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Review

The Use of Constructed Wetland for Mitigating Nitrogen and Phosphorus from Agricultural Runoff: A Review

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Citation: Li, J.; Zheng, B.; Chen, X.; Li, Z.; Xia, Q.; Wang, H.; Yang, Y.; Zhou, Y.; Yang, H. The Use of Constructed Wetland for Mitigating Nitrogen and Phosphorus from Agricultural Runoff: A Review. *Water* **2021**, *13*, 476. https://doi.org/10.3390/w13040476

Academic Editor: Christos S. Akratos

Received: 22 January 2021
Accepted: 9 February 2021
Published: 12 February 2021

Abstract: The loss of nitrogen and phosphate fertilizers in agricultural runoff is a global environmental problem, attracting worldwide attention. In the last decades, the constructed wetland has been increasingly used for mitigating the loss of nitrogen and phosphate from agricultural runoff, while the substrate, plants, and wetland structure design remain far from clearly understood. In this paper, the optimum substrates and plant species were identified by reviewing their treatment capacity from the related studies. Specifically, the top three suitable substrates are gravel, zeolite, and slag. In terms of the plant species, emergent plants are the most widely used in the constructed wetlands. *Eleocharis dulcis*, *Typha orientalis*, and *Scirpus validus* are the top three optimum emergent plant species. Submerged plants (*Hydrilla verticillata*, *Ceratophyllum demersum*, and *Vallisneria natans*), free-floating plants (*Eichhornia crassipes* and *Lemna minor*), and floating-leaved plants (*Nymphaea tetragona* and *Trapa bispinosa*) are also promoted. Moreover, the site selection methods for constructed wetland were put forward. Because the existing research results have not reached an agreement on the controversial issue, more studies are still needed to draw a clear conclusion of effective structure design of constructed wetlands. This review has provided some recommendations for substrate, plant species, and site selections for the constructed wetlands to reduce nutrients from agricultural runoff.

Keywords: substrates; plants; site selection; construction

1. Nitrogen and Phosphorus in Agricultural Runoff

Nitrogen (N) and phosphorus (P) are the main pollutants in agricultural runoff, contributing to the diffused pollution. Hazards caused by N and P residues in agricultural runoff have posed serious threats to the sustainable development of many countries, particularly the developing countries [1,2]. Excessive N and P from agricultural runoff can pollute the environment [3,4], cause algae bloom [5,6], disturb fisheries and tourism [7–9], and threaten water safety [10–12].

It is very challenging to consistently reduce the use of N and P fertilizers to protect the agroecosystems [13,14] because world grain production still largely depends on N and P fertilizers [15,16]. Farmers often overuse fertilizers to pursue high crop yield [17,18].

Therefore, fertilizer use has been increasing continuously at a growth rate of around 5% per year [19]. However, only 30–35% of N and 10–20% of P are absorbed by crops, and the majorities are lost along with the agricultural runoff, exacerbating the diffused pollution [20]. Currently, excessive N and P retention in the aquatic environment has become a worldwide environmental problem [21], and it is vital and urgent to find an effective solution to mitigate N and P from agricultural runoff.

Some countries have started to take some measures to limit the total consumption of chemical fertilizers to mitigate the environmental damages [22,23], but pollution from overuse fertilizers has been a chronic problem [24]. Because of the characteristics of diffusion, N and P in agricultural runoff need to be treated in large areas and specific locations [25]. Ecological engineering is one of the main approaches to control agricultural diffused pollution, including source control and process weakening [26]. Compared with source control, process weakening is a more widely used methodology. Process weakening refers to the process of intercepting pollutants and recycling by constructing ecological facilities. Constructed wetland is one of the widely used approaches for process weakening. Therefore, it is of great significance to review comprehensively the documents related to the removal of N and P using the constructed wetland.

The main aims of this review are to (i) identify the optimum substrates and plant species of constructed wetland for mitigating N and P from agricultural runoff, (ii) elucidate the site selection of constructed wetland based on Geographic Information System (GIS) technology, and (iii) sort out the relations of wetland constructional structure and the mitigating performances of N and P in agricultural runoff. In addition to the perspectives of economic feasibility, regional suitability, and environmental sustainability, this article reviewed the substrates and plant performances, technical methods of site selection, and structural designs to mitigate N and P from agricultural runoff. The abstract picture of the review is shown in Figure 1.

