge, attitudes, and behavior as integral aspects of water literacy (Amahmid et al., 2019; Çoban et al., 2011; Johnson & Courter, 2020; Sammel, 2014; Simonds et al., 2019). Definitions and standards for water literacy suggest global perspectives on teaching and learning outcomes related to water.

It is important to understand water literacy, which is relevant to various fields and is part of a global perspective on Earth system education. Water literacy is a key component of scientific literacy, encompassing earth science literacy (Wyession et al., 2010) and environmental literacy (Covitt et al., 2009). Global understanding is essential, but it is also vital to execute unique programs customized for each area (solving the global water crisis through local solutions) to address various worldwide water challenges effectively (Shamsudduha, 2024). Formal education is a crucial chance for numerous people, especially at the K-12 level, to gain insight into socio-hydrological systems and address socio-ecological water challenges. Therefore, it is crucial to have standards and practices that are adaptable to the local environment where they are applied (Mostacedo-Marasovic et al., 2022).

Translating literacy skills into local and global settings can be accomplished through the concept of glocalization. Glocalization presents an alternative to the deficit models of internationalization, which do not fully recognize or appreciate the diversity of local contexts, resulting in a less comprehensive and inclusive approach (Båge et al., 2021; Caniglia et al., 2018; Gamal, 2023; Patel and Lynch, 2013). Glocalization demonstrates the fusion of global and local contexts, acknowledging the valuable contributions from diverse communities and cultural backgrounds. The way local communities perceive water often contrasts with Western modern scientific understandings. Indigenous groups are typically strongly bonded with the environment and transmit particular knowledge and values about conscientious environmental stewardship. This ancestral wisdom underscores the significance of local knowledge in preserving water sustainability (Maniam et al., 2021). Ecological wisdom, also referred to as traditional ecological knowledge (TEK) and other related terms and concepts (Zidny et al., 2020), encompasses a wealth of insights and understanding about locally derived resource utilization methods, emphasizing the ecological connections among different natural components as comprehended through the interplay between human societies and their local ecosystems (Asad et al., 2022).

In relation to water literacy and formal science education, there is a need for suggestions to incorporate glocalization into educational theory and practice to achieve Sustainable Development Goal (SDG) 4, "Quality education," preparing for lifelong learning. With one of the SDG 4 targets, 4.7, the SDGs advocate for global citizenship, appreciation of cultural diversity, and the role of culture in sustainable development (Amponsah & Babarinde, 2022). It is crucial for education to integrate sustainable development into the core curriculum so that students can understand the complex interrelationships among economic, social, environmental, and political systems in real-world contexts (Birkeland & Li, 2019). Thus, TEK can become an important part of the student's educational context for sustainability. Sustainable development sets the goal of achieving societal advancement while safeguarding the welfare of both present and future generations (Kyle, 2020). The foundation of sustainability education lies in worldwide efforts and decisions that underscore its crucial contribution to progress and safeguarding the environment, a fact supported by numerous studies and acknowledged by UNESCO (Hermann & Bossle, 2020). Awareness and feelings regarding global issues, in this case, water resources, can positively impact student learning and their ability to participate in sustainable development in their own region (van Herten & Perez, 2022). Education for Sustainability (EfS), which as a concept is closely related to Education for Sustainable Development (ESD), although some differences are suggested in the literature (Herranen et al., 2021), promotes the cultivation of cross-sectoral competencies in students. This empowers individuals to contribute to sustainable development through social, economic, and political transformation and influences behavioral change (Birkeland & Li, 2019). In the end, this literature review explores how the idea of glocalization can be effectively integrated into science education to promote sustainability, with a specific focus on enhancing water literacy. The review consolidates research on glocalization in education, its implications on science education for sustainability (SEfS), and strategies for developing water literacy through a glocalized approach.

We start with clarifying the term of glocalization and its connection to education and literacy. This discussion leads into a systematic review of the research literature using the following databases: Web of Science (WoS), Scopus, Dimensions, and ERIC. The search process ended in the identification of 27 research papers relating the concept of glocalization to science education. These papers are finally discussed to create a framework about strategies for science education to promote a deeper understanding of the interconnectedness

between global and local issues, as well as a conceptual framework that may provide guidance to operate water education for sustainability.

2 Glocalization, Education, and Literacy

2.1 The Concept of Glocalization

The term "glocal" combines "global" and "local." The term and its noun form, "glocalization," originate from the Japanese word "dochakuka," which initially referred to adapting farming techniques to local conditions (Kerkhoff et al., 2020). In business, it signifies global localization, where products are tailored to local tastes while maintaining global applicability. Roland Robertson, a sociologist, popularized this concept and noted that many global products and practices acquire local characteristics (Robertson, 1995). Khondker (2005) further described glocalization as involving macro-localization (expanding local ideas globally) and micro-globalization (integrating global processes locally).

Giddens suggested that glocalization revives local identities, while Ritzer introduced glocalization to describe the global expansion's impact on localities (Ritzer, 2003). Glocalization differs from related concepts like indigenization, which adapts Western modern social sciences to non-Western contexts (Nederveen Pieterse, 2009). Indigenization involves deeply adapting and modifying foreign concepts to align with local cultural contexts and traditions (Ferguson, 2005). In contrast, glocalization emphasizes the adaptability of global products or ideas to local conditions while retaining their global essence, making it a highly relevant and applicable concept (Khondker, 2005). Robertson (1995) saw globalization as neither recent nor solely modern, emphasizing the mutual influence of global and local processes. In terms of culture, Nederveen Pieterse (2009) identified three views on globalization: cultural clash, homogenization, and hybridization. Glocalization aligns with hybridization, integrating global and local elements to create a unified approach. In discussions about glocalization, some writers tend to equate it with hybridization, which can be somewhat misleading. Glocalization involves blending or adapting two or more processes, one of which must be global and one local. However, hybrid versions can exist without involving local elements (Khondker, 2005).

Glocalization is a great example of blending and connecting global and local contexts while valuing the significant contributions of different communities and cultural contexts. Glocalization is based on the idea of creating a "third culture" where diverse cultural communities work together to build respectful, engaging, and inspiring spaces. This "third culture" is a place where different cultural groups come together and interact through dialogue, negotiation, and meaningful engagement (Patel & Lynch, 2013). Boyd (2006) explained that glocalization is the connection between "global and local togetherness." Khondker (2004) described glocalization as similar to globalization and stated that its strong appeal is eliminating the fear of difference without eliminating difference itself. Eliminating the fear of difference is one of the desired goals of glocalization in education.

The main ideas of glocalization are (1) embracing diversity as central to social life; (2) acknowledging that globalization preserves differences; (3) recognizing the significance of history and culture for groups' experiences; (4) alleviating fears of identity loss; and (5) offering a realistic, historically informed perspective that acknowledges ongoing conflicts and tensions (Amponsah & Babarinde, 2022; Khondker, 2005). These five points illustrate how glocalization allows cultural diversity and local identities to remain and develop in the

context of globalization. "Glocal" describes an educational environment that merges global and local knowledge, experiences, and engagement, considering ontology, epistemology, and ethics. It highlights the interconnectedness of global and local realities, the need to address sustainability by integrating global and local perspectives, and the ethical implications of knowledge, challenging existing values and power structures (van Herten & Perez, 2022).

2.2 Glocalization in Science Education

The concepts of "glocal" and "glocalization," originally developed in business and sociology, are now being increasingly recognized in education, especially through the lens of critical educational cosmopolitanism. The aim of glocal education is to bridge global and local perspectives and help students develop identities that are rooted in their local contexts while being connected to the wider world (Kerkhoff, 2017; Kerkhoff & Cloud, 2020). Glocal teaching is based on four dimensions: situated practice, which makes learning relevant to local contexts; integrated global learning, which connects global perspectives to traditional curricula; critical literacy instruction, which focuses on the power dynamics of language; and intercultural experiences that encourage dialogue and reflection on complex social issues (Kerkhoff, 2017; Kerkhoff & Cloud, 2020; Niemczyk, 2019).

