Environmental Challenges 12 (2023) 100733

Contents lists available at ScienceDirect

Environmental Challenges

journal homepage: www.elsevier.com/locate/envc

Eutrophication: Causes, consequences, physical, chemical and biological techniques for mitigation strategies

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ARTICLE INFO

Keywords:
Eutrophication
Adsorption
Coagulation
Nano-filtration
Phosphate
Nitrate
Biological techniques

ABSTRACT

Eutrophication is reckoned as an ecological challenge that exhibits adverse effects on the aquatic ecosystem as well as the sustenance of portable water required by humans for their unremitting survival on the earth. There has been a range of techniques for the prevention of eutrophication, consequent on the need for the provision of portable water and the protection of water bodies and the aquatic ecosystem. The employment of chemical coagulants such as lime, magnesium sulphate and ferric sulphate has been reported to yield more than 95% removal of nitrate and phosphate. Moreover, adsorption studies revealed that at optimum pH and a contact time of 60 min, glutaraldehyde cross-linked chitosan exhibited the highest adsorption capacity of 139.4 mg/g, compared to epichlorohydrin cross-linked chitosan and unmodified chitosan that exhibited adsorption capacity of 108.24 and 44.38 mg/g respectively for phosphate removal. The use of nano-filtration membrane coupled with bioreactor (NF-MBR) for 62 days at a flux rate of 16 l/m.h and hydraulic retention time of 2.9 h has been posited to display percentage removal of 95, 90, 89, 87 and 68% for COD, N-NH_3, N-NO_2, N-NO_3^- and P-PO_4^{3-} respectively from wastewater. Lastly, biological techniques such as wetland have been posited to be effective in combating eutrophication by exhibiting percentage removal efficiencies of 86–98% (N-NH_4), 99% (N-NO_2), 82–99% (N-NO_3^-), 95–98% (total inorganic nitrogen), 71.2–31.9% (phosphate), 25–55% (COD) and 47–86% (suspended solids). Nevertheless, the success of wetland treatment techniques is slightly impeded by the hydraulic loading rate.

1. Introduction

The word ‘eutrophic’ originates from the Greek word eutrophos which means well-nourished. Eutrophication is described as a condition of an aquatic network with a high level of nutrient concentrations, that include nitrogen and phosphorus which result in algal blooms, thus degrading the water quality in the aquatic ecosystems (Bali and Gueddari, 2019; Sonarghare *et al.*, 2020). Eutrophication is a process of both natural and anthropogenic origin, which has been defined in numerous ways, that ranges from the natural ageing of a water body to a eutrophic status. This takes place over a long geological time, to a quick rise in trophic position of a water body as an outcome of anthropogenic activities, and this is called cultural eutrophication (Sonarghare *et al.*, 2020). Eutrophication is categorized by excessive growth of plants and algae ensuing from increased availability of limiting growth factors (for example sunlight, carbon dioxide, and nutrient fertilizers) required for photosynthesis (Sonarghare *et al.*, 2020; Zhang *et al.*, 2023). Naturally, over centuries, eutrophication occurs as the lake ages and sediment fills in the aquatic system. Yet, the point-source discharges as well as non-point loadings of limiting nutrients that include nitrogen and phosphorus, into aquatic ecosystems by human activities have fast-tracked the rate and magnitude of eutrophication, with disastrous consequences for drinking water sources, aquatic life, in addition to recreational water bodies (Zhang *et al.*, 2023; Knight, 2021).

Thus rendering eutrophication a detrimental factor that results in the pollution of water bodies which threatens the continued existence of aquatic organisms as a result of algae blooms ensuing from the nutrient enrichment of water bodies attributed to the dependence of the human populace on nutrient fertilizers for food production (Carpenter, 2008; Akinnawo, 2021; Zhang, 2022). Portable water resources constitute about 2–3% of natural existing water supplies with an approximated significance of 2.97% of it, available in glaciers and polar ice caps while a protracted sector of 0.3% is accessible as freshwater in lakes, streams and rivers. Eutrophication has also contributed to the diminished access to portable water due to algae blooms-related problems in freshwater lakes, streams, coastal marine and reservoir systems, and this is detrimental to the continuous supply of potable water to the human populace and ecosystem (Akinnawo, 2021; Chang *et al.*, 2022; Hou *et al.*, 2022; Chen, *et al.*, 2022).

