EEET ECOLOGICAL ENGINEERING
& ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2024, 25(1), 321–331
https://doi.org/10.12912/27197050/175652
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Received: 2023.11.16
Accepted: 2023.11.30
Published: 2023.12.14

Agricultural Practices and their Impact on Aquatic Ecosystems – A Mini-Review

El Mostapha Albou[1*], Mohamed Abdellaoui[1], Abdellali Abdaoui[1], Ali Ait Boughrous[1]

[1] Biology, Environment and Health, Faculty of Science and Technology of Errachidia, Moulay Ismail University of Meknes, Marjane 2, BP: 298, Meknes 50050, Morocco

* Corresponding author's e-mail: elmostaphaalbou@gmail.com

ABSTRACT

This mini-review delved into the intricate interplay between agricultural practices and aquatic environments, highlighting the global imperative to enhance water quality. Drawing insights from diverse sources, it underscored the complex web linking water management and agriculture with the health of aquatic ecosystems. The expansion and intensification of agriculture have led to widespread fertilizer and pesticide use, impacting the water quality of groundwater, rivers, lakes, and marine habitats. Large-scale irrigation systems, while vital for food security, have inadvertently contributed to land and water salinity issues. As agricultural activities intensify, they often alter aquatic ecosystems, affecting aquatic fauna and overall ecosystem functioning. The sustainable use of chemicals and organic farming practices is paramount to mitigating environmental and ecological impacts. In the context of global changes, the adoption of ecologically based agricultural management strategies holds promise for enhancing sustainability and reducing the off-site consequences. The mini-review emphasized that integrated water resource management, advanced agricultural practices, and rigorous regulation are essential for tackling the critical water quality and quantity challenges linked to agriculture.

Keywords: agricultural practices, aquatic ecosystems, water quality, water management.

INTRODUCTION

In the past few years, aquatic ecosystems have faced substantial challenges stemming from a combination of climate change and human actions. Numerous research investigations have been conducted to assess how these environmental and human-induced factors affect the well-being of aquatic ecosystems. This brief overview specifically concentrated on the human activities that exert an influence on the condition of aquatic environments. Nonetheless, the primary goal of this study was to emphasize the detrimental effects of agricultural practices on aquatic ecosystems.

The intricate relationship between agriculture and water quality involves various aspects. Extensive irrigation projects have bolstered global food security, especially in arid regions, yet they have triggered issues like land and water salinity. Additionally, the expansion and intensification of farming have escalated fertilizer and pesticide usage, posing a threat to the water quality of rivers, lakes, and marine ecosystems (Mateo-Sagasta, 2017; Iqra et al., 2023). Agricultural practices exert a far-reaching influence on both developed and developing nations, albeit with varying degrees of impact. However, the significance of these impacts becomes particularly pronounced in developing countries. This heightened effect can be attributed to the central role that agriculture plays in the economic landscape of these nations (Iqra et al., 2023). The reliance on agriculture in developing countries extends beyond mere economic factors. It often intertwines with the issues of food security, poverty alleviation, and rural development. Many communities in these nations depend on farming not only for their livelihoods, but also for sustenance. Therefore, any challenges or alterations in agricultural practices can directly affect the well-being of these communities. Moreover, the vulnerability of agriculture in developing countries is heightened by limited access to advanced technologies and resources that are readily available in developed nations. These disparities in resources and infrastructure make developing countries more susceptible to the negative impacts of agricultural practices, such as soil degradation, water pollution, and loss of biodiversity (Subhash et al., 2022). Agriculture serves as a vital economic driver, particularly in African nations, where it offers a substantial portion of the workforce. However, in contrast to commercial agriculture, which focuses on a limited range of crops, the adoption of agricultural inputs such as enhanced seeds, synthetic fertilizers, as well as insecticides and pesticides, remains less prevalent in Africa, compared to other developing regions worldwide (Mateo-Sagasta, 2017).

The surging need for food has driven the expansion of agriculture, leading to elevated pollution levels in water ecosystems. This escalation can be chiefly attributed to the intensified application of agrochemicals, including fertilizers, pesticides, herbicides, and plant hormones, aimed at enhancing crop yields. The unsustainable utilization of these agrochemicals has resulted in heightened pollution across a range of environmental settings, encompassing rivers, lakes, underground aquifers, and coastal waters. Agricultural regions play a pivotal role as recipients of these agrochemicals, largely due to factors like runoff, direct dispersion, and leaching (Zeshan et al., 2020).

