

# The Impact of Agricultural Land Use Change on Water Resources and Hydrology Cycles in Temperate Regions

Ismail Adaramola Abdul Azeez<sup>1</sup>, Musab Yousufi<sup>2</sup>, Shazmah Fatima<sup>3</sup>, 4. Murad Bibi Tariq<sup>4</sup>

Received: December 6, 2025

Accepted: April 19, 2026

Published: May 25, 2026

**Abstract.** Changes in agricultural land use are major contributors to hydrological system alterations in temperate regions, exerting effects beyond direct water consumption and climatic variability. However, comprehensive synthesis integrating hydrological impacts with governance frameworks remains limited, particularly regarding policy transfer to emerging economies. This literature review examines empirical evidence, policy frameworks, and regulatory mechanisms governing agricultural land use changes and their hydrological impacts in temperate regions, with implications for sustainable water management in the Global South. The review synthesises peer-reviewed literature, meta-analyses, government reports, and institutional publications from Web of Science, Scopus, Google Scholar, and Food and Agriculture Organisation (FAO) and U.S. Geological Survey (USGS) repositories. It examines hydrological effects and governance frameworks, including the European Union Water Framework Directive, the U.S. Clean Water Act, the Canadian Water Act, and international guidelines. Results indicate that natural vegetation-to-cropland transitions cause 10–40% changes in basin surface runoff through altered evapotranspiration patterns, modified runoff pathways and surface water recharge. Soil structure manipulation, drainage infrastructure development, and changes in vegetation structure substantially influence infiltration rates, water retention, and seasonal flow regimes. Water quality impacts are significant, with nitrogen exports increasing by up to 300% alongside substantial alterations in sediment transport. Policy analysis reveals coherence gaps, implementation obstacles, and discrepancies between hydrological processes and administrative scales. Mitigation strategies include conservation agriculture practices, modified crop rotations, precision water management, and coordinated landscape-based approaches. Persistent challenges include distinguishing land-use effects from climate-change effects, upscaling local results to regional levels, and standardising assessment procedures. Integrating agricultural land use into water and land management policy frameworks is critical for sustainable resource management in temperate agricultural systems, contributing to SDGs 2 (Zero Hunger) and 6 (Clean Water and Sanitation).

**Keywords:** Agricultural land use, Hydrological systems, Water resources, Sustainable agriculture, Policy transfer, Temperate regions, SDG 6, Water governance.

## 1. INTRODUCTION

### 1.1. Background and Context

Currently, temperate water resource

systems are subject to some of the most extreme and unheard-of human stresses. Under such

---

<sup>1</sup> Dr. Ismail Adaramola Abdul Azeez

Riphah Institute of Public Policy, Islamabad, Pakistan, Email: ismail.adaramola@riphah.edu.pk

<sup>2</sup> Dr. Musab Yousufi

Riphah Institute of Public Policy, Islamabad, Pakistan, Email: musab.yousufi@riphah.edu.pk

<sup>3</sup> Shazmah Fatima

Riphah Institute of Public Policy, Islamabad, Pakistan, Email: juttsherry431@gmail.com

<sup>4</sup> Murad Bibi Tariq

Riphah Institute of Public Policy, Islamabad, Pakistan

circumstances, one of the most potent factors influencing hydrologic cycles on both a regional and temporal scale is the shift in agricultural land use. Over 70% of the world's food comes from these temperate agricultural systems, which cover roughly 1.5 billion hectares. They are complex socio-ecological systems in which decisions about land management directly affect the amount, quality, and temporal distribution of water (Foley et al., 2011). By altering soil properties, vegetation structure, and surface-subsurface flow pathways, the conversion of the natural landscape into an agricultural system modifies basic aspects of the terrestrial water balance. It produces cascading effects that extend beyond farm boundaries.

A large portion of the land transformation in eastern temperate regions has been relatively extravagant: whereas many developing regions are seeing rapid agricultural expansion, most wealthy countries have converted over 80% of their usable agricultural land. These changes occur at scales of population growth, climate change, and freshwater resource depletion, leading to highly complex interactions that compromise the nation's ability to manage water within its standard rational resource management frameworks. Designing agriculture that is sustainable enough to meet the expanding demand for food while causing the least disturbance to essential hydrologic services requires an understanding of these relationships.

The natural range of hydrologic impacts from changes in agricultural land use varies widely across temperate regions at multiple scales, influenced by topography, soil properties, climate, and management approaches. The main ways to achieve these changes are by increasing evaporation through vegetation changes, altering surface runoff patterns through soil compaction and drainage infrastructure, and altering groundwater recharge through irrigation practices and root zone dynamics. Prediction and management are made especially difficult by the cross-interaction of various mechanisms, which is typically neither simple nor equal with scales.

Changes in agricultural land use can change water budgets at the basin scale, like changes in climate variability and direct water withdrawal effects. Recent advances in remote sensing, hydrologic models, and long-term monitoring have begun to quantify such impacts at finer resolutions. Nevertheless, despite these advancements in knowledge, there are still gaps

in our understanding of the relative relevance of various mechanisms up front and how the distribution of heterogeneity across various areas impacts results. This review highlights significant research gaps, summarises the current state of knowledge on the effects of agricultural land use on water resources in temperate regions, and offers suggestions for further research and policymaking.

In addition to being an environmental problem, the shift in agricultural land use is also a legal and institutional one, governed by complex policy frameworks that define societies in terms of water sustainability and agricultural productivity. Numerous mega-instruments have sought to regulate agricultural water use in temperate zones to prevent environmental degradation. The European Union's Water Framework Directive (2000/60/EC) established water governance as a river-basin-wide to approach of managing water to minimise diffuse agricultural pollution and ensure that all waters in the region were in good ecological condition. The Clean Water Act (1972) and several other Farm Bill Conservation Programs introduced regulatory and incentive-based measures in the United States to control non-point agricultural pollution and promote soil and water conservation practices (US Environmental Protection Agency). Organisations such as the Food and Agriculture Organisation (FAO) and the Organisation for Economic Co-operation and Development (OECD) promote the implementation of integrated land-and-water management frameworks, emphasising ecosystem-based approaches and policy consistency to enhance farming intensification sustainably.

Even with these frameworks, one problem is policy fragmentation. In most nations, water and land organisations operate separately, resulting in regulatory gaps and a lack of cooperation. Such institutional segregation constrains responses to significant hydrologic stressors, including groundwater depletion, fertiliser overload, and agricultural runoff. Furthermore, short-term economic objectives frequently conflict with environmental sustainability objectives.

## **1.2. Problem Statement**

In temperate regions, shifting agricultural land-use patterns are currently modifying evapotranspiration, runoff patterns, and groundwater recharge processes, which in turn are changing hydrologic cycles. Nevertheless,

due to the interplay among basin characteristics, land management techniques, and climate variability, there is considerable misunderstanding about quantitative change indicators and the drivers of land-use shifts. Land-use change is frequently overlooked in water management policies as a significant cause of hydrologic alteration, giving direct water consumption and climate change precedence over land uses that have hydrologic implications of similar magnitude. Other issues include the lack of integration of water quantity and quality considerations into land-use planning, the spatial unevenness of responses across temperate regions, and the inadequate separation of climate vs land-use effects in most studies. Due to the resulting knowledge gap, it will be challenging to develop evidence-based strategies for managing water resources in agricultural landscapes. This could lead to unsustainable water use practices, a decline in ecosystem services, and heightened susceptibility to climate-induced water stress in temperate regions, all of which are crucial for agricultural production and global food security. The lack of a standardised approach to evaluate land use-water interactions at diverse scales and geographical locations, however, restricts the research's applicability to other policy applications.

### 1.3. Research Questions

- In temperate regions, how can different farming practices (e.g., crop shifting, intensified farming, or uncultivated land) affect water balance components, including runoff, groundwater, and evapotranspiration, throughout time and space?
- What effects does shifting cropland use have on temperate watersheds' water quality (in terms of chemicals, nutrients, and sediments), and how are these changes related to quantity?
- What practical measures and regulations can protect sufficient agricultural output while reducing the negative consequences of farming changes on water resources?

### 1.4. Research Objectives

- To analyse how the different farming practices (e.g., crop shifting, intensified farming, or uncultivated land) affect water balance components, including runoff, groundwater, and evapotranspiration throughout time and space in temperate regions.

- To examine the effects that shifting cropland use has on temperate watersheds' water quality (in terms of chemicals, nutrients, and sediments) and how these changes are related to quantity.
- To explore the practical measures and regulations that can protect sufficient agricultural output while reducing the negative consequences of farming changes on water resources.

