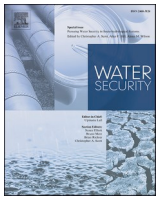
Water Security 26 (2025) 100191



Contents lists available at ScienceDirect

Water Security

journal homepage: www.sciencedirect.com/journal/water-security





Water security in the agriculture and cattle grazing activities: A systematic review

Fernando António Leal Pacheco [a,c,*], Teresa Cristina Tarlé Pissarra [b,c]

[a] CQVR/UTAD – Chemistry Center of Vila Real, University of Trás-os-Montes and Alto Douro, Quinta de Prados, Ap. 1013, 5001–801 Vila Real, Portugal
[b] FCAV/UNESP - Faculty of Agrarian and Veterinary Sciences, São Paulo State University, Access Way Prof. Paulo Donato Castellane, s/n, Jaboticabal, SP 14884-900, Brazil
[c] POLUS—Land Use Policy Group, Paulista State University (UNESP), Access Way Prof. Paulo Donato Castellane, s/n, Jaboticabal SP 14884–900, Brazil

ARTICLE INFO

Keywords:
Agriculture and livestock
Water availability and needs
Surface and groundwater pollution
Water governance
Payment for water services

ABSTRACT

This study reviewed water security issues related to agriculture and cattle grazing activities, based on the findings of 171 articles published in the past two decades, namely 23% before 2020 and 77% between 2020 and 2025. The reviewed studies represented contributions from all continents, with a larger share from Asian, European and American countries. The key results, (*a*) exposed supply–demand challenges related to increasing irrigation needs, allocation scales and regimes, and environmental flow insurance; (*b*) elected rainwater harvesting, drip irrigation and soil moisture sensors as prime water conservation measures, and conjunctive use of conventional and non-conventional water sources as strategic conservation pathway; (*c*) indicated the preservation of riparian forests and wetlands, coupled with agriculture and livestock management practices, as fundamental measures of surface water pollution control; (*d*) highlighted the need of coupling contamination risk programs with management initiatives and prioritization of action, to effectively protect groundwater resources; (*e*) brought attention to the need of optimizing the use of floodplain recession water as irrigation source in arid regions; (*f*) showed how governance is in the core of a water-secure river basin, especially if the principle of trust and engagement is broadly implemented at all institutional levels; (*g*) and finally, transported into the discussion the role of payments for water services as pathway to aid governance, bringing watersheds towards more resilient levels of water security. As whole, the current review shed light over key challenges of today's water security in the rural environment recommending solutions to overcome them.

1. Introduction

Agriculture and cattle grazing activities consume nearly 70 % of freshwater resources worldwide [1], while nitrate leachates derived therefrom are the most widespread groundwater contamination source representing a serious threat to potable water supply [2] and a challenge for contaminant removal [3]. Climate and land use changes exacerbate this already delicate condition in various ways, namely through reducing availability of water during prolonged draught periods [4], damaging crops during floods [5], and amplified water erosion and river water contamination in the course of land use changes that disrespect land capability [6]. These issues are all matters of concern in the realm of water security screened through the lens of farming activities, and for that reason are worth of a systematic review for updating the state of the art on that subject. Thus, providing a comprehensive review was the general purpose of this study. While gathering the papers to include in the study, we recollected all these concerning matters, but also framed the analysis into a broader perspective, namely the United Nations' standpoint for water security, which is: "*The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being and socio-economic development; for ensuring protection against water-borne pollution and water-related disasters; and for preserving ecosystems in a climate of peace and political stability*" (https://www.unwater.org/). Thus, starting from this definition and the way it applies to the agriculture and cattle grazing sectors, a number of general topics were assembled for review, including:

* Corresponding author at: CQVR/UTAD – Chemistry Center of Vila Real, University of Trás-os-Montes and Alto Douro, Quinta de Prados, Ap. 1013, 5001–801 Vila Real, Portugal.
E-mail addresses: fpacheco@utad.pt (F.A. Leal Pacheco), teresa.pissarra@unesp.br (T.C. Tarlé Pissarra).

https://doi.org/10.1016/j.wasec.2025.100191
Received 24 May 2025; Received in revised form 13 August 2025; Accepted 17 August 2025
Available online 20 August 2025
2468-3124/© 2025 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

- Assessing the availability and demand for water to implement farming production systems, describing the influencing factors;
- Using harvested rainwater for irrigation in agriculture, with the purpose of alleviating water scarcity during draught periods. In that regard, a special attention was given to methods for selecting optimal rainfall collection areas in a river basin and for anticipating irrigation volumes;
- The efficient use of water in agriculture, with particular emphasis on (*a*) new techniques for managing blue and green water, and the support of digital technologies for monitoring the results; (*b*) on community irrigation management; (*c*) and on the reuse of wastewater and other sources;
- Assessing the impact of agriculture on surface water and groundwater quality using hydrological and statistical models;
- Assessing vulnerability and risk of groundwater to contamination by nitrates from agricultural sources using multi-criteria like models;
- The role of floods and their impact on crop productivity of inundated areas;
- Water governance in agriculture, comprising technical training for farmers; adaptation and resilience to climate change; microcredit and other agricultural financing mechanisms; policies, institutions and governance agreements;
- Models and application of PWS – payment for water services, standing for the production of clean water in headwater watersheds with predominantly agricultural occupation.

After selecting scientific articles that have addressed the aforementioned topics in the past two decades, the review critically discussed each topic in a separate section. On the other hand, the sections were presented in a specific order, which, to the authors' view, generated a smooth flow of information that will help the reader track the story telling straightforwardly. Overall, the literature selected for review brought extensive and pertinent insights on the current status of water security in the agriculture and cattle grazing activities, that we are certain is helpful to the readership of Water Security journal. At this point, we also refer the novelty transported to the scientific literature by this review. There is a growing number of papers talking about water security from a diversity of standpoints [7–11], either focused on global- or local-scale problems [12], either touching one or all of its dimensions [13], either considering current or future land use and climate settings [14]. However, to our best knowledge, a systematic review of papers addressing water security in the agriculture and cattle grazing activities is lacking. There is a large number of publications looking at this economic dimension of water security, but the literature is fragmented and therefore requiring a comprehensive synthesis and appraisal. With the current study, we believe have produced a robust summary on that subject and therefore contributed to fill in the aforementioned hiatus.

2. Methodology

Following the searching guidelines set up in the Introduction section, the articles included in the review were compiled from *Science Direct* (https://www.sciencedirect.com/), which is the World's leading database of peer-reviewed literature, encompassing virtually all journals indexed to the most widely recognized scientific rankings such as the Clarivate's *Web of Science* (https://www.webofscience.com/) and the Elsevier's Scopus (https://www.scopus.com/). In this study, the *Science Direct* database was queried through small sentences thoroughly designed to capture the aforementioned topics and dimensions of water security. The sentences were: (1) water availability and demand in agriculture and livestock, (2) harvested rainwater for irrigation in agriculture; (3) efficient use of water in agriculture; (4) river water pollution from agriculture and livestock; (5) groundwater pollution from agriculture and livestock; (6) agriculture, floods and water security; (7) water governance in agriculture; (8) payments for water services in agriculture. The eight queries were performed in separate and the results of each query were sorted by relevance, i.e., sorted by the article's adherence to the sentence. The fifty more relevant articles of each query were considered for further screening, which represented a total of 400 articles. This extra analysis was performed manually, and aimed to include in the review solely the studies closely related to agriculture and(or) cattle grazing activities, which, simultaneously, had been focused on the queried topic. In the end, a total of 171 articles were included in the review and critically assessed for their contribution to the corresponding topic. Finally, we refer that the literature review followed the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [15,16], an approach used in many recent review studies [17–19]. Systematic reviews conducted this way comprise 6 steps: (1) scoping, (2) planning, (3) identification and search, (4) screening, (5) eligibility assessment, and (6) presentation and interpretation. Steps 1 to 5 were described above and are summarized in Fig. 1, where some technical details about the Science Direct's database inquiries are included. Step 6 is presented in Section 3 (presentation of general information about the reviewed articles) and Section 4 (discussion of key findings and integrated analysis of outcomes from different but related articles).

3. Results

The articles included in the review were distributed by the various topics as follows (Table 1): 18 related to water availability and demand; 25 interested on using rainwater harvesting as complementary irrigation source; 28 addressing efficient water use in agriculture; 25 describing impacts of farming on surface water and 30 impacts of farming on groundwater; 12 highlighting the productivity losses of inundated cropland; 19 discussing water governance principles and related issues; and finally 14 addressing the role of payment for water services (PWS) in the financing of water security in the agriculture and cattle grazing activities. The studies covered all the continents (Table 1a), with a larger contribution from Asia (84 studies) and then from Europe (35), the Americas (31), Africa (14) and Australia (7). In Asia, the largest number of studies addressed rainwater harvesting (17), surface (12) and groundwater (15) pollution, and efficient water use (13). Europe also addressed preferably surface (6) and groundwater (8) pollution, as well as efficient water use (7), but not so much rainwater harvesting (1). The concerns about surface (5 studies) and groundwater (5) pollution were also detected in South America, which were accompanied by an interest in PWS (5). In North America, however, the focus was put on efficient water use (4) and harvested rainwater (3). Finally, studies in Africa and Australia did not pay special attention to any specific topic. The reviewed studies covered the most recent years (from 2020 onwards; 77 %), but also some studies dating back to 2003 (23 %). The topics receiving more attention in the last couple of years (2023 – 2025) were efficient water use (22 studies), water availability and demand (17), surface (15) and groundwater (13) pollution.

4. Discussion

4.1. Availability and demand of water for agriculture

The balance between availability and demand for water in the farming sector is primarily a management problem (Fig. 2). In that context, studies highlighted the concerns raised by increasing planting areas or users, as well as by shifts from low- to high-requirement crops, which increased the irrigation water requirements while reducing availability, or introduced water stresses in the crop fields [20–22] Other studies showed how changes in meteorological parameters overtime affected the irrigation needs of crops [23,24], and how simulated socioeconomic development pathways were capable of detecting the impacts of climate change on irrigation requirements while proposing adaption strategies (e.g., irrigated to rainfed crop conversions)[25]. Studies on the climate change-agriculture nexus also involved

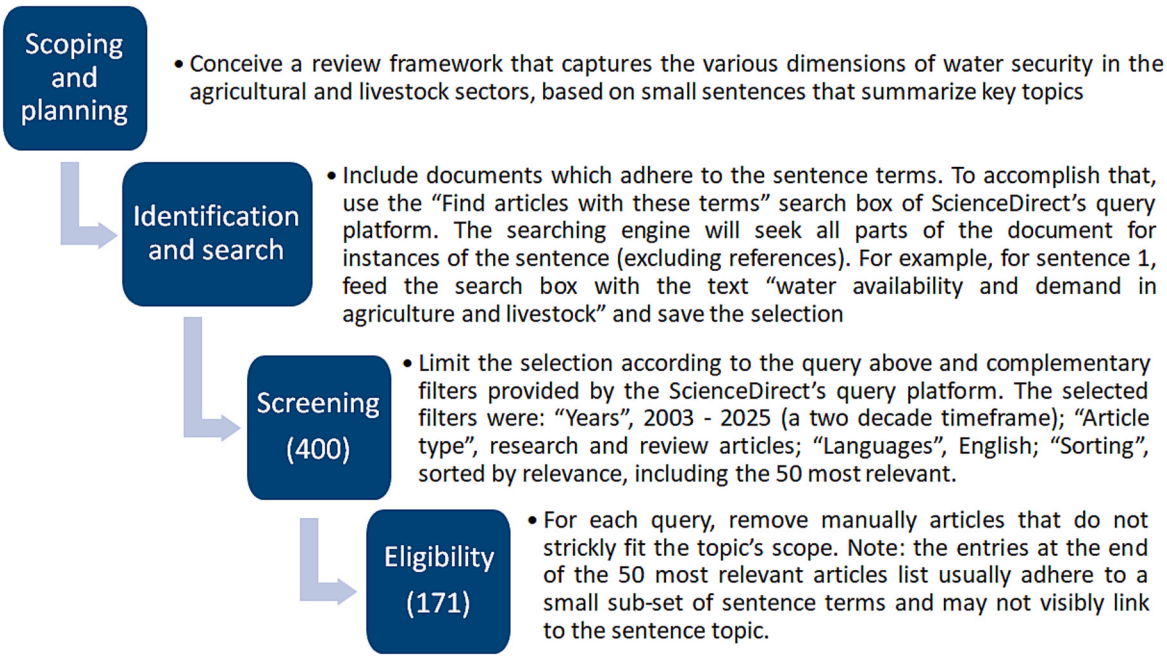


Fig. 1. PRISMA workflow used in the selection of articles for the current review.

Table 1
Distribution of reviewed articles per topic: (*a*) in keeping with their geographical distribution (continental scale); (*b*) in keeping with time (year of publication).

Topic	(a) Distribution of articles per continent						
	Africa	Asia	Australia	Europe	North America	South America	Total
Agriculture, floods and water security	3	6		2	1		12
Efficient use of water in agriculture	1	13	2	7	4	1	28
Groundwater pollution from agriculture and livestock	2	15		8		5	30
Harvested rainwater for irrigation in agriculture	3	17	1	1	3		25
Payments for water services in agriculture	1	3	1	3	1	5	14
River water pollution from agriculture and livestock		12		6	2	5	25
Water availability and demand in agriculture and livestock	2	10	1	3	2		18
Water governance in agriculture	2	8	2	5	1	1	19
Total	**14**	**84**	**7**	**35**	**14**	**17**	**171**

Topic	(b) Year of publication							
	<2020	2020	2021	2022	2023	2024	2025	Total
Agriculture, floods and water security	1	1	1			2	7	12
Efficient use of water in agriculture	3	1		2	1	7	14	28
Groundwater pollution from agriculture and livestock	14		2	1	2	6	5	30
Harvested rainwater for irrigation in agriculture	7	2	2	7	2	3	2	25
Payments for water services in agriculture	2		4	1	2	4	1	14
River water pollution from agriculture and livestock	8	1	1		6	7	2	25
Water availability and demand in agriculture and livestock				1	1	8	8	18
Water governance in agriculture	4	1	2	1	3	4	4	19
Total	**39**	**6**	**12**	**13**	**17**	**41**	**43**	**171**

evaluating how increasing irrigation water demands will affect groundwater levels and the supply of other competing uses with this resource [26]. The management of competing water uses, namely domestic, agriculture, industrial and environmental, considering driving factors such as population growth, was also addressed [27]. An example from the Lalo commune (Benin) revealed how the adjustment of irrigation times to the growth stage of vegetables allowed the sustainable exploitation of groundwater resources for crop production and drinking

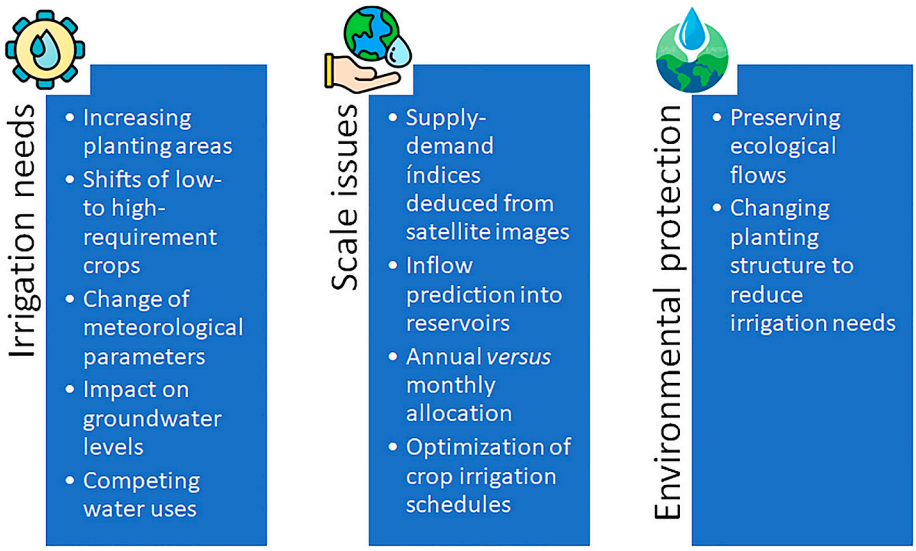


Fig. 2. Availability and demand of water for agriculture are challenged by management and environmental issues, related to irrigation needs and environmental protection, and assessed differently at various spatial and temporal scales.

water supply [28].