The excessive use of groundwater for irrigation is a farming practice that poses a significant threat to aquatic ecosystems, notably groundwater. In arid areas, characterized by high groundwater consumption and diminished recharge due to climate change, the intensive pumping of aquifer systems for irrigation has the potential to threaten the long-term sustainability of irrigated agriculture (Mateo-Sagasta, 2017). In the past century, there has been a notable rise in the extraction of freshwater from various sources, including rivers, lakes, aquifers, and artificial reservoirs, often referred to as “blue water”. This trend has persisted and expanded across most regions globally. To provide some perspective, at the start of the 20th century, global freshwater withdrawals were likely around 600 cubic kilometers per year. In 2017, recent estimates indicate that this figure had surged to approximately 3,880 cubic kilometers per year (United Nations, 2022). Asia accounts for the largest share of global freshwater withdrawals, comprising 64.5% of the total, followed by North America at 15.5%, Europe at 7.1%, Africa at 6.7%, South America at 5.4%, and Australia and Oceania at 0.7% (United Nations, 2022).

As per the data from the Food and Agriculture Organization of the United Nations (FAO), the irrigated land area has experienced significant growth in recent decades, surging from 139 million hectares (Mha) in 1961 to reach 320 Mha by 2012 (FAO, 2014). These figures underscore the gravity of the situation and underscore the imperative for implementing integrated water resource management strategies.

During the last years, several studies and investigations have been carried out to assess the effects of agricultural practices on the aquatic environment (Daniela et al., 2022; Dmitriy et al., 2020; Naveen et al., 2021; Convention on Wetlands, 2022; Nasrin et al., 2022). These investigations have consistently shown that the extensive growth of agricultural activities has led to significant alterations and influences on aquatic ecosystems. The recommendations stemming from these studies underscore the imperative to strike a balance between food production and the preservation of water resources.

AGRICULTURAL SOURCES OF CONTAMINANTS

Agrochemicals

Agrochemicals find global application in enhancing crop outcomes. Fertilizers are employed to optimize crop yields, while the timely use of pesticides shields crops against insects and diseases. Current agriculture heavily relies on a diverse range of agrochemicals, playing a substantial role in improving the efficiency and economic viability of crop production. This is essential to meet the growing food demands of the rapidly expanding global population (Mateo-Sagasta, 2017; Bruinsma, 2017).

Nutrients

Water pollution resulting from nutrient runoff in crop production arises when fertilizers are applied in the quantities exceeding the capacity of soil particles to retain them. While nutrients are vital for plant growth, an excess of specific nutrients in water can lead to various adverse ecological consequences (Zeshan et al., 2020; Kummu et al., 2012). Nutrients manifest in diverse forms which can facilitate their movement among soil and water. Typically, nutrient concentrations in water are expressed as milligrams per liter (mg/L), denoted as nitrogen or phosphorus (Zeshan et al., 2020).

Nitrogen pollution, often in the form of nitrate (NO_3^-) from agricultural sources, can lead to several adverse effects. Excess nitrates in water bodies can cause eutrophication, a process where excessive nutrients stimulate the overgrowth of algae. In addition, nitrogen pollution can disrupt aquatic ecosystems, leading to declines in fish populations and changes in the composition of aquatic flora and fauna. This can have cascading effects on the entire ecosystem (Bijay Singh et al., 2021; Khalid et al., 2020). Moreover, nitrate can leach into groundwater, which serves as a source of drinking water for many communities. Prolonged exposure to elevated nitrate levels in drinking water can pose health risks (Craswell, 2021; Khalid et al., 2020).