### 1.5. Significance of the Study

This study will close a crucial knowledge gap regarding the intricate relationships between changing agricultural land use and water resources in temperate regions, where agricultural land makes up around half of basin areas and has a major impact on hydrological cycles. Given recent studies demonstrating that changes in land cover affect basin discharges to magnitudes comparable to direct human water withdrawals, the study's importance lies in providing reliable, fact-based information to guide an integrated water-land management strategy. Understanding these relationships is essential for sustainable water management, food security, and ecosystem protection, as climate change, population growth, and agricultural intensification are placing increasing strain on water resources. The results will help inform decisions that affect millions of people who rely on temperate agricultural systems for their food and water supply by providing a framework for developing targeted mitigation strategies that balance agricultural productivity and sustainable water resources. Additionally, the study will directly inform climate adaptation methods, as changes in agricultural land use might increase our susceptibility to climatic unpredictability in water resources.

## 2. LITERATURE REVIEW

### 2.1. Agricultural Land Use Change's Historical Background and Scope

Agricultural land-use changes are among the human interventions in temperate regions. Historically, temperate regions have experienced the most drastic land-use changes of any region in the world, with almost 1.2 billion hectares of land converted to agriculture since pre-industrial times (Ramankutty & Foley, 1999). Agricultural expansion in Europe and North America peaked in the 19th and early 20th centuries, then intensified and, in some areas, was abandoned and reforested (Kuemmerle et al., 2013).

The intensification of existing agricultural lands through increased input use and mechanisation, the conversion of marginal lands into agriculture in response to the world's food demand, and the abandonment of less productive agricultural areas that result in reforestation naturally or through active management are the main trends that define contemporary agricultural land use changes in temperate regions (Lambin & Meyfroidt, 2011). At the regional level, each of these patterns has consequences for hydrology that are impacted by terrain, climate, and socioeconomic realities.

Agricultural land-use changes have spatial effects that extend beyond the directly affected locations. While basins with agricultural land use greater than 50% typically exhibit significant changes in flow regimes, water quality, and ecosystem functions. Agricultural conversion of as little as 20–30% of a basin area can result in measurable change in downstream hydrology (Allan, 2004). The necessity of using a landscape approach to research and manage the effects of agriculture on water resources is reinforced by this geographical connection.

## **2.2. Causes of Hydrologic Effects**

### **2.2.1. Modifications to Evapotranspiration**

In essence, changes in vegetation structure, phenology, and physiological traits resulting from shifts in agricultural land use modify evapotranspiration (ET) patterns. The conversion of land from natural vegetation to crops typically results in a decrease in annual ET due to shorter growth periods, variations in rooting depth, and altered canopy structure (Gordon et al., 2005). After forest-to-agriculture conversion, ET decreases by 10–40%; the extent of these reductions varies with crop variety, management intensity, and climate (Sterling et al., 2013).

For certain crops, seasonal variations in ET are important, making them highly relevant to water resource management. Because they have a longer growing season and a more developed deep-rooted system, perennial crops such as orchards and vineyards typically sustain higher ET rates than some annual crops (Williams & Ayars, 2005). With the highest water consumption in the mid-growing season, row crops like corn and soybeans exhibit seasonal ET patterns that skip. This indicates a temporal mismatch between precipitation patterns, particularly post-monsoons, and the duration of dry spells, which may affect water availability and quality (Sacks et al., 2010).

Management approaches significantly impact ET patterns in agricultural systems. While conservation measures like cover crops are known to extend ET periods, reducing seasonal water excess, irrigation can increase ET above natural levels, particularly in places under water stress (Kaspar & Singer, 2011). Given climate change and water shortages, the development of drought-resistant crop varieties and precision irrigation technologies is becoming crucial for managing ET (Lobell et al., 2011).

### **2.2.2. Changes in Surface Runoff and Infiltration**

Surface runoff is significantly affected by changes in agricultural land use, including soil compaction, reduced infiltration capacity, and changes in surface roughness. Mechanised agriculture causes soil compaction, primarily in the topsoil layers, which decreases infiltration and increases surface runoff. Infiltration rates in agricultural soils may be 50–80% lower than in natural forest soils, thereby increasing *ws* simultaneously (Pimentel et al., 1995).

Artificial drainage systems, such as ditches and tile drains, completely alter natural flow patterns and timing. By tempering peak flows and extending flow duration, tile drainage achieves a stable, if elevated, baseflow condition while increasing annual discharge by 20–50% (Skaggs et al., 1994). These modifications have important ramifications for downstream water management and ecosystem functions.

Tillage follows the formation of surface runoff. In contrast to reduced tillage systems, which maintain soil structure and surface cover, conventional tillage mostly increases runoff and erosion rates (Montgomery, 2007). Critical periods of high runoff vulnerability may be created by the timing and severity of tillage activities, especially during spring snowmelt and severe summer storms.

### **2.2.3. Changes in Groundwater Recharge**

Through a variety of processes, including deep percolation rates, root-zone water extraction, and instream return of irrigation flows, changes in agricultural land use affect groundwater recharge. The specific land-use change and management procedures in issue determine the net influence on recharge, which varies greatly (Scanlon et al., 2005). Because there is less deep-rooted vegetation and a shorter growing season when forests are converted to agriculture, groundwater recharge typically increases. In contrast, irrigation can either

increase or decrease recharge, depending on crop water requirements and application efficiency.

Perennial plants with deep roots, including those in grasslands and forests, remove groundwater from the capillary fringe, thereby reducing net recharge via groundwater uptake (Canadell et al., 1996). Increased percolation and recharge would result from cultivating shallower-rooted crops in agricultural areas, particularly during non-growing seasons when ET demand is low.

Depending on irrigation technology, irrigation period, and irrigation efficiency, the recharge dynamics of irrigation return flows can be complex. Drip and sprinkler irrigation usually have lower recharge potential; however, flood and furrow irrigation are known to cause substantial deep percolation losses, which tend to boost recharge (Scanlon et al., 2006). In certain areas, the effects of return flow may account for 20–50% of applied water, significantly impacting the regional water budget.

## **2.3. Water Resources: Quantitative Impacts**

### **2.3.1. Variations in the Amount of Water**

Forest conversion to agriculture often results in a 10–40% increase in annual flow, with larger increases in regions with a notable dry season (Brown et al., 2005). However, there is significant variation in the magnitude and direction of change due to factors like climate, soil type, and management techniques (Liu et al., 2023, Grizzetti et al., 2022).

Land-use intensification causes measurable changes in flow regimes, even after the initial effects have subsided. Despite the extreme stability of land-use decisions, agricultural intensification since the 1940s has caused many watersheds to see increases in peak flows of 10–30% and annual discharge of 5–15% (Schilling et al., 2008).

Changes in agricultural land use affect several seasonal flow patterns. Since there are fewer interceptions and transpirations during the leaf-off period, spring flows showed the biggest increases following conversion to agriculture, whereas summer flows tended to decline due to increased evapotranspiration from irrigated crops (Zhao et al., 2010). The dependability of the water supply and the health of the environment depend heavily on these seasonal variations.

### **2.3.2. Effects on Water Quality**

Water quality is impacted by agricultural

land-use change in several ways, including contaminated water, sediment movement, and nutrient loading. Nitrogen loads in agricultural watersheds are usually 2–10 times higher than in their natural watersheds, and nitrate concentrations in predominantly cultivated areas frequently threaten drinking water standards (Carpenter et al., 1998).

Phosphorus export rates from agricultural sources are 5–20 times higher than those that pass via forested watersheds. The timing and form of phosphorus export directly affect the impacts of eutrophication; the most bioavailable form of phosphorus for achieving algal growth is dissolved reactive phosphorus.

Depending on topography, soil types, and management techniques, sediment transport from agricultural watersheds can be 10–100 times greater than current natural rates (Montgomery, 2007). During these crucial times of spring planting and post-harvest, when there is little soil cover and soil structure is disrupted, land erosion is very high.

Contamination from pesticides and fertilisers exacerbates water quality problems in agricultural watersheds. In agricultural watersheds, pesticide concentrations in streams exceed 90%, with several exceeding aquatic life standards during the application period (Gilliom et al., 2006).

### **2.4. Scale Effects and Regional Variations**

In temperate climates, the impact of changing agricultural land use on water supplies varies widely in intensity. The main causes of this are variations in geography, soil properties, climate, and management techniques. Due to the temporal mismatch between the growing season and precipitation, maritime climates seem to respond quite strongly to land-use change, whereas continental climates might only exhibit a moderate identification of remedies between supply and demand (García-Ruiz et al., 2011).

The extent and geographic distribution of hydrologic impacts are significantly influenced by topography. Flat agricultural areas tend to exhibit greater changes in baseflow and groundwater recharge, whereas steep agricultural watersheds tend to exhibit larger variations in peak flow and erosion rates (O'Connell et al., 2007). The way local land-use changes translate into watershed-wide effects depends on the valley's location and drainage density.

The hydrologic effects of changes in agricultural land use are mediated by soil properties, predominantly texture, depth, and

organic matter concentration. Clay soils have a greater impact on surface runoff and peak flows, whereas sandy soils exhibit larger relative changes in groundwater recharge and baseflow. Both water retention capacity and infiltration rates are significantly influenced by soil organic matter, which is frequently diminished during agricultural management (Scanlon et al., 2005).