The glocal learning concept encourages students to critically examine their roles and responsibilities in a globalized world. It prompts them to reflect on the relationship between local or indigenous knowledge and global power dynamics. For many students, it also fostered a deeper connection with others and the world around them (Areesophonpichet et al., 2020). One effective strategy in this teaching approach is storytelling, which helps students connect with their communities and engage with a variety of knowledge, including modern Western and indigenous scientific perspectives (Samovar and Porter, 2004). This method encourages critical reflection on the historical evolution of knowledge and the power structures that influence its dissemination (Caniglia et al., 2018). By blending global and local perspectives, glocalized teaching offers the chance to create a collaborative learning environment where diverse cultural worldviews are respected and integrated, empowering students to shape sustainable futures (Patel and Lynch, 2013).

To successfully implement a glocal curriculum, we need to rethink the way we educate and address sustainability challenges across different cultures. This approach is in line with the needs of various industries, improves students' career opportunities, and enhances the expertise of educators in their local contexts (Pham, 2022). At the primary and secondary education levels, meticulous attention must be given to curriculum planning, implementation, and monitoring. The study suggested that rural universities should be the initial focus of glocalization efforts (Uleanya et al., 2018). These universities, strategically positioned to lead in glocal education, need strong support to ensure that their programs have a meaningful impact both locally and globally (Uleanya, 2022).

Short (2023) argued for incorporating global scientific advances into science education while addressing local environmental issues. This integration helps students understand the global significance of local issues and vice versa. The perspective aligns with the need to incorporate technological advancements in science education, as Zoller (2013) suggested. By linking global scientific principles with local environmental practices, students can apply technological tools and methods to address specific local challenges, thereby enhancing their problem-solving skills. The concept of globalization in science education refers to the integration of science education systems worldwide, involving the standardization

of curricula (Charlton & Andras, 2006; Chiu & Duit, 2011), enhancement of international collaboration (Chiu & Duit, 2011), and reconciliation of local educational practices with global standards (Charlton & Andras, 2006; Stacey et al., 2018). On the other hand, localization in science education aims to connect science with students' everyday lives by incorporating local contexts, cultures, and community values (Bello et al., 2023; Grapin et al., 2023). By combining these two concepts of globalization and localization, incorporating glocalization into science education possibly facilitates an integrative process that balances global standards with local relevance, enabling the adaptation of curricula, teaching methods, and learning practices to align with the cultural and geographical context of each community.

Science education should explore new ways to understand how a person is influenced by personal, local, and global factors. A key part of this exploration involves examining the role of science education in tackling global challenges within the current socio-political landscape, as we critically assess established norms, the scope of science, and conventional dialogues (Adams et al., 2018). Education, including science education, should focus on developing informed citizens capable of making decisions about contemporary issues, particularly those related to science and technology (de Bettencourt, 2000). From a critical standpoint, the main goal of science education should be to help students understand and critically assess science, thereby encouraging their participation in creating a more socially just, equitable, and environmentally sustainable world (Carter, 2008). To achieve this goal, incorporating the concept of glocalization can possibly be advantageous. In line with this concept, glocalization has the potential to support cosmopolitan perspectives in science education through three typologies (Spector, 2020). First, as a project and practice, science education connects scientific knowledge with human rights and global justice. Second, as personhood, science education shapes students' worldviews, fostering global awareness and responsibility. Third, as a cosmopolitan phenomenon, science education addresses global challenges such as climate change and pandemics, which transcend cultural and national boundaries. Through these dimensions, incorporating the concept of glocalization in science education encourages learners to engage in both global and local contexts. This integration enhances the curriculum by combining global scientific knowledge with local environmental and technological practices, deepening students' understanding and equipping them with skills to solve real-world problems contextually.

2.3 Global, Local, Scientific, and Water Literacy Toward Science Education for Sustainability (SEfS)

The concept of literacy, often seen as a single skill, is actually complex (e.g.Guerrero & Sjöström, 2024; Norris & Phillips, 2003). It involves the ability to understand and interpret symbols, words, numbers, and diagrams, and it plays a crucial role in shaping social, economic, political, and cultural dynamics. Scholars like Gee (2008) and Street (1984) argued that literacy comes in various forms that are shaped by different contexts and purposes. For instance, there are differences between vertical literacy, which is taught in schools, and horizontal literacy, which is gained through everyday experiences (Bernstein, 1996). Recognizing these distinctions is important for bridging the gap between school-based literacy and literacy practices in everyday life. This understanding encourages a more comprehensive approach to education (Wallace, 2002).

In today's interconnected world, global (scientific) literacy is becoming increasingly important (e.g.Choi et al., 2011; Georgiou & Kyza, 2023; Mun et al., 2015). This form of

literacy goes beyond basic technical skills to encompass a broad understanding of multiple cultures, languages, and global issues. It informs and is suggested to modernize all areas of education, making it essential for individuals to function effectively in a global society. The concept of glocalization encapsulates the interaction between global and local literacies, where global thinking shapes local practices and vice versa. This dual approach is essential for addressing global challenges at the local level and for preparing individuals to participate meaningfully in the global marketplace (Chew, 1999; Urry, 2003).

At the local level, literacy is an integral part of community life and is influenced by factors such as access to education, clean water, and community resources (Barton and Hamilton, 2012; Mount-Cors, 2016). Often practiced privately, local literacies play a crucial role in community development and daily activities. The concept of "translocal literacy" emerged from the need to understand how literacy practices develop and interact across different contexts, connecting the global and the local. This perspective reimagines literacy as a dynamic, socially embedded process essential for creating meaningful learning experiences in formal and informal educational settings (Medina, 2010; Omerbašić, 2015).

In this evolving landscape, scientific literacy (SL) has emerged as a key framework in science education, with Roberts outlining two main orientations: Vision I and Vision II. Vision I focuses on acquiring scientific knowledge and skills, which aligns with traditional science education that prepares students for scientific careers. In contrast, Vision II emphasizes the contextualization of scientific knowledge, making it relevant and meaningful to individuals and society, thereby broadening understanding of the role of science in everyday life (Roberts, 2007, 2011). More recently, Vision III was introduced by, for instance, Sjöström and Eilks (2018), further broadening scientific literacy by integrating critical, reflexive, and eco-philosophical perspectives, in line with the *Bildung* educational tradition (Sjöström et al., 2017). According to a recent review of different Vision III interpretations, it is about "based on broad scientific knowings, fundamental and digital literacy, and an understanding of our complex world from pluralistic perspectives (cross-disciplinary, critical, history-philosophy-sociology, intersectionality, indigenous worldviews, relationalism) being engaged and prepared for 'glocal' action." (Sjöström, 2024, p. 25). In other words, Vision III promotes critical thinking, socio-eco justice, and global sustainability, encouraging learners to engage in scientific inquiry not simply as a technical endeavor but as a pathway to socio-political action and ethical reflection (Sjöström & Eilks, 2018). This approach aligns with broader notions of global and local literacies, reinforcing the need for holistic and transformative education that prepares individuals to navigate and address the complexities of an interconnected world. This alignment drives the "glocalization" concept, where global perspectives on science and ethics inform local practices, enabling communities to address global challenges in their unique contexts. The *Bildung* tradition provides a philosophical foundation for individual development and personal judgment skills, which the glocal teacher applies by integrating and respecting both local and global contexts (Trippestad, 2015).

Water literacy is a specific application of scientific literacy that focuses on understanding the science of water, its management, and its role in the environment (McCarroll & Hamann, 2020). It involves a range of interconnected competencies (Maniam et al., 2021), such as (1) *scientific and contextual knowledge (water knowledge)*, like understanding the hydrological cycle (science), the social aspects of water (hydrosocial), and how water is used locally and functionally (functional and local knowledge); (2) *attitudinal skills (water attitude)*, which involve people's perceptions of water issues and their emotional or logical reactions (reaction); and (3) *behavioral skills (water behavior)*, such as sustainable actions and practices in everyday water usage. Water literacy is built on broader themes: (1) *water*

sources (e.g., consumption, types of resources); (2) *water management* (e.g., governance, management); and (3) *water-related issues* (e.g., health, economy, ecosystems, water supply). Collectively, these components demonstrate that water literacy encompasses not only understanding concepts but also involves practical, context-aware skills and values essential for managing water challenges at individual, community, and policy levels. This comprehensive concept supports sustainability goals and promotes both local relevance and global awareness, key aspects of glocalized education.