Phosphorus, like nitrogen, can have significant impacts on surface and groundwater, primarily in the form of phosphate (PO_4^{3-}). Excessive phosphorus levels in surface waters can contribute to eutrophication, a process where nutrient enrichment leads to the overgrowth of algae and aquatic plants. As these organisms die and decompose, they consume oxygen, creating hypoxic or anoxic conditions that harm aquatic life and reduce water quality (Wayne et al., 2019). In addition, phosphorus can leach into groundwater, particularly in the areas with high agricultural or urban runoff (Karin et al., 2015). While it is less mobile in soils than nitrate, high concentrations of phosphate in groundwater can degrade its quality and pose a risk to drinking water sources. Furthermore, elevated phosphorus levels can disrupt aquatic ecosystems by altering the composition of aquatic species. This can lead to declines in desirable species and shifts in the structure of aquatic communities (Karin et al., 2015; Liu et al., 2023).

Pesticides

Over the past few decades, there has been a significant global surge in the utilization of pesticides, aimed at safeguarding standing crops, stored grains, and human populations from the threat of pests (Häder et al., 2020). These substances contribute to the contamination of water and have an impact on a broad spectrum of aquatic life, including invertebrates and fish (Zeshan et al., 2020). Pesticides can enter groundwater through a process called leaching (by rainfall, infiltration and irrigation), which involves the downward movement of these chemicals from the surface soil into the groundwater (Zeshan et al., 2020). Numerous studies have demonstrated the involvement of pesticides in various alterations in fish, encompassing reproductive functions, morphological changes, and chromatophore patterns (Rao et al., 2020; Das et al., 2012). Improper selection and mishandling of pesticides can lead to the contamination of water sources. Furthermore, pesticides have the capacity to disturb biodiversity by eradicating weeds and insects, resulting in adverse repercussions throughout the ecological food chain (Mahmood et al., 2016).

Pesticides comprise a diverse array of chemical formulations created for the purpose of managing or eradicating pests. They can be sorted into distinct categories, characterized by their primary targets and chemical compositions, including insecticides, herbicides, fungicides, and nematicides, among others. Every year, agriculture relies on millions of tons of active pesticide components (Zeshan et al., 2020). On the basis of the data from the Food and Agriculture Organization (FAO), the United States currently leads as the largest consumer of pesticides globally, with China following closely behind in terms of usage (Mateo-Sagasta, 2017). Because of their composition and chemical properties, pesticides are regarded as some of the most perilous substances arising from agricultural practices. Furthermore, the handling and regulation of these chemicals pose significant challenges (Schreinemachers et al., 2012).

Livestock manure

Livestock manure is rich in nutrients, particularly nitrogen and phosphorus. When improperly managed or applied, these nutrients may leach into groundwater or runoff into surface water bodies, leading to eutrophication (Mateo-Sagasta, 2017). Additionally, livestock manure contains bacteria, including pathogens, which can be transported into water bodies via runoff, posing health risks to both humans and wildlife (Khan et al., 2018). Excessive manure runoff can also cause sedimentation in water bodies, altering their morphology and negatively impacting aquatic habitats, thereby reducing water quality. Furthermore, the decomposition of organic matter in manure can reduce the oxygen levels in water bodies, especially in confined areas like ponds or small streams, potentially harming aquatic life (Khan et al., 2018). Lastly, livestock manure may contain various potentially harmful chemicals and heavy metals that, if not carefully managed, can leach into water sources, posing additional risks to aquatic ecosystems as well as human health (Zhang et al., 2022).

Plastics

Plastics in the form of large debris, such as bags and packaging materials, can entangle and suffocate marine animals and fish, leading to injury or death (Rochman et al., 2015). Plastic contaminants manifest in ecosystems in diverse forms, exhibiting a range of sizes classified as megaplastic, macroplastic, mesoplastic, and microplastic (Shams et al., 2020; Thushari et al., 2020). Microplastics, tiny plastic particles less than 5 mm in size, can be ingested by a wide range of aquatic organisms, including zooplankton, fish, and filter-feeding bivalves. This ingestion can lead to physical harm, reduced feeding efficiency, and bioaccumulation of toxins (Shams et al., 2020; Thushari et al., 2020; Kara, 2017). A significant link between agriculture and plastic pollution of aquatic ecosystems lies in the use of plastic materials in agricultural practices. Agricultural activities frequently involve the use of plastic materials, such as plastic mulch films, irrigation tubing, as well as packaging for fertilizers and pesticides. These plastics can inadvertently enter aquatic ecosystems through various pathways: runoff, wind transport and microplastics from soil (Cem et al., 2021).

