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Application of riparian buffer zone in agricultural non-point source pollution control—A review

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Water is an important natural element of our environment, and its management and security are also serious concerns. Agricultural non-point source pollution (NPSP) is one of the major sources of contaminants causing water quality degradation. A riparian buffer zone is a vegetative cover adjacent to water channels that positively contributes to pollutant filtration and sediment trapping. It has the potential to filter nutrients, reduce nutrients and pesticide leakage, provide habitat and protection against floods, minimize erosion issues, improve biodiversity and ecological connectivity, and add aesthetics to the area. Moreover, it is inexpensive and requires little maintenance making buffer zone an attractive approach to NPSP control. In this review, we have enlightened the effects of the riparian buffer zone on water quality and agricultural NPSP and how its structures and mechanisms contribute to controlling water pollution effectively. We conclude that the riparian buffer zone is an effective technique for water safety, NPSP control, and creating a suitable environment for terrestrial and aquatic species. Moreover, it has the potential to reduce the water temperature due to the shading effect and sustain water habitat acting as a climate adaptation tools. Buffer zones should be adopted for agricultural non-point source pollution and achieve environmental sustainability. However, the long-term influence of the riparian buffer zone on trapping NPS pollutants, soil properties, and groundwater quality is s research gap.

KEYWORDS

agricultural production, riparian buffer, non-point, pollution, sustainability

1. Introduction

Water is an essential resource for the survival and development of living organisms therefore it is important to control environmental pollution and keep the water free of pollutants. Agricultural non-point source pollution (NPSP) is a great source of nutrients in water bodies (Xia et al., 2020). Pollutants reaching farmland mostly come from domestic sewage and agriculture sources that are further divided into inorganic contaminants (heavy metals, sediments, N, P), organic pollutants, pesticides, human pathogens, drug residues, and environmental hormones. The harmful impacts of these pollutants are not limited to the soil but also cause a threat to lakes, rivers, and aquatic ecosystems when moving with surface runoff (Yi et al., 2021). Eutrophication has been reported in many lakes in China and is one of the serious concerns of lake management (Wang et al., 2020).

The development in agriculture, urbanization, and industrialization has adversely deteriorated water quality in lakes, streams, and other water bodies (Wang et al., 2020). The expansion of intensive livestock and inadequate land-use practices has led to NPSP and also caused a threat to the aquatic ecosystem, drinking water safety, and human health (Rong et al., 2021). In addition, NPSP is a primary source of N and P in freshwater, causing water quality degradation (Wang et al., 2020), and agriculture is one of the major sources of adding N and P to water bodies (Lind et al., 2019). In United States of America (USA), agricultural activities are the major source of surface water contamination and pollution including excessive nutrients from fertilizers, herbicides and pesticides runoff, and soil erosion leading to increased turbidity (Jabbar and Grote, 2019) contributing 55% to the NPSP of surface waters. In addition, about 83% of identified sources of river and stream quality impairments were NPSP (Zhang et al., 2019).

NPSP threatens many basin systems globally where industrial and urban point-source pollution is efficiently controlled. Moreover, "South-to-North Water Diversion Project in China" is the largest cross-basin diversion project in the world and was effectively used to control point source pollution. Agricultural and rural areas are the major sources of NPSP therefore it is important to take measures to control NPSP and maintain water quality (Wang et al., 2019b). China has considerably increased agricultural products, progressing from a large to a rich agrarian farming country. But it also leads to excessive use of mineral fertilizers and pesticides, ultimately increasing agricultural non-point sources of pollution (Li et al., 2018; Liu et al., 2022). It has been reported that China has 2.58 times more average mineral fertilizer application intensity than the whole world, and the utilize approximately 30% of the global agrochemicals on 9% of the global cropland in 2016 (Zhang et al., 2021). The mineral fertilizers have increased from 8.84 million tons in 1978 to 58.59 million tons in 2017. In addition, the application of pesticides and plastic film was 0.73 million and 0.48 million tons in 1990, which increased to 1.66 million tons and 2.53 million tons in 2017, respectively (Zou et al., 2020).