Determining the volume of water necessary to supply irrigation of crops on the annual basis is also a multiscale problem, spanning the farm to the watershed, as well as the day to the year. The objectives at the various scales are however different. At farm scale, studies attempted to define supply–demand indices based on high resolution maps of locally influencing parameters, such as precipitation, soil moisture and vegetation indices, invariably obtained from remote sensed data [29], and sometimes including the irrigation process in the framework model [30]. At the watershed scale, scientific research delivered complex models that gather long-term inflow prediction into reservoirs coupled with responses from groundwater levels, reservoir operation strategies based on interval regulation, and water supply risk analyses [31,32]. Studies focused on the temporal scale showed how disaggregation of annual water allocation into the monthly steps help bridging the gap between long-term planning and short-term water management [33]. They also demonstrated how precise regulation of crop irrigation schedules on a daily basis, considering joint changes of precipitation, runoff and water demand, can simultaneously increase crop productivity and water savings [34].

Finally, setting the necessary amount of water to crops is an environmental problem. Agricultural watersheds are essentially composed of water sources, farm lands, urban areas and terrestrial and riverine ecosystems. So, when reserves of water are anticipated for crop supply, the calculations should account for environmental flows that support the aforementioned ecosystems [35]. This can be especially challenging to apply in small rural communities, which already face water scarcity problems even without environmental flow restrictions, but can be mitigated through implementing a cascade of water use restrictions starting from the watershed's spring [36]. Other environmental concerns relate with the carbon sequestration-emission balance of crop fields. Studies addressing this topic showed that changing the planting structure (e.g., areas allocated to cultures with different water requirements) not only resulted in lower irrigation requirements but also in increased yields and carbon sequestration [37].

4.2. Harvested rainwater for crop irrigation

The harvesting of rainwater in the rainy periods to irrigate crops in the dry periods is a common strategy of water security in the farming sector (Fig. 3). For that reason, many studies developed models to determine and predict suitable locations to install rainwater harvesting

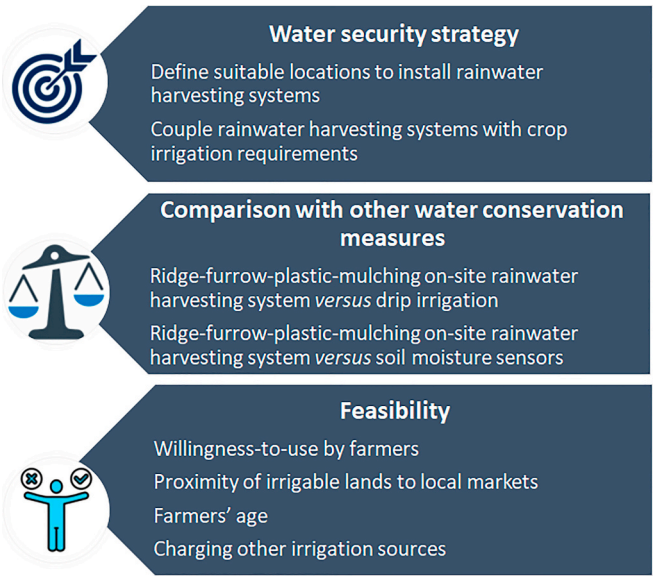


Fig. 3. Rainwater harvesting is strategic for supplemental irrigation of crops, but other water conservation measures such as drip irrigation or soil moisture sensors may perform better. Rainwater harvesting systems also face some feasibility challenges.

systems (RWH) in watersheds, based on the combination of multi-criteria analysis and Geographic Information Systems (GIS) [38–43]. Urban agriculture has also received some attention, in which cases the RWH system relied on rainfall collection areas installed on rooftops [44]. In addition to proposing the use of RWH systems as irrigation sources, some studies revealed specific strategies on how to couple crop irrigation requirements and RWH use. In some cases, the option was to install the RWH system close to the application areas and adjust crop selection to rainfall seasonality. This approach was adopted in the Gansu region (China) where potato has water requirements better fitting the local rainfall events than wheat or corn [45], and for that reason should be planted preferably. In other cases, an irrigation deficit strategy was adopted whereby the use of RWH water was restricted to critical growth periods to avoid shortages of moisture supply to the cultures that could jeopardize the production. Besides controlling soil moisture to the

minimum adequate levels, this strategy saved water in the RWH system allowing to expand the irrigated area and increase crop yields in the sequel [46]. A similar strategy was discussed in the context of onion production in Ethiopia [47]. In the Palghar district of Maharashtra state of India, on the other hand, the strategy was to optimize the RWH size within the farm, because area reductions in small properties severely constrains productivity [48]. As per the results, the RWH area capable to supplement rainfed cultures in the region was 9.9 % of total farmland area while the optimal area was 15.5 %.

The use of RWH in agriculture is frequently tackled in comparison to other irrigation or water conservation strategies. Many examples refer to comparisons with the ridge-furrow-plastic-mulching on-site RWH system [49–53], or variants of that system [54]. For example, one study that covered provinces from northwest China compared the advantages and disadvantages of using the plastic-mulching or drip irrigation in the water supply to apple trees [55]. Drip irrigation outperformed the RWH system considering the corresponding yield improvements of 54.3 % and 19.1 %, respectively. Other similar studies compared the use of plastic-mulching with alternatives based on solar-powered soil moisture sensors that form a high-efficiency rainwater irrigation apparatus. The second solution granted yields 56.2 % larger that the first [56].

A critical issue of RWH in agriculture is feasibility, including willingness-to-use by farmers, financial viability, and water quality concerns in the urban environment. A study carried out in Ethiopia revealed important determinants of RWH's willingness-to-use by farmers [57]. One key determinant was the proximity of irrigable lands to local markets, as farmers working closer to these facilities and hence with crop selling more viable invested more in RWH to avoid production setbacks resulting from water shortages. The same impetus applied to farmers with irrigable areas located away from alternative sources, such as lakes or rivers. Other determinants were the farmers' age, because young farmers invested more in RWH than old ones, and access to credit because farmers with access to credit took more the risk of paying the costs of RWH use. As regards financial viability, farmers generally adopt irrigation sources with the lowest cost. Studies have demonstrated how the financial viability of RWH decreases with the governmental options of charging other irrigation sources, namely groundwater. In Beijing, for example, the RWH systems are feasible if groundwater for irrigation is charged at values significantly larger than 2 Yuan/m^3 [58]. Other studies provided values of willingness-to-pay supplemental irrigation of rainfed cultures from RWH public water reservoirs. One report comes from Ghana, where farmers accept to supplement rainfed cultures with RWH irrigation at 6 to 7 USD/ha.season [59]. As mentioned above, water quality is an issue of RWH feasibility when these systems are used to supplement irrigation of urban agriculture. This is because rainwater collected from rooftops can be contaminated by potentially toxic metal (oid)s, synthetic and organic chemicals and waterborne pathogens, which are not entirely removed by established RWH treatment processes such as solar disinfection, bio-sand filtration or UV irradiation, among others [60–62].

4.3. *Efficient water use*

The challenge of efficient water use in agriculture can be overcome through, (*a*) implementing water conservation measures and optimal water allocation schemes; (*b*) conjunctively use various water sources including wastewater or desalinized water; and (*c*) introducing technological innovations in the irrigation system (Fig. 4). In general, water conservation measures comprise hydrological, agronomic, engineering and physiologic pathways [63]. The hydrologic pathway, essentially focused on RWH, has been the topic of Section 4.2 and will not be discussed further. The agronomic pathway deals with adjusting water supply to crop needs in space and time to optimize crop yield, where the needs represent the amount of water used by the plants through evapotranspiration. In that regard, crop yield and evapotranspiration fit to a straight-line function in which the slope describes the plant's sensitivity to water deficit. Under efficient irrigation, crop yield and water supply would fit to the same straight-line function, but in general the fit bends to a logarithmic function because water losses linked to overirrigation, non-uniform application and water restrictions, isolated or in combination, reduce the actual yield relative to the expected yield. Thus, the agronomic pathway is sought to address these issues, starting with accurate assessments of crop evapotranspiration [64]. As regards water restrictions, a couple of situations are worth mentioning: (*a*) restrictions imposed by water management agencies in response to prolonged drought events; (*b*) land adjustments in response to sustainable

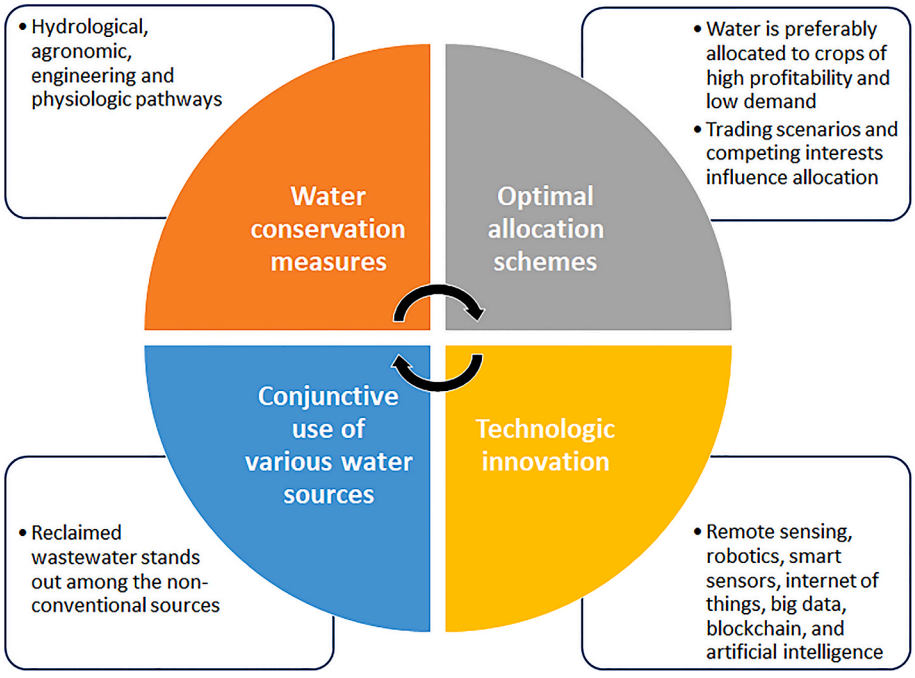


Fig. 4. Efficient water use comprises a series of measures focused on water conservation, optimal allocation, conjunctive use of conventional and non-conventional water sources, and technologic innovation.

use of water resources, namely groundwater. In the first case, addressing the problem comprises evaluating the potential impact of restrictions on yield and inform the water management agencies so they can mitigate the situation. For example, a simulation study conducted in Spain forecasted yield reductions of nearly 20 % if Lleida and Girona irrigated districts were imposed moderate water restrictions during drought periods, which would rise to 30– 50 % if the restrictions were severe [65]. In the second case, the route to the sustainable use of water resources requires compound measures such as reducing the planting area, adjusting the planting structure and improving water-saving technology, as exemplified in Beijing-Tianjin-Hebei Region (China) [66] The engineering pathway comprehends progresses in irrigation systems focused on reducing the losses mentioned above, which include subsurface drip irrigation and site specific variable rate irrigation [67,68]. Finally, the physiologic pathway explores the water requirements of plants during the growth stage to adjust water supply in the sequel. The most common measures include regulated deficit irrigation to reduce transpiration by controlling vegetative growth [69], or improved transpiration efficiency through growing crops in environments with lesser vapour pressure deficit or through breading [70].

Allocation schemes in the agriculture sector are measures of land and water use efficiency focused on optimizing the distribution of available irrigation volumes, which can derive from conventional (e.g., dams, groundwater) and non-conventional (e.g., recycled water) sources. In general, water is preferably allocated to crops of high profitability and low demand, while cropping patterns can be adjusted to optimize this result [71]. In addition, the optimization algorithms can account for the roles of aquifer's managed recharge, losses from storage or conveyance infrastructures, water quality constraints, subsidy policies, climate change forecasts [72], carbon footprints and the hydrologic regime (dry, normal and wet years) [73], among others. In the semi-arid regions that are frequently subject to prolonged water shortages, the allocation models may consider trading scenarios whereby irrigation water is conveyed from non-deficit to deficit regions under specific logistic, social and legal constraints [74]. Water shortages also trigger the need of allocating the available resources to the various economic sectors in equitable manner to accommodate competing interests. For example, Janjua and co-authors [75] integrated the WEAP – Water Evaluation and Planning model with the Nash bargaining solution to fairly distribute water resources from the Lower Bari Doab area of Punjab (Pakistan) among the domestic, industrial, crop irrigation and environmental uses.

The conjunctive use of conventional and non-conventional water sources is mandatory in many regions around the globe, where scarcity of conventional sources is systemic and enduring, and a development goal of countries that seek attaining high levels of circular water economy. As regards the conjunctive water use in agriculture, reclaimed wastewater stands out among the non-conventional sources. The advantages of using this resource are apparent [76,77]: increased food production, conservation of surface and groundwater, savings on the purchase of fertilizers, commercialization of treated wastewater that would be discarded otherwise (circular economy), obtaining biogas as by-product, among others. Despite the unequivocal advantages, this option is framed by willingness to implement factors, such as social approval and perceived control over the process [78], and faces some economic feasibility matters related to the proximity between wastewater treatment plants and application areas that impact transportation costs. Other key problems arise from quality issues, namely the mismatch between nutrients in the treated wastewater and nutrients required by the crops [79], besides the presence of contaminants of emerging concern in the wastewater [80,81] that can accumulate in the soil or propagate through the web chain threatening food security and posing health risks to humans.