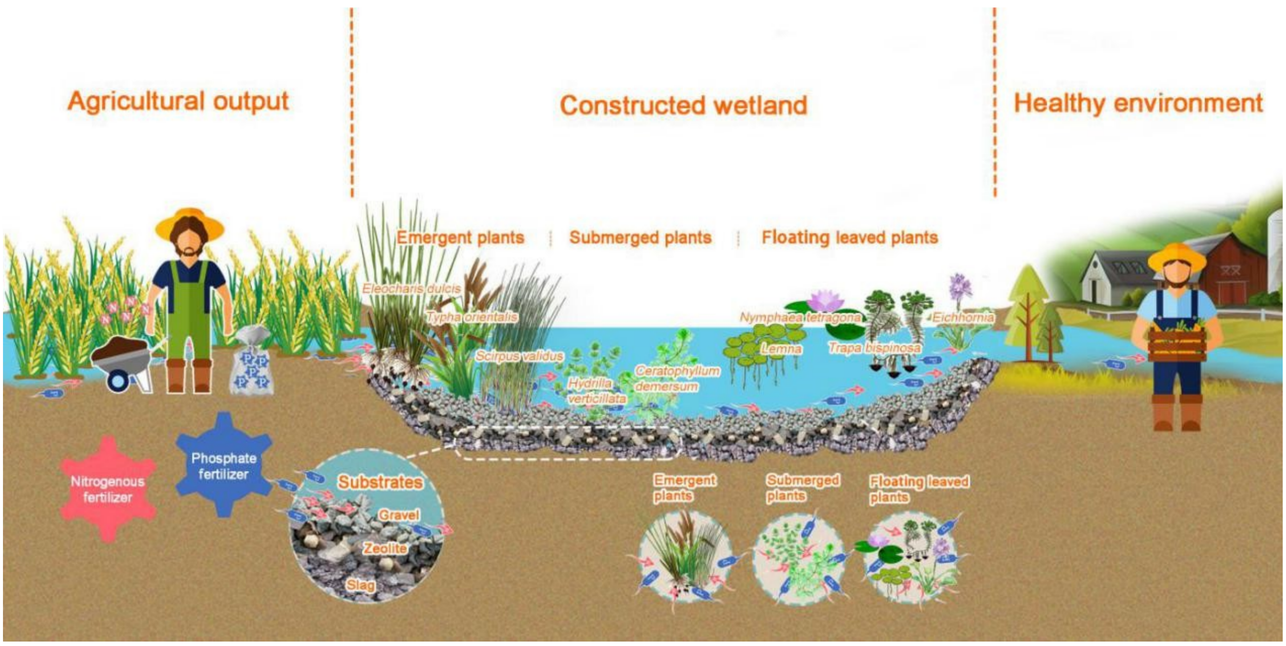

Figure 1. Graphical abstract of constructed wetland mitigating N and P from agricultural runoff.

2. Optimum Substrates and Plants of Constructed Wetland to Mitigate Nitrogen and Phosphorus

Constructed wetland is an artificial coordinated system composed of substrate, plant, microorganism, and soil [27]. In the last decade, it has played an increasingly important role in the treatment of urban domestic sewage, industrial sewage, and agricultural wastewater [28–30]. In general, constructed wetlands can be divided into three types—surface flow, subsurface flow, and vertical flow constructed wetlands [28,31]. Purification capacities of different types of constructed wetland vary greatly, especially for the specific pollutants. Pollutant removal by the constructed wetland involves several processes, including sedimentation, photolysis, hydrolysis, microbial degradation, adsorption, degradation, and plant uptake. However, it is difficult to separate the individual process clearly because it is a complex process [32] and also due to its interactions with other pollutants [33].

In terms of N and P removal, N removal is related to the processes of ammonification, nitrification, plant absorption, and ammonia adsorption [34], and P removal is achieved through the combination of substrates, plants, and microorganisms [28]. For the ecological benefits of constructed wetlands, scholars have conducted many studies, but most studies are theoretical studies at the laboratory, posing a shortcoming in the practical application.

2.1. Substrates' Identification for Mitigating Nitrogen and Phosphorus from Agricultural Runoff

Substrate plays an important role in the mitigation of N and P. The commonly used substrates are generally divided into three types—natural materials, industrial by-products, and manufactured products.

Various substrates have been used in the constructed wetlands, including gravel, clay, marble, bentonite, limestone, shale, wollastonite, zeolite, sand, calcite, vermiculite, dolomite, shell, peat, maerl, activated carbon, compost, ceramsite, lightweight aggregate, calcium silicate hydrate, coal cinder, fly ash, slag, hollow brick crumbs, wollastonite tailing, alum sludge, Moleanos limestone, oil palm shell, and others. Table 1 summarizes the characteristics, including both advantages and disadvantages, of ever-used substrates.

Table 1. Characteristics of substrates used in the constructed wetland.