The Bulletin of China's First National Pollution Source Census demonstrated that in 2017 China's significant discharges were agricultural chemical oxygen demand (43.7%), total nitrogen (N; 57.2%), and total phosphorus (P; 67.4%) of all pollutants, respectively (Zou et al., 2020; Yi et al., 2021). This showed that agriculture production is highly dependent on intensive agricultural inputs that have increased the yield but also contribute to water quality decline and disturb the aquatic ecosystem (Zou et al., 2020). From 1997 to 2018, about a 136% increase in poultry has been reported making the breeding industry another major contributor to NPSP. Thus, the excessive application of fertilizers, increased sewage sludge, and the soaring excrement of livestock and poultry have resulted in soil deterioration and water pollution (Zhang et al., 2021).

For the past three decades, China's economy has rapidly increased, leading to high pressure on the environment and drinking water resources, causing environmental threats due to anthropogenic activities (Wang et al., 2019a).

Considering all the hazards, it is a need today to develop management strategies for both point and NPSP. Unlike point source pollution, NPSP is challenging to monitor and control (Wang et al., 2019a). The riparian buffer zone is one of the best ways to control NPSP reported and can be implemented globally (Liu et al., 2022). It has long history back in 1700's when treed corridors buffer zones where implemented along the water bodies in European forest management (Lee et al., 2004). A riparian zone is a natural buffer between waterways and the terrestrial environment to protect and manage the near water streams, lakes, and other surface water systems (Figure 1) (Lind et al., 2019), mainly to reduce the transportation of contaminants through subsurface and overland flow (Hill, 2019). Buffer zones also act as filters for nutrients, reduce the leakage of N, P, and pesticides, provide habitat to animals and plants, minimize erosion issues, protect against floods, improve biodiversity and ecological connectivity, and create recreational areas (Lind et al., 2019).

The effectiveness of buffer zones depends on various factors, including topography, size, and width of the buffer zone, vegetation and soil type, management mode, climatic conditions, the extent of nutrient load, and kind, intensity, and transformation of pollutants (Lind et al., 2019; Jin et al., 2022). It is also essential for preventing and controlling NPSP, ecosystem restoration, and mitigating lake ecological environment deterioration. In China, riparian buffer zones are disturbed due to land clearing for vegetation, town development, and other anthropogenic activities are also reported (Wang et al., 2020). Moreover, pollution density was negatively associated with forest and grassland areas, organic pollution was correlated with industrial land use, and chemical oxidation demand, biological oxidation demand, total N, and P showed a positive correlation with urban land use (Xu et al., 2021). In addition, plant buffer zones have a good impact on minimizing water pollutants (Jin et al., 2022), but the relationship between water quality and land use needs to be studied (Xu et al., 2021).

Here, based on the literature review, we studied the benefits and constraints of the riparian buffer zone. Particularly, the review shed light on the role and impacts of the riparian buffer zone on water quality and agricultural NPSP. We also reviewed the structures and mechanisms of the riparian buffer zone to control water pollution effectively. The review aimed to answer the following queries: What is a riparian buffer zone? How do the systems impact water quality and safety? How do riparian buffer zone influence water quality and agricultural NPSP? What are the structure of a riparian buffer zone and its effectiveness? What are the mechanisms behind the working of the riparian buffer zone? What research queries needs to be addressed in the future?

The review comprises eight sections, the general background of the riparian buffer zone and the objectives of the review (section 1), review methodology (section 2), water quality and safety challenges (section 3), application of riparian buffer zone in water quality and agricultural non-point source pollution (section 4), the structure of riparian buffer zone and its effectiveness (section 5), mechanism of the riparian buffer zone (section 6), future research directions (section 7), and conclusion (section 8), respectively.

2. Review methodology

The scope of this article is to provide a need for the riparian buffer zone and its application specifically in agriculture and to explore its impacts on controlling agricultural NPSP. To ensure the