Conservation measures, allocation schemes and conjunctive water use, as discussed above, all contribute to water use efficiency in agriculture. But further gains can be achieved if they go together with innovative technological solutions. For example, conservation measures and allocation schemes can be assisted by numerous digital technologies such as remote sensing, robotics, smart sensors, internet of things, big data, blockchain, and artificial intelligence, despite of some implementation challenges related with cost, lack of technical expertise, connectivity constraints, cybersecurity issues, among others [82–84]. The technological solutions available to help implementing the use of non-conventional water sources in agriculture are also abundant. Anaerobic membrane bioreactors proved efficient in producing treated wastewater in keeping with legal norms [85], and revealed promising results when coupled with hydroponic controlled environment agriculture [86]. On the other hand, saline-alkaline water can be treated with plasma hydrogel evaporators and used to irrigate crops with favorable growth trends, as demonstrated experimentally by Sun et al. with maize [87]. Bio-desalination with bacteria have also proved efficient in reducing salinity while fortifying nutrient contents of reverse osmosis rejected wastewater, with promising results in tomato seed germination [88]. For the production of freshwater from brackish groundwater in remote desert regions, the study of Sezer and Bayhan [89] proposed a stand-alone solar-powered freeze-desalination and electrolysis system. Canal water used for irrigation can also be recycled through coagulation, catalytic ozonation, and filtration [90].

4.4. *Impact of agriculture and cattle grazing activities on surface water quality*

Agriculture and cattle grazing activities are sources of stream water contamination described in many scientific studies [91–93], while land use changes are key triggers of stream water quality changes expressed as elevated or depressed nitrogen and phosphorus concentrations [94,95], depending on whether the change is a farm or a forest expansion, respectively (Fig. 5). A specific type of land use change stands out among the rest, because it exacerbates soil losses and nutrient exports towards streams and rivers [6,96]. That kind of change is characterized by deviations of actual uses from land capability (the natural use), called "environmental land use conflicts", which in a first stage promote drops in the soil organic matter accompanied by soil structure disruption [97], and then a cascade of environmental impacts that include the

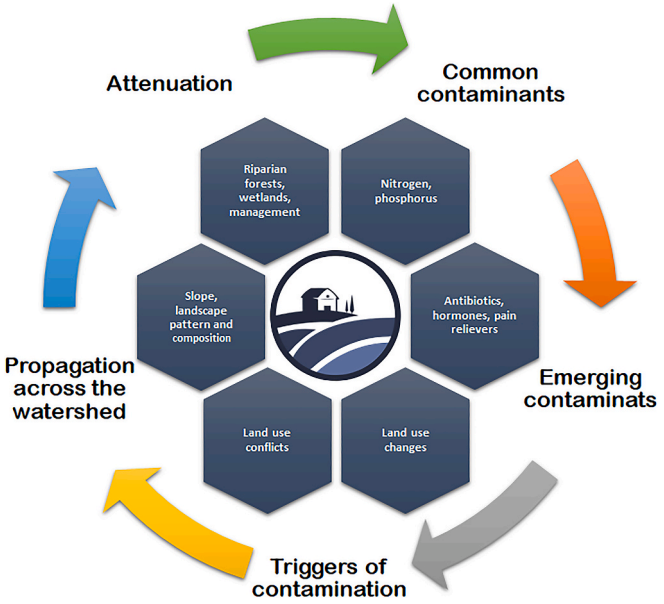


Fig. 5. Agriculture and cattle grazing activities are sources of common and emerging contaminants that propagate across the watersheds until reaching the receiving surface water bodies (rivers, lakes, sea). The extent of contaminant transport depends on the watershed characteristics and may be reduced by natural sinks such as riparian forests or wetlands as well as through implementation of adequate management practices in the farms.

aforementioned amplification of nutrient exports. The propagation of contaminants from the source areas into the receiving water bodies depends on numerous factors. Some studies highlighted the contribution of terrain slope to erosion and nutrient losses from agricultural lands [98], while others set up cause and effect relationships between stream water contamination and landscape characteristics, namely composition (percentage of farmland area in the watershed) and configuration (spatial distribution and shape of farmlands within the watershed) [99,100]. Preservation of stream water quality within agricultural watersheds is usually linked to the predominance of forests in the catchments [101,102], but other factors are also important. For example, the association of improved stream water quality to management practices has been addressed in the context of nutrient application modeling [103] and pasture conservation measures [104], while other works showed how small ponds can work as sinks of contaminants sourced from farmlands located nearby [105], as well as how riparian forests can prevent contaminants from entering the stream channels [106,107].

The contamination of streams and rivers with elements sourced from agriculture and cattle grazing activities is mostly related with nutrient (nitrogen, phosphorus) and pesticide inputs [108,109], but emerging contaminants are increasingly reported in the scientific literature [110]. For example, the use of antibiotics, hormones or pain relievers in livestock farming can result in the presence of residues from these drugs in runoff water [111,112]. On the other hand, nano- a micro-plastics can disrupt soil structure potentially reducing the soil's capacity to retain water and nutrients [113]. This boom era of emerging contaminants call for remediation strategies, including the use of biochar as proposed in the study of Hou and co-authors [114].

4.5. Risk of groundwater contamination

Leachates from livestock manure, fertilizers and pesticides applied on farmland often result in groundwater contamination expressed as elevated nitrate concentrations accompanied by variable amounts of ammonium, dissolved organic matter, heavy metals, and pesticide compounds [115–118] (Fig. 6). Groundwater contamination has reached severe levels in shallow aquifers [119–122] and even affected deeper aquifers [123–125], while soils have also accumulated geogenic contaminants like arsenic through continued crop irrigation over decades [126]. Conversely, self-depuration processes such denitrification, clay formation and uptake by ion-exchange, contributed to reducing the concentrations of contaminants in the soil water and shallow groundwater flowing underneath [127,128]. On a global scale, nitrate has emerged as one among the most alarming and widespread aquifer contaminants, calling for urgent remediation [2].

Remediation can restore groundwater quality to safe levels but does not ensure enduring results unless protection measures are implemented in complement to prevent further contamination. The most common pathway to groundwater protection comprises predictions of contamination potential coupled with land use planning and monitoring of hazardous activities. The literature on groundwater contamination potential is abundant and mostly focused on the assessment of aquifer vulnerability and related media parameters, spatial distribution of hazardous activities, and land use change scenarios, all embedded in multicriteria frameworks [129–131], multivariate statistical or artificial intelligence models [132–134], hydrologic analyses, among others, sometimes used in combination [135,136]. Hydro-economic models are also used to investigate the balance between economic profits derived from increasing crop productions and the likelihood of groundwater contamination derived from the consequent fertilizer application growth [137–139]. In all cases, the ultimate goal is to help decision makers protecting the groundwater geosphere.

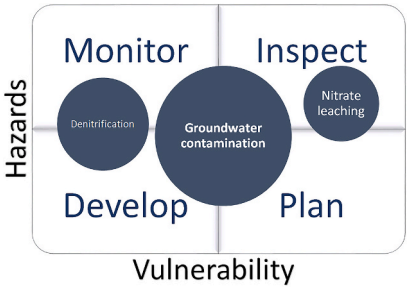


Fig. 6. Groundwater contamination sourced by agriculture and cattle grazing activities is fingerprinted by elevated nitrate and concentrations leached from farmlands. Attenuation of nitrate levels can be accomplished naturally through self-depuration (e.g., denitrification) but also proactively through protection measures implemented at the watershed scale in the context of groundwater contamination risk programs. Measures include inspecting, monitoring or planning the activities, considering the levels assessed for aquifer vulnerability and potential hazardous effects derived from the activity.

To implement groundwater protection efficiently, decision makers need to prioritize action. For that reason, besides providing a diagnosis on groundwater contamination potential in a target region, risk assessments must recommend action to stakeholders according to emergency levels. Some models attained that goal through relating increasing aquifer vulnerability (V) and exposure to hazardous activities (H) with measures of growing rigor [140,141], namely: developing the activity (low V and low H), framing the activity in landscape plans (high V and low H), monitoring the activity (low V and high H), and inspecting the activity (high V and high H). Prioritizing the action is also detecting dominant anthropogenic pressures in the target region (e.g., fertilizing, domestic or industrial effluents) and implement measures to reduce their potential hazardous effect [142]. At the inspecting level, measures to reduce the contamination potential should be mandatory. In farms, some effective measures comprise straw return to enhance denitrification and reduce nitrate leachates in the sequel [143,144].

4.6. Role of floods

Floods are a dimension of water security because they represent a water-related threat to the urban and rural landscapes [145], including

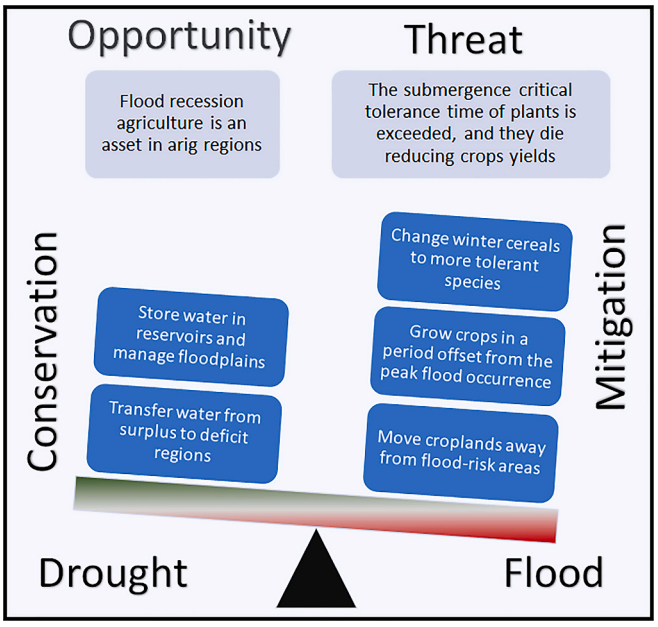


Fig. 7. Floods can threat crops when the submergence time exceeds a critical threshold, but can also be an asset in arid regions, where farmers use the moisture left in the floodplains as irrigation source in flood recession agriculture. In both situations, action is needed to mitigate the effects or conserve flood water as indicated in the balance above.

to croplands (Fig. 7). Croplands may represent a large share (e.g., 50 %) of inundated areas during extreme rainfall events [146]. And inundated areas impact agriculture when they are settled during the growth stage of crops and cumulatively are deep and stay long on the fields. In those cases, the submergence critical tolerance time of plants is likely exceeded and they die [147]. In the sequel, crop yields reduce severely generating economic losses. Thus, the potentially inundated areas of agricultural watersheds are generally viewed as crop damaging areas, which are frequently used in models to estimate yield and economic losses. Using rice crops as example and large return period monsoon rainfall events as reference for damaging floods, Syldon et al. [148] estimated yield and economic losses in agricultural regions of Bhutan, while Rahman et al. [149] did a similar analysis in Bangladesh. Other agriculture-related impacts of floods are the weakening of plant immunity, soil health and microorganisms, which can be linked to legacy effects [150]. Floods can bring good news in some cases. In arid regions such as Ghana or Senegal, flood water stored in the river banks and adjacent plains extend the crop growing season beyond the short rainy periods, allowing flood recession agriculture that relies on residual soil moisture left by the flood [151,152]. Studies even show that flood recession agriculture can be comparatively more advantageous than conventional rainfed agriculture because yields are usually higher [153]. The role of floods in agriculture can also be watched from the conservation and mitigation standpoints. Conservation strategies involve storing flood water in large to small reservoirs behind dams or weirs, or water transfers from surplus to deficit areas, besides the use of floodplains as mentioned above. These many strategies have been exemplified for the Indian territory by Jain [154]. Mitigation pathways are usually related with agricultural management. For example, Lucaora et al. [155] showed how changing winter cereals to more flood-tolerant species, or growing crops in a period offset from the peak flood occurrence, could minimize yield losses in a coastal area of central Italy. Shen et al. [156], on the other hand, used the results of a TOPSIS-based agricultural resilience assessment combined with artificial intelligence algorithms, to propose the exchange of high-standard farmlands located in flood-risk areas of Heshun County, Shanxi Province, China, by alternative high-quality plots located away from them, to ensure the long-term sustainability of High Standard Farmland projects in course in the region.

4.7. *Water governance*

According to the OECD – Organization for Economic Cooperation and Development, water governance that really works is ruled by *effectiveness* (clear roles and responsibilities, appropriate scales within basin systems, policy coherence, capacity), *efficiency* (data and information, financing, regulatory frameworks, innovation), and *trust and engagement* (integrity and transparency, stakeholder engagement, trade-off management, monitoring and evaluation) principles [157] (Fig. 8). When these principles are ignored or disregarded, natural water scarcity is exacerbated and can ultimately lead to conflicts. An example of inappropriate water governance in the agricultural sector was brought into the scientific literature by Nouri et al. [158] who, among other issues, highlighted the consequences for Iranian water resources: disproportionate groundwater depletion, deterioration of water quality, decline of environmental flows, contraction of wetlands, and water conflicts. In another study, Nazemi et al. [159] discussed potential way outs from this situation in the Iranian watershed of Zayandehrud, based on five scenarios: *status quo* continues; Iranian capitalism reigns; planed agriculture economy; interpreting traditions to shape the future; and collaborative rural development. The authors commented on the various scenarios but left the choice of a best scenario for the decision-makers, because the aim was not to forecast the future of water security in the country but rather to explore alternative pathways and corresponding outcomes to this problem. Regardless the choice, however, building trust and strengthening cooperation among stakeholders will generally



Fig. 8. Water governance is in the core of a water-secure environment. In the agriculture sector, the application of OECD principles of effectiveness, efficiency and trust and engagement translate into the optimization of water-food-energy nexus, implementation of accountability measures (e.g., metering), and anticipation of pathways to overcome the challenges of scalability (e.g., geographic, institutional), interaction among competing water-use sectors (e.g., urban, industry), financing (e.g., microcredit to small hold farmers) and pollution.

be routes to success, as anticipated in studies of other regions [160].

The OECD principles of water governance would be successfully ruled in the agriculture sector through the implementation of a coherent water-food-energy (WFE) nexus strategy, and there were models developed to do so [161]. The nexus can be interpreted as interactions among sectors within the nexus system. Thus, water is indispensable for production of both energy and food. The process of water abstraction, distribution and treatment requires the utilization of energy. And food can also be used to generate energy in the form of biofuels [162]. The nexus approach was applied and evaluated in countries such as Iran [163], Ghana and Uganda [164], Singapore [165] or the United States [166], mostly through interviews and workshops with stakeholders. In all cases, strengths and weaknesses were underlined. For example, in the Inkomati-Usuthu river basin of South Africa, Sievers et al. [167] cross-tabulated *quality criteria* (comprehensiveness, coherence, flexibility, intensity of action, fit) and *dimensions* (actors and networks, levels and scales, problem perspectives and goal ambitions, strategies and instruments, responsibilities and resources) to evaluate the nexus and highlighted as positive features the pressure of relevant actors across the WEF sectors for more WFE nexus-oriented governance, and the involvement in nexus-oriented governance of all levels and scales across all WFE sectors. The negative features were, however, prevalent, and comprised: uncooperative as well as mistrusted interactions among relevant actors and networks across all WFE sectors; lack of nexus-oriented strategies and instruments as well as lack of impetus to change the paradigm; the management of responsibilities and resources was rigid (resistant to changes) and competitive rather than cooperative, with no accountability or transparency.