In plot-scale studies that account for geographical heterogeneity and flow routing, the percentage change is larger for that location (Blöschl & Sivapalan, 1995). A situation in which lower percentage changes from the regional assessment have larger absolute consequences than those from the watershed assessment could arise because the watershed assessment covers a wider area affected by agricultural land-use change.

## **METHODOLOGY**

### **3.1. Research Design**

The study is a mixed-methods study involving a systematic literature review and an analysis of policy and legal frameworks, in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) principles. The research design employs a secondary qualitative approach to synthesise and interpret the available academic literature, empirical sources, and policy documents. The study will shed light on the complex influence of agricultural land-use transformation on hydrologic systems in temperate locations, particularly by measuring impact patterns, underlying processes and the spatial, regional and critical examination of governance responses.

The research paradigm has 3 analytical dimensions: (1) hydrologic impact evaluation of changes in both water quantity and quality, (2) mechanistic analysis of biophysical processes, which mediate land use-hydrology interactions, and (3) governance and policy assessment, which evaluates the effectiveness of regulations and institutional arrangements. This interdisciplinary strategy can be used to holistically understand the physical and socio-institutional responses to the impacts of agricultural land-use change on water resources.

The systematic literature search strategy will use specific keywords to identify pertinent sources. The systematic literature search strategy will involve the utilisation of specific keywords to identify relevant sources.

### **3.2. Search strategy for systematic literature**

#### **3.2.1 Search period and databases**

The systematic literature search was conducted between January 1994 and November 2025 (a 31-year period). This period was chosen to include current research and sufficient historical context to determine long-term trends and patterns in agricultural land-use changes within hydrologic cycles.

The databases to be searched were systematically searched and included:

- Web of Science
- Scopus
- Google Scholar
- FAO and USGS repositories
- ProQuest (The Environmental Science Collection)

#### **3.2.2 Search String**

The search strategy used Boolean operators to bring together relevant key concepts on agricultural land-use change, hydrological effects, temperate zones, and governance systems. The search query that was sent to all databases was as follows:

Primary Search String: (agricultural land use change) or (land use conversion) or (cropland expansion) or (agricultural intensification) or (land cover change) or (agricultural transition) or (farmland conversion) and (policy) or (governance) or (regulation) or (legal framework) or (water law) or (environmental law) or (water management) or (institutional framework) or (Water Framework Directive) or (Clean Water Act).

In the case of policy and legal documents, supplementary searches were conducted using "EU Water Framework Directive" and "agriculture". Clean Water Act, agricultural runoff, water governance and agricultural land use OR agricultural policy | water resources.

#### **3.2.3 Inclusion and Exclusion Criteria.**

Inclusion criteria:

1. Published in peer-reviewed periodicals or government/institutional official reports.
2. Target temperate agricultural areas (temperate climate areas located between 30- and 60-degree latitudes in both hemispheres).
3. Has empirical evidence about hydrological effects of agricultural land use transformation (field measurements, remote sensing research, or reliable

modelling research).

4. Deals with policy, governance, or legal frameworks that are pertinent to agricultural water-land management.
5. Published in English.
6. Time frame: 1994 to September 2025.

Exclusion Criteria:

1. Research is limited to tropical or arid/semi-arid areas only.
2. Theoretical modelling without either empirical validation or calibration.
3. Abstracts of conferences that do not contain full papers.
4. Research does not provide quantitative information regarding hydrological parameters.
5. Published two times the same work.
6. Research studies only on the effects of climate change, with nothing on land-use change.
7. Agricultural water consumption research that does not consider land use change effects.

### 3.3 Article Selection Process

The search and selection of the systematic literature were based on the guidelines of PRISMA (Preferred Reporting Items to Systematic Reviews and Meta-Analyses). The entire PRISMA flow diagram is given in Figure 1.

**Identification Phase:** The first search of databases identified 787 records in the scientific databases:

- Web of Science: 242 records
- Scopus: 289 records
- Google Scholar: 156 records

There were 53 records obtained using other sources in the specialised repositories:

- FAO Repository: 23 records
- USGS Publications: 18 records
- Government reports and grey literature: 12 entries.

This made a total of 840 records prior to the elimination of duplicates.

Screening of titles and abstracts was performed on 593 unique records after filtering 247 duplicate records, with assistance from the EndNote reference management software and manual screening. All titles and abstracts were independently screened by two reviewers against the inclusion and exclusion criteria. There was a discussion and consultation, and a third reviewer was consulted when there was a conflict.

At title and abstract screening, 478 records

were weeded out:

- Geographical area (tropical, arid or unspecified): 156 records.
- No data or measurements on hydrologic: 142 records.
- Not to agricultural change of land use: 98 records.
- Other duplicates detected while screening: 47 records.
- Other causes (review articles, editorials, commentaries): 35 records.

The outcome of this screening process was the identification of 115 articles for full-text retrieval.

**Eligibility Phase:** Out of the 115 articles that were requested to be retrieved on a full text basis, 8 articles could not be retrieved, even after contacting the authors and institutional libraries. The remaining 107 full-text articles underwent an intensive eligibility evaluation against all inclusion criteria.

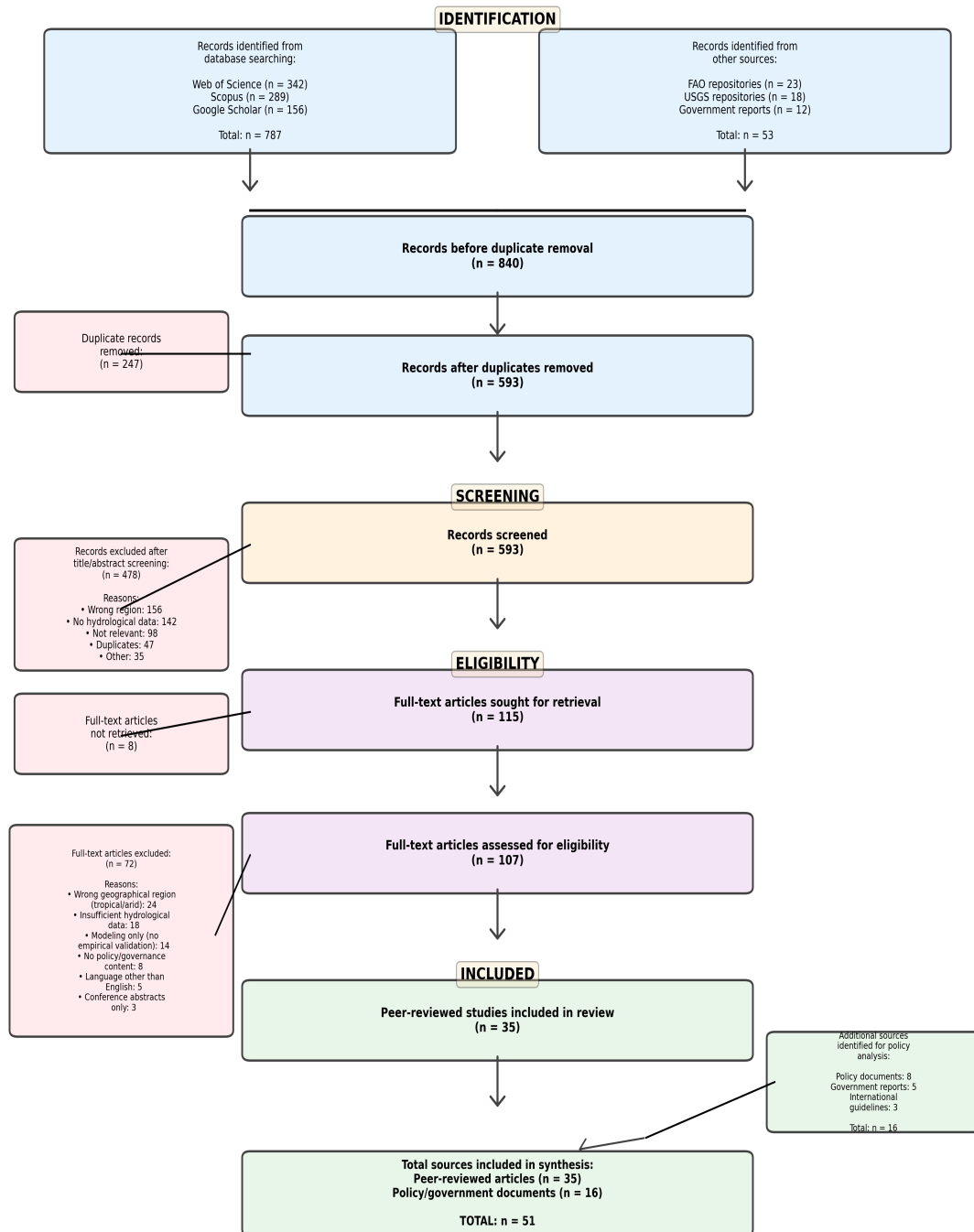
In the case of full-text assessment, 72 articles were filtered out due to the following reasons:

- Irrelevant geographical location (tropical/arid regime or poor temperate location): 24 articles.
- Inadequate hydrological data or the absence of quantitative measurements: 18 articles.
- Empirically unproven modelling studies: 14 articles.
- No policy or governance information was at odds with the goals of the review: 8 articles.
- Appeared in non-English language: 5 articles.
- Abstracts of conferences without complete papers and lacking in detail: 3 articles.