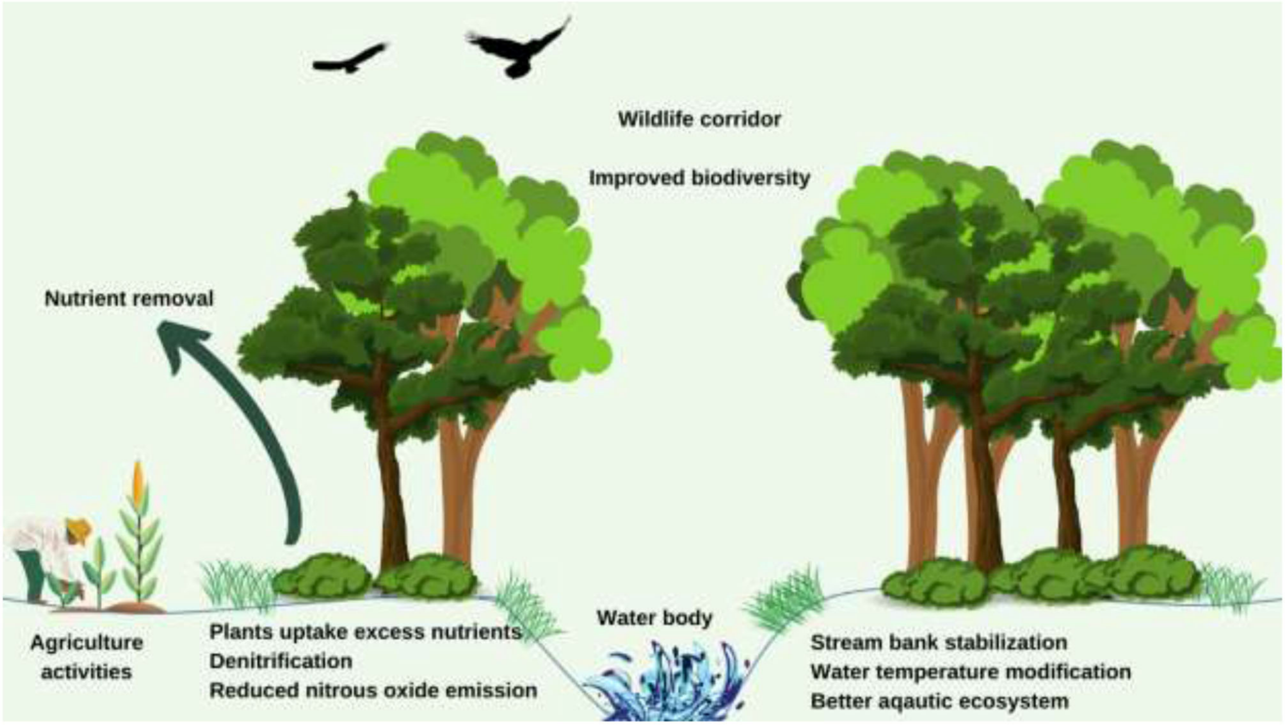

FIGURE 1
Riparian buffer zone.