Heavy metals

Recent research has underscored the significant relevance of studying the contamination of aquatic ecosystems by agricultural-derived heavy metals. Cadmium, lead, and zinc, among other metals, possess various pathways by which they can enter aquatic environments, resulting in disturbances to these ecosystems. The involvement of agricultural practices further aggravates the release of heavy metals into water bodies, whether through runoff or the use of contaminated fertilizers and pesticides. Consequently, once these metals find their way into aquatic ecosystems, they tend to accumulate within sediments and water, thus introducing a spectrum of potential risks (Zhang et al., 2018; Moyan et al., 2022). Heavy metals are classified as emerging contaminants that pose a threat to both surface water and groundwater. Despite their low initial concentrations, these metals have the capacity to accumulate within the aquatic environment, including water bodies, sediment, and aquatic organisms like macroinvertebrates. Due to their persistent nature and toxicity, heavy metals represent a potential hazard to water quality, and by extension, human health (Long at al., 2022; Jéssica et al., 2019; Jastrzębska et al., 2021).

Pathogens

Livestock manure contains a variety of microorganisms, including bacteria, viruses, and parasites, some of which can be harmful to humans and aquatic ecosystems (Mateo-Sagasta, 2017; Iqra et al., 2023). Improper handling and storage of livestock manure can lead to the release of pathogens into the environment. When manure is not adequately contained or treated, it can be washed into surface water bodies during rain events or can infiltrate into groundwater (Mateo-Sagasta, 2017; Iqra et al., 2023). The bodies of water that receive contaminated runoff from agricultural areas can become reservoirs for pathogens, serving as a source of ongoing contamination downstream (Zhang et al., 2022; Ji et al., 2012). Contaminated water sources can lead to outbreaks of waterborne diseases among the humans who consume or come into contact with the contaminated water. Pathogens such as E. coli and Salmonella, and Cryptosporidium, which are commonly found in livestock manure, can cause serious illnesses in humans (WHO, 2012).

Salts

Agriculture plays a significant role in elevating water salinity levels. Various salts, such as sodium, potassium, calcium, and sulfate, have the propensity to accumulate in the soil through agricultural practices and subsequently migrate into adjacent water bodies, triggering a process known as salinization (FAO, 2014; Mateo-Sagasta, 2017). Moreover, in certain regions, farmers resort to using the water sources for irrigation that inherently contain high salt concentrations. This infusion of saline water onto agricultural fields further compounds the soil salinity issues (Khalid et al., 2020). Additionally, suboptimal drainage systems can contribute to the accumulation of excess water within fields. As this water accumulates, it dissolves salts in the soil and facilitates their downward movement, ultimately culminating in their infiltration into groundwater or neighboring surface water bodies (Pulido-Bosch et al., 2018; Foster et al., 2018).

Salinity can have significant impacts on aquatic biodiversity. The changes in salinity can affect the movement and migration patterns of aquatic species. Some may need to relocate to find more suitable salinity conditions, which can be challenging and disruptive. Moreover, the changes in aquatic biodiversity can impact the ecosystem services provided by aquatic ecosystems, including water purification and nutrient cycling (Lorenz et al., 2014; Mohammad et al., 2017).

Emerging contaminants

Over the past two decades, new categories of agricultural pollutants have emerged in the farming industry. These pollutants include antibiotics, vaccines, growth promoters, and hormones (OECD, 2019). Here is a brief description of each:

- antibiotics – traditionally used in agriculture to treat and prevent infections in livestock.
- vaccines – employed to protect animals from various diseases.
- growth promoters – substances administered to livestock to enhance their growth and feed efficiency.
- hormones – these include synthetic growth hormones and reproductive hormones, used in animal agriculture to regulate various aspects of animal growth and reproduction.

The introduction of antibiotics, vaccines, growth promoters, and hormones into aquatic ecosystems, via leaching or runoff, poses notable risks and impacts. Collectively, these agricultural pollutants can disturb the balance of aquatic ecosystems, degrade water quality, and harm aquatic life, emphasizing the need for responsible agricultural practices and stringent regulatory measures to mitigate their detrimental effects on aquatic ecosystems as well as safeguard both environmental and human health (Svetlana et al., 2020; Cheng et al., 2020; Ronquillo et al., 2016).