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https://doi.org/10.1016/j.envc.2023.100733
Received 5 March 2023; Received in revised form 15 May 2023; Accepted 15 May 2023

Eutrophication, which is caused by nitrate and phosphate runoff from farmlands, effluent from aquaculture ponds as well as municipal and industrial discharge, is a major predicament because of its momentous contributions to the socio-economic and environmental health problems (Carpenter, 2008; Akinnawo, 2021). Moreover, cyanobacterial blooms are amongst the stern consequences of eutrophication that cause the coating of shorelines as well as boat hulls with stinking scum resulting in odour and taste problems in water bodies, thereby rendering it unfit for desirable use due to its potential hazard to wildlife and the human populace (Carpenter, 2008; Chislock *et al.*, 2013; Soon-Jin, 2020; Xu, *et al.*, 2022).

The statistical evidence on the occurrence of eutrophication in different regions of the world has been reported in some scientific findings. For instance, environmental studies conducted in Lake Changhu, in Jingzhou City, Hubei province, China before 2013 and 2015 as well as after 2017 and 2018, have documented higher concentrations of total nitrogen and chlorophylla, in the districts of Lake Haizihu, Ahongtai Channel and Lake Dahu during the year 2017 compared to other years. Further, the Lake Haizihu district reportedly exhibited a higher predicted degree of eutrophication compared to the Lake Haizihu and Ahongtai Channel (X. Li et al., 2021). In addition, mean values of trophic level index (TLI) reportedly ranged from 62.99 to 78.93 in the considered years, and the year 2017 recorded the highest level of eutrophication (Y. Li et al., 2021).

Moreover, in the UK, agricultural run-off and sewage effluent have been recognized as the main sources of phosphorus in freshwater resources with about 70% of eutrophication occurrence being attributed to sewage discharges (Bunce *et al.*, 2018). Furthermore, environmental studies in European countries from the year 2005 to 2012 have revealed that only an estimated 40–60% of nitrate and phosphate in the applied fertilizer was reportedly used up by plants. The percentage leftover is reportedly leached into runoff reaching water bodies, with a 0.26–0.30 TgP/yr phosphate discharge load into European seas (Matei and Racoviteanu, 2021; Pytka-Woszczyło *et al.*, 2022). Further studies in the year 2017, on the level of eutrophication in the Jatiluhur reservoir have reportedly revealed trophic state index (TSI) and trophic index (Trix) levels exceeding 4 and 50 respectively. This indicated the eutrophic-hypertrophic level, characterized by a high level of chlorophyll-a and total phosphorus content of the Jatiluhur reservoir (Astuti *et al.*, 2022).

The scientific findings on eutrophication of moving water resources in the continental US, reported 130 mg m^{-3} concentration of total phosphorus concentration from 381 riverine sites, this exceeded the mesotrophic-eutrophic total phosphorus boundary of 75 mg m^{-3}. Similarly, in the US, it has been established that 61% of 2048 cataloguing units reportedly failed to meet the EPA standard. Also, the concentrations of nutrients occurrence have been recounted to be 60% of nitrogen load from wastewater in New York, Long Island Sound, 25% nitrogen and phosphorus load in Chesapeake Bay as well as 10% of nitrogen and 40% of phosphorus in Mississippi River. This is an indication of poor water quality in the majority of US rivers and streams which are at the standpoint of eutrophication (Smith *et al.*, 1987; Dodds *et al.*, 1998; Rathore *et al.*, 2016; Chapin *et al.*, 1997). In addition, it has been recounted that there has been an increase in the inputs of phosphorus eroding from landscape run-off and human wastewater into the earth's rivers and oceans reaching just about three times higher than the historic levels of ca. 8 million metric tons per year to the present loadings of ca. 22 million metric tons per year (Rathore *et al.*, 2016). The outcome of an environmental monitoring study on the relationship between the occurrence of algal bloom and nutrients ratio has been recounted to reveal a concentration range of 0.01–2.5 μg/L and 0.01–15.89 μg/L respectively for phosphate and nitrate as well as 0.2 - 45.4 for the nutrient ratio of nitrate to phosphate in Jakarta bay as conducted between the years 2008 to 2015 (Sidabutar *et al.*, 2020). It was concluded that there is a strong relationship between nitrate to phosphate nutrient ratio and algal bloom. In addition, it was recounted that the nutrient ratio may be used to control the occurrence of algal bloom in an aquatic ecosystem (Sidabutar *et al.*, 2020).