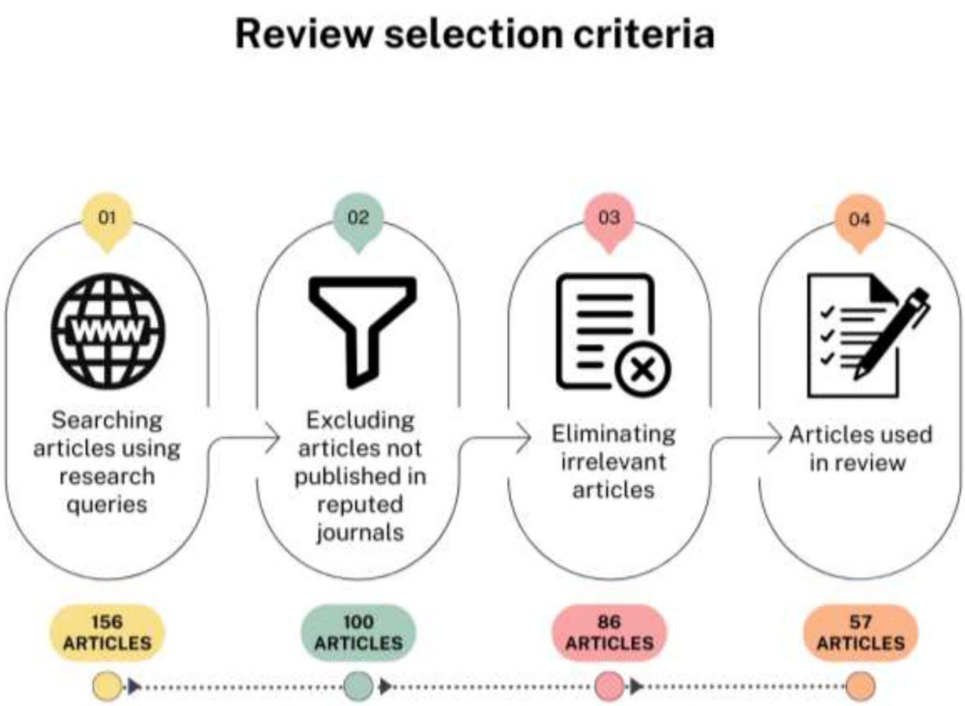

FIGURE 2
Review selection criteria and articles sorted at each step.

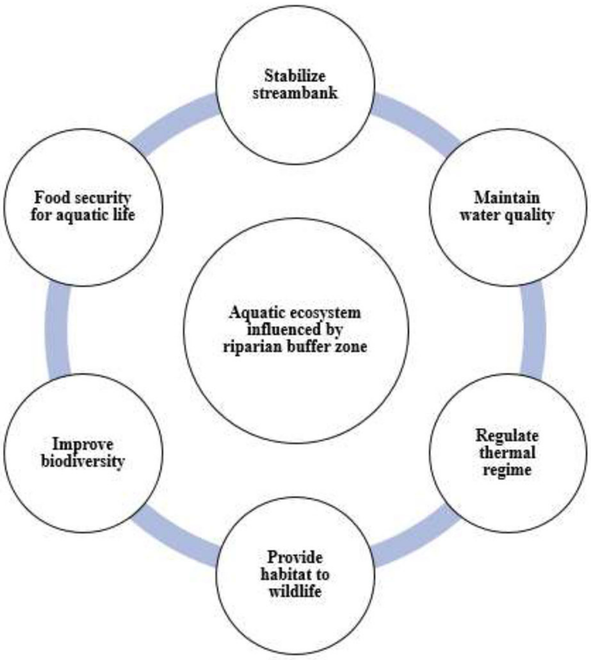

FIGURE 3
Influence of riparian buffer zone on aquatic ecosystem.

quality of the review, we collected review papers, journal articles, research articles, books, and research reports indexed by Web of Science, Scopus, Science Direct, and Google Scholar databases. Initially, a list of keywords related to the scope of the article. Later, the pool of references was searched using the keywords "riparian buffer zone," "agricultural non-point source pollution," "water quality," "water pollution," "vegetative buffer zone," and "water contaminants." Following the given criteria, we identified the references for the review.

2.1. Literature review

In this review, we considered the significance of the riparian buffer zone and NPSP. Therefore, we do not focus on any specific contaminant or structure of the buffer zone and include all water pollutants and different types of buffer zones. The review provides general knowledge about the riparian buffer zone to the agriculturist, water management authorities, and practitioners associated with agriculture and water quality management systems to utilize and manage land and water resources properly. In our study, we selected articles that have studied riparian buffer zones for water quality, NPSP control, and environmental quality.

2.2. Selection criteria

To maintain the quality of the review, we selected reports and articles only published by reputed journals and publishers (Figure 2). Moreover, we excluded articles unrelated to the riparian buffer zone, water quality, and agricultural NPSP. The guidelines were obtained from previous studies for selection criteria and research methodology (Raza et al., 2021).

- The questions discussed in the introduction were considered while sorting out the articles.
- Articles that were not published in international well-reputed journals were excluded.
- We also excluded articles unrelated to our primary aims (riparian buffer zone, water quality, and water pollution, specifically NPSP).
- From the selected articles, the role of the riparian buffer zone in association with controlling NPSP was studied and represented in tables and graphs.

3. Water security and quality challenges

Water is an important natural element of our environment, and its management and security are also serious concerns (Dou et al., 2021). The major threats to water security include droughts, floods, erosion, landslides, water-borne diseases, climate change, population growth, urbanization, and water pollution due to agricultural, industrial, and other contaminations (Mishra et al., 2021). Additionally, rivers are the primary source of renewable water for the freshwater ecosystem and humans, but water pollution has adversely affected the river functioning for humans, specifically in China (Tang et al., 2022). The term 'water security' covers the concept of creating a balance between water resource usage, protection, and water management. The United Nations defines water security as a balance between water resource protection and support for human deeds. It means that humans have sustainable access to sufficient quantities and good quality water while managing socioeconomic and environmental safety issues (Yu and Wang, 2022). China is facing water security problems related to water shortage, water environment deterioration, and safety concerns (Zhao et al., 2021).