Type of substrates	Characteristics	References
Natural material		
Gravel	Widespread and common; good adsorption; low cost; phosphorus and nitrate removal is not good.	[35]
Clay	Plentiful and cheap; excellent effect, green environmental protection; high adsorption of organic compounds; low removal rate of COD, NH_3-N, and TN.	[36]
Marble	High removal ability of phosphorus and ammonia nitrogen; economic accessibility; susceptible to weathering and dissolution.	[37]
Bentonite	Natural adsorbents with strong adsorption capacity; good coordination with the environment.	[38]
Shale	High removal ability of phosphorus and ammonia; good overall performance; derived from the lower limestone group of the Carboniferous system; high content of acid; higher specific surface area.	[39]
Apatite material	Lasting effect on the adoption of P; high economic cost of quality apatite.	[40]
Zeolite	High displacement ability to target ions; high porosity; high surface ratio; provide the environment for wetland system microorganisms; super to gravel in removing biodegradable-organics and nitrides; environmental damage caused by zeolite mining.	[41]
Sand	Widely distributed; low adsorption capacity and weak cation exchange capacity.	[42]
Calcite	Efficient removal of phosphorus and ammonium nitrogen; inefficient removal of nitrate.	[43]
Vermiculite	Good adsorption and ion exchange performance; selective adsorption for ammonia nitrogen; high ammonia nitrogen saturation adsorption capacity; low price.	[44]
Dolomite	Composed of calcium carbonate and magnesium carbonate; high phosphorus removal rate; low adsorption capacity and cation exchange capacity.	[45]
Shell	A sea-culture by-product or agriculture by-product; waste reuse; good adsorption capacity of P and N.	[46]
Bauxite	Excellent source of Al and Fe oxides; strong p-combining ability; high efficient adsorption capacity for toxic metals; high alkalinity treated water.	[47]
Rice straw	Agricultural waste; carbon source removal of nitrogen compounds; low cost; no secondary pollution; availability limited to harvest time.	[48]
Peat	Complex material composition; large amount; strong phosphorus adsorption capacity; lack of research on species.	[49]

Table 1. *Cont.*

Type of substrates	Characteristics	References
Artificial products		
Activated carbon	Environmentally friendly; high cost and low adsorbing effect; complex production process.	[50]
Biochar	Wide source of raw materials; realize recycling; high porosity, high CES, and high surface area ratio; high efficiency of organic matter and nutrient removal; emission reduction N_2O; high energy consumption of pyrolysis.	[51]
Compost	Low investment; simple technology; recycling of resources; not environmental-friendly.	[52]
Ceramsite	Made of coal fly ash, sediment, etc., with drying and heating; high mechanical strength and developed microporous structures; re-utilization of waste; efficient in N and P removal; high preparation cost.	[48]
Lightweight aggregate	Hydraulic performance; light and handy; high cost; low intensity.	[53]
Calcium silicate hydrate	Porous; Large specific surface area; strong surface activity; lightweight; poor compatibility with organic polymers.	[54]
Polyethylene plastic	High porosity; no in-depth study.	[55]
Industrial by-product		
Fly ash	Solid waste discharged from coal-fired boilers such as coal-fired power plants; plentiful and cheap; large specific surface area; high activation energy, abundant pore structure, and strong adsorption; not environmental-friendly.	[56]
Slag	Made from smelting industry waste; low cost; abundant raw material; recycling waste; high P adsorption capacity of arc furnace steel slag; different physicochemical properties of different slags.	[57]
Hollow brick crumbs	Active nitrogen and phosphorus adsorb abilities; construction waste; utilization of waste.	[50]
Wollastonite tailing	Efficient phosphorus removal; general adsorbability.	[58]
Alum sludge	A waste of waterworks; abundant; waste reuse; high transportation cost; high efficiency of phosphorus removal; low efficiency of nitrogen removal.	[59]
Moleanos limestone	Low cost and good usability; good performance in phosphorus removal.	[60]
Wood mulch	By-products of wood industry; waste reuse; abundant; Organic carbon source of heterotrophic denitrification; Strong ability to remove nitrogen compounds; no practical application.	[61]
Anthracite	High-density coal; long-lasting and efficient phosphorus removal effect; mining anthracite destroying the environment.	[62]
Calcite	Crushed stone and brick mixed; good for the growth of plants and microorganisms; ability to absorb phosphorus; facilitate microorganisms and plant growth; effective in P adsorption.	[63]
PHBV and PLA blend	A polymer biodegraded by microorganisms; improving nitrogen removal ability as a carbon source.	[64]
Red mud	A waste of aluminum industry; abundant; cheap; reuses waste; strong alkalinity; having ability to remove phosphorus.	[65]

For the selection of substrates used in the constructed wetland, cost and availability of raw materials should be given priority, especially in economically deprived areas [66]. Considering the cost and availability of raw materials, gravel, bentonite, shale, zeolite, sand, shell, rice straw, fly ash, hollow brick crumbs, and slag are suitable for mitigating N and P in agricultural runoff. To select the substrates with low cost and wide availability, the N and P removal capacities of 10 substrates were reviewed in detail.