Besides the WFE framing discussed in the previous paragraph, a successful (effective) water governance system requires reliable water accounts [168]. A consistent account system comprises a water metering network for the monitoring of withdrawals, linked to a database of water rights for evaluating the balance between availability and demand or detecting potential illegal abstractions. In complement, the system should be linked to remote sensed time series of evapotranspiration maps for dynamically adapt allocation to water needs [169] and hence

make the system more resilient to seasonality and climate change. Digitalization is another step forward towards effective water governance. Platforms capable of receiving, integrating and processing information from satellite sensors, monitoring stations (stream discharge rate, water quality), piezometers, etc., and providing them to farmers and administrators as services, are much welcome and have been implemented already [170]. For all these tools to work and communicate effectively, providing an asset to society, it is essential to invest in the technical training of all those involved.

Regardless of being effective, a water governance scheme in the agriculture sector has a number of challenges, namely of scale, interaction with schemes from other sectors (urban, industry), and financing. The challenge of scale encompasses improving the degree of spatial and temporal alignments between the jurisdictional and agroecological scales. The jurisdictional scale spans the village to the state levels and the agroecological scale the plot to the ecosystem levels, while both scales can be implemented at the levels of day to centuries [171]. A low scalar alignment frequently produces conflicts among the competing interests for water. For example, in south Australia the competition between irrigated agriculture and forestry production was heading towards legal proceedings, which were halted when the water allocation procedure was transferred from local to state governance [172]. The interaction among governance schemes involves framing the exchange of water between sectors (e.g., agriculture and urban water supply) into formal, holistic and transparent agreements, to avoid uneven burden and benefit-sharing among sectors as occurred in Valencia, Spain, between urban and rural users [173]. According to the FAO [174], the challenge of financing can be overcome through building an ecosystem of value chain actors able to create and capture value through increased production, protection of natural an infrastructure resources an reclamation of degraded areas; building trust to attract external funding through blended public–private projects, grants provided by public or philanthropic institutions, loans and bonds (e.g., microcredit), compensation via the offsetting or in setting of carbon emissions, corporate water stewardship, among other funds; and allowing the chain actors to take, manage and share risks.

Pollution is another challenge to water governance needing attention and action. In China, local governments have established the River Chief System, which involves appointing a named official to protect a specific waterway. This reform reduced the impact of manure output from animal breeding operations but failed to reduce pollution caused by fertilizer use [175]. In a theoretical approach based on the game theory, Xiao et al. [176] proposed a cross-sectoral water pollution governance involving the industrial and agriculture sectors to synergically reduce non-point source water pollution through cooperation. In Europe, however, there is some skepticism about the role of governance structures in addressing the "wicked problem" of diffuse nutrient pollution [177].

A synthesis of governance elements recommended to strengthen water security in the agriculture and cattle grazing activities, emerging from the reviewed articles, covers the following key areas: (*a*) reinforcing the role of river basins as geographic domain for the assessment of all security dimensions. This was considered vital to ensure a continuous understanding about the functioning of river basins under ongoing land use and climate changes, as well as to warrant efficient, sustainable and equitable water allocation and uses; (*b*) developing the water tenure concept. This was considered vital to extend the debate about water rights and competition for water uses, with linkages to land tenure, resource-use efficiency and food security; (*c*) The governance of irrigation. This was considered essential to increase water productivity in irrigated agriculture, as a central solution to water scarcity; (*d*) The governance of groundwater. This was considered of paramount importance to prevent water crises; (*e*) Governance for pollution control. Agriculture is a cause and a victim of water quality deterioration, and governance for pollution control is needed to mitigate the related consequences, namely food insecurity. Among governance elements essential to improve water quality in the agriculture and livestock sectors, those seen as the most urgent were tailored quality standards, guidelines on treatment and recycling, environmental impact assessments, measurement and monitoring.

4.8. Payment for water services to finance governance in the agriculture sector

The production of clean water from watersheds where human activities dominate is a challenge to governance, because the activities generally threat water security through quantity and quality declines. In the agriculture sector, reduction of forested areas in headwater catchments to expand farming lands, coupled with inadequate fertilizing and erosion control practices, usually lead to severe water quantity and quality declines. One pathway to revert this situation relies on the implementation of governance schemes whereby the water users (e.g., urban consumers) pay an incentive to water producers (e.g., farmers located in headwater catchments) for their commitment to adapt their food production systems (Fig. 9). The incentive system is called payment for water services (PWS) and comprises land use conversions capable of restoring spring discharge rates in the agricultural watersheds, such as monoculture to agroforestry conversions, as well as technical assistance for improved fertilizer application and erosion control, among other best management practices. Studies on this topic include PWS models with pilot case studies included [178–182], cost-effectiveness analyses [183–186], pos-implementation assessments [187,188], obstacles to PWS application [189], and overviews on national or regional programs' performance [190,191]. Taken together, the various studies show the mechanics of PWS models and how their implementation benefited water quantity and quality in the watersheds, as well as co-benefited carbon sequestration and recreation, among other features. The other side of the coin exposes the resistance to implementation posed by consumers, who may question the extra cost of water resulting from circumstances they were not involved (e.g., diffuse pollution from farmlands), but also posed by land owners who may consider the land use conversion's incentive inappropriate. The details of each study are addressed in the next paragraphs.

The design of PWS models in the agriculture sector generally links the production of water from headwater catchments to the economic value of catchment's yield, combined with the cost of crop production losses driven by the conversion of monocultures to agroforestry uses or other conversions capable of raising water quantity and quality. The conversion costs, on the other hand, depend on the crop type and on environmental factors that make the land use change more or less challenging to accomplish (e.g., geologic type, terrain slope, etc.). An example of such model was applied to the Brazilian watershed of Fazenda Glória composed of various catchments, where the authors proposed financial incentives to local farmers ranging from 218.73 to 576.5 US$/ha/year, to be paid by consumers for the conversion of sugar cane lands to agroforestry systems [182], depending on the aforementioned catchment's water yield and environmental factors. Other models shifted the focus to the link between the economic accounting of water through PWS and water policy, as done in the Australian Capital Territory [178]; to the use of PWS in the optimization of water allocation models between the agriculture and the urban sectors, as proposed for the Chancay-Huaral watershed in coastal Peru [179]; to the adaption of PWS models to optimize the potential of agriculture to improve the provision of good water quality, coupled with the demand from users for good quality water, as tested across the United Kingdom [180]; or to the use of PWS as tool for managing water conflicts between upstream producers and downstream consumers, as exemplified for the Okavango River basin (Angola, Namibia) [181].

The design of PWS models is just one step of governance approaches based on the "provider gets principle". Other steps comprise cost-effective analyses and post-implementation assessments. Cost-effective analyses include the quantification of PWS implementation costs

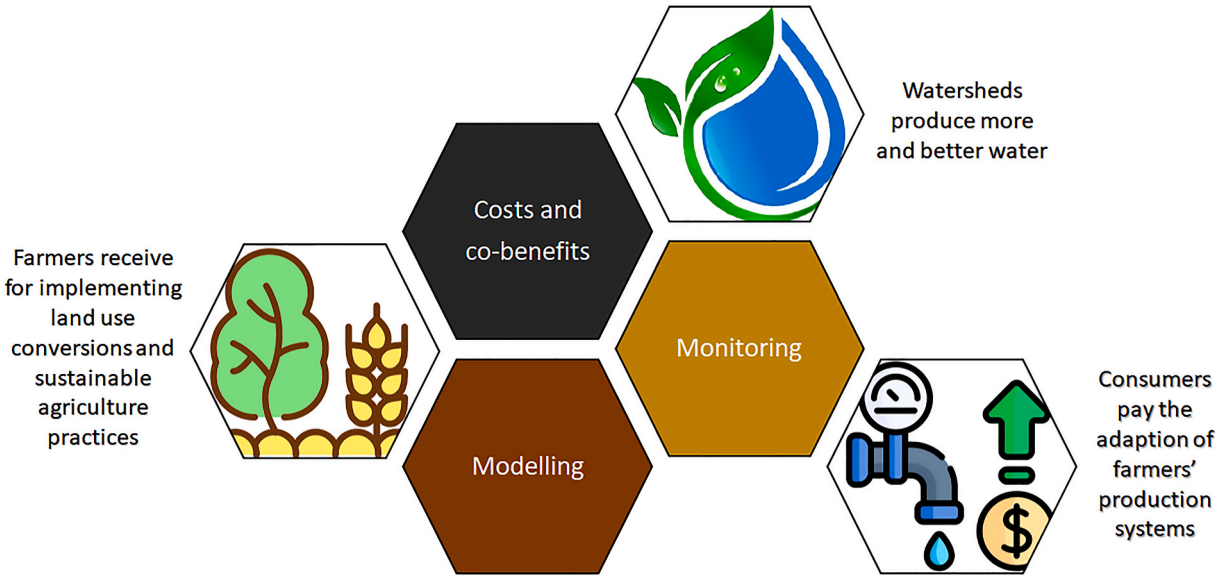


Fig. 9. The governance of water resources may resort to Payment for Water Services programs, which are designed to bring watersheds towards more resilient levels of water security. They rely on land use conversions (e.g., monocultures to agroforestry systems) coupled with best management practices (nutrient, pesticide and erosion control), implemented by farmers in headwater catchments with the purpose to increase yields and water quality, which are paid by water consumers. Cost-effectiveness of implemented programs is measured by the balance of land conversion / management costs and co-benefits (e,g,. carbon sequestration), assessed periodically in the context of monitoring protocols.

combined with the assessment of co-benefits. The costs represent the amount required to compensate land owners for changing their production systems, while the co-benefits are positive externalities resulting from the land conversions (improved carbon sequestration or more valuable recreation activities) and application of sustainable management practices (agriculture without pesticides, organic farming to prevent nitrate pollution). The cost-effectiveness is measured as difference between the costs and the co-benefits: if this difference is negative, the PWS scheme is effective. An application of cost-effective analysis this way in Denmark showed how afforestation, ban of pesticides and generalization of organic farming would have much larger co-benefits than PWS implementation costs [183]. Cost-effectiveness analyses also tackle the willingness-to-pay and willingness-to-receive problems. The first problem relies on the reluctance of consumers to pay an extra value for water, which derives from land use conversions and best management practices they believe should be supported by the farmers who originally contaminated the surface and groundwater. Put another way, consumers may not accept peaceably a governance model based on the "provider gets principle" but rather prefer one based on the "polluter pays principle". The second problem relies on the averseness of land owners to adopt the PWS practices if their financial revenue reduces substantially, a situation anticipated for small coffee producers of Honduras by Camarillo et al. [184]. Other obstacles to PWS' social acceptance relate to the wide range of perceptions regarding rights and responsibilities in relation to water, as well as the challenges of identifying the proper intermediary in the current institutional framework [189]. Despite the resistance to accept or adopt PWS schemes, their implementation has proven efficient in specific cases. For example, in the Huai River watershed (China), the implementation of a PWS program from 2006 to 2013 decreased the average COD (chemical oxygen demand) and NH3-N (ammonia–nitrogen) concentrations of stream water by 18.03 mg/L and 4.82 mg/L, respectively, while reducing significantly pollution treatment costs [187]. Efficiency is also recognized at National levels, such as in Brazil, irrespective of concerns about lack of monitoring and transparency, as well as poor spatial and financial distribution [190].

5. Conclusion

The current review identified challenges to water security in the agriculture and cattle grazing activities, comprising water scarcity, flooding, and deterioration of surface and groundwater quality, besides threats related to increasing demand and competition for the water resources with other economic sectors, as well as weaknesses in governance including water pricing. It also prognosed improvements brought by technological innovation in irrigation. Taken together, the challenges, threats and weaknesses may incite conflicts between economic sectors over access rights, undermine food security, fuel public health crises leading to social disruptions, and hamper economic growth worsening poverty. In a few words, water insecurity hinders the utopia of a sustainable Earth. Thus, future studies should continue addressing these problems and propose new solutions to overcome them. Key messages to decision-makers comprise: (*a*) Develop or improve distribution networks of rainwater harvesting systems, implement watershed restoration via PWS schemes, and democratize the use of advanced irrigation technologies, to make supplies more reliable and improve their quality; (*b*) Advance water resources governance by empowering local stakeholders in community-based irrigation systems, spring and river flow metering, pricing incentives, to make water resources management more efficient; (*c*) At the individual level, via school education or other municipal initiatives, people can help to protect the water resources in the rural environment by learning more about how they cope with the agriculture and cattle grazing activities. As whole, the setting up of all these recommendations would help reducing water insecurity, before it reaches an overwhelming status.

Declarations

Funding

This study was financed by National Funds of CAPES – Coordination for the Improvement of Higher Education, Process no. 88881.979820/2024–01, via the Postgraduate Programme in Agronomy – Soil Science, held at the UNESP – São Paulo State University "Júlio de Mesquita Filho", FCAV – School of Agricultural and Veterinary Sciences, Campus of Jaboticabal, Brazil. The study was financed with the purpose of being a solid reference in the field of "Water security in the agriculture and cattle grazing activities", which is also the name of a discipline

registered in the aforementioned Postgraduate Program, lectured by the authors. We also thank the support of POLUS research group, registered in the CNPq – National Council for Scientific and Technological Development, to which the two co-authors are affiliated. For the author Fernando António Leal Pacheco, integrated in the CQVR – Chemistry Center of Vila Real, the research was additional supported by National Funds of FCT – Portuguese Foundation for Science and Technology, under the projects UIDB/00616/2023 and UIDP/00616/2023. The author Teresa Cristina Tarlé Pissarra received a productivity grant from the CNPq – National Council for Scientific and Technological Development, PQ – Process: 311791/2023–9.

CRediT authorship contribution statement

Fernando António Leal Pacheco: Writing – original draft, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Teresa Cristina Tarlé Pissarra:** Writing – review & editing, Visualization, Validation, Funding acquisition, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

[1] UNESCO, Water for prosperity and peace: Facts, Figures and Action Examples, The United Nations World Water Development Report 2024, UNESCO World Water Assessment Programme, Office for Global Water Assessment, Division of Water Sciences, UNESCO 06134 Colombella, Perugia, Italy, 20p., available on line at: https://unesdoc.u, 2024.

[2] S. Shukla, A. Saxena, Global Status of Nitrate Contamination in Groundwater: Its Occurrence, Health Impacts, and Mitigation Measures, in: Handb. Environ. Mater. Manag., Springer International Publishing, Cham, 2019: pp. 869–888. DOI: 10.1007/978-3-319-73645-7_20.

[3] E. Abascal, L. Gómez-Coma, I. Ortiz, A. Ortiz, Global diagnosis of nitrate pollution in groundwater and review of removal technologies, Sci. Total Environ. 810 (2022) 152233, https://doi.org/10.1016/j.scitotenv.2021.152233.

[4] G. Pegram, global water scarcity: Risks and challenges for business, 2010. Lloyd's 360° Risk Insight, Lloyd's , One Lime Street, London, 32p.