Point sources and non-point sources are two modes of pollutant influx into water bodies. Point source pollution is the industrial, municipal sewage, and urban sewer discharge, while the NPSP is due to surface runoff over agricultural farms, mines, forests, urban areas, and construction sites. However, point source pollution has been controlled in many developed countries, but NPSP is a severe threat to surface water quality (Han et al., 2021). Six water quality levels are designed according to the water functionality and quality standards (Grade I, II, III, IV, V, inferior V). Grade 1 is given to pristine surface water that must be protected at any cost. Grade II to III is good water and can be used for drinking and industries. At the same time, Grade IV to V is bad water and can be used for irrigation and recreation. Grade inferior V is the worst and most useless (Zhou et al., 2014).

Available water resources per capita in China are nearly 2300 m^3. China's population is estimated to reach 1.6 billion in 2030, with water resources declining to 1750 m^3 per capita. Consequently, China will face severe water stress due to water

TABLE 1 Worldwide use of riparian buffer use and key findings.

Location	Vegetation	Key findings	References
Manitoba, Canada	A mix of forbs and grass species	Harvest vegetation to reduce nutrient losses	Kieta et al., 2022
Anhui, China	Multiple: (grassland, forest, wetland, farmland, and forest/grassland)	Adopt wetlands and forests with grass in riparian buffers to reduce P leaching	Cao et al., 2019
Mazandaran, Iran	Vetiver-grass (*Chrysopogon zizanioides*) and native turf-grass (*Festuca arundinacea*)	Reduce pollutant transport (nitrates) and soil erosion	Kavian et al., 2018
Jiangxi, China	Centipede grass (*Eremochloa ophiuroids*), tall fescue (*Festuca elata*), and vetiver grass (*Vetiveria zizanioides*)	Grasses and slope gradient significantly influenced the water flow and NO_3-N loss	Sheng et al., 2021
North-East Italy	Trees (*Platanus hybrida Brot.*) and shrubs (*Viburnum opulus* L.), with grass (*Festuca arundinacea* L.)	Reduced runoff volumes and nutrient losses	Borin et al., 2005
Clovis, United States	Switchgrass (*Panicum virgatum*), Big Bluestem (*Andropogon gerardi*), Indiangrass (*Sorghastrum nutans*), Sideoats Grama (*Bouteloua curtipendula*), Sand Bluestem (*Andropogon hallii*), Tall Wheatgrass (*Thinopyrum ponticum*) and Western Wheatgrass (*Pascopyrum smithii*).	Improved microbial biomass, soil health, and environmental quality. Also, reduced CO_2 and N_2O emissions from	Musfiq-Us-Salehin et al., 2020
Illinois, USA	Riparian forest buffers	Increase macroinvertebrate and fish abundance	Effert-Fanta et al., 2019
Hafren Forest, Plynlimon	Riparian buffer zones (natural vegetation)	Reduce stream-suspended sediment loads	Stott, 2021

shortage. Moreover, water pollution and climate change have also pressured China to deal with resources and quality water shortages (Zhou et al., 2014). With an increase in population and socioeconomic development, the demand for food has also risen, ultimately creating pressure on agriculture production (Wang et al., 2021). China uses more chemical fertilizers as compared to other countries globally. However, the studies demonstrated that plants only uptake about 30-50% of fertilizers while others are lost, causing various environmental issues (Xin, 2022). In this scenario, the use of fertilizers and pesticides has expanded, leading to adverse agricultural NPSP conditions, water quality decline, disturbed ecology, and increasing eutrophication cases (Wang et al., 2021).