Gravel is a commonly used filler substrate, with physical adsorption to achieve pollutant removal [67]. By artificial aeration, the constructed wetland with gravel can remove 58% of total nitrogen (TN) [67]. As a wetland substrate, bentonite can remove 66% of total phosphorus (TP) [68], showing good application prospects. In two constructed wetlands with shale as substrate and reed as plant, around 98–100% of P was removed in 10-month cycling time [69]. In the constructed wetland with reeds as the plant, ammonia–nitrogen was removed nearly entirely; in the constructed wetland without reeds, the removal rate was only 40–75% [69]. The zeolite, a natural ore, has a large adsorption rate for N and P due to its internal composition and spatial structure [70]. Specifically, zeolite-filters can enhance the removal ability of constructed wetland, with the removal percentages of organic matter, N and P being 95%, 80%, and 70%, respectively [71]. When the zeolite was used as the hybrid substrate, the removal rate of TN reached 80.3–92.1% [72]. In constructed wetland with tall sheep grass as the plant, sand-soil was better than coarse sand soil in removing N [73]. In the wetland with sand as substrate, the removal capacity of P was 42~91% [74]. Shells from both aquaculture and agriculture were proved to be effective removal of N and P [46]. For instance, palm kernel shells were effective in improving the N removal efficiency in constructed wetlands, compared with the counterpart with sand as the substrate [75]. Rice straw is also an effective material to remove nitrogenous compounds. In the floating constructed wetlands with rice straw as the substrate, the average removal rates of TN, ammonium nitrogen (NH_4^+-N), and nitrate–nitrogen (NO_3^--N) were 78.2%, 81.2%, 62.1%, respectively [48]. Hollow brick crumbs and fly ash are also superior in the removal of TN and TP. The constructed wetland with hollow brick crumbs mixed with fly ash can cut down 89% of NH_{4+}-N and 81% of TP [28,76]. Slag was effective for the treatment of wastewater in constructed wetlands, and the removal rate of P was maintained at a high level [57,77,78]. Slag was 20% higher than gravel in respect of adsorption capacity of TP and the experiments witnessed a quick absorption saturation of TP by slag. A two-year experiment indicates similar N removal rates for slag and gravel [79].

The above review indicates that some substrates have been examined in the field, while others remain theoretical tests in the laboratory. The combination of substrates can enhance the removal performance of N and P. Considering the removal performance, availability, cost, toxicity, and recyclability [80], the top three optimum substrates for mitigating N and P from agricultural runoff are gravel, zeolite and, slag (including coal slag).

2.2. Plants Identification for Mitigating Nitrogen and Phosphorus from Agricultural Runoff

The plants commonly used in constructed wetlands can be divided into emergent plants, submerged plants, and free-floating plants [28]. More than 150 kinds of macrophytes have been used in constructed wetlands, but a systematic study in the field is still lacking [81]. Emergent plants have been identified as the most widely used plants in constructed wetlands [81] to treat agricultural runoff [82]. The plant species in wetlands play an important role in purifying agricultural runoff, which has been investigated in many countries, including China, Australia, Finland, Ireland, Italy, Korea, Norway, Singapore, Poland, Spain, Sweden, Ukraine, UK, and the USA (Table 2).

Table 2. Constructed wetland plants for the purification of N and P from agricultural runoff.

Vegetation	Country	References
Phragmites sp. *(australis)*	Australia, China, Poland, Spain, UK, Ukraine, France, Slovenia	[83–88]
Phragmites sp. *(japonica)*	Korea	[89]
Phragmites sp. *(karka)*	Singapore	[90]
Scirpus sp. *(californicus)*	USA	[91]
Scirpus sp. *(bulrush)*	USA	[91]
Scirpus sp. *(validus)*	Australia	[84]
Scirpus sp. *(sylvaticus)*	Finland	[92]
Scirpus sp. *(mucronatus)*	Singapore	[90]