Water literacy is both complementary to and integrated within the broader domains of Earth science literacy (Wyession et al., 2010) and environmental literacy (Covitt et al., 2009; Febriani, 2017). While Earth science literacy emphasizes understanding Earth's systems (e.g., geosphere, hydrosphere, atmosphere), water literacy addresses in detail how water flows and transforms across these systems, from the atomic–molecular scale (e.g., changes of state and solutions) to large-scale human and natural systems (e.g., watersheds, water treatment infrastructure). Environmental literacy encompasses competencies for making responsible decisions regarding environmental issues. Water literacy supports this by equipping learners with knowledge and values to participate in sustainable water management, environmental justice, and conservation.

Water literacy embodies both the scientific-technical aspects of water science (aligned with Vision I) and the broader socio-environmental context (aligned with Vision II). The inclusion of Vision III perspectives in water literacy highlights the importance of critically and reflectively thinking about water issues, socio-economic justice, and global sustainability. Glocalization connects these concepts by aligning global perspectives on water science and ethics with local practices. This approach allows communities to tackle global water challenges within their specific local contexts, using Vision III principles to develop more effective and contextually relevant solutions. This is the main orientation in this paper.

Water literacy is one of the disciplinary competencies essential for sustainable transformation. This literacy strengthens sustainability education by providing the essential disciplinary depth necessary for contextual and impactful application of sustainability competencies (Redman & Wiek, 2021). Water literacy complements independent competencies, such as systems-thinking, future-thinking, and values-thinking, when someone applies sustainability competencies in the context of water. Water literacy naturally involves systems thinking, as it requires understanding how water flows through interconnected natural and human-made systems (e.g., Boon, 2024; Lee et al., 2019). It also involves future-focused thinking, since water issues such as scarcity or pollution require long-term perspectives (e.g., Daniell, 2024; Rosestone et al., 2025). Additionally, values-based reasoning is essential to water literacy, as it helps individuals navigate complex socioscientific issues like water justice, access, or conservation (e.g., Jimenez et al., 2024; Petitt & Forbes, 2019). Concretely, water-literate students should potentially participate in local water monitoring, critically discuss fair water distribution, and advocate for sustainable water use in their communities.

The term science education for sustainability (SEfS) is used in this discussion. Specifically concentrating on water resources, "water education for sustainability" refers to science education focused on water-related contexts. Sustainability education is a broad term that includes several related ideas, such as environmental education, education for sustainable development, education for sustainability, and ecological education, among others (Bianchi et al., 2022). As Sterling (2010) noted, despite differences in terminology, all sustainability education frameworks (e.g., education for sustainability (EfS), education for sustainable development (ESD), sustainability education, and sustainable education) share the same vision of quality education for societies that are in balance with the earth's

carrying capacity. This requires a shift from mechanistic to ecological and holistic education (Jeronen, 2023). This paper adopts the term EfS as the lens considered most appropriate for addressing water literacy, as it aligns with Vision III of scientific literacy, which emphasizes critical thinking, socio-eco justice, and action-oriented learning (Sjöström & Eilks, 2018). Although rooted in Western science, EfS recognizes the role of indigenous knowledge in fostering contextually relevant sustainability education (Zidny et al., 2020). Compared to the term ESD, which is often policy-driven (UNESCO, 2012; Wals, 2014), EfS is assumed to provide a more holistic and flexible approach, allowing for a deeper analysis of water issues in a local context and introducing solutions that are better suited to the specific conditions of a region.

3 Glocalization in the Science, Technology, and Environmental Education Literature

3.1 Method

This section presents a systematic review of web-accessible research literature using several databases: Web of Science (WoS), Scopus, Dimensions, and ERIC. The Web of Science (WoS) and Scopus are considered standard databases for the international research literature. The Dimensions database has a focus similar to Scopus. Dimensions was employed to enhance the scope of document findings as an alternative to Web of Science and Scopus (Thelwall, 2018). ERIC was selected due to its comprehensive coverage of education literature, encompassing all levels of education from early childhood to adult education, with a broad range of publication types referenced. Furthermore, ERIC is suggested to provide a global perspective on education (Canterbury Christ Church University, 2024; Gusenbauer & Haddaway, 2020).

As proof of the broad use of the concept of glocalization, a search in the Web of Science database for the term "glocal*" yielded 2,584 results as of July 3, 2024. This term, with the asterisk, allows for variations like "glocalize," "glocality," "glocalized," "glocalizing," "glocalization," and "glocalisation." The majority of results was in education and educational research (277), sociology (181), and arts (180), with other significant fields including business, communication, and interdisciplinary social sciences. A similar search in Scopus produced 3201 hits, primarily in social sciences (2188), arts and humanities (1051), and business, management, and accounting (470). In Dimensions, the term "glocalization OR glocalisation" yielded 1819 hits, mainly in language, communication, and culture (529), human society (480), and commerce, management, tourism, and services (294). ERIC produced 69 peer-reviewed hits across various educational levels. This broad usage underscores the relevance of glocalization in diverse academic contexts. It also justifies a combination of different databases since the different numbers of hits show that foci and indexing in the different databases are obviously varying.

In this article, we focus on the idea of glocalization in science education to promote education for sustainability, specifically directed at the development of water literacy. Our search was limited to English-language documents in the form of journal articles and book chapters in the WoS, Scopus, and Dimensions databases, as well as peer-reviewed documents in ERIC. Our search is focusing on the idea of glocalization in science and sustainability education. Considering the relationship between science and technology and solving global environmental issues that lead to sustainability, the search included a view

on science, technology, and environmental education. Searching on the "Topic" feature in WoS and "title, abstract, and keywords" in Scopus used the Search Query: glocal* AND (science* OR scientif*) AND (literac* OR educat* OR teach* OR learn*). While in the Dimensions and ERIC databases, we used the Search Query: (glocal OR glocalized OR glocalised OR glocalizing OR glocalising) AND (science OR scientific) AND (literacy OR education OR learn OR teach).

We repeated the search by replacing "(science* OR scientif*)" with (techno*), (environment* OR eco*), and (sustain*) to get an overview of the number of hits in each search category related to science, technology, environmental education, and education for sustainability. We narrowed the focus by selecting the field of research related to education in the database feature. Next, we screened and deleted a number of duplicate documents, documents that were not in English, irrelevant, and did not indicate an empirical research base. The inclusion and exclusion criteria for documents in this literature review are presented in Table 1.

By reading more details on the abstracts and keywords, we compiled a collection of documents related to the concept of glocalization and science, technology, and environmental education, with 4, 7, and 14 documents, respectively. The concept of glocalization related to sustainability in the context of education yielded 15 documents. Our further search focused on water education and literacy, and in the same way as the previous stage, the final results showed two documents that met the criteria related to the discussion of this article. From the entire search for article documents, a total of 42 documents were obtained, with 15 duplicate documents. Therefore, the final number of articles that were included in the review was 27 (these are all marked with * in the reference list). Figure 1 illustrates the literature review flow, from the search process to obtaining the reviewed article. The results in each database were recorded and are shown in Table 2.

These findings set the stage for an integrated discussion on the role of glocalization in science education, sustainability, and literacy. See Table 2 for an easy reference. The discussion of the found references integrates the findings from all three rounds of analysis to examine how science education, sustainability, and literacy intersect within a glocalization framework and how they can inform education about teaching and learning to contribute to water literacy.

3.2 Findings

Incorporating glocalization into science education means adjusting global scientific knowledge and practices to tackle local environmental and sustainability challenges. This approach may help to create a globally informed and locally relevant curriculum. The integration of glocalization may not only improve science education but also overlap with technology and environmental education, offering a framework for comprehending and addressing environmental issues.