EFFECTS OF AGRICULTURAL POLLUTION

Agricultural practices have far-reaching consequences for aquatic ecosystems, presenting a multitude of challenges (Fig. 1). Water pollution, chiefly caused by the excessive use of agrochemicals

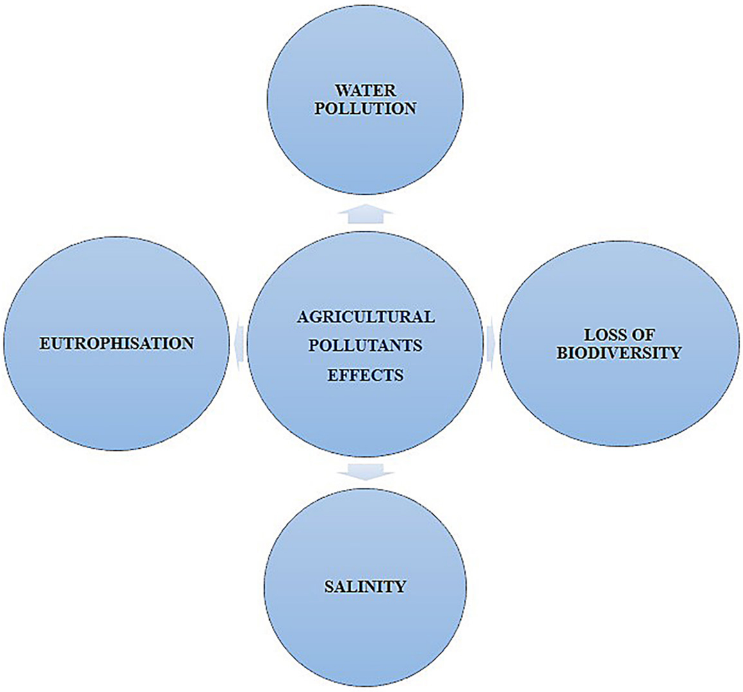

Fig. 1. Agricultural pollutants effects on aquatic ecosystems

Table 1. An overview of Sustainable farming methods and their principles

Sustainable farming methods	Principles
Integrated pest management (IPM)	IPM involves the judicious use of pesticides, focusing on minimizing their environmental impact. It integrates various pest control techniques, including biological control, crop rotation, and targeted pesticide application, to reduce chemical usage while maintaining crop health (Bueno et al., 2021; Alyokhin et al., 2020; Grasswitz, 2019).
Precision agriculture	This technology-driven approach uses data and tools to optimize the use of fertilizers, pesticides, and water. It is also considered as an accurate approach to livestock management. By applying these inputs precisely where and when they are needed, precision agriculture reduces chemical runoff and minimizes environmental impact (Monteiro et al., 2021; Bucci et al., 2018; Aubert et al., 2012).
Zero tillage	Zero tillage farming, also known as no-till or conservation tillage, is a sustainable agricultural practice characterized by the minimal disturbance of the soil during crop planting and cultivation. In zero tillage systems, farmers refrain from traditional practices such as plowing or extensive soil tillage, which disrupt the soil structure. This approach aims to maintain crop residues on the field’s surface, reducing erosion, preserving soil health, enhancing water conservation, and promoting sustainable agricultural practices (Somasundaram et al, 2020; Llewellyn et al., 2012).
Buffer zones and vegetative strips	Establishing buffer zones or strips of vegetation along water bodies can trap and filter agricultural runoff, reducing the transport of chemicals and nutrients into aquatic ecosystems. Buffer zones refer to areas of land or vegetation strategically designed and managed to provide a protective barrier or transition zone between two different land uses or ecosystems. While, vegetative strips are narrow strips of planted or naturally occurring vegetation. These strips are strategically placed to reduce runoff, control soil erosion, and manage environmental impacts (Valkama et al., 2019; Haddaway et al., 2018; Saleh et al., 2018).
Crop diversification	Crop diversification is a sustainable agricultural practice characterized by the cultivation of a variety of crop species or cultivars within a specific farming system or area. This practice involves the deliberate introduction of different crops in a rotation, intercropping, or mixed cropping system, as opposed to the continuous mono-cropping of a single crop. Crop diversification aims to optimize resource use, reduce pest and disease pressures, enhance soil health, and promote resilience in agricultural systems. It is an essential component of sustainable agriculture, promoting ecological balance, economic stability, and the long-term viability of farming systems (Barman et al., 2022; Bobojonov et al., 2013).
Organic farming	Organic farming is an agricultural system and production method that emphasizes the use of environmentally friendly and sustainable practices to cultivate crops and raise livestock. It is characterized by the avoidance of synthetic chemicals such as synthetic fertilizers, pesticides, and genetically modified organisms (GMOs), as well as the promotion of soil health, biodiversity, and ecological balance. Organic farming relies on natural processes, composting, crop rotation, and the use of organic materials to enhance soil fertility and manage pests and diseases (Renu et al., 2022; Santhoshkumar et al., 2017).