There have been numerous reports on the occurrence and removal of pollutants such as heavy metals and organic pollutants from the water supply chain with the aid of different techniques due to the negative outcome of these pollutants on the ecosystem (Akinnawo, 2016; S.O. Akinnawo et al., 2016a; Kolawole *et al.*, 2019; Yetunde *et al.*, 2019; S. Akinnawo et al., 2016; K.A. Adegoke et al., 2022a, 2022b; Adegoke *et al.*, 2023; Akinnawo, 2019). In like manner, the investigation of suitable and effective techniques for removing nutrients from wastewater before they are been discharged into the environment is essential. This is significant, in preventing eutrophication which results in the degradation of water quality, extinction of submerged plants, loss of biodiversity in an aquatic ecosystem, increased microbial biomass and productivity, recurrent presence of cyanobacterial blooms, increased level of waterborne diseases and economic loss in aquatic food products and finances (Chislock *et al.*, 2013; Soon-Jin, 2020; Qin *et al.*, 2013; Zeng, et al., 2022; Li *et al.*, 2022). It has been estimated that nitrate and phosphate respectively display a contribution input of 20 to 50% and 35 to 55% to the occurrence of eutrophication of water bodies. These percentage contribution inputs of nitrate and phosphate have been reportedly dominated and resulting from agricultural sources such as effluent from aquaculture and concentrated animal feed operations and run-off of fertilizer applied to farmlands. Therefore it is important to remove nitrate and phosphate from wastewater for the prevention of eutrophication (Zou *et al.*, 2014; Beusen *et al.*, 2016; Dupas *et al.*, 2015; Sui *et al.*, 2022). Furthermore, this is also significant in the recovery of nitrate and especially phosphate, which has been classified as a primary limiting nutrient in global supply. This nutrient can be recovered and engineered into the production of fertilizer and feed required for agriculture farm produce (Walter *et al.*, 2009; Taylor and Robert, 2018; Smith *et al.*, 1999). Nutrient removal which involves the reduction in the concentration of phosphate and nitrate in the wastewater is essential to prevent eutrophication in the receiving water bodies. This has necessitated the need for a recirculation system for the treatment of nutrient-enriched wastewater via feasible and efficient techniques for nitrate and phosphate recovery for fertilizer production and reuse of the treated water (Akinnawo, 2021; Wei *et al.*, 2009; Baker *et al.*, 2015; Penn and Bryant, 2016; Khatum, 2017; Akinnawo, 2018). This review article is aimed at recounting the progress and challenges as well as prospect in the line of nitrate and phosphate recovery as well as treatment of nutrient-enriched wastewater with the sole purpose of mitigating eutrophication.

2. Types, causes and consequences of eutrophication

2.1. Types of eutrophication

2.1.1. Natural eutrophication

Natural eutrophication has been going on for millennia and is acknowledged as the buildup, flow, as well as addition of nutrients to water bodies thus resulting in primary compositional changes in the production and community species (Knight, 2021). The run-off of nutrients in storm water into receiving water bodies such as lakes, estuaries as well as slow-moving streams leads to an increase in the level of nitrate and phosphate in water bodies. Thus enriching young water bodies (usually oligotrophic due to low concentration of nutrients) and old water bodies (usually eutrophic water bodies due to a high concentration of nutrients), resulting in respective low and high levels of biological activity in young and old water bodies (Sonarghare *et al.*, 2020). Some of the naturally occurring water bodies such as lakes lose their self-purification capacity over certain decades. This results in the accumulation of transported large quantities of solid materials in the sediments of these water bodies by flooding and run-off, the consequent ability of these sediments to adsorb large quantities of nitrate and phosphate as well as filling up the basin. Thus creating an interaction between these sediment-containing nutrients and aquatic plants that ease the process of eutrophication which result in further deterioration of water quality, accentuating the processes connected with eutrophication (Sonarghare *et al.*, 2020).