According to recent reports, the problem of eutrophication has been observed in more than 60% of lakes in China. Moreover, the origin of N and P in more than half of the lakes is NPSP (Hou et al., 2022). These excessive nutrients cause eutrophication leading to algal blooms, threats to aquatic life, deterioration of drinking water quality, and disturbing the health of residents surrounding water bodies (Wang et al., 2021). Agriculture and rural areas are the prime sources of NPSP; studies reported that agriculture production added approximately 31 million tons of N and 2.9 million tons of P to fresh water globally annually. In addition, about 57% of N reached water bodies from the agriculture sector in China (Wang et al., 2018b).

Apart from China, other countries also face a similar situation. In Minnesota, the leading cause of N pollution is fertilizer application. Moreover, agriculture production caused nitrate losses and accounted for 86% of the watershed in Prince Edward Island, Canada. The studies in Ghana, Poland, and Ganges River Basin in India reported that the high concentration of N and P in water bodies is associated with agriculture production (Wang et al., 2021). High nitrate content in drinking water increases the risk of cancer, and water pollution results in a high cancer mortality rate in China (Zhou et al., 2014; Wang et al., 2021). The damage to water due to high concentrations of hazardous and toxic substances is always tricky to undo (Zhou et al., 2014). NPSP and nutrient loss are significant issues disturbing water ecology and human health that must be addressed (Table 1).

4. Application of riparian buffer zone in water quality and agricultural non-point source pollution

The riparian buffer zone effectively protects the aquatic ecosystem from NPS pollutants. The pollutants are transformed following various purification processes such as precipitation, adsorption, volatilization, filtration, microbial processes, and plant uptake. It is inexpensive and requires little maintenance; therefore, enhancing its purification performance is a serious and attractive concern (He et al., 2020). Previous literature demonstrated that various factors significantly impact the efficiency of the riparian buffer zone, including the composition and configuration of land cover and land use regarding water environment quality. The width of a riparian buffer zone is positively related to its efficiency in improving water quality and protecting the aquatic environment (Wang et al., 2020).

Riparian buffer zone acting as a vegetative cover adjacent to water channels positively contributes to pollutant filtration and sediment trapping. Moreover, the buffer zone between agricultural land and water can act as a natural barrier in protecting the ecosystem of agricultural containments (Jaja et al., 2022). To control NPS nitrogen pollution, the commonly proposed ways are: (1) reduce surface runoff and transportation of contaminants (2) increase the distance between cultivation land and water bodies to that increase the retention time of groundwater and allow microbial degradation (3) N uptake. These procedures are temporary and can

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be achieved without regular cleaning and harvesting (Lyu et al., 2021).

The riparian buffer zone can effectively retain nitrogen in surface runoff. Nitrogen retention efficiency depends upon the buffer zone's physical properties, including width, soil texture, slope, and vegetation biomass (Lyu et al., 2021). In addition, the biochemical capacity for N retention, removal, and transfer also depends upon the seasonal variation, design of riparian corridors, and hydrological conductivity (Rai et al., 2022). The high nutrient application increases the risk of high nutrient fluxes in surface water runoff. Therefore, vegetation or planting and harvesting wetland plants can effectively remove excess nutrients from the system (Walton et al., 2020). Moreover, the application of porous concrete in a riparian buffer zone can develop revetment stability, reduce environmental pollution and provide a steady growing platform for plants (Zhang et al., 2022).

A grassed vegetative buffer zone is also helpful in reducing the water flow, ultimately minimizing the NO_3-N losses (Sheng et al., 2021). Moreover, converting pastures to hayfields and rational grazing at the fenced buffer zones are reported to reduce N runoff losses (Pilon et al., 2019). Rural areas that lack wastewater treatment plants can install the limestone-based barrier and riparian buffer zone to reduce ecosystem restoration and P removal from wastewater. It is a cost-effective strategy to improve measures for the reduction of diffuse pollution (Fratczak et al., 2019). The riparian zone also positively influences the aquatic ecosystem by stabilizing streambanks and reducing streambank erosion. Moreover, it filters sediments, nutrients, and toxic substances, thus improving water quality. It also regulates the thermal regime of water and creates a suitable environment for aquatic species. Tree leaves, after decomposition, become food for marine life and provide a habitat for wildlife (Figure 3) (Singh et al., 2021).