Table 2. *Cont.*

Vegetation	Country	References
Typha sp. *(latifolia)*	Finland, Norway, Poland, Sweden, UK, USA, France	[86–88,92–95]
Typha domingensis	USA	[91]
Typha sp. *(Cattail)*	USA	[91]
Typha sp. *(angustifolia)*	Singapore, Korea	[89,90]
Iris sp. *(pseudacorus)*	Finland, Norway, UK	[88,92,93]
Phalaris sp. *(arundinaces)*	Finland, Norway	[92,93]
Alisma sp. *(plantago-aquatica)*	Finland	[92]
Filipendula sp. *(ulmaria)*	Finland	[92]
Juncus sp. *(conglomeratus)*	Finland	[92]
Carex sp. *(riparia)*	UK	[88]
Juncus sp. *(effuses)*	Korea	[89]
Miscanthus sp. *(sinensis)*	Korea	[89]
Eleocharis sp. *(dulcis)*	Singapore	[90]
Lepironia sp. *(articulate)*	Singapore	[90]
Sparganium sp. *(erectum)*	Norway, UK	[88,93]
Zizania sp. *(caduciflora)*	China, Korea	[85,89]
Glyceria maxima	Poland	[87]
Typha orientalis	China, Korea	[85,89]
Cyperus malaccensis	China	[85]
Juncus effusus	Korea	[89]

Table 2 indicates that *Typha* spp., *Phragmites* spp. and *Scirpus* spp. are the most frequently used plants in the purification of agricultural runoff. Similarly, Vymazal et al. [96] found that *Phragmites* spp. (*Poaceae*), *Scirpus* spp. (*Cyperaceae*), *Typha* spp. (*Typhaceae*), *Juncus* spp. (*Juncaceae*), *Iris* spp. (*Iridaceae*), and *Eleocharis* spp. (*Spikerush*) are the most commonly used emergent plants in constructed wetlands. Compared with submerged plants and floating plants, emergent plants are more frequently used in constructed wetlands [81]. Hence, priority was given to the review of emergent plants for mitigating N and P in constructed wetlands.

The wetland planted with *Phragmites australis* can remove 60.74% TN, 93.07% NH_4-N, and 47.76% TP in an overall hydraulic residence time of four months [97]. Wetlands planted with *Phragmites* sp. and *Typha* sp. can remove TN by 79% and 77%, PO_4-P by 21% and 14%, within the overall hydraulic residence periods of 21 h and 27 h, respectively [98]. Similarly, *Typha angustifolia* was investigated in a pilot-scale constructed wetland, removing 80% NH_4^+-N and 40% NO_3^--N [99]. In the wetland planted with *Typha orientalis*, the TN, NH_4-N, and TP removal efficiencies were 60.94%, 88.27%, and 63.21%, respectively, in an overall hydraulic residence time of four months [97]. Comparatively, the NO_3^--N, NH_4^+-N, and P removal efficiencies of *Scirpus grossus* and *Typha angustifolia* were 52.1%, 59.4%, and 11.2%, and 51.6%, 56.5%, and 9.1%, respectively [100]. The wetland planted with *Scirpus mucronatus* witnessed the obvious reductions of TN (66.86%), NH_4-N (89.35%), and TP (66.53%) in an overall hydraulic residence time of four months [97]. Similarly, remediation efficiency of *Juncus effuses* was examined, showing that *Juncus* plants fixed N and P around 28.5 g/m^2 and 1.69 g/m^2 [101]. Moreover, storm-water experienced a constant decline in TN (15.7%) and TP (47.7%) after 13 months of reaction in *Juncus effuses* planted wetlands [102]. Wetlands planted with *Iris pseudacorus* testified drops of TN, NH_4-N, and TP by 39.47%, 84.65%, and 26.28%, respectively, after an overall hydraulic residence time of four months [97]. Likewise, *Eleocharis dulcis* also showed the removal of TN and TP by 64.4% and 24.4%, respectively [103]. Apart from the most common emergent plants reviewed above, researchers also recommended *Eleocharis dulcis*, *Typha angustifolia*, and *Scirpus mucronatus* as the optimum plant species in surface flow wetlands [103].

In addition to single plant species, the combination of different plant species, substrate, climate, and management of constructed wetland all can affect the performance of N and P removals [104]. For example, the combination of *Typha* spp. with *Phragmites* spp. witnessed a gradual increase in the removal efficiency of nutrients such as N and P in constructed wetlands, which confirms the enhanced purification capacity by the combined plants [105]. The combination of plants with substrates can also improve the removal efficiency. *Iris pseudacorus* planted wetlands with fine gravel removed 49.4% TN and those with coarse gravel removed 31.4% TN, while unplanted wetlands were less (43.4% and 26.8%) [106].

Some researchers have compared the removal efficiencies of N and P between different species in the same conditions. For example, Sim et al. [103] ranked four common emergent plant species on the P removal (*Eleocharis dulcis* > *Scirpus mucronatus* > *Typha angustifolia* > *Phragmites karka)* and TN removal (*Eleocharis dulcis* > *Typha angustifolia* > *Scirpus mucronatus* > *Phragmites karka)*. In addition, Wu et al. [97] compared the removal efficiencies of TN, NH_4^+-N, and TP by *Typha orientalis*, *Iris pseudacorus, Phragmites australis*, and *Scirpus validus*. The four plants demonstrated the order of TP removal abilities (*Typha orientalis* > *Scirpus validus* > *Phragmites australis* > *Iris pseudacorus*).