The first finding of the literature review indicates that with approximately 2500 hits on the Web of Science and about 3000 hits on Scopus, it is a widely discussed concept in academia. However, based on the specific queries used in this review, only a limited number of relevant publications explicitly address science, technology, and environmental education in relation to glocalization, particularly concerning practical applications in educational settings. Nonetheless, contributions are coming from various regions of the world, including Europe, Latin America, and Asia.

Table 1 Criteria for including and excluding documents in the literature review

	Inclusion criteria	Exclusion criteria	Purposes
Document characteristic screening			
Language	English-only articles	Documents might be available in other languages besides English or be incomplete in English	To ensure worldwide access to the literature and address issues of international importance
Document Type	Peer-reviewed articles or book chapters	Conference papers, books, reports, newspapers, newsletters, magazines, and various other formats of publications	To ensure documents are high-quality by utilizing peer review. Non-article and non-book chapter sources may present varying academic perspectives standards
Content characteristic screening			
Types of evidence sources	The study included empirical data on the execution of educational activities	Documents that are conceptual or theoretical reviews, or that express opinions without offering empirical data	To guarantee that the analysis relies on pertinent real-world practices and offers implementation insights
Content and context	There are discussions about education concerning science, technology, or the environment, as well as the overlaps between these three areas fields	There are no discussions about education related to science, technology, or the environment at all	To ensure the analysis is informed by real-world practices relevant to educational studies concerning science, technology, and the environment, which often overlap

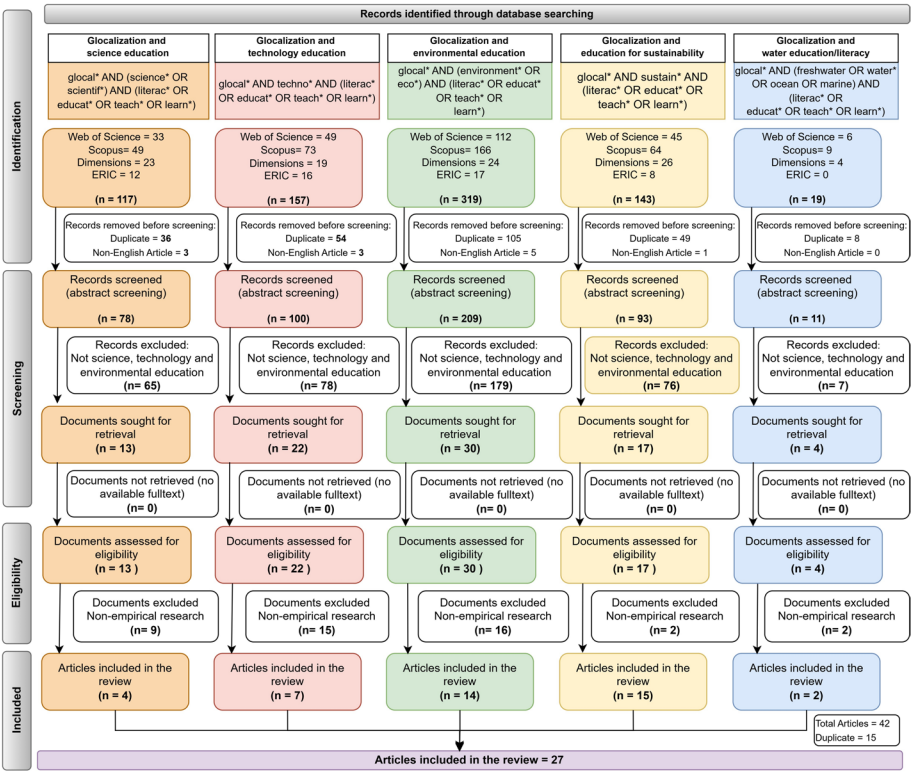

Fig. 1 The process of the literature review

Table 2 Publications addressing the nexus of glocalization, science education, sustainability, and water education/literacy

Related topic	Refined papers and representative references
Glocalization and science education	*N* = 4 (Bruna and Roth 2010; Lachica & Arintoc, 2023; Sharma, 2008; Zuin et al., 2019)
Glocalization and technology education	*N* = 7 (Barker et al., 2013; Caniglia et al., 2018; Hocutt & Brown, 2018; Kidd & Murray, 2020; Smith, 2022; Wang et al., 2022; Ziemba et al., 2016)
Glocalization and environmental education	N = 14 (D'Amico, 2016; Eriksen, 2018; Greenhalgh-Spencer, 2015; Liu & Li, 2019; Mavromatidis, 2020; Meschini et al., 2021; Moreno-Fernandez, 2017; Müller, 2020; Rueda-Ruzafa et al., 2023; Todorovic, 2022; Toffolo et al., 2022; van Herten & Perez, 2022; Velibeyoğlu & Mengi, 2019; Zuin et al., 2019)
Glocalization and education for sustainability	*N* = 15 (Barker et al., 2013; Caniglia et al., 2018; D'Amico, 2016; Eriksen, 2018; Liu & Li, 2019; Malavoloneque & Costa, 2022; Meschini et al., 2021; Rueda-Ruzafa et al., 2023; Siivonen, 2018; Todorovic, 2022; Toffolo et al., 2022; van Herten & Perez, 2022; Velibeyoğlu & Mengi, 2019; Wang et al., 2022; Zuin et al., 2019)
Glocalization and water education/literacy	*N* = 2 (D'Amico, 2016; Dubey & Mishra, 2021)

It should be noted that glocalization concerns not only the local context but also how the local context influences the global community. Therefore, it is crucial to devise strategies for adjusting the curriculum to advocate for glocalization. From a science educator's standpoint, it is essential to bear in mind the following strategies:

(1) *Understanding local realities:* To successfully adapt the curriculum for glocalization, it is essential to have a profound understanding of the local context. This entails a comprehensive grasp of the local culture, history, language, and traditions (Zidny et al., 2020). Equipped with this knowledge, educators can carefully customize the curriculum to align with and respect the local culture and traditions. Moreno-Fernandez (2017) associated the idea of "glocal" with environmental education by examining the Eco-School program. This program provides local and global perspectives on social and environmental issues, demonstrating how glocalization is integrated into education. Environmental education within the Eco-School movement often includes scientific components to understand environmental challenges. This highlights the connection between environmental education and science education in analyzing and understanding social and environmental issues.

Sharma's (2008) study showcased how science teachers in India used a bricolage approach to adapt global science discussions for the rural context of Madhya Pradesh. This illustrates glocalization, where global concepts meet local needs. The research underscores a sociocultural approach in science education, promoting pedagogical adaptability to make learning relevant to students' environments. It highlights the importance of empowering teachers to create meaningful, adaptive learning experiences. Zuin et al. (2019) demonstrated how the idea of green chemistry, a global concern, was implemented within the Brazilian citrus processing industry. This embodies the concept of glocalization, where global issues are tailored to local circumstances and significance. Integrating green and sustainable chemistry into university curricula is a part of science education that aligns with the SDGs. The goal is to prepare future professionals who can think critically and apply sustainable solutions to address environmental challenges at both local and global levels. This research links environmental and science education by using green chemistry experiments to instill sustainability awareness among university students.

(2) *Incorporating global perspectives:* To provide a well-rounded education, it is essential to not only acknowledge the local context but also integrate global perspectives. This involves educating students about diverse cultures, various belief systems, and different customs from around the world. Müller (2020) highlighted the concept of glocalization by illustrating how educational and capacity-building practices within the REDD + (Reducing Emissions from Deforestation and Forest Degradation) practices, particularly through the Norwegian International Climate and Forest Initiative, seek to harmonize global interests with local actors, including Indigenous communities. In this context, environmental education is crucial in bridging local knowledge with global objectives in carbon governance, fostering a more interconnected understanding between local stakeholders and global environmental initiatives. Educational materials tailored for local actors impart environmental principles and incorporate scientific insights on ecology, carbon, and climate change. As a result, environmental education in this context encompasses elements of core science education.