Habitat heterogeneity is also an important factor that impacts the biodiversity of agricultural land. The biodiversity of water bodies is directly associated with the type and conditions of vegetation and farming practices in the nearby areas. While riparian buffer zone can improve the habitat heterogeneity of terrestrial species (McCracken et al., 2012). It also creates carbon sources for the community and increases demand for N and P (Stockan et al., 2012). Riparian buffer zone plays key roles in various aspects such as slowing down the water flow and contributing to flooding management, lower water temperature with shades, trees having high transpiration rates causing a cooling effect, providing habitat to animals, and the deep rooting system improving water holding capacity and reduce the water table (Stockan et al., 2012). In addition, it can significantly improve surface hydrologic retention and mitigate downstream nutrient transport (Weigelhofer et al., 2012).

A study conducted at Sulejów Reservoir (Poland) concluded that enhancing a buffer zone comprising a plant riparian land/water ecotone and a limestone-based barrier effectively reduces diffuse pollution and ecosystem restoration. It also has the potential for P removal from contaminated shallow groundwater (Fratczak et al., 2019). Buffer strips significantly have greater P sorption and saturation; even after 57 years, it doesn't get saturated with P exports from adjacent land (Habibiandehkordi et al., 2019). Using wetlands and forests as a buffer zone is recommended to minimize P leaching and equilibrium P concentration (Cao et al., 2019). In addition, Pennsylvania has proposed buffer strips as an effective tool to reduce N (25%) and P (80%) goals and utilize the benefits of forest and grass buffers (Jiang et al., 2020). However, the benefits of the buffer zone are not limited to NPSP as it also improves biodiversity, conserves water and soil, controls erosion, and adds aesthetic value (Yi et al., 2021).

5. Vegetative structure of riparian buffer zone and its effectiveness

Riparian buffer zone or vegetative filter strips can be classified into shrub filters and tree or grass filter belts and are composed of stripes with more than two types of vegetation (Yi et al., 2021). Apart from physical properties, slope, and width, the plant community's structure also impacts the riparian buffer zone's effectiveness and performance. A study demonstrated that the woody riparian buffer zone could trap 86.1% nitrate, while the grassy buffer zone traps 68.1% nitrate (Prosser et al., 2020). The foundation species of the riparian buffer zone also depends upon the vegetation, such as wooded zones that give more suitable living conditions to fish communities than the open canopy (Rai et al., 2022). Moreover, the plant community type also impacts the buffer zone's ability to retain pesticides through better infiltration (Prosser et al., 2020). In contrast, atrazine (herbicide) runoff was significantly minimized with grass hedges in northern China under a slope gradient (Wang et al., 2018a).

The selection of appropriate plant species is also essential to minimize nutrient losses and improve nutrient efficiency. The ability of plants to immobilize P in soil is a critical factor in determining P leaching (Roberts et al., 2020). Vegetation condition, including collocation methods, vegetation type, growth period, and stage, also influences the vegetation characteristics, its impact on soil properties, and its efficiency in removing pollutants from the buffer zone. Therefore, it is important to choose suitable plant species targeting the pollutant and improve the efficiency of the buffer zone (Sheng et al., 2021). Moreover, grass buffer strips provide a protective barrier for the crop against wind impacts, conserve water, and increase agrobiodiversity (Musfiq-Us-Salehin et al., 2020).

Management strategies are also required besides the significance of vegetated buffer strips. Studies also reported that buffer strips containing vetiver grass and plant species create resistance to climatic conditions, improve soil and water conversation, and control runoff losses. Furthermore, plants' periodic cutting should be adopted because they are also a source of nutrients and sediments (Saleh et al., 2018). Harvestable vegetated strips release P into the subsoil surface in winter, leading to P losses through runoff or leaching. Thus it is recommended to harvest vegetation in cold climates (Kieta et al., 2022). A meta-analysis reported that buffer zones have the potential to reduce NO_3-N losses in surface runoff (30%) as well as groundwater (70%). Moreover, the N concentration is directly related to N retention and the width of the buffer zone revealed no impact on N retention (Valkama et al., 2019). Another meta-analysis studied the surface runoff in Chinese farmlands and reported that N losses are correlated with the N fertilizer type and rate and precipitation rate. Moreover, fertilization increases N losses from 3.3 to 10.0 kg ha^{-1} in paddy fields and from 3.0 to 11.2 kg ha^{-1} in upland fields respectively (Hou et al., 2021).