2.1.2. Cultural eutrophication

Cultural eutrophication, which is also called anthropogenic eutrophication, is the occurrence of eutrophication resulting from human activity leading to the run-off of nutrients such as phosphates and nitrate into lakes and rivers as a result of land runoff. Human anthropogenic activities such as the use of fertilizers, and detergents as well as the disposal of untreated sewage and aquaculture effluent have significantly increased the level of nutrient loading into water bodies. These anthropogenic activities continuously increase the level of nutrients (nitrate and phosphate) in the water body to a level that exceeds the self-purifying capacity of these water bodies, consequently leading to cultural eutrophication. Thus, increasing the rate of eutrophication beyond the natural level results in undesirable changes to the natural ecological system (Sonarghare *et al.*, 2020; Knight, 2021).

2.2. Causes of eutrophication

2.2.1. Natural events

The seasonal occurrence of rainfall and storm that result in flooding has been recognized as the key factor that sweeps additional nutrients from the land into the receiving water bodies. In addition, the ageing of lakes results in sediment buildup of organic matter in aquatic systems, thus contributing to a high growth rate of cyanobacteria blooms and phytoplankton (Knight, 2021; Yang, 2022).

2.2.2. Fertilizers (nitrates and phosphates)

The over-dependence of the human populace on nitrate and phosphate fertilizer for agricultural production has resulted in the enrichment of water bodies via the run-off from agricultural farms (Knight, 2021; Zhang, et al., 2022; Yang, 2022). Thereby making humans the most significant cause of eutrophication as a result of the accumulation of nitrate and phosphate resulting from agricultural-related activities carried out by humans. The accumulation of nitrate and phosphate fertilizer in agricultural run-off has reportedly resulted in a dense proliferation of aquatic plants (such as hyacinths) and algal blooms (Knight, 2021; Qi *et al.*, 2022). The transportation of animal feeds and animal dung via run-off from farmland coupled with phosphorus mining as well as the industrial production of nitrate fertilizer has been attributed to the increase in the level of nutrients in water bodies, thus resulting in eutrophication (Sonarghare *et al.*, 2020).

2.2.3. Aquaculture and concentrated feeding operations

The effluent from aquaculture and other concentrated animal feed operations have been noted to contribute to the occurrence of nitrate and phosphate in wastewater discharged into the environment. The nitrate and phosphate content in aquaculture effluent, concentrated animal feed and animal dung applied as organic manure are regarded as the primary source of nutrients that are leached into water bodies through flooding during rainfall (Knight, 2021). The direct discharge of wastewater from the industrial production of concentrated animal feeds cannot be left out in the role they play in contributing to the eutrophication of water bodies and the resultant consequences (Knight, 2021; Yang, 2022).

2.3. Consequences of eutrophication

The consequences of eutrophication have been stated to vary from enhanced growth of aquatic vegetation (phytoplankton such as green algae, diatoms and cyanobacteria, also known as blue-green algae) resulting in algal blooms to the poisoning of water bodies by making them unfit for drinking, recreation activities as well as the sustenance of aquatic life (Costa *et al.*, 2018).

The condition of eutrophication renders water to become cloudy with a colour shade of green that reduces sunlight penetration thus decreasing the rate of photosynthesis of submerged aquatic plants. In addition, the death and decomposition of algae result in a low level of dissolved oxygen, which is required for the sustenance of aquatic life, thus resulting in the death of aquatic species that live below the surface of water bodies (Sonarghare *et al.*, 2020; Rathore *et al.*, 2016; Kim *et al.*, 2020; Hwang, 2020).

The major characteristic of eutrophic water bodies is the swing in the direction of cyanobacteria (blue-green algae) dominance that results in the production of toxins, thus creating a dead zone in an aquatic ecosystem (Rathore *et al.*, 2016). The occurrence of dead zone resulting from the impact of eutrophication (that consists of alga bloom and hypoxia) has been reported to result in the loss of biodiversity of aquatic life. Algal blooms are sometimes referred to as “red or brown tides” depending on the colour of the algae, and the organism responsible for the red tides is called cyanobacteria. Moreover, it has been recounted that cyanobacteria produce harmful substances such as off- flavour and toxins that are potentially hazardous to the health of both humans and wildlife (Sonarghare *et al.*, 2020; Rathore *et al.*, 2016; Park *et al.*, 2020; Hwang, 2020; Le Moal *et al.*, 2019; Wan *et al.*, 2020; Zulkefli *et al.*, 2019). The occurrence of low levels of dissolved oxygen resulting from algal bloom leads to fewer number of fishes, which is a consequential loss of important food sources for mammals (that include sea lions) and wading birds (such as herons), thereby leading to the death of shore birds and marine animals that depends on fish for their survival (Sonarghare *et al.*, 2020; Kim *et al.*, 2020). Furthermore, an overabundance of algae has been reported to choke water bodies by clogging irrigation and water pipes as well as turbine thereby affecting transportation and power generation. In addition, eutrophication restricts sunlight penetration required by other plants such as sea grasses for photosynthesis, thus resulting in an eventual elimination of sea grass bed (Sonarghare *et al.*, 2020; Kim *et al.*, 2020; Almanassra *et al.*, 2021).