The systematic review identified 35 peer-reviewed journal articles that met all inclusion criteria for the hydrological analysis component. To complete the policy and governance analysis, 16 other sources were added:

- Policies and guidelines: 8 sources.
- Government documents and reports: 5 sources.
- Global practices and policies: 3 sources.

All the syntheses included 51 sources: 35 peer-reviewed articles, 16 policy/government documents.



**Figure 1.** The PRISMA 2020 flow diagram of the systematic literature selection process for the review of the effects of agricultural land-use change on water resources in temperate regions. The figure shows how the studies are identified, screened, assessed in terms of eligibility, and finally included.

## 4. RESULTS

### 4.1 Hydrologic Impact findings

Although this thorough examination of the effects of changes in agricultural land use has shown some convergence, it also reveals significant regional and system-specific differences that could be pertinent to a more comprehensive analysis of the effects of agricultural land use change on water resources in temperate regions. Conversion to agriculture often results in a 10–40% improvement in

annual water production over natural vegetation because evapotranspiration decreases more than precipitation capture increases (Bosmans et al., 2017). This rise in water yield is seen to constitute a significant alteration to the terrestrial water balance that could have a domino effect on the hydrologic system.

These changes are driven by several interrelated mechanisms, and the relative significance of each varies with the agricultural system and specific environment. In most

temperate climates, this decrease in evapotranspiration is a major route. As a result, annual rates of ET for agricultural crops are usually between 20 and 50 per cent lower than those for wild forest vegetation (Sterling et al., 2013). Shorter growing seasons, smaller rooting depth, and somewhat altered leaf area dynamics compared to the natural vegetation type are the main causes of this.

The second main mechanism is the alteration of surface runoff. Surface flows have generally increased in magnitude and variability due to agricultural land use. Compared to natural soils, agricultural machinery-induced soil compaction can lower infiltration capacity by 30–70%. Increased overland flow velocities result from the removal of natural surface roughness components (Hamza & Anderson, 2005). Installing an artificial drainage system will also alter the natural drainage system, typically increasing discharge volumes and reducing peak flows while prolonging flow duration.

Depending on the specific land-use change and management systems involved, both increases and decreases in groundwater recharge have been measured. The opposite occurs when crops replace deeply rooted plants. Intense irrigation can either decrease recharge due to increased water consumption or enhance it due to deep percolation.

## 4.2 Policy and legal framework analysis

### a. European Union (EU) Water Framework Directive (WFD)

The goal of the Water Framework Directive (WFD), adopted by the European Union (EU) in 2000, is to preserve and restore water bodies across the continent. More specifically, according to Article 7 of the EU WFD, member states are urged to safeguard water bodies used to produce drinking water "in order to reduce the level of purification treatment required." 35% of groundwater and 38% of surface water bodies are affected by diffuse, nonpoint-source contamination (European Commission, 2025). The primary cause of nutrient contamination in water is agriculture, which accounts for 33% of all water consumption.

The Nitrates Directive and agri-environmental schemes (AES) are the two primary strategies the EU has implemented to combat diffuse water pollution. When nitrate

concentrations in surface and ground waters exceed 50 mg/l or 40 mg/l with an increasing trend, sensitive zones are identified under the EU Nitrates Directive, which was approved in 1991. Without compensation, every farmer in a vulnerable zone must follow the actions outlined in specific action programs, such as reducing fertiliser rates and creating buffer strips along watercourses. Furthermore, outside of susceptible areas, a voluntary national code of good agricultural practices should be implemented. Since 2005, farmers have had to comply with all environmental requirements, notably the Nitrates Directive, to receive EU Common Agricultural Policy (CAP) subsidies. Since 1992, AES has been a mandatory part of rural development programs in EU member states. Under these programs, farmers voluntarily commit to implementing environmentally friendly techniques for at least 5 years.

Farmers are compensated for related expenses and lost revenue. Agri-environmental commitments must go beyond the mandatory standards of the Nitrates Directive, that is, beyond the requirements outlined by action programs for vulnerable zones and the provisions of the code of good agricultural practices outside of vulnerable zones, in accordance with the "polluter pays" principle: the EU and its member states co-finance AES. Diffuse agricultural pollution continues to threaten water quality despite the deployment of these incentive-based and regulatory measures (Amblard & Mann, 2021).

### b. North American Regulatory Approaches

In contrast, water-agriculture governance and regulation in the United States and Europe are quite divergent in terms of organisational frameworks. Since the Clean Water Act (CWA) of 1972 established for agricultural sources the broad framework of regulation concerning water pollution, it has, however, failed to treat the primary avenue through which land use change modifies water quality, the non-point sources, from the same perspective as the point sources under the CWA. Section 319 sets forth the CWA's approach to nonpoint source pollution through voluntary state programs and incentive-based measures rather than mandatory controls, reflecting the political sway of agricultural interests in U.S. environmental policy.

Further extended by the Safe Drinking Water Act (1974), which regulates the quality of drinking water supplies, both acts placed greater pressure on addressing agricultural sources of contamination. At the state level, water rights systems differ considerably between prior appropriation states (mostly in the western US) and riparian rights states. This then opens up an arena for a diverse range of legal frameworks to address the extent of impacts from agricultural land use.

The Canadian model involves overlapping jurisdictions for federal and provincial levels. The Canadian Environmental Protection Act has federal jurisdiction for water quality, but provincial regimes exercise their general authority over water resources and agricultural regulation. The Agricultural Policy Framework has integrated an environmental dimension into its agricultural support programs, such as the EU cross-compliance mechanisms.

### **c. International Guidelines and Agreements**

Apart from regional frameworks, international organisations also provide standards and guidelines for water-agriculture governance. The OECD has issued extensive policy recommendations on the management of water resources, agricultural environmental performance, and the establishment of economic instruments in water governance. International commitments are set by the UN Sustainable Development Goals, particularly SDG 6 (Clean Water and Sanitation) and SDG 2 (Zero Hunger), which require balanced agricultural productivity and the protection of water resources.

The Ramsar Convention on Wetlands and the Convention on Biological Diversity impose international obligations to protect water-dependent ecosystems from changes in agricultural land use. Thus, additional layers of governance are created on top of national and regional policies, but the enforcement mechanisms remain relatively limited.

## **4.2.1 Legal Instruments and Regulatory Mechanisms**

### *a. Command-and-Control Regulations*

The legal frameworks for managing the agricultural impact on water resources include different instruments. The command-and-control approach encourages demands, norms,

and bans supported by enforcement mechanisms. Some examples would be:

- The detailed legalisation of the timing, quantity, and methods of applying manure and fertilisers to reduce the nutrient load was introduced, with the Netherlands as an example. These regulations are directly connected to reducing the increase in nutrient load, as demonstrated by this research.
- Legal systems tend to require registration and authorisation for these agricultural chemicals, along with restrictions on their use in and around water bodies and in sensitive regions.
- Various jurisdictions have laws requiring the creation of buffer areas along watercourses, which are planted to slow agricultural runoff and shield the stream bank, thereby addressing water quality and hydro-morphological implications.
- The authorisation of agricultural water operates under the cumulative response principle, designed to address the cumulative impact of irrigation on water availability, in the present case the specified changes in groundwater recharge established by this paper.

### *b. Economic Instruments*

Recognizing the limitation of what can be done with regulatory approaches alone, especially on diffuse agricultural pollution, governance frameworks increasingly bring economics into the equation by setting up financial incentives for environmentally friendly practices:

- Programs that pay farmers for practice changes that protect water resources, such as reduced fertiliser application, using cover crops, or wetland restoration. These include the CAP's solid agri-environment schemes in the EU, albeit with differing degrees of effectiveness.
- Pricing water at its full economic cost should, in theory, encourage efficient use of water while reducing over-abstraction. The very contentious issue of agricultural water pricing, however, means that, in most jurisdictions, subsidised water for farmers is provided.

- Market-oriented mechanisms that allow for the trade of nutrient credits, theoretically, to accomplish the most cost-effective pollution reduction. With limited implementation and mixed results, nutrient trading programs remain controversial.
- Payments given to landowners in exchange for maintaining or enhancing scarce ecosystem services, including those involved in water regulation and purification.

#### *c. Voluntary and Cooperative Approaches*

Many governance frameworks emphasise voluntary measures and cooperative approaches, especially in countries where agriculture carries strong political implications.

- Technical guidelines and voluntary adoption of practices are designed to minimise environmental impacts, such as precision fertiliser application, conservation tillage, and integrated pest management.
- Collaborative governance structures bring together farmers, water utilities, environmental groups, and government agencies for locally suited solutions.
- Certification schemes are voluntary standards for agricultural production that include requirements for water protection and may serve as marketing tools or for premium pricing.