6. Mechanism of the riparian buffer zone

The efficiency of buffer zones depends upon various factors, including width, plant community, density, soil parameters, nutrients and chemicals input, topography, and soil properties. Therefore, the mechanism behind the ability of the riparian buffer zone to eliminate pollutants is complicated. Nitrogen-based pollutant purification depends upon microorganisms that convert it into plant-available forms of N through nitrification and denitrification. Afterward, plants absorb ammonia and nitrate N obtained from pollutants. Similarly, plants and microbes absorb and assimilate P in the buffer zone's runoff. Plant root secretion also affects enzyme degradation (Yi et al., 2021).

Buffer strips also stabilize stream banks and act as a barrier for sediment transport from fields to water bodies, thus mitigating the disturbance of the aquatic ecosystem. In addition, buffer zones also provide wildlife shelter, increase biodiversity, and protect native plant species (Prosser et al., 2020). The buffers containing enriched organic deposits showed that denitrification is the dominant mechanism in nitrate removal in groundwater (Hill, 2019). Furthermore, it has also been reported that the efficiency of a buffer zone to improve nutrient use efficiency significantly influenced the nutrient level of the water column in the adjacent aquatic ecosystem, especially in littoral zones. However, nutrient removal efficiency depends upon the planting community and physiochemical properties of the riparian buffer zone. The diverse buffer zones are more capable of capturing more nutrients than the signal type of vegetation (Cao et al., 2018).

The efficiency of the buffer zone also depends on the soil infiltration rate related to soil organic matter, plant roots, and soil physical properties. A high penetration rate will result in low surface runoff, and nutrients will be trapped by the soil particles and plant roots and transformed by the processes such as nitrification, soil adsorption, vegetation assimilation, denitrification, and microbial immobilization. Moreover, a smaller slope reduces the runoff velocity and ultimately increases the infiltration and nutrient removal (Cai et al., 2022). Riparian woody vegetation influences the riparian microclimate maintains a cool temperature and provides shelter against predators, thus creating suitable habitats for insects and invertebrates, leading to improved biodiversity (Forio et al., 2020).

7. Future research directions

The literature regarding the distribution of pollutants between riparian zones and river quality is limited; therefore, scientists need to address the influence of and mechanism behind contaminant distribution in riparian zones and hydrological characteristics in nearby water bodies. Moreover, the restoration and management of buffer zone, improving their ability for a long duration, and their response to climate changes are also open challenges. The knowledge about the interaction and role of soil properties, texture, and land management is also limited.

In addition, a riparian buffer zone cannot filter the water if it does not flow over the soil surface. Therefore, the runoff water flowing rapidly, or water passing through ditches can reduce the ability of the buffer to filter. In such cases, it needs to identify what soil type, vegetation, and management practices need to be introduced. Furthermore, the long-term influence of the riparian buffer zone and specific vegetation on aquatic habitat, biodiversity, and river management strategies are essential. To improve the water quality and achieve the benefits of riparian buffer zones, it is crucial to educate the residential and agricultural landowners and support them in implementing buffer zones. However, the conservation management strategy might not be their concern, but adding aesthetic value (watching natural beauty, enjoying biodiversity, fish catching) to their property can be helpful.

8. Conclusion

The riparian buffer zone is an effective conservation management strategy to reduce NPSP and improve water quality. A healthy buffer zone having vast and dense vegetation with restricted anthropogenic activities can act as a natural barrier for water bodies. Riparian buffer zones have also been identified as climate adaptation tools. It has the potential to reduce the water temperature due to the shading effect and sustain water habitat by maintaining the survival and reproduction of species even as climate changes. The temporal climate impact of the riparian system is still a research gap. The effectiveness of a buffer zone depends upon several factors, including vegetation type, width, slope, stream size, landform, soil properties, management practices, soil microbial activities, and contaminants. Due to numerous factors, the mechanism behind the effectiveness of the buffer zone is complicated. Further studies on the long-term influence of the riparian buffer zone on trapping NPS pollutant and modifying it into useful nutrients needs to be studied. However, the change in soil properties and groundwater quality of riparian zone requires attention.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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