By reviewing the above comparative studies, these commonly used emergent plants can be ranked on the mitigation of N and P in the following order: *Eleocharis dulcis* > *Typha orientalis* > *Scirpus validus* > *Phragmites australis* > *Iris pseudacorus*.

Compared with emergent plants, submerged plants and floating plants are less prominent in the constructed wetland. Among the submerged plants, *Ceratophyllum demersum*, *Hydrilla verticillata*, *Myriophyllum verticillatum*, *Vallisneria natans*, and *Potamogeton crispus* are commonly used in constructed wetland [28]. *Ceratophyllum demersum* played an important role in the removal of TN and TP, with 27.5% and 86.19%, respectively [107]. *Hydrilla verticillata* dominated constructed wetland experienced a fall in TP concentration from 126 μg/L to 106 μg/L [108]. *Myriophyllum verticillatum*, a plant in surface flow constructed wetlands, displayed the outstanding removal ability of TP by roughly 70.1% [77]. *Potamogeton Crispus* with *Hydrilla verticillata* in the wetland can remove organic N and organic P by 81.28% and 83.54%, respectively [109]. Despite no study stating clearly the purification capacity of *Vallisneria natans*, it was verified that P absorption by *Vallisneria natans* can be promoted by organic acids [110]. Some studies have compared the N and P removal performance of different submerged plants in the same conditions. The highest removal efficiency of N and P occurred in *Hydrilla verticillata*, followed by *Ceratophyllum demersum*, *Vallisneria natans*, *Myriophyllum spicatum*, and *Potamogeton maackianus*, in laboratory simulated hydrostatic conditions [111]. Therefore, the top optimum three submerged plants in the constructed wetland are *Hydrilla verticillata*, *Ceratophyllum demersum*, and *Vallisneria natans*.

Different from emergent plant and submerged plants, floating plants are divided into free-floating species and floating-leaved species. The commonly used free-floating plants in constructed wetlands include *Lemna minor, Eichhornia crassipes, Salvinia natans*, and *Hyrocharis dubia.* Meanwhile, floating-leaved species in constructed wetlands are mainly *Nymphoides peltata, Trapa bispinosa*, *Nymphaea tetragona, and Marsilea quadrifolia* [28].

Applying *Lemna minor* in constructed wetlands, the removal rates of TN and TP exceeded 50% and 90% [112]. Moreover, *Najas minor*'s removal efficiencies on TN and TP were 55% and 93% [113]. *Eichhornia crassipes* and *Salvinia natans* used for the wastewater treatment can remove 53.0% TN and 56.6% TP [114]. A 100-day reaction indicated that *Eichhornia crassipe* removed 57% TN and 52% TP, while *Hydrocharis dubia* eliminated less (46% TN and 45% TP) [115]. Moreover, *Nymphaea tetragona* [116], *Trapa bispinosa*, and *Marsilea quadrifolia* were used as constructed wetland plants to remove N and P [117]. Some scholars have compared the removal performances of floating plants. For the free-floating plants, the highest N and P removal performances occurred in *Eichhornia, followed by Lemna, Salvinia* [118]. *Eichhornia* is also far superior to *Hydrocharis dubia* in the view of removing N and P [119]. For the floating-leaved plants, Greenway [120] ranked the plants on the N and P removal (*Lemna minor* > *Nymphaea tetragona* > *Nymphoides peltate)*. Moreover, Marion and Paillisson [121] sorted three species on the N and P removal performance in the order: *Nymphaea tetragona* > *Trapa bispinosa* > *Nymphoides peltata*.

Based on the above comparative studies, it can be drawn that *Eichhornia crassipes* and *Lemna minor* are the optimum free-floating plants, and *Nymphaea tetragona and Trapa bispinosa* are the optimum floating-leaved plants for mitigating N and P from agricultural runoff.

Among the aquatic plants mentioned above, emergent plants are most widely used in constructed wetlands [81]. *Phragmites* spp. is the most frequent species in Asia and Europe [82]. *Scirpus* spp., including *lacustris*, *validus*, and *californicus*, are commonly used in North America, New Zealand, and Australia [28]. *Juncus* and *Eleocharis* spp. are utilized commonly in Europe, North America, and Asia [82]. *Iris* spp. is mainly used in tropical and subtropical regions [122].