Additionally, the accelerated rate of eutrophication of aquatic ecosystems has been connected with the emergence of new diseases through host-pathogen interaction, such as in the case of bacterial flora and saliva that results in converting nitrates to nitrites (Matei and Racoviteanu, 2021; Park *et al.*, 2020; Hwang, 2020; Ajisafe and Akinnawo, 2018). In addition, the occurrence of nitrates in drinking has been reported to form compounds such as nitrosamides and nitrosamine, which have been categorized to be potentially carcinogenic. Similarly, the occurrence of nitrates and nitrites in drinking water has been reported to induce methemoglobinemia that affects children less than one age-old with about a 100% reduction of nitrates to nitrites in infants compared to a 10% reduction in adults. Thus, the occurrence of symptoms that include suffocation, lethargy and blue baby syndrome and in some situations, anoxia and death results when the concentration of methemoglobin attains the range of 5 to 10% (Matei and Racoviteanu, 2021). The dominance of cyanobacteria in freshwater bodies has been attributed to the nitrogen fixation capacity of cyanobacteria when there is a low ratio of nitrogen to phosphorus. Additionally, cyanobacteria have been recounted to produce a high volume of toxins that display adverse effects (such as liver damage, diarrhoea, skin irritation and neurotoxicity) on humans as well as other mammals (Rathore *et al.*, 2016; Usman *et al.*, 2022).

The most commonly recounted cyanobacterial toxin produced by cyanobacteria is hepatotoxin microcystin (MCs), which has been stated to be produced in higher concentration with the tendency to bioaccumulate in aquatic animals (such as fishes) compared to other toxins. The consumption of aquatic animals with certain levels of bioaccumulated MCs poses a great risk to the health of humans due to the movement of the toxin through the food web from lower to higher trophic levels (Usman *et al.*, 2022). Scientific findings have revealed that MCs are highly toxic to organs that include but are not limited to the kidney, heart, gastrointestinal tract, the nervous system as well as gonads of invertebrates. However, the liver is the most important target