D'Amico (2016) explained how rural communities in the Ecuadorian Cloud Forest established local and regional institutions to govern the environment by combining global ideas with local input. This approach to glocalization integrates local sustainability practices with global perspectives to address environmental challenges effectively. The project on environmental education linked with the development of governance institutions emphasizes scientific concepts related to ecology, water security, and food security. This proactive initiative educates communities about sustainability and enhances their scientific knowledge, which is essential for effective environmental practices. In a study conducted by Velibeyoğlu and Mengi (2019), it was demonstrated how local environmental practices in Izmir (Turkiye) aimed at meeting EU standards and contributing to environmental policy learning at the city level and beyond. This illustrates glocalization by adapting global policies to local contexts through innovative practices. Environmental education in this context involves understanding environmentally friendly practices and integrating them into local policies. This environmental education also encompasses science education, as it involves applying scientific knowledge to practical solutions and innovations in environmental management.

In 2018, Eriksen connected global environmental issues to local challenges in Gladstone, Australia, emphasizing the clash between industrial growth and sustainability. This reflects glocalization, linking global impacts to local conditions. The study stressed combining environmental education with scientific knowledge to grasp the industry's effects on health and the environment. Similarly, Todorovic (2022) showed how sustainable food production in Serbia reflects global trends while addressing local contexts, illustrating glocalization by aligning global issues like food ethics with local practices. Sustainable food production discussions require an understanding of ecosystems, agriculture, and health. Environmental education in this context focuses on understanding the environmental effects of food production methods and requires scientific knowledge to guide decisions and policies. It encompasses science education elements, including ecology, biotechnology, and agricultural practices' environmental impacts.

(3) *Making use of technology:* Technology has the potential to promote glocalization effectively. Educators can utilize technology to establish connections with classrooms globally, exchange resources, and engage in collaborative projects. Greenhalgh-Spencer (2015) discussed the use of glocal pedagogy to merge global awareness with local practices in an ecosophical context. This demonstrated how glocalization applies in education to deepen the understanding of social, economic, and environmental links. The ecosophical method integrates technology and pedagogy in environmental education, emphasizing the understanding of living systems and impacts. This approach is vital for science education, focusing on human–environment relationships and applying scientific knowledge globally and locally.

In a study, Wang et al. (2022) demonstrated how SnehAI, an AI chatbot developed for social impact in India, incorporates the concept of glocalization by customizing global technology (AI chatbot) for local contexts (Hinglish, India-specific sexual health issues). This exemplifies glocalization, where global technology addresses local needs. SnehAI demonstrates how AI can engage vulnerable groups interactively and support science education by making reproductive health concepts more accessible. Additionally, Hocutt and Brown (2018) explained how the implementation of global technologies like Google Apps for Education (GAFE) necessitates adaptation to local institutional policies and

specific needs, reflecting glocalization whereby global technology is modified to fulfill local requirements and limitations, taking into account global ramifications. The use of GAFE in education exemplifies how digital technologies can effectively facilitate teaching and learning, enabling collaboration across different times and locations while also navigating local policies and practices, which is fundamental to technology education.

In the UK, Kidd and Murray (2020) discussed how teacher education adapted to digital spaces due to COVID-19 while upholding global principles. This reflected the concept of glocalization, where local educational practices are transformed and innovated in a wider global context. This study highlighted how educational technology was used to move teaching practices online, addressing the challenges posed by the pandemic. It emphasized the role of technology education in sustaining and adapting pedagogy when traditional methods are unfeasible. In a similar context, Barker et al. (2013) reflected on glocalization by showing how information technology, such as e-learning, was adapted in a local context with limited resources while still aligning with global education and health trends and addressing the specific needs of students at the University of Nairobi (Kenya). It enhances global learning and health information access but needs local adaptation for sustainability and effectiveness. Furthermore, Smith (2022) related the concept of glocalization to technology design for older adults, integrating the specific needs of a local community with global design practices that prioritize usability and accessibility, benefiting all users. This reinforced the importance of tailoring technology education to meet the needs of older adults, requiring information literacy and adjustments to their mental models. Lastly, technology education for older adults is closely related to science education, as both require a deep understanding of technology and scientific principles, for example, teaching online maps that include technological skills and knowledge of navigation and geography.

Caniglia et al. (2018) developed a global–local (glocal) model as part of The Global Classroom, a joint project between Arizona State University (USA) and Leuphana University of Lüneburg (Germany). This study illustrated how the glocal model facilitates transnational collaboration using digital technologies to connect universities worldwide and promote local learning. It highlighted the significant role of technology education in promoting cross-border sustainability teaching. Ziemba et al. (2016) showcased the concept of glocalization by linking nursing students from the USA and Haiti through video conferencing, enabling them to learn from and about different local contexts. This application of international video conferencing illustrated how technology education can overcome geographical obstacles and facilitate cross-border collaborative learning.

(4) *Supporting student perspectives:* Encouraging student voices in the classroom is crucial. Students should have ample opportunities to express their ideas and viewpoints, fostering the development of critical thinking skills and promoting glocalization. For instance, an educator could prompt students to reflect on their experiences with various languages, enabling them to not only contemplate their encounters but also gain exposure to different languages and cultures.

Lachica and Arintoc (2023) examined how science communication concepts are applied globally and their impact on postgraduate education in the Philippines. The discussions indicated how science communication is perceived on a global scale and its local application. Science communication serves as a means to make science relevant and influential in various social settings by sharing accurate information and engaging with scientific and technical knowledge. Another study by Bruna and Roth (2010)

highlighted the connection between glocalization and science education. It emphasized the importance of adapting the curriculum and teaching methods to reflect individual uniqueness and local experiences, while also addressing students' global needs and circumstances. Glocalization in science education involves tailoring the curriculum to incorporate the cultural backgrounds of students, including immigrant students, and enabling them to explore their uniqueness and integrity within a global context. Science education should empower students, particularly those from marginalized backgrounds, to recognize their potential and address social injustices. This can be achieved through curriculum and instructional reforms that focus on self-improvement and individual uniqueness, granting students a voice and acknowledgment in both global and local contexts.

Van Herten and Perez (2022) discussed an online learning program that illustrates how climate change education combines global perspectives with students' local experiences. The LivExpCC (Lived Experiences of Climate Change) model allowed students to link their personal and local experiences to global impacts, demonstrating the concept of glocalization, where global issues are understood through specific local contexts. This program's environmental education integrates scientific, economic, and social knowledge about climate change, highlighting how education concerning environmental issues often involves scientific understanding. Student essays that connect local experiences to global impacts showed how environmental education interacts with science education to provide a comprehensive understanding of ecological issues. Another study by Mavromatidis (2020) connected the concept of glocalization to architecture education through the development of the idea of "climate heterotopia," which combines local and global dimensions in space design. This concept creates an architectural design studio that considers local social and climatic characteristics while integrating global perspectives, thereby addressing environmental challenges at various scales and contexts. Student outputs might include essays that present a personal interpretation of the term climate heterotopia and develop an architectural and/or urban program based on this interpretation in relation to glocal social and urban characteristics, as well as collages or photomontages depicting the spatial atmosphere they aim to create. This education involves not only environmental aspects but also scientific elements, such as the principles of physics and ecology that influence contemporary architectural design. Thus, this approach demonstrates the relationship between environmental education and science education through practical applications in space design and planning.

(5) *Providing experiential learning opportunities:* Experiential learning opportunities are an effective tool for promoting glocalization, which encompasses field trips, service-learning projects, and cultural immersion programs. Regarding field trip activities, in a study by Meschini et al. (2021), the concept of "Glocal Education" was explored, which involved blending global environmental knowledge with local educational activities to enhance tourists' environmental awareness and interest. This study demonstrated the application of glocalization in the context of ecotourism, highlighting the connection between environmental education and science. The research revealed that activities like biology lessons and excursions can effectively increase tourists' environmental knowledge and awareness. Toffolo et al. (2022) further connected the glocal concept to tourism through the Glocal Education project. This initiative aimed to enhance environmental knowledge and awareness in tourist destinations by linking global tourism impacts to local tourist actions. The study suggested that informal environmental edu-

cation activities can improve tourists' environmental literacy by integrating scientific elements, such as understanding environmental impacts and promoting conservation actions, to support science-based environmental learning.