Overall, to mitigate N and P in the agricultural runoff by constructed wetland, in terms of emergent plants, *Eleocharis dulcis*, *Typha orientalis*, and *Scirpus validus* are the top three optimum species; as regards to submerged plants, *Hydrilla verticillata*, *Ceratophyllum demersum*, and *Vallisneria natans* are advocated; for the free-floating plants, *Eichhornia crassipes*, and *Lemna minor* are appropriate; and regarding the floating-leaved plants, *Nymphaea tetragona* and *Trapa bispinosa* are the promoted species.

3. Site Selection of Constructed Wetland to Mitigate Nitrogen and Phosphorus in Agricultural Runoff

During the process of selecting sites for constructed wetlands, multiple factors should be considered comprehensively, completely, and correctly [123]. From the perspective of practical operation, a series of maps containing the topographic map, geological map, aerial image map, soil survey map, and hydrological map should be compiled for the comprehensive selection of wetland sites [124]. Many studies have demonstrated the importance of climate, rainfall, geography, surface water, soil, biology, and socio-economic factors [125–127].

Natural factors play an important role in the site selection of constructed wetland, especially the elemental items—(i) closing to pollution sources as possible as it can, (ii) minimizing earthwork by maximizing natural slope, and (iii) estimating watershed area to control wastewater retention time. Apart from natural factors, the protection of human and natural resources is an assignable part, requiring keeping away from nature reserves, historical and cultural reserves, archaeological control areas, planned and construction areas, and others. The Geographic Information System (GIS) is one of the important technologies for geographic exploration, which has been widely used in land administration, traffic planning, environmental analysis, and planning [128]. At present, it has been increasingly used in the site selection of public service facilities such as hospitals and schools. Furthermore, GIS combined with remote sensing (RS) has been used to map the isolated wetlands in a karst landscape [129]. Moreover, GIS has been used for site evaluation of constructed wetlands and restored wetlands in the agricultural catchment [130]. Combining the existing research and the characteristics of constructed wetlands, this paper reviewed and sorted out the technical method using GIS for the site selection of constructed wetlands to mitigate N and P from agricultural runoff (Figure 2).

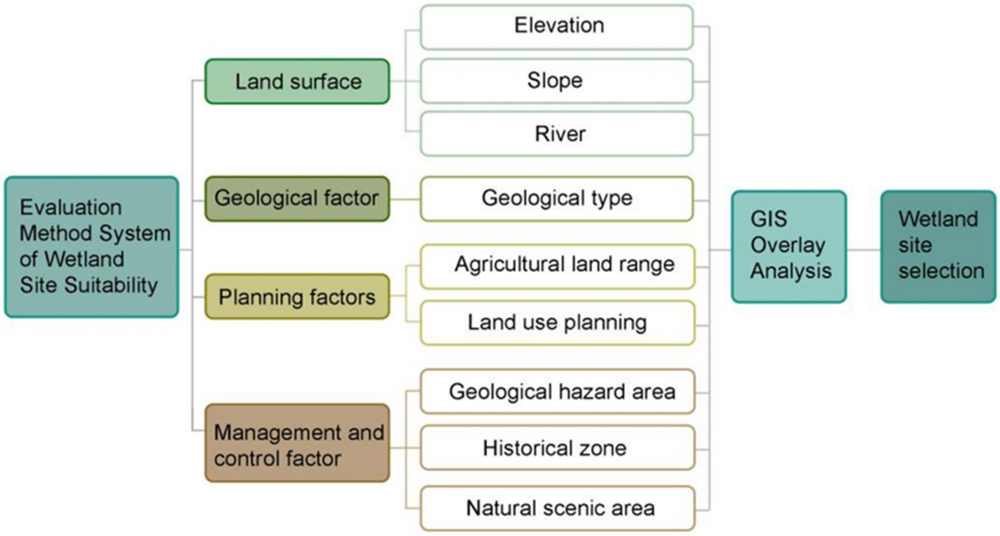

Figure 2. Technical route of constructed wetland site selection using Geographical Information System (GIS).

4. Structural Design of Constructed Wetland to Mitigate Nitrogen and Phosphorus in Agricultural Runoff

The design parameters of constructed wetlands consist of wetland substrate, plants, water depth, aspect ratios, and others [131]. These substantial factors are possibly expressed in various forms, for instance, water depth, hydraulic load and retention time, and feeding mode of the inlet [132].

Fillers play a key role in the construction of wetlands. Various substrates have been elaborated in Section 2.1. When the substrate species were selected, attention will be paid to the particle size of the filler, which has a significant effect on the removal efficiency [133]. The comparison of four types of wetland beds with different particle sizes in the same environmental conditions indicates that the smaller the particle size, the better the P removal efficiency [134]. Specifically, the maximum P adsorption capacities of three filter media with the sizes of 4–10 mm, 2–4 mm, 0.1–2 mm were 7.7 mg/kg, 11.6 mg/kg, and 22.5 mg/kg, respectively, indicating that the adsorption capacity increased with the decrease of media sizes [135].