Soil health management	Soil health management is a holistic and science-based approach to maintaining and improving the physical, chemical, and biological properties of soil. It focuses on enhancing soil quality and functionality to support sustainable agricultural production while minimizing environmental impacts. Soil health management involves practices that promote soil fertility, structure, and biological diversity, ultimately contributing to long-term soil sustainability (Mehmet, 2020; Monther et al., 2020).
Cover crops	Cover crops, also known as green manure or living mulch, are plant species deliberately grown to cover and protect the soil surface during periods when the primary cash crop is not growing. These crops are typically sown in between regular crop plantings or during fallow periods. Planting cover crops during fallow periods helps prevent soil erosion, enhances nutrient retention, and reduces the need for synthetic fertilizers and pesticides (Nakajima et al., 2020; Wayman et al., 2017; Alexander et al., 2014).
Dry farming	Dry farming is an agricultural method characterized by the cultivation of crops in regions with limited water availability, particularly in arid or semi-arid climates, where rainfall is scarce or unreliable. This farming approach relies on efficient water conservation techniques and specific crop varieties adapted to endure prolonged periods of drought or water stress. Dry farming aims to maximize water use efficiency, reduce evaporation and runoff, and optimize soil moisture retention through various practices such as mulching, reduced tillage, and deep-rooted crop selection. By utilizing these strategies, dry farming seeks to sustain crop production while minimizing water consumption and promoting resilience to water scarcity (Chambers et al.,2020; Ghimire et al., 2018; Haileslassie et al., 2016).
Drip irrigation	Drip irrigation is a precise and efficient method of delivering water and nutrients directly to the root zone of plants through a network of tubing, pipes, valves, and emitters. This irrigation system is designed to release small, controlled amounts of water at or near the base of individual plants or along rows of crops. Drip irrigation systems are characterized by their ability to deliver water slowly and directly to the root zone, minimizing evaporation, runoff, and water wastage. This technology can be customized to suit the specific water requirements of different crops and is often used in both agricultural and horticultural applications (Pérez-Blanco et al., 2020; Velasco-Muñoz et al., 2019; Suryavanshi et al., 2015).
Aquaponics and hydroponics	Hydroponics is a method of growing plants without soil by providing them with a nutrient-rich water solution. Instead of obtaining nutrients from soil, plants grown hydroponically receive essential elements directly through water, with their roots immersed in or exposed to the nutrient solution. While, Aquaponics is a sustainable agricultural system that combines aquaculture (the cultivation of aquatic organisms like fish) and hydroponics (the cultivation of plants in a soilless medium with nutrient-rich water). In Aquaponics, the waste produced by aquatic organisms, such as fish, provides essential nutrients for plants, while the plants naturally filter and purify the water for the aquatic organisms (Kamareddine et al., 2021; Ali et al., 2017; Tahseen et al., 2016).
Solar-powered irrigation	Solar-Powered Irrigation is a sustainable agricultural practice that utilizes solar energy to power irrigation systems for the purpose of delivering water to crops. This method involves the conversion of sunlight into electricity through photovoltaic (PV) panels, which then powers water pumps or other irrigation equipment. It offers numerous benefits, including cost savings, energy efficiency, and reduced environmental impact, making it a valuable tool for modern and sustainable farming (Ullah et al, 2023; Ashraf et al., 2022; Grant et al., 2022).