In service-learning projects, Rueda-Ruzafa et al. (2023) highlighted the concept of glocalization by combining local public health knowledge with global citizenship values. Their study on nursing students' management of acute pesticide poisoning in a simulated primary healthcare scenario demonstrated how environmental education intertwines with science education. The simulation used scientific knowledge from toxicology, biology, and environmental health, helping students address local environmental issues while preparing them to contribute to the global Sustainable Development Goals (SDGs). This approach suggested the integration of environmental and science education in practical clinical settings. In another activity related to the cultural immersion program, Liu and Li (2019) involved 26 teacher education students in an a/r/tographic exploration of local cultures and ecologies during a 1-week global teacher education program at a large urban university in China. Participants from eight Chinese provinces/municipalities, as well as the countries of Brazil, Canada, South Africa, South Korea, and the USA, shared and reflected on local cultures and ecologies through activities such as creating photo collages, writing autobiographical reflections, creating children's books, and planning lessons. This approach demonstrates how generosity, as a universal value, is expressed through exploring local cultures and ecologies in a global context. By engaging students from different countries in reflecting on and sharing their local cultures and ecologies, this study reflects the concept of glocalization, where local perspectives and values interact with global understandings to enhance educational experiences. This exploration highlights how knowledge of local ecologies can shape global perspectives.

The various studies discussed above show that integrating the concept of glocalization into science education possibly provides a powerful framework for fostering a curriculum that is globally informed and locally relevant. By aligning global scientific knowledge with local environmental and sustainability challenges, educators can develop a more holistic approach to teaching. This approach has the potential to enhance scientific literacy, intertwine with technology and environmental education, and encourage students to understand and address environmental issues within their specific contexts while recognizing the broader global implications. Through strategies such as understanding local realities, incorporating global perspectives, utilizing technology, supporting student voices, and providing experiential learning opportunities, science education can promote a deeper understanding of the interconnectedness between global and local issues. Finally, this glocalized approach is suggested to prepare students to become active participants in addressing global challenges through locally grounded solutions, fostering a sense of social responsibility and sustainability.

4 Implications of the Concept of Glocalization for SEfS with a Focus on Promoting Water Literacy

The concept of sustainability encompasses a broad range of definitions, but at its core, it embodies an evolving state that strives to meet the needs of both present and future generations while operating within the limits of our environment (World Commission on Environment & Development, 1987). When approached from the perspective of human action,

the concepts of sustainability and sustainable development offer a framework for evaluating the interplay between contemporary human endeavors and their enduring impact on the future (Persson & Erlandsson, 2014). In the context of education, sustainability education aims to equip students with the knowledge, methods, and tools to address sustainability issues, emphasizing self-determination, diverse perspectives, and a holistic approach through real-world and collaborative problem-solving (Larsson & Holmberg, 2018).

4.1 The Concept of Glocalization for SEfS

The analysis of the literature reveals a clear connection between the concept of glocalization and the promotion of sustainability through STEM education (i.e., Liu & Li, 2019; Malavoloneque & Costa, 2022; Rueda-Ruzafa et al., 2023; Zuin et al., 2019), technology-based education (i.e., Barker et al., 2013; Caniglia et al., 2018; van Herten & Perez, 2022; Wang et al., 2022), and science education for citizenship (i.e., Eriksen, 2018; Meschini et al., 2021; Siivonen, 2018; Todorovic, 2022; Toffolo et al., 2022; Velibeyoğlu & Mengi, 2019). STEM education provides individuals with the knowledge and skills to address environmental challenges using customized solutions that are relevant to their local communities, e.g., the protection of water resources. At the same time, technology-based education allows for the application of global knowledge in local contexts through interactive tools and media. Science education for citizenship empowers students to understand and take responsibility for scientific issues in society, combining global perspectives with local initiatives. These diverse educational approaches complement each other in developing the understanding and skills needed to address sustainability concerns from a global and local perspective.

Klekotko et al. (2018) suggested empowering local communities by challenging the narrative of neoliberal globalization, thereby transforming the idea of "Think Global, Act Local" into "Think Locally, Act Globally." This approach emphasizes the importance of local communities becoming more goal-oriented and leveraging functional proximity globally. Persson and Erlandsson (2014) presented three essential levels for incorporating a glocal perspective: the personal, local, and planetary dimensions. The concept emphasizes viewing each individual as a transactional process that cannot be separated from its environment, whether that environment is local or global. This perspective emphasizes the interconnection between individuals and the planet as a whole. It indicates that work performance and human action can be executed in a way that is either ecologically sustainable or unsustainable. Figure 2 illustrates the relationship from a glocal perspective.

The connection between individuals and social creatures and the ecological environment is emphasized in the various literature discussing glocalization in the context of sustainability and education. This connection is significant because sustainability and glocalization are relevant to people across generations and ecological boundaries (Persson & Erlandsson, 2014; Schröter et al., 2017). To understand this, we can analyze it from the perspective of social systems and ecological systems. This approach aligns with the framework put forward by Ostrom (2009) and utilized by Narh et al. (2023) to study the Social-Ecological System (SES). SES involves the complex interplay between human (social) and natural (ecological) environments. Social systems encompass human interactions and interdependence governed by rules, norms, social relationships, and economic factors. On the other hand, ecological systems represent the interconnected components of the natural environment that sustain ecological balance. The subsystems in SES mutually influence each other. These subsystems consist of resource systems, resource units, governance systems,

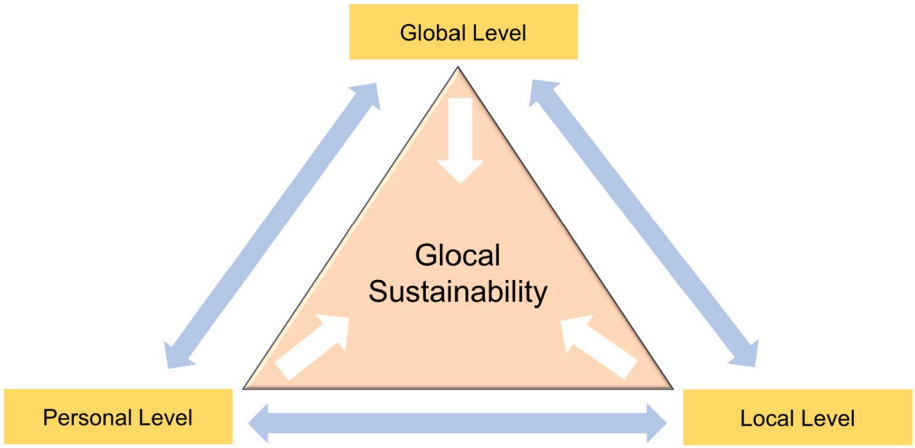

Fig. 2 A glocal perspective contributing to sustainability (adapted from Persson & Erlandsson, 2014)

and actors (Ostrom, 2009). Resource systems and units are ecological components, while governance systems and actors are social components.

The idea behind SES is that the natural environment provides resources for humans, and in utilizing these resources, humans also impact the biophysical environment (Narh et al., 2023; Ostrom, 2009). The link between society and the biophysical environment underscores the importance of the functioning of ecological systems and ethical management, which are crucial for our survival (Fischer et al., 2021). This SES is in line with the principle of sustainability, which emphasizes the balance between human needs and planetary boundaries. Sustainability prioritizes all life and the planet, ensuring human activity remains within planetary boundaries (Bianchi et al., 2022). In the SES perspective, sustainability can only be achieved when the interaction between social systems and ecological systems is in a condition that allows for ecosystem regeneration and social well-being simultaneously. In essence, the interactions within socioecological systems play a crucial role in shaping life on Earth, and the use and availability of water are one of the central components thereof. Thus, the concept of glocalization for SEfS within the SES framework refers to an educational approach that integrates global and local perspectives to help students understand the complex interactions between human and environmental systems.