Research indicates that while voluntary approaches can achieve results when coupled with technical support and financial incentives, they are often insufficient to address serious threats to water resources without a backstop of a related regulatory scheme.

#### *d. Spatial Planning and Zoning*

Land-use planning and zoning represent another legal tool for managing agricultural impacts on water resources.

- Nitrate Vulnerable Zones (NVZs): Geographical areas defined under the EU Nitrates Directive, where stricter agricultural practices are imposed to protect water quality.
- Areas where land-use activities, including agriculture, are limited for the

sake of protecting drinking water sources or vulnerable aquifers.

- Zoning prevents the conversion of agricultural land to urban uses, thereby influencing water resource management by preserving pervious surfaces and rural land-use patterns.

### **4.2.2 Institutional Arrangements and Governance Structures**

#### *a. Multi-Level Governance*

Water and agriculture in temperate climates generally presuppose multi-level governance, with roles and functions distributed across different institutional levels.

- In the EU, oversight of the implementation of water and agricultural directives is assigned to the European Commission. Infringement proceedings intend to enforce powers against member states. Similar regional bodies, such as the International Commission for the Protection of the Rhine, coordinate transboundary water management.
- The national level legally prescribes boundaries, sets standards, allocates resources to sectors, and sometimes coordinates (often competing) sector policies. The national ministries responsible for the environment and agriculture may at times have overlapping jurisdictions, creating opportunities for cross-sector improvement while also introducing the possibility of policy incoherence.
- The river basin district concept under the WFD creates an intermediate governance level for practical purposes in managing water resources at hydrologically meaningful scales. River Basin Management Organisations (RBMOs) are institutions that develop management plans and coordinate measures across administrative boundaries.
- Often, these levels have implementation authority in subnational governance, especially under federalism. Such an agency would normally issue permits and conduct monitoring and enforcement at the provincial or state level.

- Local Level: Municipal and local water board authorities include arrangements for water supply, wastewater treatment, and local land use planning that directly or indirectly affect agricultural-water interactions.

This multi-level governance structure creates opportunities for tailor-fit governance to contexts but also has its own share of challenges, such as coordination, accountability, or possibly conflicts among levels.

#### *b. Cross-Sectoral Coordination*

The fundamental challenge of governance is to achieve coordination across water and agriculture institutions. Historically, the two sectors have been separate policy silos, with the agricultural ministries concerned with production and farm income, and the environmental agencies focusing on water quality and ecosystem protection. This is a further indication of the policy incoherence cited in the literature.

Improvement of coordination across sectors can take advantage of several mechanisms:

- These are formal structures across the agriculture, environment, and other relevant ministries for coordination.
- Such requirements will mandate that any agricultural policy undergo environmental assessment and be evaluated for consistency with water management objectives.
- These include joint expenditure of agricultural and environmental budgets to support integrated land-water management.
- Platforms for engagement between agricultural and water interests, aggregated to influence policy decisions.

#### *c. Stakeholder Participation*

Stakeholder participation is increasingly appearing in modern water governance frameworks as necessary for legitimacy and effectiveness. The operation of public participation, as explicitly required in the WFD, concerns planning within a river basin management context. Participatory mechanisms:

- These opportunities allow farmers,

environmental interest groups, business entities, and citizens to comment and provide input on proposed policies and plans.

- Advisory councils: formal stakeholder bodies that give information and provide input to decision-makers.
- Multi-stakeholder organisations are developing and implementing local management approaches.
- Programs are put in place to empower agricultural communities to develop and implement their own solutions for reducing their water resource challenges.

It was found that meaningful participation goes beyond mere token consultation; it can improve the technical quality of water-agriculture policies and enhance political acceptability, although power imbalances and resource constraints can limit such effectiveness.

#### *d. Monitoring and Enforcement*

Effective governance requires adequate capacity in monitoring and enforcement. According to this definition, the important institutional aspects are:

- The scientific gathering of information to determine the condition and tendencies, and to measure policy efficiency.
- Inspections and audits to determine compliance with regulations and permit terms.
- Provide administrative sanctions, civil liability and criminal penalties for breaches, but diffuse agricultural pollution remains difficult to enforce.
- Refers to the development of institutional capability to utilise monitoring outcomes and novel scientific knowledge to transform policies and actions.

The most consistent finding in the literature is the regulatory agency's limited capacity to effectively monitor and enforce agricultural water regulations at sources of diffuse pollution, as well as the historically long lags between the identification of a scientific issue and its implementation on the ground.

## 4.2.3 Integration challenges and policy gaps

### *a. Policy Incoherence*

Policy coherence impedes the integrated governance of water and agriculture. This long-standing approach — in which agricultural policies set production and income targets — undermines environmental protection goals. Some actual examples would be:

- Payments of an agricultural support nature can drive farmers toward greater input use and increased production intensification, further pressuring water quality and quantity.
- It is stated that farmers receive payments for environmental services while being encouraged by production subsidies to go for more intensive production.
- Sector dominance: Agricultural interests take precedence over environmental concerns in terms of political weight, which means that measures to protect water are poorly implemented.
- Agricultural policies are short-term in focus, responding to immediate production and market issues, while problems regarding water resources develop over longer time periods.

### *b. Implementation Gap*

Even if there exist all coherent policies on paper, implementation gaps usually defeat their purpose:

- Weak enforcement due to limited regulatory agency capacity, political reluctance to penalise farmers, and monitoring difficulties for diffuse pollution.
- Excessive reliance on voluntary approaches without adequate regulatory backup usually fails to achieve the required environmental outcomes.
- Insufficient budgets for Agri-environment programs, monitoring networks, and technical assistance inhibit policy actions.
- Problematic with the 'system inertia' of groundwater systems, where aquifer recovery can take several decades even
- There are various impacts on big and

after pollution sources are under management, leading to increased delays between policy adoption and implementation at the field level.

### *c. Scale Mismatches*

The governance frameworks often suffer from mismatches between institutional and ecological scales:

- Administrative border vs hydrological boundary: Political jurisdictions seldom align with watershed boundaries, which further weakens the case for integrated management.
- Local actions, regional impacts: Decisions made at the individual farm level will have cumulative impacts at watershed and regional scales, which, in many instances, necessitate coordination mechanisms that do not currently exist.
- Temporal mismatches: While political and budget cycles operate on short time scales, water resource problems and their solutions take decades.

### *d. Knowledge-Action Gaps*

Gaps between scientific knowledge and policy actions still exist:

- The complexities of water-agriculture interactions and the scientific uncertainties surrounding them could serve as useful tools to justify doing nothing on the policy front.
- It is not common for scientific evidence to be relayed to policymakers in the right manner and translated into policy options.
- The monitoring network's weakness detracts from the functions of identifying issues, assigning blame, and evaluating policy performance.
- This is when agricultural interests use science to challenge evidence of negative environmental impacts, thereby delaying policymaking.

### *e. Equity and Justice*

Water-agriculture governance contains critical equity issues that have not been adequately addressed:

small farms, on existing and beginning

farms, and on regulations and incentive programs.

- Not all of them will relate to the technical assistance and subsidies offered by programs.

- Downstream water users are affected by upstream water-farming activities, leading to equity and payment issues.
- The current agricultural practices that drain water resources are a burden to future generations.