In addition to particle size, the substrates with additives, for example, iron oxides, iron hydroxides, Lu oxides, Lu hydroxides, and calcium, can increase the P removal efficiency of constructed wetlands [135–137]. The comparison of adding Ca, Mg, Al, and Fe to a filter medium indicated that Ca had the maximum enhancement of nutrient removal [135]. Similarly, a study on the oyster shell as the additive indicated that adding 2% of oyster shell could increase the adsorption capacity of P from 23 mg/kg to 36 mg/kg, and adsorption capacity rose until the oyster shell concentration came over 60% [135].

Plants are an important part of constructed wetlands, and different species have been reviewed in Section 2.2. Notably, priority should be given to local plants to prevent the invasion of alien species [138].

Water depth is an important factor affecting the water load and oxygen permeability [139]. A comparison in the denitrification effects of subsurface flow horizontal wetlands between depths of 0.27 m and 0.50 m indicated that the wetlands at depth of 0.27 m worked better than those of 0.50 m [140].

In addition, the ratio of length to width of wetland bed can affect the removal of N and P [141]. The ratio can affect the linear velocity of water flow, causing head loss [142]. Therefore, the ratio should not be too large. On the other hand, some scholars suggest that the ratio of length to width had a limited effect on N and P removal [140]. However, the existing research related to the ratio of length to width has not yet reached an agreement.

Therefore, the impact of the length-width ratio of constructed wetland on its performance is far from clearly understood and further study is still necessary.

5. Concluding Remarks and Future Outlooks

Constructed wetland plays an irreplaceable role in the mitigation of N and P, especially in the economically deprived areas. Despite many studies on the related topics of constructed wetland, most of the studies only focused on the interaction of a certain substance with the performance of constructed wetland under artificially designed experimental conditions, suggesting the limited practical application of the findings. This review summarized the principles, influencing factors, site selection, and structural design of constructed wetlands in the treatment of N and P from agricultural runoff, which has a strong application.

This review suggests that the top three recommended substrates for mitigating N and P from agricultural runoff are gravel, zeolite, and slag (including coal slag). Emergent plants are the most widely used plants in constructed wetlands, and *Eleocharis dulcis*, *Typha orientalis*, and *Scirpus validus* have better performance in mitigating N and P from agricultural runoff. Similarly, *Hydrilla verticillata*, *Ceratophyllum demersum*, and *Vallisneria natans* are the recommended submerged plants; *Eichhornia crassipes* and *Lemna minor* are the advocated free-floating plants; and *Nymphaea tetragona* and *Trapa bispinosa* are the promoted floating-leaved plants. Moreover, the selection of wetland site was summarized, and the technical route of site selection using GIS was put forward. However, the optimal structure design of constructed wetland has not been obtained, due to the lack of systematic research on the wetland structure design.

Despite the progress of the studies on the constructed wetlands, research gaps still exist in our understanding of constructed wetlands for mitigating N and P in agricultural runoff. In addition, climate change will further influence the N and P diffusion pollution from agricultural runoff [143]. To fill these research gaps, the following issues deserve more attention:

(1) It is important to conduct more comparative studies on substrates' performance under the same external conditions in different climatic regions.
(2) The current plant selection focused on the effects of plant species on the mitigation of N and P, ignoring the complexity of plants' contribution to the performance constructed wetland. It is essential to study the competitive effects between different plant species and the interactions between plants and substrates.
(3) Because the relationship between constructed wetland structure and performance is still debated, more studies on the effect of wetland structure on its performance of removing N and P are largely needed.

Author Contributions: Conceptualization, Y.Z.; methodology, J.L. and B.Z.; validation, Z.L., and H.Y.; formal analysis, J.L. and Q.X.; investigation, H.W.; resources, B.Z.; data curation, B.Z.; writing—original draft preparation, J.L.; writing—review and editing, Y.Y. and H.Y.; visualization, X.C.; supervision, Y.Z.; project administration, B.Z.; funding acquisition, B.Z. and J.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Hunan Provincial Innovation Foundation for Postgraduate, grant number CX20200375; the Fundamental Research Funds for the Central University of Central South University, grant number 2020zzts012; the National Natural Science Foundation of China, grant number 52078484; and the China Scholarship Council. The APC was funded by the Hunan Provincial Innovation Foundation for Postgraduate.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: Thanks are given to Zilong Li for his work in data collection.

Conflicts of Interest: The authors declare no conflict of interest.

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