[5] FAO, The impact of natural hazards and disasters on agriculture and food security and nutrition: A call for action to build resilient livelihoods, 2015. Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla% 0A 00153, Rome, Italy, 16p.

[6] F.A.L. Pacheco, L.F. Sanches Fernandes, Environmental land use conflicts in catchments: a major cause of amplified nitrate in river water, Sci. Total Environ. 548–549 (2016) 173–188, https://doi.org/10.1016/j.scitotenv.2015.12.155.

[7] Y. Yang, Y. Liu, H. Wang, R. Zhang, Y. Li, A new water security resilience indicator based on ternary connection number projection method: a case study of Beijing-Tianjin-Hebei region, Ecol. Indic. 178 (2025) 114012, https://doi.org/10.1016/j.ecolind.2025.114012.

[8] X. Tong, Z. Xiang, L. You, J. Zhang, K.-Y.-H. Gin, Modelling Approach to Understanding the Nexus of Emerging Contaminants, climate Change, and Water Security, Curr. Opin. Environ. Sci. Heal. (2025) 100650, https://doi.org/10.1016/j.coesh.2025.100650.

[9] A. Dhaarna, Kashyap, Water security modeling in low-income regions in India: a system dynamics approach, Environ. Sustain. Indic. 27 (2025) 100781, https://doi.org/10.1016/j.indic.2025.100781.

[10] N.Z. Mohd Nazir, K.E. Lee, T.L. Goh, M. Mokhtar, N.A. Sharani, A. Mohd Aris, B. C. Khor, W.A.R. Wan Abdullah, H. Husain, R.B. Raja Mamat, Enhancing water security through mobile constructed wetlands: a decentralised approach for wastewater reclamation and reuse, J. Environ. Chem. Eng. 13 (2025) 117859, https://doi.org/10.1016/j.jece.2025.117859.

[11] N.H. Rafaai, K.E. Lee, N.Z. Mohd Nazir, A. Abdul Kadir, A.R. Ab Rahim, M. Mokhtar, T.L. Goh, From fragmentation to consolidation: an integrated approach for multidimensional analysis of water security in Langat River Basin, Malaysia, Environ Sci Policy 169 (2025) 104067, https://doi.org/10.1016/j.envsci.2025.104067.

[12] UNESCO, Water security: responses to local, regional and global challenges; achievements of the IHP-VIII (2014-2021), Available on-line at https://unesdoc.unesco.org/ark:/48223/pf0000391752, accessed in 13 august 2025, 2024. DOI: 10.54677/ZYPR3728.

[13] J. Marcal, B. Antizar-Ladislao, J. Hofman, Addressing Water Security: an Overview, Sustainability 13 (2021) 13702, https://doi.org/10.3390/su132413702.

[14] B. Mishra, P. Kumar, C. Saraswat, S. Chakraborty, A. Gautam, Water Security in a changing Environment: Concept, Challenges and Solutions, Water. 13 (2021) 490, https://doi.org/10.3390/w13040490.

[15] D. Moher, Preferred Reporting items for Systematic Reviews and Meta-analyses: the PRISMA Statement, Ann. Intern. Med. 151 (2009) 264, https://doi.org/10.7326/0003-4819-151-4-200908180-00135.

[16] M.J. Page, J.E. McKenzie, P.M. Bossuyt, I. Boutron, T.C. Hoffmann, C.D. Mulrow, L. Shamseer, J.M. Tetzlaff, E.A. Akl, S.E. Brennan, R. Chou, J. Glanville, J. M. Grimshaw, A. Hróbjartsson, M.M. Lalu, T. Li, E.W. Loder, E. Mayo-Wilson, S. McDonald, L.A. McGuinness, L.A. Stewart, J. Thomas, A.C. Tricco, V.A. Welch, P. Whiting, D. Moher, The PRISMA 2020 statement: an updated guideline for reporting systematic reviews, BMJ 88 (2021) 105906, https://doi.org/10.1136/bmj.n71.

[17] A.B. Duche Pérez, C. Vera Revilla, O.A. Gutierrez Aguilar, S. Chicaña Huanca, B. Chicaña-Huanca, Religion and Spirituality in University students: a Systematic Review of the Literature, Int. J. Relig. Spiritual. Soc. 14 (2023) 135–162, https://doi.org/10.18848/2154-8633/CGP/v14i03/135-162.

[18] M. Ștefănică, C.B. Sandu, G.I. Butnaru, A.-P. Haller, The Nexus between Tourism Activities and Environmental Degradation: Romanian Tourists' opinions, Sustainability 13 (2021) 9210, https://doi.org/10.3390/su13169210.

[19] M. Kalinauskas, Y. Shuhani, L.V. Pinto, M. Inácio, P. Pereira, Mapping ecosystem services in protected areas. a systematic review, Sci. Total Environ. 912 (2024) 169248, https://doi.org/10.1016/j.scitotenv.2023.169248.

[20] Y. Feng, Y. Guo, Y. Shen, G. Zhang, Y. Wang, X. Chen, Change of crop structure intensified water supply-demand imbalance in China's Black Soil Granary, Agric Water Manag 306 (2024) 109199, https://doi.org/10.1016/j.agwat.2024.109199.

[21] J. Zhang, L. Wang, G. Cheng, L. Jia, Characteristics of water supply and demand in an agroforestry ecosystem under long-term continuous cropping assessed using the RZWQM2 model, Agric Water Manag 307 (2025) 109245, https://doi.org/10.1016/j.agwat.2024.109245.

[22] H. Sharofiddinov, M. Islam, K. Kotani, How does the number of water users in a land reform matter for water availability in agriculture? Agric Water Manag 293 (2024) 108677 https://doi.org/10.1016/j.agwat.2024.108677.

[23] H. Peng, Y. Zhang, T. Nan, X. Yang, S. Pacenka, T.S. Steenhuis, J. Niu, Climate change impacts on spatiotemporal variability of soybean water demands in North China Plain, Agric Water Manag 310 (2025) 109381, https://doi.org/10.1016/j.agwat.2025.109381.

[24] P. Marcinkowski, M. Piniewski, T. Okruszko, Towards sustainable agricultural water management in Poland – how to meet water demand for supplemental irrigation? Agric Water Manag 306 (2024) 109214 https://doi.org/10.1016/j.agwat.2024.109214.

[25] J.P.C. Eekhout, I. Delsman, J.E.M. Baartman, M. van Eupen, C. van Haren, S. Contreras, J. Martínez-López, J. de Vente, How future changes in irrigation water supply and demand affect water security in a Mediterranean catchment, Agric Water Manag 297 (2024) 108818, https://doi.org/10.1016/j.agwat.2024.108818.

[26] T.S. Wilson, P.C. Selmants, R.M. Boynton, J.H. Thorne, N.D. Van Schmidt, T. A. Thomas, Will there be water? climate change, housing needs, and future water demand in California, J. Environ. Manage. 369 (2024) 122256, https://doi.org/10.1016/j.jenvman.2024.122256.

[27] F. Arslan, F. Alcon, S. Kartal, K. Erdoğan, D.A. Zema, Sustainability of collective irrigation under water competition between agriculture and civil uses: the case study of Alanya Water Users Association (Türkiye), Agric Water Manag 306 (2024) 109167, https://doi.org/10.1016/j.agwat.2024.109167.

[28] D.F. Badou, C. Nouvewa, C. Allé, A.M. Adango, L.O. Sintondji, Ensuring irrigation water availability for off-season vegetable production in the face of competition from rural domestic water supplies in the commune of Lalo (Benin), Agric Water Manag 308 (2025) 109282, https://doi.org/10.1016/j.agwat.2024.109282.

[29] A.M. da Costa, L.F.S. Fernandes, F.A.L. Pacheco, C.A. Valera, Quality Indicators to Subsidize Soil Conservation under Pasture in Brazil, L. Degrad. Dev. (2025), https://doi.org/10.1002/ldr.5504.

[30] Y. Zhang, Z. Wu, V.P. Singh, Q. Lin, S. Ning, Y. Zhou, J. Jin, R. Zhou, Q. Ma, Agricultural drought characteristics in a typical plain region considering irrigation, crop growth, and water demand impacts, Agric Water Manag 282 (2023) 108266, https://doi.org/10.1016/j.agwat.2023.108266.

[31] Z. Shu, Y. Kang, Y. Gao, X. Shi, W. Li, S. Zhang, S. Song, L. Li, An interval bilateral regulation framework of water resources supply and demand in irrigation area under water sources uncertainty, Agric Water Manag 307 (2025) 109266, https://doi.org/10.1016/j.agwat.2024.109266.

[32] M. Rahimi Jamnani, Z. Kayhomayoon, N. Arya Azar, S. Ghordoyee Milan, S. Najafi Marghmaleki, R. Berndtsson, Large discrepancy between future demand and supply of agricultural water in northwestern Iran; evidence from WEAP-MODFLOW-machine learning under the CMIP6 scenario, Comput. Electron. Agric. 216 (2024) 108505, https://doi.org/10.1016/j.compag.2023.108505.

[33] A.A.M. Ahmed, Q.J. Wang, A.W. Western, T.D.J. Graham, W. Wu, Monthly disaggregation of annual irrigation water demand in the southern Murray Darling Basin, Agric Water Manag 302 (2024) 108961, https://doi.org/10.1016/j.agwat.2024.108961.

[34] M. Li, X. Zhang, Y. Chen, Y. Xu, R. Li, L. Zhao, Q. Fu, Multiobjective optimization of daily scale irrigation schedules for rice in irrigation districts considering joint uncertainties in water supply and demand, Comput. Electron. Agric. 231 (2025) 110054, https://doi.org/10.1016/j.compag.2025.110054.