4.2 The Concept of Glocalization for SEfS with a Focus on Promoting Water Literacy

In the context of water education for sustainability, viewed through a glocalization lens using the SES framework, resource systems can be approached from two perspectives: as water systems on Earth and as educational systems, each with its own units. The social system includes management, which will be examined from the perspective of water management as a natural resource and educational management as a societal practice. All these components interact to produce the outcome of water education for sustainability. In particular, these interactions consider the concept of glocality, which was previously discussed, to achieve sustainability. This is illustrated in Fig. 3.

The SES framework helps identify relevant variables in sustainability studies, including water resources sustainability. Without this framework, research on various resource systems remains fragmented. SES provides common variables for instrument design, data

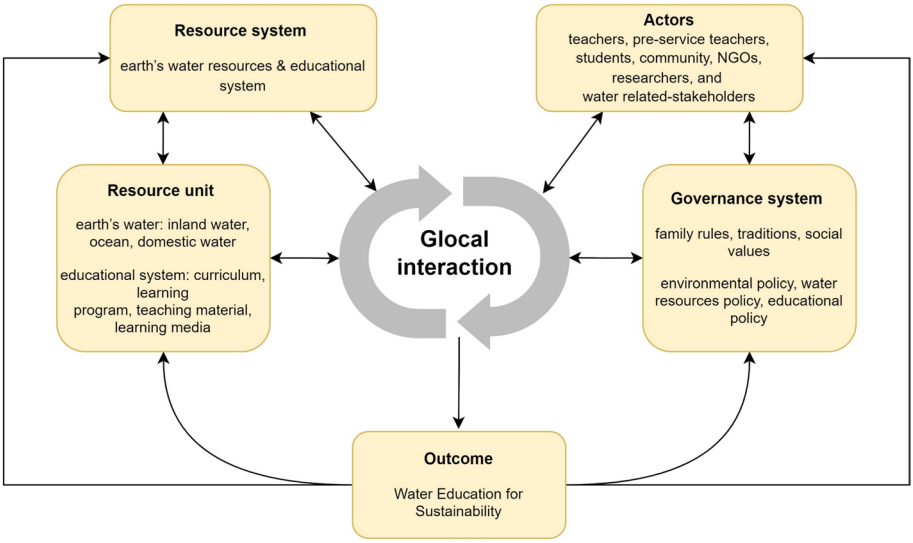

Fig. 3 A Social-Ecological Systems (SES) framework promoting water education for sustainability through glocal interactions (modified from Narh et al., 2023; Ostrom, 2009)

analysis, and evaluation of sustainability policies (Ostrom, 2009). Looking further into the SES subsystems, involving actors and their governance systems, this aligns with the community-involved water education design framework previously proposed by Imaduddin and Eilks (2024). SES offers a clearer interpretation of how social and ecological subsystems can interact in real situations through a glocal perspective, leading to the implementation of water education for sustainability. Based on the literature review, we found only a few examples of practical implementation of glocalization concepts in water education that promote sustainability in non-formal education settings (i.e., D'Amico, 2016; Dubey and Mishra, 2021). These practices are presented in Table 3.

D'Amico (2016) and Dubey and Mishra (2021) highlighted how global practices are applied and modified in local contexts for water sustainability, but do not specifically integrate this concept in the context of formal water education. D'Amico (2016) reviewed implicitly how water education is linked to sustainability in Intag, Ecuador, through environmental education in schools and community-based water management. Local residents, including women, link healthy forests to water security and well-being. Awareness of the importance of clean water and forest conservation is part of sustainability efforts. The concept of glocalization emerges in how local communities link healthy forests to water security, as well as the role of international organizations in supporting local initiatives. Dubey and Mishra (2021) did not discuss water education directly, but there are initiatives that aim to increase community awareness of sustainable water management. This article highlights the increase in community awareness of water management through community-based programs. The concept of glocalization is seen in the collaboration between local communities, NGOs, and government agencies to adapt global practices to local contexts, such as social norms in water management and the use of rain gauges. Both studies focus more on environmental awareness and community participation without a systematic approach that connects global water issues and local challenges in the science curriculum. In addition, these studies are more descriptive in nature without offering a concrete educational model.

Table 3 Examples of glocalization in water education viewed on the Social-Ecological Systems (SES) framework

References	Resource system	Resource unit	Governance system	Actors
D'Amico, 2016	The environmental resources are managed and protected by rural communities in the Ecuadorian Cloud Forests, focusing on water and food security	The specific elements within the resource system, such as water sources and food production systems, that are actively managed and utilized by the communities	The regional and trans-regional institutions and communities of practice are created by rural women and men to manage environmental governance and sustainability	Rural women and men in the Ecuadorian Cloud Forests who engage in creating and sustaining environmental governance practices, as well as drawing upon global discourses and civic participation
Dubey & Mishra, 2021	The watershed management programs and water resources in the Velchal watershed area in Rangareddy District, Telangana (India)	Water resources within the Velchal watershed, including potable water and watershed infrastructure	The management and policy frameworks established by the Government of India for watershed management, including local, regional, and national oversight	Government officials and policymakers; local stakeholders and beneficiaries; Researchers and facilitators; NGOs

Thus, the implications of glocalization for SEfS need to be further discussed to ensure that science learning is community-based and builds students' understanding of global–local linkages in water management for future education.

Glocalization for SEfS, emphasizing water literacy, refers to the integration of global water concerns, such as climate change, transboundary pollution, and governance, with local issues like community access to water, watershed management, and conservation practices into the science curriculum. This concept gives rise to the following ideas:

(1) Glocalization fosters systems thinking, helping students understand the interplay between global influences and local contexts in water sustainability.
(2) Glocalization connects global frameworks like the SDGs with local water management strategies and incorporates real-world water-related issues into science subjects.
(3) Community-based learning engages students with local stakeholders, including water quality monitoring and conservation projects.
(4) Adaptive teaching is crucial for tailoring global models to varied socio-ecological contexts, making water education relevant.

By embedding glocalization into water education, science learning has the potential to become more community-focused, enhance students' scientific and water literacy, and prepare them as informed decision-makers for sustainability efforts at both local and global levels.

4.3 A Proposed Framework on Glocalization for SEfS with a Focus on Promoting Water Literacy

EfS is closely connected to the challenges and opportunities brought about by the move towards sustainability, e.g., in sustainable water use. They represent a transformative and comprehensive educational approach that includes curriculum, students, and teachers, as well as knowledge, attitudes, behaviors, and values (Gorski et al., 2023). While sustainable development has been integrated into the educational curriculum in various countries as a compulsory subject (Martínez-Borreguero et al., 2019), several studies suggested that school approaches should include community environmental education programs to enhance citizens' knowledge, attitudes, and behaviors in this area (Biasutti & Frate, 2017; Grodzińska-Jurczak, 2001). This also includes providing education on sustainability for teachers in general and on water education in particular. Emphasizing sustainability necessitates enhancing teachers' transformative learning (van Der Klink, 2023). Fletcher-Wood and Zuccollo (2020) emphasized the potential of professional development to impact learning outcomes significantly. Therefore, improving teacher capacity is a top priority to ensure the successful adoption and implementation of water education worldwide.

Improving teacher capacity has implications for implementing professional development programs that should be oriented towards a transformative approach. This approach in water education has great potential to be the basis for glocalization in SEfS, ensuring that science learning is not only based on local contexts but also connected to global challenges and solutions. This leads to awareness and action for long-term sustainability, as the orientation of the critical Vision III of scientific literacy (Sjöström & Eilks, 2018). This transformative approach involves a process that unfolds across three interconnected and interacting spheres (O'Brien & Sygna, 2013).

(1) In the practical sphere, science education needs to incorporate water literacy into the curriculum through a glocalized approach, connecting global issues like climate change and water crises with locally based solutions, such as water resource management by local communities.
(2) In the political sphere, educational transformation requires policy support that accommodates the glocalization perspective in science education. This includes developing a curriculum based on social-ecological systems and collaboration between schools, governments, local communities, and maybe international organizations to design learning that is globally and locally relevant.
(3) In the personal sphere, teachers serve as glocalization agents by fostering a critical understanding of water sustainability in both global and local contexts.