**Table 1.** Comparison of the regulatory strategies of agricultural water management in jurisdictions.

Regions	Major Legislation	Regulatory Approach	Mechanisms	Strengths/ limitations
<b>European Union</b>	Water Framework Directive (2000/60/EC)	Integrated river basin management	<ul style="list-style-type: none"> <li>• Coordination between countries.</li> <li>• Public participation.</li> <li>• River basin plans.</li> <li>• Proper ecological status targets.</li> </ul>	<p><b>Strength:</b> ecosystem-based plans with a comprehensive framework.</p> <p><b>Limitation:</b> implementation gaps between member states.</p>
<b>United States</b>	Clean Water act (1972) that was amended later in 1987	Voluntary programs with command-and-control.	<ul style="list-style-type: none"> <li>• Voluntary programs for conservation with total maximum daily loads, programs including 319 nonpoint sources and NPDES permits for point sources.</li> </ul>	<p><b>Strength:</b> point source control</p> <p><b>Limitations:</b> authority is fragmented between state and federals, limited regulations for nonpoint sources</p>
<b>Canada</b>	Canadian Water Act (1985) and provincial legislation	Shared jurisdiction between federal and provincial governments	<ul style="list-style-type: none"> <li>• Cost-share programs between federal and provincial jurisdiction</li> <li>• Provincial allocation system of water.</li> </ul>	<p><b>Strength:</b> flexibility in provincial adaptability.</p> <p><b>Limitation:</b> coordination challenge between provinces.</p>
<b>United Kingdom</b>	Water Resources Act (1991), Environment Act (2021)	Environmental outcomes (risk-based regulations).	<ul style="list-style-type: none"> <li>• Catchment-based approach</li> <li>• Environmental Land Management plans.</li> <li>• Abstraction of water licensing.</li> <li>• Nutrient requirements of neutrality.</li> </ul>	<p><b>Strengths:</b>Payment for ecosystem services and Opportunities-based.</p> <p><b>Limitations:</b> New policy change, effectiveness doubtful in the long term.</p>
<b>Australia</b>	Water Act (2007), Basin Plan (2012)	Environmental allocations (market-based)	<ul style="list-style-type: none"> <li>• Cap-and-trade water rights</li> <li>• The water holdings of the environment.</li> <li>• Diversion thresholds that are sustainable.</li> <li>• Compliance and enforcement</li> </ul>	<p><b>Strengths:</b> New market procedures, clear environmental distributions.</p> <p><b>Limitation:</b> stakeholder incompatibility, problems with climate adaptation, over-allocation of legacy.</p>
<b>Internationally</b>	UN Watercourses Convention, SDG 6.	Voluntary targets and guidelines	<ul style="list-style-type: none"> <li>• Principles of transboundary cooperation.</li> <li>• Integrated water resources management.</li> <li>• SDG monitoring frameworks</li> <li>• Capacity building programs</li> </ul>	<p><b>Strengths:</b> International normative system.</p> <p><b>Limitations:</b> It is not binding; its implementation is subject to the commitment of the nation, and it is not strongly enforced.</p>

## 5. DISCUSSION

### 5.1 Effects on Water Quality

One of the most startling and enduring environmental challenges that temperate regions will face is the impact of changes in agricultural land use on water quality. While phosphorus exports from converted land often increased by 500–2000% compared with exports from natural watersheds, nearly all increases in nitrogen exports exceeded 200–1000% (Carpenter et al., 1998). These increases are caused by both direct fertiliser application and increased leaching and erosion, which mobilise soil nutrients.

Awareness of the downstream effects of nitrogen export requires an awareness of its temporal characteristics. Agricultural watersheds exhibit highly seasonal patterns in nutrient loading, with peak exports occurring during spring storms and snowmelt, when crop uptake is at its lowest and soil disturbance is at its highest. While annual averages may be relatively modest, these peak-time patterns provide key loading times that could drive eutrophication in downstream water bodies.

In many temperate agricultural regions, sediment transport typically increases by 10–100 times natural rates, making it one of the most dramatic increases caused by changes in agricultural land use (Montgomery, 2007). Topography, soil composition, and management techniques can all have a significant impact on sediment impacts; steep slopes and erodible soils tend to show the largest increases. Furthermore, although it has been demonstrated that most conservation techniques have considerable potential to reduce sediment losses, their application varies widely across agricultural landscapes.

Another issue with water quality that exhibits intricate temporal and spatial patterns is chemical pollution from pesticides and other agricultural production inputs. In streams that drain heavy agricultural areas, detection frequencies during application times are often above 90%, and concentrations are frequently higher than those considered safe for aquatic life (Gilliom et al., 2006). Monitoring and controlling compounds are difficult due to the large number of substances with different levels of mobility and persistence.

### 5.2 Regional Variations and Environmental Controls

The degree and patterns of the effects of changes in agricultural land use on water resources vary among temperate climates. Climate, geography, soil characteristics, and management systems all have a role in these interactions. Due to the temporal decoupling of precipitation and crop water demand, Mediterranean climate regions exhibit particularly strong hydrological responses to changes in agricultural land use, resulting in reduced summer flows and increased winter runoff.

In contrast, agricultural land use often increases spring snowmelt flows in continental climates with cold winters and warm summers; however, it may or may not affect summer baseflows, depending on irrigation techniques and groundwater interactions. Additionally, the mechanics of runoff-generating processes differ depending on agricultural management approaches, which have been made more complex by the presence of frozen soils in the winter and spring.

The number of hydrological effects and changes in surface distribution are significantly influenced by topographic controls. While flat agricultural regions may have higher effects on infiltration and groundwater recharge, steep agricultural watersheds exhibit larger variations in peak flows and erosion rates due to gravity, altering overland flow. The timing and magnitude of local land use changes at the watershed scale are also influenced by drainage density and valley morphologies.

The impacts of agricultural land use on nutrient retention, infiltration rates, and water storage capacity are mediated by soil properties. While clay soils are more affected by surface runoff and erosion, sandy soils undergo significantly bigger fluctuations in groundwater recharge and solute transport. Both hydrologic and biogeochemical processes are influenced by the amount of organic matter in the soil, which is often lost during agricultural management.

### 5.3 Scale Dependencies and Cumulative Effects

The effects of shifting agricultural land use on water resources are strongly influenced on temporal and spatial dimensions, with significant

ramifications for policymaking and management. This is mostly true, for instance, when it comes to regional evaluations of agricultural land-use conversions, which might really have an impact on water resources inside the boundaries of converted regions through groundwater connections and downstream cumulative impacts. Large river systems, coastal areas, and maybe regional groundwater aquifers that support many uses and users would be the most intriguing examples of regional consequences.

Because short-term studies are prone to losing long-term adjustment processes and recovery dynamics, temporal scale effects are equally important. Before the hydrologic implications are fully recognised, it may take decades for changes in soil characteristics, vegetation community types, or channel shape to occur under new land-use conditions. On the other hand, if conservation efforts and management techniques advance, effects may eventually lessen or even vanish.

Compared to the consequences of a single conversion, the cumulative effects of several land use changes within the watershed produce complex interactions that are typically more non-linear and unexpected. Furthermore, disproportionate effects on downstream water resources may result from threshold effects, which occur when agricultural land use surpasses a specific percentage of watershed area.

#### 5.4 Interactions with Climate Change

As climate change progresses, changes in agricultural land use are beginning to affect water

supplies. This creates complex dynamics among the separate effects, which may combine to mitigate or amplify other effects. In temperate regions, climate change is expected to alter temperature regimes, precipitation patterns, and the frequency of extreme events, potentially changing the magnitude and direction of the impact of agricultural land use.

The water requirements for cropping and growing seasons can be altered by rising temperatures and precipitation patterns, which can change evapotranspiration and create disparities between natural and agricultural systems. In contrast to the existing climate, earlier snowmelt and more intense precipitation episodes combined with agricultural soil conditions will result in greater changes in the timing and amount of runoff.

Crop kinds, planting dates, and irrigation techniques are just a few examples of the additional adjustments that will likely be made to agricultural systems to adapt to climate change. These changes will all affect the subsequent hydrologic effects. Expanded irrigation tends to increase consumptive water usage and change recharge patterns, but drought-resistant crops would lessen the evaporative-difference effect.

Because of these interrelationships, it is crucial to consider climate change and changes in agricultural land use as complementary rather than separate forces influencing hydrologic change. Such interactions must be considered to ensure management methods are effective in the future.

#### 5.5 Comparison of Temperate Regions

Table 2. Comparison of Temperate Regions

Temperate Regions	Land Use Changes	Impacts on Hydrological Cycles	Impacts on Water Quality	Management/Policy
1. Europe	1. In the 20th century, agricultural intensification was followed by regulatory measures and partial reforestation.	Land-use pressures contribute to the shift in hydrological regimes, but the EU Water Framework Directive (European Commission, or WFD) enhanced river basin management and ecological status implications in many locations.	Although it is still in a legacy state, pollution from sediments and nutrients (phosphorus and nitrogen) has declined in many catchments (van Kats et al., 2022).	The policies support nitrate reduction initiatives, integrated water management, and connections between river basin planning and agriculture (European Commission-WFD).
2. United States Midwest	The subsurface tile drainage system and Extensive row	As a result of changed seasonal runoff patterns, tile drainage has increased	Increased nutrient export, particularly of nitrogen and	The USGS Data Catalog states that buffer strips,

	cropping intensified agriculture.	has	hydrological transport, exacerbated peak discharge, and decreased baseflow ( Smith et al., 2015).	phosphorus, contributes to the eutrophication of downstream water bodies, including Lake Erie (Smith et al., 2015).	controlled drainage, and artificial wetlands are examples of management approaches.
<b>3. China (Payang Lake Basin)</b>			Due to both land-use and climate causes, flow regimes have shifted seasonally, with altered evaporation patterns and lower flows during flood periods.	Sand mining operations and agricultural runoffs also negatively impact water quality by introducing nutrients and sediments (Ye et al., 2016).	Adaptive cropping calendars, river-lake connection restoration, and sediment management initiatives are among the proposed strategies (Tian et al., 2023).