[35] X. Zhu, X. Su, V.P. Singh, H. Wu, J. Niu, L. Wu, J. Chu, Improving synergy of the water-agriculture-ecology system in arid areas using a novel co-optimization model, Agric Water Manag 312 (2025) 109408, https://doi.org/10.1016/j.agwat.2025.109408.
[36] C. Whitney, G. O'Brien, V. Dlamini, I.J. Greffiths, C. Dickens, E. Luedeling, Balancing ecosystem sustainability and irrigated smallholder agriculture: a modeling approach for water resource management, J. Hydrol. 651 (2025) 132560, https://doi.org/10.1016/j.jhydrol.2024.132560.
[37] P. Qi, J. Sun, G. Zhang, Optimal allocation of water and land resources considering crop water demand process from the perspective of water-carbon-economy nexus, J. Hydrol. 654 (2025) 132831, https://doi.org/10.1016/j.jhydrol.2025.132831.
[38] D.P.S. Terêncio, L.F. Sanches Fernandes, R.M.V. Cortes, F.A.L. Pacheco, Improved framework model to allocate optimal rainwater harvesting sites in small watersheds for agro-forestry uses, J. Hydrol. 550 (2017) 318–330, https://doi.org/10.1016/j.jhydrol.2017.05.003.
[39] S. Halder, S. Bose, Addressing water scarcity challenges through rainwater harvesting: a comprehensive analysis of potential zones and model performance in arid and semi-arid regions–a case study on Purulia, India, HydroResearch. 7 (2024) 201–212, https://doi.org/10.1016/j.hydres.2024.04.001.
[40] A. Bera, B.P. Mukhopadhyay, Identification of suitable sites for surface rainwater harvesting in the drought prone Kumari River basin, India in the context of irrigation water management, J. Hydrol. 621 (2023) 129655, https://doi.org/10.1016/j.jhydrol.2023.129655.
[41] X. Du, A. Tariq, F. Islam, S. Aziz, L.A. Waseem, M.N. Ahmad, M. Amin, N.U. Amin, S. Ali, M. Aslam, W. Soufan, Integrated study of GIS and Remote Sensing to identify potential sites for rainwater harvesting structures, Phys. Chem. Earth, Parts a/b/c. 134 (2024) 103574, https://doi.org/10.1016/j.pce.2024.103574.
[42] W.H. Hassan, K. Mahdi, Z.K. Kadhim, Optimal rainwater harvesting locations for arid and semi-arid regions by using MCDM-based GIS techniques, Heliyon 11 (2025) e42090, https://doi.org/10.1016/j.heliyon.2025.e42090.
[43] X. Zheng, A. Sarwar, F. Islam, A. Majid, A. Tariq, M. Ali, S. Gulzar, M.I. Khan, M. A. Sardar Ali, M. Israr, A. Jamil, M. Aslam, W. Soufan, Rainwater harvesting for agriculture development using multi-influence factor and fuzzy overlay techniques, Environ. Res. 238 (2023) 117189, https://doi.org/10.1016/j.envres.2023.117189.
[44] I.V. Hume, D.M. Summers, T.R. Cavagnaro, Lawn with a side salad: Rainwater harvesting for self-sufficiency through urban agriculture, Sustain. Cities Soc. 87 (2022) 104249, https://doi.org/10.1016/j.scs.2022.104249.
[45] T. Yuan, L. Fengmin, L. Puhai, Economic analysis of rainwater harvesting and irrigation methods, with an example from China, Agric Water Manag 60 (2003) 217–226, https://doi.org/10.1016/S0378-3774(02)00171-3.
[46] S. Mandal, V.K. Vema, C. Kurian, K.P. Sudheer, Improving the crop productivity in rainfed areas with water harvesting structures and deficit irrigation strategies, J. Hydrol. 586 (2020) 124818, https://doi.org/10.1016/j.jhydrol.2020.124818.
[47] S. Assefa, B. Biazin, A. Muluneh, F. Yimer, A. Haileslassie, Rainwater harvesting for supplemental irrigation of onions in the southern dry lands of Ethiopia, Agric Water Manag 178 (2016) 325–334, https://doi.org/10.1016/j.agwat.2016.10.012.
[48] A. Deo, S. Karmakar, A. Arora, Rainwater harvesting and water balance simulation-optimization scheme to plan sustainable second crop in small rain-fed systems, J. Environ. Manage. 323 (2022) 116135, https://doi.org/10.1016/j.jenvman.2022.116135.
[49] X. Liu, Y. Wang, Y. Zhang, X. Ren, X. Chen, Can rainwater harvesting replace conventional irrigation for winter wheat production in dry semi-humid areas in China? Agric Water Manag 272 (2022) 107852 https://doi.org/10.1016/j.agwat.2022.107852.
[50] G. Xiao, Q. Zhang, Y. Xiong, M. Lin, J. Wang, Integrating rainwater harvesting with supplemental irrigation into rain-fed spring wheat farming, Soil Tillage Res. 93 (2007) 429–437, https://doi.org/10.1016/j.still.2006.06.001.
[51] A.N. Munyasya, K. Koskei, R. Zhou, S.-T. Liu, S.N. Indoshi, W. Wang, X.-C. Zhang, W.K. Cheruiyot, D.M. Mburu, A.B. Nyende, Y.-C. Xiong, Integrated on-site & off-site rainwater-harvesting system boosts rainfed maize production for better adaptation to climate change, Agric Water Manag 269 (2022) 107672, https://doi.org/10.1016/j.agwat.2022.107672.
[52] C. Zhang, Z. Dong, Q. Guo, Z. Hu, J. Li, T. Wei, R. Ding, T. Cai, X. Ren, Q. Han, P. Zhang, Z. Jia, Ridge–furrow rainwater harvesting combined with supplementary irrigation: Water-saving and yield-maintaining mode for winter wheat in a semiarid region based on 8-year in-situ experiment, Agric Water Manag 259 (2022) 107239, https://doi.org/10.1016/j.agwat.2021.107239.
[53] S. Ali, X. Ma, Q. Jia, I. Ahmad, S. Ahmad, Z. Sha, B. Yun, A. Muhammad, X. Ren, S. Shah, H. Akbar, T. Cai, J. Zhang, Z. Jia, Supplemental irrigation strategy for improving grain filling, economic return, and production in winter wheat under the ridge and furrow rainwater harvesting system, Agric Water Manag 226 (2019) 105842, https://doi.org/10.1016/j.agwat.2019.105842.
[54] X. Zhao, Q. Wang, A. Qadeer, Y. Sun, R. Azim, I. Awuku, F. Masoumkhani, W. Ma, Q. Liu, X. Cui, H. Dong, X. Li, B. Liu, Optimized length and application rate of chopped straw for alfalfa production in ridge-furrow rainwater-harvesting in semi-arid regions in China, Agric Water Manag 311 (2025) 109393, https://doi.org/10.1016/j.agwat.2025.109393.
[55] W. Zhang, J. Sheng, Z. Li, D.C. Weindorf, G. Hu, J. Xuan, H. Zhao, Integrating rainwater harvesting and drip irrigation for water use efficiency improvements in apple orchards of northwest China, Sci. Hortic. (amsterdam). 275 (2021) 109728, https://doi.org/10.1016/j.scienta.2020.109728.
[56] M. Sun, X. Gao, Y. Zhang, X. Song, X. Zhao, A new solution of high-efficiency rainwater irrigation mode for water management in apple plantation: Design and application, Agric Water Manag 259 (2022) 107243, https://doi.org/10.1016/j.agwat.2021.107243.
[57] M.B. Wakeyo, C. Gardebroek, Share of irrigated land and farm size in rainwater harvesting irrigation in Ethiopia, J. Arid Environ. 139 (2017) 85–94, https://doi.org/10.1016/j.jaridenv.2017.01.002.
[58] X. Liang, M.P. van Dijk, Economic and financial analysis on rainwater harvesting for agricultural irrigation in the rural areas of Beijing, Resour. Conserv. Recycl. 55 (2011) 1100–1108, https://doi.org/10.1016/j.resconrec.2011.06.009.
[59] F.H. Kemeze, Economic valuation of supplemental irrigation via small-scale water harvesting, Water Resour. Econ. 31 (2020) 100160, https://doi.org/10.1016/j.wre.2020.100160.
[60] L. Zheng, Y. Deng, Advancing rainwater treatment technologies for irrigation of urban agriculture: a pathway toward innovation, Sci. Total Environ. 916 (2024) 170087, https://doi.org/10.1016/j.scitotenv.2024.170087.
[61] Y. Deng, Pollution in rainwater harvesting: a challenge for sustainability and resilience of urban agriculture, J. Hazard. Mater. Lett. 2 (2021) 100037, https://doi.org/10.1016/j.hazl.2021.100037.
[62] M.E. Morgado, C.L. Hudson, S. Chattopadhyay, K. Ta, C. East, N. Purser, S. Allard, M.D. Ferrier, A.R. Sapkota, M. Sharma, R.R. Goldstein, The effect of a first flush rainwater harvesting and subsurface irrigation system on E. coli and pathogen concentrations in irrigation water, soil, and produce, Sci. Total Environ. 843 (2022) 156976, https://doi.org/10.1016/j.scitotenv.2022.156976.
[63] L. Mateos, J.L. Araus, Hydrological, engineering, agronomical, breeding and physiological pathways for the effective and efficient use of water in agriculture, Agric Water Manag 164 (2016) 190–196, https://doi.org/10.1016/j.agwat.2015.10.017.
[64] M. Rahman, M.M. Hasan, M.A. Hossain, U.K. Das, M.M. Islam, M.R. Karim, H. Faiz, Z. Hammad, S. Sadiq, M. Alam, Integrating deep learning algorithms for forecasting evapotranspiration and assessing crop water stress in agricultural water management, J. Environ. Manage. 375 (2025) 124363, https://doi.org/10.1016/j.jenvman.2025.124363.
[65] J. Bellvert, M. Pamies-Sans, J. Casadesús, J. Girona, Evaluating the impact of drought and water restrictions on agricultural production in irrigated areas through crop water productivity functions and a remote sensing-based evapotranspiration model, Agric Water Manag 309 (2025) 109319, https://doi.org/10.1016/j.agwat.2025.109319.
[66] J. Luo, Y. Guo, Y. Qi, Y. Shen, Pathways to balancing water and food for agricultural sustainable development in the Beijing-Tianjin-Hebei Region, China, Agric Water Manag 310 (2025) 109344, https://doi.org/10.1016/j.agwat.2025.109344.
[67] B. Jayant, K. Dahiya, A. Rukhiyar, R. Raj, R.K. Meena, A review of the drip irrigation system, J. Eng. Res. Appl. 01 (2022), https://doi.org/10.55953/JERA.2022.1103.
[68] R.G. Evans, J. LaRue, K.C. Stone, B.A. King, Adoption of site-specific variable rate sprinkler irrigation systems, Irrig. Sci. 31 (2013) 871–887, https://doi.org/10.1007/s00271-012-0365-x.
[69] B. Yang, P. Fu, J. Lu, F. Ma, X. Sun, Y. Fang, Regulated deficit irrigation: an effective way to solve the shortage of agricultural water for horticulture, Stress Biol. 2 (2022) 28, https://doi.org/10.1007/s44154-022-00050-5.
[70] A.G. Condon, Breeding for high water-use efficiency, J. Exp. Bot. 55 (2004) 2447–2460, https://doi.org/10.1093/jxb/erh277.
[71] M. Li, Y. Xu, Q. Fu, V.P. Singh, D. Liu, T. Li, Efficient irrigation water allocation and its impact on agricultural sustainability and water scarcity under uncertainty, J. Hydrol. 586 (2020) 124888, https://doi.org/10.1016/j.jhydrol.2020.124888.
[72] C. Konstantinou, M. Giakoumi, C.F. Panagiotou, A game-theoretic framework for sustainable water allocation in agriculture: Enhancing economic and water efficiency in Akrotiri district (Cyprus), Sci. Total Environ. 966 (2025) 178691, https://doi.org/10.1016/j.scitotenv.2025.178691.
[73] H. Cheng, A. Wang, J. Zhang, X. Nong, X. Jiang, H. Wu, Z. Chen, M. Wang, J. Cheng, Divergent responses of optimal land and water allocation to different hydrological regimes in the agricultural water-food-carbon nexus system, J. Hydrol. 653 (2025) 132730, https://doi.org/10.1016/j.jhydrol.2025.132730.
[74] F.A. Ward, N.A. Potter, R.A. Hrozencik, Managing agricultural water use in the Western United States: a search for efficient climate adaptation institutions, Agric Water Manag 308 (2025) 109279, https://doi.org/10.1016/j.agwat.2024.109279.
[75] S. Janjua, D.-A. An-Vo, K. Reardon-Smith, S. Mushtaq, Resolving water security conflicts in agriculture by a cooperative Nash bargaining approach, Agric Water Manag 306 (2024) 109205, https://doi.org/10.1016/j.agwat.2024.109205.
[76] M.S.N. dos Santos, J.H.C. Wancura, C.E.D. Oro, F.D. Vezaro, L.P. Ody, M.V. Tres, G.L. Zabot, Urban agriculture and water recycling: a comprehensive outlook on current panorama, Environ. Dev. 54 (2025) 101156, https://doi.org/10.1016/j.envdev.2025.101156.
[77] R.R. Palatnik, O. Raviv, J. Sirota, M. Shechter, Water scarcity and food security in the mediterranean region: the role of alternative water sources and controlled-environment agriculture, Water Resour. Econ. 49 (2025) 100256, https://doi.org/10.1016/j.wre.2025.100256.
[78] M. Savari, M.S. Amghani, A. Malekian, Factors influencing the use of treated wastewater for irrigation in the agricultural sector: evidence from Iran, Clean. Eng. Technol. 24 (2025) 100901, https://doi.org/10.1016/j.clet.2025.100901.
[79] C. Di Marcantonio, F. Mangiagli, M.R. Boni, J. Bartolucci, S. Bongirolami, R. Romano, A. Martelli, D. Rapinesi, F. Altobelli, A. Chiavola, Are we ready for the application of the EU Regulation on wastewater reuse in agriculture? a techno-economic preliminary evaluation based on a case-study, J. Environ. Manage. 373 (2025) 123973, https://doi.org/10.1016/j.jenvman.2024.123973.