– such as fertilizers and pesticides – results in nutrient runoff, mainly nitrogen and phosphorus, infiltrating water bodies. This surge in nutrient levels disrupts aquatic ecosystems, compromising water quality and endangering aquatic life. Furthermore, misapplied pesticides harm a wide range of aquatic organisms, leading to the decline of biodiversity and the disruption of food chains. The excess nutrient runoff also triggers eutrophication, characterized by algae overgrowth and subsequent oxygen depletion, further harming aquatic organisms. Salinity levels rise due to agricultural practices, causing salinization, which disrupts aquatic biodiversity and essential ecosystem services. Emerging contaminants like antibiotics, vaccines, growth promoters, whereas hormones further exacerbate the situation, infiltrating aquatic ecosystems and upsetting their balance. In fact, urgent measures, including responsible agricultural practices and stringent regulations, are imperative to mitigate these severe impacts on aquatic environments as well as protect the health of ecosystems and human communities (Mateo-Sagasta, 2017; Bruinsma, 2017; Wayne et al., 2019; Shamim et al., 2015; Khan et al., 2018; Cem et al., 2021; Zhang et al., 2018; Pulido-Bosch et al., 2018; OECD, 2019).

WATER MANAGEMENT PRACTICES FOR SUSTAINABLE AGRICULTURE

Agriculture stands as the most water-demanding sector and a substantial contributor to water contamination. Effective water management within agriculture holds pivotal importance, as it profoundly influences crop productivity, ecological sustainability, and global food security. With the dual challenges of climate change and burgeoning populations exerting pressure on water resources and posing risks to aquatic ecosystems, it is imperative for farmers to embrace intelligent and sustainable approaches to water utilization in agriculture. Nevertheless, transitioning to more sustainable farming practices often entails departing from traditional methods and acquiring new approaches (David et al., 2018; Shackelford et al., 2015; Tess et al., 2014; Mroczek et al., 2013).

Implementing sustainable chemical use and organic farming practices is essential to mitigate the environmental and ecological impacts on aquatic ecosystems. The Table 1 shows options to apply for a sustainable management:

CHALLENGES AND BARRIERS TO SUSTAINABLE AGRICULTURE

The adoption of sustainable agricultural practices is confronted by a multitude of formidable challenges and barriers. Climate change and the consequent rise in the frequency and severity of extreme weather events, such as droughts, floods, and heatwaves, pose substantial threats to crop production and food security (Borrelli et al., 2020; Lesk et al., 2016). Soil degradation and erosion, stemming from unsustainable land management practices like deforestation, overgrazing, and intensive tillage, diminish soil fertility as well as agricultural productivity (Montgomery, 2021; Borrelli et al., 2020). In the regions marked by aridity, the over-extraction of water resources for irrigation, coupled with escalating agricultural water demand, intensifies water scarcity, which can restrict crop yields and heighten competition for this vital resource (Montgomery, 2021; Carlisle et al., 2019). The transition to sustainable farming practices, while essential, frequently necessitates significant initial investments in infrastructure and technology, creating economic and financial barriers for farmers (Carlisle et al., 2019). The dearth of awareness and knowledge regarding sustainable farming practices impedes their adoption, highlighting the importance of education and extension services (Jiangning et al., 2023; Lindumusa et al., 2019). Inadequate policies, subsidies favoring conventional agriculture, and lax enforcement of environmental regulations discourage sustainable practices (DeBoe, 2020).

CONCLUSIONS

In conclusion, agriculture stands at the intersection of providing food security for a growing global population and facing the daunting challenge of mitigating its profound impact on aquatic ecosystems and water resources. The extensive use of agrochemicals, such as fertilizers and pesticides, has led to severe water pollution, causing nutrient runoff, eutrophication, and contamination of water bodies. Furthermore, agricultural practices have contributed to the loss of biodiversity, salinity, as well as the introduction of emerging contaminants into aquatic ecosystems, posing significant threats to both the environment and human health. The multifaceted challenges posed by the impact of agriculture on aquatic ecosystems and water quality require a comprehensive approach that combines sustainable farming practices, technology, and policy interventions. It is imperative that governments, agricultural stakeholders, and communities collaborate to implement positive recommendations as well as work towards a more sustainable and harmonious coexistence between agriculture and aquatic ecosystems. By prioritizing responsible agricultural practices and the protection of water resources, a healthier future can be ensured for both people and the environment.

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