In line with the significance of a transformative approach, Boeve-de Pauw et al., (2022) stressed the significance of incorporating environmental principles into well-crafted professional development programs. These principles include holism, which addresses the intricate interconnectedness of sustainability issues; pluralism, which values diverse perspectives; and action orientation, which contributes to solutions for global environmental challenges. Designing professional development for sustainability, including water issues, requires collaboration among education, industry, subject associations, academia, and professional development organizations. These sectors bring technical expertise, curricular knowledge, and experience in teacher professional development. Hoath & Dave (2020) advocated collaboration between different sectors to support the development of teachers so that they are better prepared to help learners tackle complex environmental issues over the years. Aside from a better and comprehensive inclusion of water education concepts and pedagogy in initial teacher education, Maashi et al. (2022) proposed a framework that includes four methods for the continuing professional development of teachers: communities of practice (CoP), professional learning communities (PLC), action research (AR), and external experts (EE). This framework can be adapted to promote science education for sustainability, particularly in the context of promoting water literacy globally (Fig. 4).

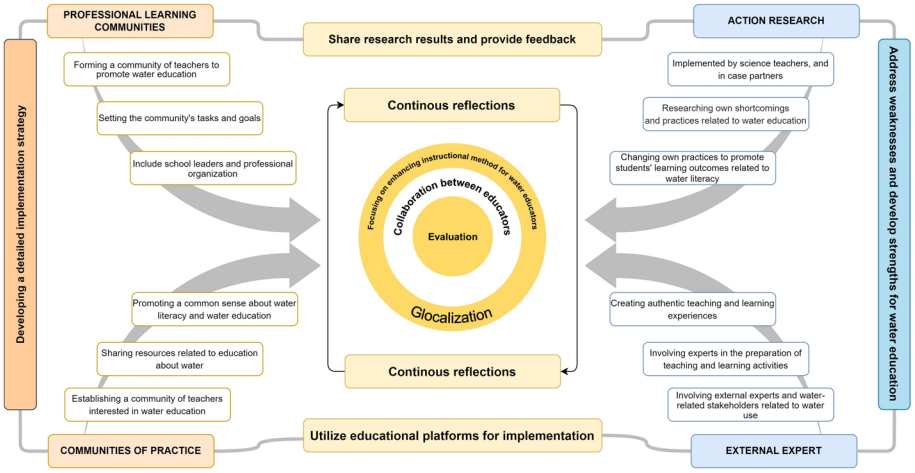

Fig. 4 A proposed conceptual framework for implementing water (science) educators' professional development (modified from Maashi et al., 2022)

In the field of professional development for educators focused on water education and literacy, the illustration represents a trans-local learning approach, opportunities for transdisciplinary research collaborations, engagement with external stakeholders in water education and resources, and the growth of water literacy through the use of educational platforms designed to enhance educators' expertise.

Various professional development programs for teachers arise from partnerships between government agencies, nonprofits, and local communities. For instance, Project WET (Water Education for Teachers) offers science-based resources and training to educators worldwide, aiming to enhance water literacy and promote responsible environmental actions (https://www.projectwet.org/). Additionally, the Clean Water Education Partnership (CWEP) combines efforts from local governments, state agencies, and nonprofits to protect water quality in the Tar-Pamlico, Neuse, and Cape Fear River Basins in North Carolina, USA. CWEP emphasizes public education and outreach through school programs, libraries, community festivals, and mass media campaigns in English and Spanish (https://nc-cleanwater.com/). The Allen County Partnership for Water Quality (ACPWQ) in IN, USA, is a locally funded initiative addressing water quality issues like stormwater, sewer overflows, and conservation. ACPWQ provides resources and engagement opportunities to improve water quality through local collaborations (https://acwater.org/). Furthermore, the Korea Water Forum (KWF) is a South Korea-based organization addressing water issues such as policy, management, and international cooperation. KWF also promotes water education initiatives that contribute to teachers' professional development, including the Asia Pacific Regional Training of Trainers Workshop for educators and trainers in the region. It serves as a platform for discussions among stakeholders like government, academia, industry, and civil society to tackle water challenges globally and nationally (https://eng.koreawaterforum.org/). These examples highlight the need for stakeholder collaboration to foster teacher professional development and environmental education.

Water teacher training programs exist, but more research is needed to see if they actually help teachers and students. Future research could focus on how these similar programs can be implemented in schools or pre-service teacher educational programs, adapted to local cultures, and scaled up with technology. It is also important to find ways to make water education more community-involved and encourage real action. By tailoring to local contexts, the glocalization concept has the potential to ensure the relevance and effectiveness of professional development programs, enabling transformative education where science teachers possibly empower students to tackle local and global water challenges. The transformative approach to teacher professional development is oriented towards systemic thinking skills, enabling educators to implement learning that connects global challenges with students' local realities. This transformation process can occur through both outside-in and inside-out approaches (O'Brien & Sygna, 2013), where global policies and external resources enhance teachers' capacities (outside-in), while teachers' critical awareness of local realities allows them to create more contextual and meaningful learning for students (inside-out). Ultimately, glocalization for SEfS, with an emphasis on water literacy, not only educates about water as an external resource but also reorganizes socio-ecological relationships that strengthen the role of individuals and communities in promoting water sustainability.

5 Conclusion

This article discusses the concept of glocalization based on a systematic literature review with a focus on science, technology, and environmental education in general, as well as on developing the concept of water literacy in particular. The literature review shows that glocalization is a widely discussed concept in academia with several thousand contributions. It also shows that this discussion reached science, technology, and environmental education only very slowly, only in recent years, and when it comes to water education, only two examples were found (D'Amico, 2016; Dubey & Mishra, 2021).

It is, however, that we also saw that water education is in high demand since water quality and availability are directly and indirectly bound to several SDGs. It is not only the SDGs 6 and 14 that directly address issues of water quality and availability; many others are also connected to the use of water resources, like 2 "Zero hunger," 3 "Good health and well-being," or 13 "Life on land," among others. All these challenges impact life on Earth locally but are connected to the global water cycles and the influence of climate change on the availability of water in local places. Given the increasing urgency of the climate crisis, this review highlights how water literacy can possibly serve as an entry point for fostering critical climate awareness in science education (Clark, 2024) and contribute to more transformative environmental learning toward a just and sustainable future (Sezen-Barrie et al., 2025).

The concept of glocalization for SEfS within the SES framework potentially serves as an educational strategy that blends both global and local viewpoints. This approach aims to equip students to understand the complex relationships between human activities and environmental processes. Through this integration, learners can better grasp how different scales of systems interact and influence one another, fostering a more informed perspective on sustainability issues. Glocalization for SEfS focusing on water literacy should combine global water challenges with local issues, like community water access, watershed management, and conservation practices, in the science curriculum. At the same time, it connects with global challenges, like global food supply, health, or migration caused by the lack of water resources in certain areas of the world. Taking the concept of glocalization into science education can enrich the practice of science teaching. This article's discussion shows that integrating the concept of glocalization, if taken into account in science education, can create an opportunity for a powerful framework for developing the science curriculum to make it globally informed and locally relevant. To make the most of the concept of glocalization in science education, curriculum development, integration in pre-service teacher education, and continuous professional development of teachers are needed. A suggested framework may involve creating communities of practice, professional learning communities, action research, and engaging external experts to implement the professional development of water (science) educators.

Author Contribution This review article is part of Muhamad Imaduddin's doctoral dissertation project. Muhamad Imaduddin conceived the idea for this article under the supervision of Ingo Eilks and in collaboration with Jesper Sjöström. The literature search and data analysis were conducted by Muhamad Imaduddin, with additional insights provided by Jesper Sjöström and Ingo Eilks. Muhamad Imaduddin wrote the initial draft of the manuscript, and all authors contributed to reviewing and critically revising it. All authors have read and approved the final version of the manuscript.

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Data Availability This study is a literature review and does not involve original data collection. The supporting information consists of metadata and articles retrieved from subscription-based databases, including Web of Science, Scopus, Dimensions, and ERIC. Access to these sources is subject to institutional or individual subscription policies.

Declarations

Competing Interests The authors declare no competing interests.

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(Articles marked with * were identified by the review in section 3 of this article)

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