[80] H.E. Al-Hazmi, A. Mohammadi, A. Hejna, J. Majtacz, A. Esmaeili, S. Habibzadeh, M.R. Saeb, M. Badawi, E.C. Lima, J. Mąkinia, Wastewater reuse in agriculture: prospects and challenges, Environ. Res. 236 (2023) 116711, https://doi.org/10.1016/j.envres.2023.116711.
[81] L. Penserini, B. Cantoni, M. Antonelli, Modelling the impacts generated by reclaimed wastewater reuse in agriculture: from literature gaps to an integrated risk assessment in a one Health perspective, J. Environ. Manage. 371 (2024) 122715, https://doi.org/10.1016/j.jenvman.2024.122715.
[82] C. Parra-López, S. Ben Abdallah, G. Garcia-Garcia, A. Hassoun, H. Trollman, S. Jagtap, S. Gupta, A. Aït-Kaddour, S. Makmuang, C. Carmona-Torres, Digital technologies for water use and management in agriculture: Recent applications and future outlook, Agric. Water Manag. 309 (2025) 109347. DOI: 10.1016/j.agwat.2025.109347.
[83] U.B. Antu, M.S. Islam, S. Ahmed, M. Arifuzzaman, S. Saha, P.R. Mitu, A.R. Sarkar, N.A. Mahiddin, Z. Ismail, K.A. Ibrahim, A.M. Idris, Emerging technologies for efficient water use in agriculture: a review of current trends and future directions, J. Water Process Eng. 68 (2024) 106317, https://doi.org/10.1016/j.jwpe.2024.106317.
[84] A. Morchid, B. Et-taibi, Z. Oughannou, R. El Alami, H. Qjidaa, M.O. Jamil, E.-M. Boufounas, M.R. Abid, IoT-enabled smart agriculture for improving water management: a smart irrigation control using embedded systems and Server-Sent events, Sci. African. 27 (2025) e02527, https://doi.org/10.1016/j.sciaf.2024.e02527.
[85] L.A. Bermúdez, V.D. Mendoza, J.C.L. Díaz, J.M. Pascual, M. del Mar Muñio, J.M. P.C. Martínez, Investigation of the agricultural reuse potential of urban wastewater and other resources derived by using membrane bioreactor technology within the circular economy framework, Sci. Total Environ. 955 (2024) 177011, https://doi.org/10.1016/j.scitotenv.2024.177011.
[86] A.B. Alayande, W. Qi, R. Karthikeyan, S.C. Popat, D.A. Ladner, G. Amy, Use of reclaimed municipal wastewater in agriculture: Comparison of present practice versus an emerging paradigm of anaerobic membrane bioreactor treatment coupled with hydroponic controlled environment agriculture, Water Res. 265 (2024) 122197, https://doi.org/10.1016/j.watres.2024.122197.
[87] J. Sun, Y. Xin, T. Sun, B. Sun, Y. Yang, Q. Yang, X. Fan, Advanced plasma hydrogel evaporator for efficient solar-driven saline-alkaline water treatment and agricultural application, Chem. Eng. J. 501 (2024) 157740, https://doi.org/10.1016/j.cej.2024.157740.
[88] M. Rank, N. Chaturvedi, K.D. Vyas, A. Singh, Biodesalination of RO reject water by salinity-tolerant bacteria and nutrient fortification for agricultural applications - a sustainable energy-efficient solution to valorize wastewater, Desalination 600 (2025) 118484, https://doi.org/10.1016/j.desal.2024.118484.
[89] N. Sezer, S. Bayhan, Integrated solar-powered freeze desalination and water electrolysis system with energy recovery and storage for sustainable agriculture in desert environments, Desalination 595 (2025) 118321, https://doi.org/10.1016/j.desal.2024.118321.
[90] O.S. Rizvi, F. Ashfaq, A. Ikhlaq, A. Akram, Z. Masood, U.U. Ashar, A. Naeem, F. Qi, Novel hybrid treatment for canal water recycling by integrating coagulation, catalytic ozonation, and filtration for agricultural sustainability, J. Water Process Eng. 67 (2024) 106263, https://doi.org/10.1016/j.jwpe.2024.106263.
[91] Z. Feng, R. Zhang, X. Liu, Q. Peng, L. Wang, Agricultural nonpoint source pollutant loads into water bodies in a typical basin in the middle reach of the Yangtze River, Ecotoxicol. Environ. Saf. 268 (2023) 115728, https://doi.org/10.1016/j.ecoenv.2023.115728.
[92] S. Zhang, L. Zhang, Q. Meng, C. Wang, J. Ma, H. Li, K. Ma, Evaluating agricultural non-point source pollution with high-resolution remote sensing technology and SWAT model: a case study in Ningxia Yellow River Irrigation District, China, Ecol. Indic. 166 (2024) 112578, https://doi.org/10.1016/j.ecolind.2024.112578.
[93] K. Chen, Q. Liu, W. Peng, Y. Liu, Z. Wang, Source apportionment of river water pollution in a typical agricultural city of Anhui Province, eastern China using multivariate statistical techniques with APCS–MLR, Water Sci. Eng. 16 (2023) 165–174, https://doi.org/10.1016/j.wse.2022.12.007.
[94] W. Wang, Y. Fan, G. Chen, L. Liu, R. Wang, X. Tang, Y. Li, X. Li, Balancing river water pollution and agricultural development: a tradeoff threshold approach, J. Environ. Manage. 367 (2024) 121985, https://doi.org/10.1016/j.jenvman.2024.121985.
[95] D. Zuo, Y. Bi, Y. Song, Z. Xu, G. Wang, G. Ma, K.C. Abbaspour, H. Yang, The response of non-point source pollution to land use change and risk assessment based on model simulation and grey water footprint theory in an agricultural river basin of Yangtze River, China, Ecol. Indic. 154 (2023) 110581, https://doi.org/10.1016/j.ecolind.2023.110581.
[96] F.A.L. Pacheco, S.G.P. Varandas, L.F. Sanches Fernandes, R.F. Valle Junior, Soil losses in rural watersheds with environmental land use conflicts, Sci. Total Environ. 485–486 (2014) 110–120, https://doi.org/10.1016/j.scitotenv.2014.03.069.
[97] C.A. Valera, R.F. Valle Junior, S.G.P. Varandas, L.F. Sanches Fernandes, F.A. L. Pacheco, The role of environmental land use conflicts in soil fertility: a study on the Uberaba River basin, Brazil, Sci. Total Environ. 562 (2016) 463–473, https://doi.org/10.1016/j.scitotenv.2016.04.046.
[98] C. Hu, Q. Wu, G. Liu, H. Ran, M. Guo, J. Zhu, J. Zeng, Nitrogen and phosphorus non-point source pollution in the upper Wujiang River Karst Basin: critical source areas identification and influencing factors, Ecol. Indic. 170 (2025) 112989, https://doi.org/10.1016/j.ecolind.2024.112989.
[99] K. Mei, H. Shi, Y. Wu, R.A. Dahlgren, X. Ji, M. Yang, Y. Guan, Impact of landscape patterns on river water quality: Spatial-scale effects across an agricultural-urban interface, Ecol. Indic. 170 (2025) 113019, https://doi.org/10.1016/j.ecolind.2024.113019.
[100] A.C.P. Fernandes, L.M. de Oliveira Martins, F.A.L. Pacheco, L.F.S. Fernandes, The consequences for stream water quality of long-term changes in landscape patterns: Implications for land use management and policies, Land Use Policy 109 (2021), https://doi.org/10.1016/j.landusepol.2021.105679.
[101] F. Clément, J. Ruiz, M.A. Rodríguez, D. Blais, S. Campeau, Landscape diversity and forest edge density regulate stream water quality in agricultural catchments, Ecol. Indic. 72 (2017) 627–639, https://doi.org/10.1016/j.ecolind.2016.09.001.
[102] M. Qiu, X. Wei, Y. Hou, S.A. Spencer, J. Hui, Forest cover, landscape patterns, and water quality: a meta-analysis, Landsc. Ecol. 38 (2023) 877–901, https://doi.org/10.1007/s10980-023-01593-2.
[103] J. Rocha, P. Roebeling, M.E. Rial-Rivas, Assessing the impacts of sustainable agricultural practices for water quality improvements in the Vouga catchment (Portugal) using the SWAT model, Sci. Total Environ. 536 (2015) 48–58, https://doi.org/10.1016/j.scitotenv.2015.07.038.
[104] C.F.C.F. Oliveira, R.F.R.F. do Valle Junior, C.A.C.A. Valera, V.S.V.S. Rodrigues, L. F.L.F. Sanches Fernandes, F.A.L.F.A.L. Pacheco, The modeling of pasture conservation and of its impact on stream water quality using Partial Least Squares-Path Modeling, Sci. Total Environ. 697 (2019). DOI: 10.1016/j.scitotenv.2019.134081.
[105] W. Liu, S. Li, W. Shen, Y. Zhuang, X. Li, F. Ling, L. Zhang, Small water bodies influence river water quality in agricultural watersheds, Agric Water Manag 304 (2024) 109070, https://doi.org/10.1016/j.agwat.2024.109070.
[106] T.C.T. Pissarra, C.A. Valera, R.C.A. Costa, H.E. Siqueira, M.V.M. Filho, R.F. Valle Júnior, L.F. Sanches Fernandes, F.A.L. Pacheco, A regression model of stream water quality based on interactions between landscape composition and riparian buffer width in small catchments, Water 11 (9) (2019) 1757, https://doi.org/10.3390/w11091757.
[107] C. Valera, T. Pissarra, M. Filho, R. Valle Júnior, C. Oliveira, J. Moura, L. Sanches Fernandes, F. Pacheco, The Buffer Capacity of Riparian Vegetation to Control Water Quality in Anthropogenic Catchments from a Legally Protected Area: A Critical View over the Brazilian New Forest Code, Water 11 (2019) 549, https://doi.org/10.3390/w11030549.
[108] J.L. Gallego, E.R. Shipley, P. Vlahos, J. Olivero-Verbel, Occurrence and toxicological relevance of pesticides and trace metals in agricultural soils, sediments, and water of the Sogamoso River basin, Colombia, Chemosphere. 354 (2024) 141713, https://doi.org/10.1016/j.chemosphere.2024.141713.
[109] J. Yi, P.W. Gerbens-Leenes, M.M. Aldaya, Spatial and temporal grey water footprints of agricultural pesticide use: improved pesticide use options to decrease water pollution in China, Energy Nexus. 16 (2024) 100349, https://doi.org/10.1016/j.nexus.2024.100349.
[110] M. Naeem, R. Gill, S.S. Gill, K. Singh, A. Sofo, N. Tuteja, Editorial: Emerging contaminants and their effect on agricultural crops, Front. Plant Sci. 14 (2023), https://doi.org/10.3389/fpls.2023.1296252.
[111] L. Charuaud, E. Jarde, A. Jaffrezic, M.-F. Thomas, B. Le Bot, Veterinary pharmaceutical residues from natural water to tap water: sales, occurrence and fate, J. Hazard. Mater. 361 (2019) 169–186, https://doi.org/10.1016/j.jhazmat.2018.08.075.
[112] A.H.A. Khan, R. Barros, Pharmaceuticals in Water: risks to Aquatic Life and Remediation strategies, Hydrobiology 2 (2023) 395–409, https://doi.org/10.3390/hydrobiology2020026.
[113] A. Zeb, W. Liu, N. Ali, R. Shi, Q. Wang, J. Wang, J. Li, C. Yin, J. Liu, M. Yu, J. Liu, Microplastic pollution in terrestrial ecosystems: Global implications and sustainable solutions, J. Hazard. Mater. 461 (2024) 132636, https://doi.org/10.1016/j.jhazmat.2023.132636.
[114] R. Hou, J. Zhang, Q. Fu, T. Li, S. Gao, R. Wang, S. Zhao, B. Zhu, The boom era of emerging contaminants: a review of remediating agricultural soils by biochar, Sci. Total Environ. 931 (2024) 172899, https://doi.org/10.1016/j.scitotenv.2024.172899.
[115] Z. Wu, Y. Wu, Y. Yu, L. Wang, P. Qi, Y. Sun, Q. Fu, G. Zhang, Assessment of groundwater quality variation characteristics and influencing factors in an intensified agricultural area: an integrated hydrochemical and machine learning approach, J. Environ. Manage. 371 (2024) 123233, https://doi.org/10.1016/j.jenvman.2024.123233.
[116] Y. Deng, X. Ye, J. Feng, H. Guo, X. Du, Assessment of soil-groundwater nitrogen cycling processes in the agricultural region through flux model, stable isotope, J. Hydrol. 639 (2024) 131604, https://doi.org/10.1016/j.jhydrol.2024.131604.
[117] Y. Ma, Z.-H. Liu, B.-D. Xi, X.-S. He, Q.-L. Li, Y.-J. Qi, M.-Y. Jin, Y. Guo, Characteristics of groundwater pollution in a vegetable cultivation area of typical facility agriculture in a developed city, Ecol. Indic. 105 (2019) 709–716, https://doi.org/10.1016/j.ecolind.2018.10.056.
[118] E. Crayol, F. Huneau, E. Garel, L.E. Zuffianò, P.P. Limoni, A. Romanazzi, A. Mattei, V. Re, K. Knoeller, M. Polemio, Investigating pollution input to coastal groundwater-dependent ecosystems in dry Mediterranean agricultural regions, Sci. Total Environ. 954 (2024) 176015, https://doi.org/10.1016/j.scitotenv.2024.176015.
[119] H. Wang, Q. Yang, H. Ma, J. Liang, Chemical compositions evolution of groundwater and its pollution characterization due to agricultural activities in Yinchuan Plain, northwest China, Environ. Res. 200 (2021) 111449, https://doi.org/10.1016/j.envres.2021.111449.
[120] J. Wu, J. Lu, X. Wen, Z. Zhang, Y. Lin, Severe Nitrate Pollution and Health risks of Coastal Aquifer simultaneously Influenced by Saltwater Intrusion and Intensive Anthropogenic Activities, Arch. Environ. Contam. Toxicol. 77 (2019) 79–87, https://doi.org/10.1007/s00244-019-00636-7.

[121] A. Khedidja, A. Boudoukha, Risk assessment of agricultural pollution on groundwater quality in the high valley of Tadjenanet-Chelghoum Laid (Eastern Algeria), Desalin. Water Treat. 52 (2014) 4174–4182, https://doi.org/10.1080/19443994.2013.874702.
[122] X. Zhu, P. Miao, J. Qin, W. Li, L. Wang, Z. Chen, J. Zhou, Spatio-temporal variations of nitrate pollution of groundwater in the intensive agricultural region: Hotspots and driving forces, J. Hydrol. 623 (2023) 129864, https://doi.org/10.1016/j.jhydrol.2023.129864.
[123] A. Cabrera, D.I. Cendón, V. Aparicio, M.J. Currell, Intensive agriculture, a pesticide pathway to >100 m deep groundwater below dryland agriculture, Cordoba Pampas, Argentina, J. Hydrol. 643 (2024) 131989, https://doi.org/10.1016/j.jhydrol.2024.131989.
[124] L.H.E. Winkel, P.T.K. Trang, V.M. Lan, C. Stengel, M. Amini, N.T. Ha, P.H. Viet, M. Berg, Arsenic pollution of groundwater in Vietnam exacerbated by deep aquifer exploitation for more than a century, Proc. Natl. Acad. Sci. 108 (2011) 1246–1251, https://doi.org/10.1073/pnas.1011915108.
[125] G.D. Liu, W.L. Wu, J. Zhang, Regional differentiation of non-point source pollution of agriculture-derived nitrate nitrogen in groundwater in northern China, Agric. Ecosyst. Environ. 107 (2005) 211–220, https://doi.org/10.1016/j.agee.2004.11.010.
[126] S.K. Mohakud, S.H. Farooq, Seasonal variability of arsenic concentrations in irrigation water and its impact on arsenic accumulation in agriculture soils: a study from Bengal Delta, Groundw. Sustain. Dev. 29 (2025) 101415, https://doi.org/10.1016/j.gsd.2025.101415.
[127] J.A. Torres-Martínez, A. Mora, J. Mahlknecht, L.W. Daesslé, P.A. Cervantes-Avilés, R. Ledesma-Ruiz, Estimation of nitrate pollution sources and transformations in groundwater of an intensive livestock-agricultural area (Comarca Lagunera), combining major ions, stable isotopes and MixSIAR model, Environ. Pollut. 269 (2021) 115445, https://doi.org/10.1016/j.envpol.2020.115445.
[128] J. Virgílio Cruz, M.O. Silva, M. Isabel Dias, M. Isabel Prudêncio, Groundwater composition and pollution due to agricultural practices at Sete Cidades volcano (Azores, Portugal), Appl. Geochemistry. 29 (2013) 162–173, https://doi.org/10.1016/j.apgeochem.2012.11.009.
[129] A. Neshat, B. Pradhan, S. Javadi, Risk assessment of groundwater pollution using Monte Carlo approach in an agricultural region: an example from Kerman Plain, Iran, Comput. Environ. Urban Syst. 50 (2015) 66–73, https://doi.org/10.1016/j.compenvurbsys.2014.11.004.
[130] M.L. Lima, A. Romanelli, H.E. Massone, Assessing groundwater pollution hazard changes under different socio-economic and environmental scenarios in an agricultural watershed, Sci. Total Environ. 530–531 (2015) 333–346, https://doi.org/10.1016/j.scitotenv.2015.05.026.
[131] W.A. Ashagrie, T.G. Tarkegn, R.L. Ray, G.W. Tefera, S.F. Demessie, L. Tsegaye, A. A. Adem, A.W. Worqlul, P.R. van Oel, E. Adgo, A. Haileslassie, Y.T. Dile, M. Mekonnen, A.D. Chukalla, Assessing the vulnerability of groundwater to pollution under different land management scenarios using the modified DRASTIC model in Bahir Dar City, Ethiopia, Heliyon 11 (2025) e42660, https://doi.org/10.1016/j.heliyon.2025.e42660.
[132] R. Chen, Y. Teng, H. Chen, B. Hu, W. Yue, Groundwater pollution and risk assessment based on source apportionment in a typical cold agricultural region in Northeastern China, Sci. Total Environ. 696 (2019) 133972, https://doi.org/10.1016/j.scitotenv.2019.133972.
[133] V. Rodriguez-Galiano, M.P. Mendes, M.J. Garcia-Soldado, M. Chica-Olmo, L. Ribeiro, Predictive modeling of groundwater nitrate pollution using Random Forest and multisource variables related to intrinsic and specific vulnerability: a case study in an agricultural setting (Southern Spain), Sci. Total Environ. 476–477 (2014) 189–206, https://doi.org/10.1016/j.scitotenv.2014.01.001.
[134] K. Nakagawa, M.S. Islam, S.S.H. Shah, Z. Li, Y. Takao, R. Berndtsson, Relationship between nitrate, heavy metal, and sterols contents in Japanese agricultural soils with risk of groundwater pollution, Chemosphere 361 (2024) 142335, https://doi.org/10.1016/j.chemosphere.2024.142335.
[135] F.A.L. Pacheco, L.M.O. Martins, M. Quininha, A.S. Oliveira, L.F. Sanches Fernandes, Modification to the DRASTIC framework to assess groundwater contaminant risk in rural mountainous catchments, J. Hydrol. 566 (2018) 175–191, https://doi.org/10.1016/j.jhydrol.2018.09.013.
[136] X. Yang, J. Du, C. Jia, T. Yang, S. Shao, Unravelling integrated groundwater management in pollution-prone agricultural cities: a synergistic approach combining probabilistic risk, source apportionment and artificial intelligence, J. Hazard. Mater. 481 (2025) 136514, https://doi.org/10.1016/j.jhazmat.2024.136514.
[137] S. Peña-Haro, M. Pulido-Velazquez, A. Sahuquillo, A hydro-economic modelling framework for optimal management of groundwater nitrate pollution from agriculture, J. Hydrol. 373 (2009) 193–203, https://doi.org/10.1016/j.jhydrol.2009.04.024.
[138] C. Llopis-Albert, D. Palacios-Marqués, J.M. Merigó, A coupled stochastic inverse-management framework for dealing with nonpoint agriculture pollution under groundwater parameter uncertainty, J. Hydrol. 511 (2014) 10–16, https://doi.org/10.1016/j.jhydrol.2014.01.021.
[139] S. Peña-Haro, C. Llopis-Albert, M. Pulido-Velazquez, D. Pulido-Velazquez, Fertilizer standards for controlling groundwater nitrate pollution from agriculture: El Salobral-Los Llanos case study, Spain, J. Hydrol. 392 (2010) 174–187, https://doi.org/10.1016/j.jhydrol.2010.08.006.
[140] F.A.L. Pacheco, V.H.S. Lima, T.C.T. Pissarra, R.F. do Valle Junior, M.M.A.P. de M. Silva, M.C. de Melo, C.A. Valera, J.P. Moura, L.F.S. Fernandes, A framework model to determine groundwater contamination risk based on a L-Matrix of aquifer vulnerability and hazardous activity indices, MethodsX 9 (2022) 101858, https://doi.org/10.1016/j.mex.2022.101858.
[141] V.H.S. Lima, F.A.L. Pacheco, J.P. Moura, T.C.T. Pissarra, R.F. do Valle Junior, M. M.A.P. de Melo Silva, A. Monteiro da Costa, C.A. Valera, M.C. de Melo, L. F. Sanches Fernandes, Protection of groundwater resources from multi-hazards: an integration of risk assessment and watershed management, Groundw. Sustain. Dev. 27 (2024) 101326, https://doi.org/10.1016/j.gsd.2024.101326.
[142] F.A.L. Pacheco, V.H.S. Lima, J.P. Moura, M.D. de Oliveira, L. Akabassi, L.F. S. Fernandes, A framework model to prioritize groundwater management actions based on the concept of dominant risk: an application to the state of Espírito Santo, Brazil, Case Stud. Chem. Environ. Eng. 11 (2025) 101032, https://doi.org/10.1016/j.cscee.2024.101032.
[143] L. Jia, J. Xin, H. Wu, S. Gong, H. Wu, Z. Zhang, Enhancing nitrate attenuation in groundwater via selectively applying surface agricultural practices: a novel and sustainable strategy for non-point source pollution mitigation, Water Res. 239 (2023) 120052, https://doi.org/10.1016/j.watres.2023.120052.
[144] M. Li, P. Zhang, A. Yang, X. Wang, Y. Sha, Q. Fu, Achieving sustainable goals in agroecosystems through the optimization of agricultural resources integrating the water-nitrogen-carbon nexus, Iscience 28 (2025) 112101, https://doi.org/10.1016/j.isci.2025.112101.
[145] T. Octavianti, Rethinking water security: how does flooding fit into the concept? Environ Sci Policy 106 (2020) 145–156, https://doi.org/10.1016/j.envsci.2020.01.010.
[146] J. Qiu, X. Yang, Z. Zheng, P. Tarolli, High-resolution mapping of China's flooded croplands, Sci. Bull. 70 (2025) 1165–1173, https://doi.org/10.1016/j.scib.2025.01.053.
[147] F. Zhong, X. Xu, Z. Li, W. Luo, X. Zeng, X. Li, H. Gao, Responses of crops to flood and implications for agriculture planning in subtropical humid karst peak-cluster depressions, J. Hydrol. 641 (2024) 131728, https://doi.org/10.1016/j.jhydrol.2024.131728.
[148] P. Syldon, B.B. Shrestha, M. Miyamoto, K. Tamakawa, S. Nakamura, Assessing the impact of climate change on flood inundation and agriculture in the Himalayan Mountainous Region of Bhutan, J. Hydrol.: Reg. Stud. 52 (2024) 101687, https://doi.org/10.1016/j.ejrh.2024.101687.
[149] M.A. Rahman, M.S. Alam, R. Sultana, R. Sultana, Assessing the interrelationship between monsoon flood disasters and major crop production in Bangladesh, Int. J. Disaster Risk Reduct. 121 (2025) 105401, https://doi.org/10.1016/j.ijdrr.2025.105401.
[150] E.N. Ngumbi, Could flooding undermine progress in building climate-resilient crops? Trends Plant Sci. 30 (2025) 85–94, https://doi.org/10.1016/j.tplants.2024.07.017.
[151] B.B. Balana, S. Sanfo, B. Barbier, T. Williams, S. Kolavalli, Assessment of flood recession agriculture for food security in Northern Ghana: an optimization modelling approach, Agric. Syst. 173 (2019) 536–543, https://doi.org/10.1016/j.agsy.2019.03.021.
[152] L. Bruckmann, A. Ogilvie, D. Martin, F.B. Diakhaté, A. Tilmant, Mapping seasonal flood-recession cropland extent in the Senegal River Valley, Remote Sens. Appl.: Soc. Environ. 37 (2025) 101473, https://doi.org/10.1016/j.rsase.2025.101473.
[153] F.N. Mabe, Effects of flood-recession production system on rice yield in Ghana, Sci. African. 28 (2025) e02689, https://doi.org/10.1016/j.sciaf.2025.e02689.
[154] S.K. Jain, Providing water security in India by conserving and utilizing flood flows, Water Secur. 14 (2021) 100105, https://doi.org/10.1016/j.wasec.2021.100105.
[155] T. Lucaora, A. Annis, F. Nardi, M.C. Rulli, D.D. Chiarelli, Distributed hydrodynamic modelling for assessing flood impacts on crops: Assessing flood-resilient crop management in a coastal basin of central Italy, Agric Water Manag 309 (2025) 109352, https://doi.org/10.1016/j.agwat.2025.109352.
[156] Y. Shen, Q. Guo, Z. Liu, Y. Shen, Y. Jia, Y. Wei, Prediction of drought-flood prone zones in inland mountainous regions under climate change with assessment and enhancement strategies for disaster resilience in high-standard farmland, Agric Water Manag 309 (2025) 109349, https://doi.org/10.1016/j.agwat.2025.109349.
[157] OECD, A Handbook of what works: Solutions for the local implementation of the OECD principles on water governance, 2024. https://www.oecd.org/en/topics/sub-issues/water-governance/the-oecd-principles-on-water-governance-and-implementation-strategy.html, assessed in May 3, 2025.
[158] M. Nouri, M. Homaee, L.S. Pereira, M. Bybordi, Water management dilemma in the agricultural sector of Iran: a review focusing on water governance, Agric Water Manag 288 (2023) 108480, https://doi.org/10.1016/j.agwat.2023.108480.
[159] N. Nazemi, R.W. Foley, G. Louis, L.W. Keeler, Divergent agricultural water governance scenarios: the case of Zayanderud basin, Iran, Agric Water Manag 229 (2020) 105921, https://doi.org/10.1016/j.agwat.2019.105921.
[160] D. Anghileri, M. Pastori, P. Marcos-Garcia, G. Umlauf, E. Crestaz, R. Seliger, A. Iervolino, E. Cordano, L. Cattaneo, C. Carmona-Moreno, Global Water challenges in Sub-Saharan Africa and how to strengthen science-policy dialogues on transboundary governance and cooperation, J. Environ. Manage. 365 (2024) 121417, https://doi.org/10.1016/j.jenvman.2024.121417.
[161] F. Bayat, A. Roozbahani, S.M. Hashemy Shahdany, An integrated risk-based water-food-energy nexus assessment framework for surface water operation governance, Comput. Electron. Agric. 229 (2025) 109659, https://doi.org/10.1016/j.compag.2024.109659.
[162] C. Zhang, X. Chen, Y. Li, W. Ding, G. Fu, Water-energy-food nexus: Concepts, questions and methodologies, J. Clean. Prod. 195 (2018) 625–639, https://doi.org/10.1016/j.jclepro.2018.05.194.