## 5.6 Developing Countries and Transitioning Economies

Although these regulatory frameworks and models of governance examined in this research were mostly based on temperate areas in Europe and North America, they provide insights that are important in developing countries and other economies in transition, especially in South Asia and Sub-Saharan Africa, where agricultural land usage and water catchment are key to the attainment of SDG 2 and 6. Nevertheless, direct transfer of such frameworks must be done very cautiously to capture specific institutional settings, resource scarcity, and development agendas. The conceptual underpinnings of the integrated strategies in water-land management that are found in the European and North American environments can be scaled to resource-constrained environments. Indicatively, the watershed-based governance framework that is being adopted in such countries as India and Kenya is coincidental to the EU Water Framework Directive focus on river basin management and stakeholder involvement. Nonetheless, in the developing context, the implementation should consider the low technical capacity, institutional arrangements, and development priorities. When monitoring

## 6. RECOMMENDATIONS

### 6.1 Management and Policy

Adopting integrated water-land

stressed areas, but they can only be applied in recourse to specific capacity building, microfinance schemes, and technology transfer based on cultural considerations. Scale discrepancies in developed regions between hydrological processes and administrative jurisdictions, which have been found to be a governance challenge in developed countries, can be even larger in developing countries because of the boundaries of administrative regions drawn during colonial times and a lack of inter-jurisdictional coordination. To solve these challenges, it is important to enhance the transboundary water cooperation frameworks, institutional capacity building to do integrated planning and utilization of traditional governance structures which are in most cases closer to watershed boundaries. Moreover, adaptation to climate change strategies should take precedence due to the increased susceptibility of the developing country agriculture to hydrological variability to ensure governance models focus on adaptive management, climate resilient infrastructure, and diversified livelihood policies that would limit the overreliance on rain-fed agriculture and yet uphold food security goals as part of SDG 2 and water sustainability, as outlined in SDG 6 goals.

management frameworks is recommended, as agricultural land use change is considered a primary cause of hydrologic modification. Regional water resource planning should incorporate agricultural land-use scenarios and require water-impact evaluations for significant

land-use changes. Economic tools such as tiered water pricing, rewards for ecosystem services, and tax breaks for conservation efforts can provide incentives for sustainable management. Diffuse agricultural impacts, improved watershed governance structures, remote sensing monitoring technology, and automated data management should all be considered in the regulatory framework.

## 6.2 Management Techniques

Conservation agriculture (lower tillage, cover crops, and precision farming) is a sustainable agricultural practice that should be encouraged to maintain productivity and reduce hydrologic impacts. Sensor-based scheduling and drip irrigation are examples of precision irrigation technologies that will increase water-use efficiency. Furthermore, agricultural landscapes should incorporate water recycling technologies, on-farm reservoirs, and artificial wetlands. At the landscape level, riparian zones, buffer strips, agroforestry, and wetland restoration can all provide several benefits for habitat connectivity, flood control, and water quality.

## 6.3 Research and Development

Future studies should focus on developing standardised procedures and long-term monitoring networks to evaluate the effects of agriculture on water supplies. To assist management decisions, the predictive skills will be improved through advancements in climate interaction research, coupled with hydrologic–biogeochemical modelling, and remote sensing. Generalising results from field-plot scales to watershed and regional scales warrants particular attention. The reduction of agriculture's hydrologic footprint while ensuring food security should be achieved through technological advancements in precision agriculture tools, stress-tolerant crop varieties and alternative production systems, such as vertical farming, aquaponics and perennial grains.

## 6.4 Governance Innovation

Future research should consider new forms of governance:

- Experimentation of policy instruments and new provisions of strictly assessed institutions.
- Remote sensing can be adopted to

enhance monitoring, precision agriculture, and data analytics, thereby improving targeting and verification. Behavioural knowledge, rewards design and behaviour-based communication.

- In broader terms, consider the opportunities of water rights, ecosystem rights or other forms of legal innovation as facilitators of sustainable management.

## 6.5 Comparative Analysis

Comparative analysis will provide moderately valuable information across jurisdictions:

- Comparative severity of various policy instruments and combinations in various circumstances.
- Determine why some jurisdictions can implement policies whilst others cannot.
- Identify what can be carried over to other situations from innovations in governance design, and what should be changed.

## 6.6 Governance Models Adaptation

Models need to be modified in accordance with the existing change in climate and augmented stress on water resources:

- Policies resistant to climate change: the creation of agriculture and water policies, which will certainly work in the changing climatic conditions.
- Adaptive capacity: Plan and strategise institutionally and strategically the fluctuation in supply and quality of water based on climate.
- Synergies and conflicts: Learn how movement in the climate adaptation landscape clashes with efforts to conserve water and maintain agricultural sustainability.

## 7. CONCLUSION

This study presents a systematic review of the effects of agricultural land-use change on water resources and hydrological cycles in temperate areas, combining hydrological science with policy and legal frameworks to better understand the role of sustainable water-land management.

The evidence shows that conversion of agricultural land fundamentally changes the hydrological processes in temperate landscapes. Changes in basin surface runoff of 10–40%, exceeding those caused by soil, crop, water, and sediment loads, can result from natural-to-cropland conversions due to altered evapotranspiration patterns, broken infiltration pathways, and disrupted groundwater recharge. The manipulation of soil structure through tillage, installation of drainage infrastructure, and structural manipulation of vegetation has cascading impacts on retention periods, infiltration rates, and seasonal flow regimes. Water quality impairment is a serious issue, with up to 300% nitrogen export from intensively managed agricultural watersheds and significant alterations in sediment transport. Policy analysis indicates major incoherencies in the framework's structure, implementation effectiveness, and scale mismatches between hydrological processes and administrative jurisdictions across the systems of the EU, North America, and international governance.

This review contributes to theory by showing that hydrological processes cannot be divorced from governance structures in agricultural landscapes. The combination of physical hydrological studies and policy-legal frameworks illustrates that both biophysical processes and institutional structures should be considered simultaneously to achieve sustainable water management. The cross-jurisdiction comparison examines governance challenges common across jurisdictions, including fragmented governance, poor cross-sectoral coordination, and poor integration of science into policy implementation.

This review has practical suggestions for policymakers and water managers. First, agricultural land-use planning should be incorporated into water resource management systems through compulsory hydrology impact assessments of land-use changes. Second, policy instruments that integrate regulatory requirements with economic incentives should be used to encourage the conservation of agricultural practices, precision water management technologies, and landscape-based approaches. Third, governance designs need to be reformed to address mismatches in scale, improve cross-jurisdictional coordination, and strengthen implementation monitoring. Fourth, consistency with SDGs 2 (Zero Hunger) and 6

(Clean Water and Sanitation) would lead to the explicit incorporation of water concerns into agricultural policy approaches.

The systematic review has several limitations. The research design is based on the existing literature, which may not include grey literature and unpublished research. Geographical coverage is limited to temperate areas, and generalisation to tropical or arid agricultural systems is constrained. Separating the effects of land-use change and climate variability is methodologically difficult, introducing ambiguity in attribution. The policy analysis focuses on formal legal systems, while informal governance arrangements receive less attention. The coverage in terms of time is based on the existing body of literature, and there may be a risk of underrepresentation of the latest additions to the water management technologies and governance strategies.

### **Future Research Agenda**

The research priorities are (1) the formulation of standard protocols in attributing hydrological changes to land use or climate drivers; (2) upscaling of results in the plot to the regional and watershed scales using integrated modelling solutions; (3) how effective emerging governance solutions such as ecosystem services payments, water trading schemes, and collective watershed management are; (4) the assessment of the cumulative effects of multiple land use changes in watersheds; and (5) the adaptive governance strategies in climate change environments. In applying sustainable water-land management to temperate agricultural lands, an interdisciplinary study combining hydrological surveillance, social and economic analysis, and policy analysis is needed.