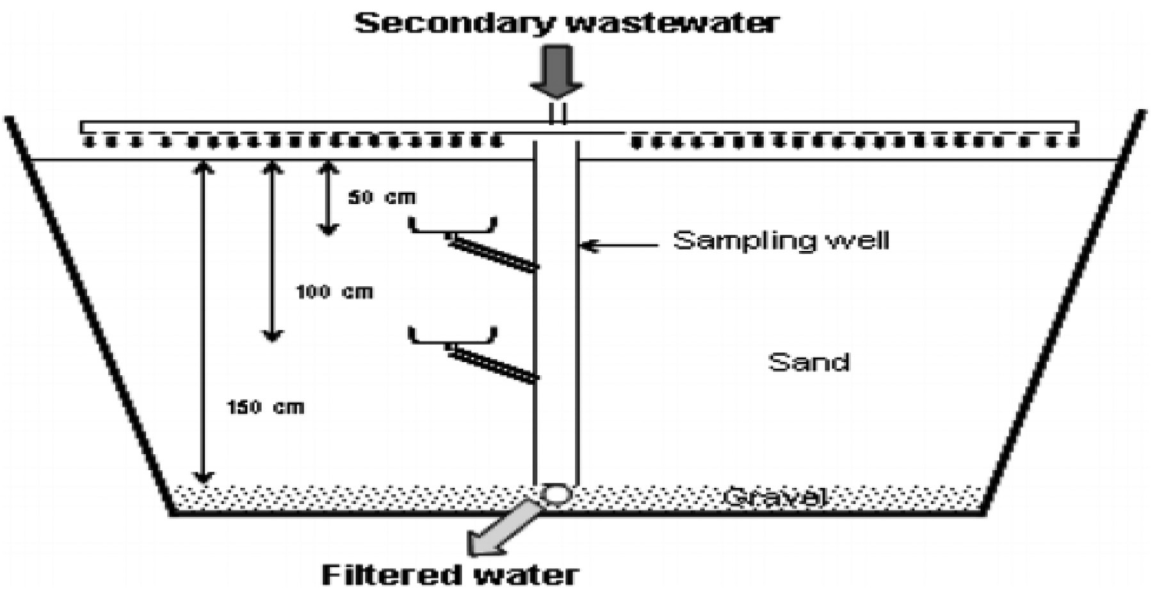

Fig. 1. Schematic diagram of sand filter in Infiltration-percolation technique (Bali and Gueddar, 2019).

of MCs. Moreover, the resistant nature of MCs to oxidation and hydrolysis at neutral pH, in addition to the impact of food cooking processes such as boiling in concentrating MCs has been reported to worsen the environmental and health impact of eutrophication on humans (Usman *et al.*, 2022; Lone *et al.*, 2015). Further, it has been discovered that MCs poses the ability to inhibit the release of inflammatory cytokines effects on the expression of immune-related genes located in the intestine, thereby constituting intestinal damage and inhibiting the secretion of digestive enzymes (Usman *et al.*, 2022; Wu *et al.*, 2019; Kubickova *et al.*, 2019). Lastly, the consumption of water obtained from rivers with high concentrations of MCs has been associated with higher occurrences of colorectal cancer (Koto *et al.*, 2022).

3. Physical, chemical and biological techniques for mitigating eutrophication

3.1. Physical techniques

3.1.1. Dredging and aeration

Dredging is a physical technique employed for controlling eutrophication when there is a high concentration of nutrients ensuing internal recycling. Dredging employs the ultimate excavation and removal of the bottom sediments, which have been highly enriched with nitrates and phosphate thus propagating the growth of algae. However dredging results in deepening a water body, this could alter the nutrient concentration and abiotic system of the water column, thus changing the dynamics of the ecological system (Rathore *et al.*, 2016). Additionally, dredging has been recounted to expose seeds to more ideal conditions thus reestablishing macro-vegetation by creating a photosynthetic competitor for the dominant algae populations (Rathore *et al.*, 2016).

Aeration is a physical technique that is employed to increase the oxygen levels in a pond to lessen the occurrence of stratification. Oxygen is connectively used to control eutrophication by creating an anoxic environment that can release P from the soil to stimulate internal cycling. Consequently, limited internal cycling can be attained by increasing the level of oxygen to abate the rate of eutrophication (Rathore *et al.*, 2016). The method of extended aeration has been reportedly incorporated in a wastewater treatment for the removal of nutrients, the findings revealed 15 and 28% average removal of total phosphorus and orthophosphate in addition to 98% removal of ammonia from wastewater (Sotirakou *et al.*, 1999).

3.1.2. Infiltration-percolation

Infiltration-percolation is a physical technique that can be employed as a tertiary treatment to remove contaminants from secondary wastewater effluent as shown in Fig. 1. An Infiltration-percolation technique employed the use of a filter such as a trapezoidal basin that exhibits a 2.0 m height in addition to having been filled with 30 cm of coarse gravel as well as 1.5 m of sand for the removal of contaminants (Bali and Gueddar, 2019). A report on the removal of orthophosphate from wastewater recounted the utilization of a sand filter that has been incorporated with activated sludge from a treatment plant in a continuous operation mode of a 7-day cycle consisting of a 4-day flooding period and 3-day drying period with daily hydraulic loads of 0.27 and 0.40 m^3/m^2 of the sand basin. The research study revealed an orthophosphate reduction with a removal rate of orthophosphate recorded at 61.4, 71.6 and 77.2% for the daily number of feeding-drainage cycles (Bali and Gueddar, 2019). Furthermore, it was recounted that removal of orthophosphate was highly dependent on both the daily hydraulic load and the filter depth, for example, the mean percentage phosphate removal at 0.27 m^3m^2/day was reported to be 43.40, 55.35 and 64.61% at respective filter depth of 50, 100 and 150 cm (Bali and Gueddar, 2019). Moreover, for the removal of nitrogen from wastewater using an infiltration-percolation technique, it has been recounted that the utilization of a sand filter with a load of 0.40 m^3m^2/day was very effective for the removal of ammonium-nitrate and total Kjeldahl nitrogen with a removal efficiency of 84.92 and 86.46%, respectively (Bali and Gueddar, 2019).