[163] M. Ghanian, Exploring the food, energy, and water governance in South-West Iran, Reg. Sci. Policy Pract. 16 (2024) 12578, https://doi.org/10.1111/rsp3.12578.
[164] M. Oulu, D. Darko, R. Osaliya, F. Aziz, D. Wekesa, Governing the nexus: Water-energy-food nexus governance strategies in Ghana and Uganda, Environ. Dev. 48 (2023) 100933, https://doi.org/10.1016/j.envdev.2023.100933.
[165] J.L. Jones-Crank, The contribution of water-energy-food nexus governance to sustainability: a case study of Singapore, Environ Sci Policy 160 (2024) 103849, https://doi.org/10.1016/j.envsci.2024.103849.
[166] J. Kong, M. Gao, H. Alofaysan, D. Fayziyeva, Z. Liu, Enhancing urban agriculture networks: a clustering and multicriteria decision-making approach to sustainability indicators and governance, Ecol. Indic. 170 (2025) 112997, https://doi.org/10.1016/j.ecolind.2024.112997.
[167] E. Sievers, I. Canovas, D. Kristensen, F. Hüesker, Assessing to act: a water-energy-food-ecosystem (WEFE) nexus governance assessment for the Inkomati-Usuthu river basin in South Africa, Environ Sci Policy 164 (2025) 103986, https://doi.org/10.1016/j.envsci.2025.103986.
[168] M.J. Vardon, T.H.L. Le, R. Martinez-Lagunes, O.B. Pule, S. Schenau, S. May, R. Q. Grafton, Accounting for water: a global review and indicators of best practice for improved water governance, Ecol. Econ. 227 (2025) 108396, https://doi.org/10.1016/j.ecolecon.2024.108396.
[169] I. Fuentes, R.W. Vervoort, J. McPhee, L.A.R. Rojas, Agricultural water accounting: Complementing a governance monitoring schema with remote sensing calculations at different scales, Agric Water Manag 292 (2024) 108676, https://doi.org/10.1016/j.agwat.2024.108676.
[170] J.E. Argente García, B. Yazici, A. Richa, S. Touil, V.J. Richart Díaz, A.P. Ramallo-González, A.F. Skarmeta Gómez, Digitalising governance processes and water resources management to foster sustainability strategies in the Mediterranean agriculture, Environ Sci Policy 158 (2024) 103805, https://doi.org/10.1016/j.envsci.2024.103805.
[171] G. Özerol, H. Bressers, Scalar alignment and sustainable water governance: the case of irrigated agriculture in Turkey, Environ Sci Policy 45 (2015) 1–10, https://doi.org/10.1016/j.envsci.2014.09.002.
[172] V. Gillet, J. McKay, G. Keremane, Moving from local to State water governance to resolve a local conflict between irrigated agriculture and commercial forestry in South Australia, J. Hydrol. 519 (2014) 2456–2467, https://doi.org/10.1016/j.jhydrol.2014.08.031.
[173] C. Sanchis-Ibor, M. García-Mollá, T. Torregrosa, M. Ortega-Reig, M. Sevilla Jiménez, Water transfers between agricultural and urban users in the region of Valencia (Spain). a case of weak governance? Water Secur. 7 (2019) 100030 https://doi.org/10.1016/j.wasec.2019.100030.
[174] FAO, Unlocking finance for water and agriculture, volume 1, 2023. DOI: DOI: 10.4060/cc3917en, WASAG - The Global Framework on Water in Agriculture, Rome, 27 p.
[175] L. Zhou, L. Li, J. Huang, The river chief system and agricultural non-point source water pollution control in China, J. Integr. Agric. 20 (2021) 1382–1395, https://doi.org/10.1016/S2095-3119(20)63370-6.
[176] L. Xiao, J. Liu, J. Ge, Dynamic game in agriculture and industry cross-sectoral water pollution governance in developing countries, Agric Water Manag 243 (2021) 106417, https://doi.org/10.1016/j.agwat.2020.106417.
[177] M. Wiering, S. Kirschke, N.U. Akif, Addressing diffuse water pollution from agriculture: do governance structures matter for the nature of measures taken? J. Environ. Manage. 332 (2023) 117329 https://doi.org/10.1016/j.jenvman.2023.117329.
[178] Y. Chen, M. Vardon, Accounting for water-related ecosystem services to provide information for water policy and management: an Australian case study, Ecosyst. Serv. 69 (2024) 101658, https://doi.org/10.1016/j.ecoser.2024.101658.
[179] R. Haavisto, D. Santos, A. Perrels, Determining payments for watershed services by hydro-economic modeling for optimal water allocation between agricultural and municipal water use, Water Resour. Econ. 26 (2019) 100127, https://doi.org/10.1016/j.wre.2018.08.003.
[180] W.M. Roberts, L.B. Couldrick, G. Williams, D. Robins, D. Cooper, Mapping the potential for Payments for Ecosystem Services schemes to improve water quality in agricultural catchments: a multi-criteria approach based on the supply and demand concept, Water Res. 206 (2021) 117693, https://doi.org/10.1016/j.watres.2021.117693.
[181] X. Wang, E.-A. Nuppenau, Modelling payments for ecosystem services for solving future water conflicts at spatial scales: the Okavango River Basin example, Ecol. Econ. 184 (2021) 106982, https://doi.org/10.1016/j.ecolecon.2021.106982.
[182] T.C.T. Pissarra, L.F. Sanches Fernandes, F.A.L. Pacheco, Production of clean water in agriculture headwater catchments: a model based on the payment for environmental services, Sci. Total Environ. 785 (2021) 147331, https://doi.org/10.1016/j.scitotenv.2021.147331.
[183] G. Valatin, P. Ovando, J. Abildtrup, C. Accastello, M.B. Andreucci, A. Chikalanov, A. El Mokaddem, S. Garcia, M. Gonzalez-Sanchis, F. Gordillo, B. Kayacan, D. Little, M. Lyubenova, T. Nisbet, A. Paletto, C. Petucco, M. Termansen, K. Vasylyshyn, S.E. Vedel, R. Yousefpour, Approaches to cost-effectiveness of payments for tree planting and forest management for water quality services, Ecosyst. Serv. 53 (2022) 101373, https://doi.org/10.1016/j.ecoser.2021.101373.
[184] A.L. Quiñónez Camarillo, P.W. Schuhmann, T. Randhir, J. Orellana, Coffee farmers willingness to accept payments for ecosystem services: evidence from a choice experiment in Honduras, J. Environ. Manage. 378 (2025) 124787, https://doi.org/10.1016/j.jenvman.2025.124787.
[185] J. Sheng, H. Yang, Linking water markets with payments for watershed services: the eastern route of China's South-North Water transfer Project, Agric Water Manag 295 (2024) 108733, https://doi.org/10.1016/j.agwat.2024.108733.
[186] S. Shukla, A. Shukla, Retrofitting agricultural detention systems can economically enhance nitrogen treatment with payment for services approach, Sci. Total Environ. 954 (2024) 176145, https://doi.org/10.1016/j.scitotenv.2024.176145.
[187] T. He, Y. Lu, Y. Cui, Y. Luo, M. Wang, W. Meng, K. Zhang, F. Zhao, Detecting gradual and abrupt changes in water quality time series in response to regional payment programs for watershed services in an agricultural area, J. Hydrol. 525 (2015) 457–471, https://doi.org/10.1016/j.jhydrol.2015.04.005.
[188] Q. Zeng, R. Brouwer, Y. Wang, L. Chen, Measuring the incremental impact of payments for Watershed Services on water quality in a transboundary river basin in China, Ecosyst. Serv. 51 (2021) 101355, https://doi.org/10.1016/j.ecoser.2021.101355.
[189] L. Kuhfuss, V. Burns, O. Shortall, A. Vinten, Obstacles to local payments for ecosystem services schemes for water management at the catchment scale: a case study from Eastern Scotland, Land Use Policy 139 (2024) 107057, https://doi.org/10.1016/j.landusepol.2024.107057.
[190] I. Mamedes, A. Guerra, D.B.B. Rodrigues, L.C. Garcia, R. de F. Godoi, P.T. S. Oliveira, Brazilian payment for environmental services programs emphasize water-related services, Int. Soil Water Conserv. Res. 11 (2023) 276–289, https://doi.org/10.1016/j.iswcr.2023.01.001.
[191] K.W. Jones, S.M. López-Ramirez, R.H. Manson, V.S. Ávila-Foucat, The emergence and persistence of payments for watershed services programs in Mexico, Water Resour. Econ. 42 (2023) 100217, https://doi.org/10.1016/j.wre.2023.100217.