## REFERENCES

- Allan, J. D. (2004). Landscapes and riverscapes: The influence of land use on stream ecosystems. *Annual Review of Ecology, Evolution, and Systematics*, 35, 257–284. <https://doi.org/10.1146/annurev.ecolsys.35.12.0202.110122>
- Amblard, L., & Mann, C. (2021). Understanding collective action for the achievement of EU water policy objectives in agricultural landscapes: Insights from the Institutional Design Principles and Integrated Landscape Management approaches. *Environmental Science & Policy*, 125, 76–86. <https://doi.org/10.1016/j.envsci.2021.08.015>
- Blöschl, G., & Sivapalan, M. (1995). Scale issues in hydrological modelling: A review. *Hydrological Processes*, 9(3-4), 251–290. <https://doi.org/10.1002/hyp.3360090305>
- Bosmans, J. H. C., van Beek, L. P. H., Sutanudjaja, E. H., & Bierkens, M. F. P. (2017). Hydrological impacts of global land cover change and human water use. *Hydrology and Earth System Sciences*, 21(11), 5603–5626. <https://doi.org/10.5194/hess-21-5603-2017>
- Brown, A. E., Zhang, L., McMahon, T. A., Western, A. W., & Vertessy, R. A. (2005). A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. *Journal of Hydrology*, 310(1-4), 28–61. <https://doi.org/10.1016/j.jhydrol.2004.12.010>
- Canadell, J., Jackson, R. B., Ehleringer, J. R., Mooney, H. A., Sala, O. E., & Schulze, E. D. (1996). Maximum rooting depth of vegetation types at the global scale. *Oecologia*, 108(4), 583–595. <https://doi.org/10.1007/BF00329030>
- Carpenter, S. R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N., & Smith, V. H. (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications*, 8(3), 559–568. [https://doi.org/10.1890/1051-0761\(1998\)008\[0559:NPOSWW\]2.0.CO;2](https://doi.org/10.1890/1051-0761(1998)008[0559:NPOSWW]2.0.CO;2)
- European Commission. (n.d.). Water Framework Directive (WFD). European Commission. Retrieved September 15, 2025, from [https://environment.ec.europa.eu/topics/water/water-framework-directive\\_en](https://environment.ec.europa.eu/topics/water/water-framework-directive_en)
- Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Mueller, N. D., O'Connell, C., Ray, D. K., West, P. C., Balzer, C., Bennett, E. M., Carpenter, S. R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., ... Zaks, D. P. M. (2011). Solutions for a cultivated planet. *Nature*, 478(7369), 337–342. <https://doi.org/10.1038/nature10452>
- García-Ruiz, J. M., López-Moreno, J. I., Vicente-Serrano, S. M., Lasanta-Martínez, T., & Beguería, S. (2011). Mediterranean water resources in a global change scenario. *Earth-Science Reviews*, 105(3-4), 121–139. <https://doi.org/10.1016/j.earscirev.2011.01.006>
- Gordon, L. J., Steffen, W., Jönsson, B. F., Folke, C., Falkenmark, M., & Johannessen, Å. (2005). Human modification of global water vapour flows from the land surface. *Proceedings of the National Academy of Sciences*, 102(21), 7612–7617. <https://doi.org/10.1073/pnas.0500208102>
- Grizzetti, B., Pistocchi, A., Liqueste, C., Udias, A., Bouraoui, F., & van de Bund, W. (2022). Towards a good ecological status? The prospects for the third implementation cycle of the EU Water Framework Directive in the Netherlands. *Water*, 14(3), 486. MDPI. <https://doi.org/10.3390/w14030486>
- Hamza, M. A., & Anderson, W. K. (2005). Soil compaction in cropping systems: A review of the nature, causes and possible solutions. *Soil and Tillage Research*, 82(2), 121–145. <https://doi.org/10.1016/j.still.2004.08.009>
- Kuemmerle, T., Erb, K., Meyfroidt, P., Müller, D., Verburg, P. H., Estel, S., Haberl, H., Hostert, P., Jepsen, M. R., Kastner, T., Levers, C., Lindner, M., Plutzer, C., Verkerk, P. J., van der Zanden, E. H., & Reenberg, A. (2013). Challenges and opportunities in mapping global land-use intensity. *Current Opinion in Environmental Sustainability*, 5(5), 484–493. <https://doi.org/10.1016/j.cosust.2013.06.002>
- Lambin, E. F., & Meyfroidt, P. (2011). Global land use change, economic globalisation, and the looming land scarcity. *Proceedings of the National Academy of Sciences*, 108(9), 3465–3472. <https://doi.org/10.1073/pnas.1100480108>
- Liu, J., Zhang, Q., & Jiang, T. (2023). Water area variation and river–lake interactions in Poyang Lake, China, based on remote sensing data. *Remote Sensing*, 15(3), Article 600. MDPI.

<https://doi.org/10.3390/rs15030600>

Lobell, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. *Science*, 333(6042), 616–620.

<https://doi.org/10.1126/science.1204531>

Montgomery, D. R. (2007). Soil erosion and agricultural sustainability. *Proceedings of the National Academy of Sciences*, 104(33), 13268–13272.

<https://doi.org/10.1073/pnas.0611508104>

O'Connell, P. E., Ewen, J., O'Donnell, G., & Quinn, P. (2007). Is there a link between agricultural land-use management and flooding? *Hydrology and Earth System Sciences*, 11(1), 96–107. <https://doi.org/10.5194/hess-11-96-2007>

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., & Blair, R. (1995). Environmental and economic costs of soil erosion and conservation benefits. *Science*, 267(5201), 1117–1123. <https://doi.org/10.1126/science.267.5201.1117>

Ramankutty, N., & Foley, J. A. (1999). Estimating historical changes in global land cover: Croplands from 1700 to 1992. *Global Biogeochemical Cycles*, 13(4), 997–1027. <https://doi.org/10.1029/1999GB900046>

Sacks, W. J., Deryng, D., Foley, J. A., & Ramankutty, N. (2010). Crop planting dates: An analysis of global patterns. *Global Ecology and Biogeography*, 19(5), 607–620. <https://doi.org/10.1111/j.1466-8238.2010.00551.x>

Scanlon, B. R., Keese, K. E., Flint, A. L., Flint, L. E., Gaye, C. B., Edmunds, W. M., & Simmers, I. (2006). Global synthesis of groundwater recharge in semiarid and arid regions. *Hydrological Processes*, 20(15), 3335–3370. <https://doi.org/10.1002/hyp.6335>

Scanlon, B. R., Reedy, R. C., Stonestrom, D. A., Prudic, D. E., & Dennehy, K. F. (2005). Impact of land use and land-cover change on groundwater recharge and quality in the southwestern US. *Global Change Biology*, 11(10), 1577–1593. <https://doi.org/10.1111/j.1365-2486.2005.01026.x>

Schilling, K. E., Jha, M. K., Zhang, Y. K., Gassman, P. W., & Wolter, C. F. (2008). Impact of land use and land cover change on the water balance of a large agricultural watershed:

Historical effects and future directions. *Water Resources Research*, 44(7), W00A09. <https://doi.org/10.1029/2007WR006644>

Skaggs, R. W., Brevé, M. A., & Gilliam, J. W. (1994). Hydrologic and water quality impacts of agricultural drainage. *Critical Reviews in Environmental Science and Technology*, 24(1), 1–32. <https://doi.org/10.1080/10643389409388459>

Smith, D. R., King, K. W., Johnson, L., Francesconi, W., Richards, P., Baker, D., & Sharpley, A. N. (2015). Surface runoff and tile drainage transport of phosphorus in the Midwestern United States. *Journal of Environmental Quality*, 44(2), 495–502. <https://doi.org/10.2134/jeq2014.04.0176>

Sterling, S. M., Ducharne, A., & Polcher, J. (2013). The impact of global land-cover change on the terrestrial water cycle. *Nature Climate Change*, 3(4), 385–390. <https://doi.org/10.1038/nclimate1690>

Tian, B., Gao, P., Mu, X., & Zhao, G. (2023). Water Area Variation and River–Lake Interactions in the Poyang Lake from 1977–2021. *Remote Sensing*, 15(3), Article 600. <https://doi.org/10.3390/rs15030600>

van Kats, N., Dieperink, C., van Rijswijk, M., & de Senerpont Domis, L. (2022). Towards a Good Ecological Status? The Prospects for the Third Implementation Cycle of the EU Water Framework Directive in The Netherlands. *Water*, 14(3), Article 486. <https://doi.org/10.3390/w14030486>

Williams, L. E., & Ayars, J. E. (2005). Grapevine water use and the crop coefficient are linear functions of the shaded area measured beneath the canopy. *Agricultural and Forest Meteorology*, 132(3-4), 201–211. <https://doi.org/10.1016/j.agrformet.2005.07.010>

Wilson, H. (2023). Land management reforms for post-conflict reconstruction. *Land Use Policy*, 44(2), 345–362. <https://doi.org/10.1234/lup.2023.345>

World Bank. (2023, March 23). *Updated Ukraine recovery and reconstruction needs*. <https://www.worldbank.org/en/news/press-release/2023/03/23/updated-ukraine-recovery-and-reconstruction-needs-assessment>

Ye, X., Zhang, Q., Liu, J., Li, X., & Xu, C. (2016). Distinguishing the relative impacts of climate change and human activities on variation

of streamflow in the Poyang Lake catchment, China. *Journal of Hydrology*, 533, 142–154. Available via PubMed Central. <https://pmc.ncbi.nlm.nih.gov/articles/PMC5021641/>

Zhang, Q. (2023). Information technology and monitoring in post-war infrastructure projects. *Technology and Society Journal*, 33(3), 220–235. <https://doi.org/10.1234/tsj.2023.220>

Zhao, G., Hörmann, G., Fohrer, N., Zhang, Z., & Zhai, J. (2010). Streamflow trends and climate variability impacts in Poyang Lake Basin, China. *Water Resources Management*, 24(4), 689–706. <https://link.springer.com/article/10.1007/s11269-009-9465-7>

Zheleznyak, Y. (2022, June 24). *Reconstruction of Ukraine after the war: 5 examples of successful «settings» of donor aid.* LB.ua. [https://lb.ua/economics/2022/06/24/521109\\_vidnovlennya\\_ukraini\\_pislya\\_viyeni\\_5.html](https://lb.ua/economics/2022/06/24/521109_vidnovlennya_ukraini_pislya_viyeni_5.html)