Similarly, infiltration-percolation techniques have been reportedly performed by using layers of sorbents that were poured onto a supporting layer of fine stones restricted in two filtration columns for removal of nitrogen and phosphorus in secondary wastewater obtained from the biological treatment. The experimental findings at a constant hydraulic surface load of 0.5 $m^3/(m^2 \cdot h)$ for the filters recorded significant nitrogen and phosphorus removal efficiency without any contribution to secondary pollution. Consequently, recommending the infiltration-percolation technique as an environmentally friendly wastewater treatment technique (Mažeikien and Šarko, 2022). Moreover, a comparative study on using infiltration-percolation filter media that include quartz sand used in drinking water treatment plants, Purolite A502PS resin, as well as natural zeolite for the removal of nitrogen and phosphorus from wastewater has been reportedly described. There was a recounted decline from 8.22 to 1.5 mg/L, 2.46 to 0.44 mg/L and 1.56 to 0.45 mg/L respectively for NH_4-N, NO_3^--N and PO_4-P. In addition, the tested materials respectively recorded 80 to 83% and 65 to 67% removal

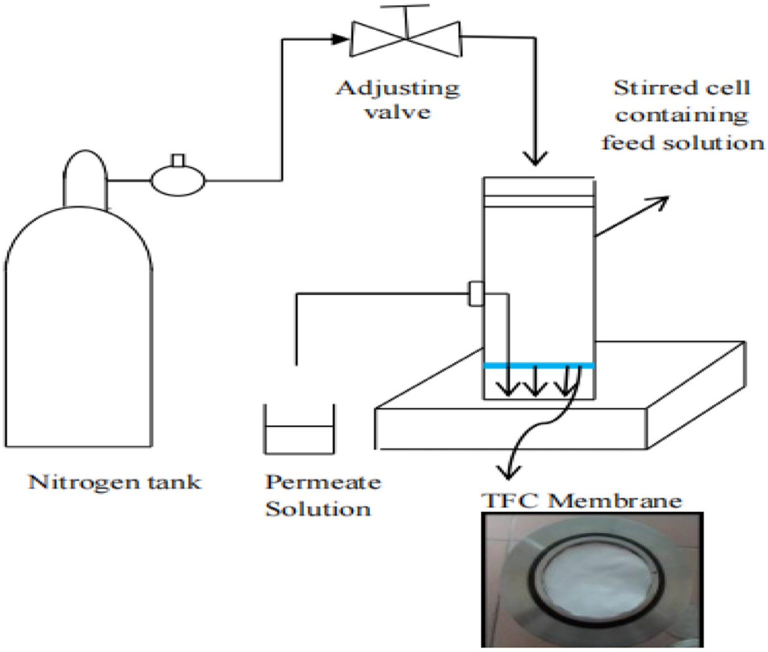

Fig. 2. Schematic diagram of membrane filtration apparatus set (Sulaiman and Shaari, 2016).

of nitrogen and phosphorus from wastewater (Mažeikien and Šarko, 2022).

3.1.3. Membrane separation technology

There have been experimental findings that certain factors such as pressure, concentration, zeta potential and pH have a positive effect on the removal efficiency (rejection) of phosphorus by nano-filtration. While the presence of competing ions such as sulphate and chloride reduces the rejection of phosphorus by nano-filtration. However, at a pH value above 8.3, the removal rate of phosphorus decreases, while a higher flux rate results in a higher phosphorus removal rate (Roy, 1995; Sperlich *et al.*, 2007; Zheyi, 2012). The use of microfiltration has experimentally shown that an increase in pore size results in an increase in flux but a decrease in removal efficiency. Also, it has been noted that at a pressure of 200 kPa, membranes with pore sizes of 0.2 and 0.05 μm, there is a steady state flux of 50 and 23.54 L/m^2.h, respectively and phosphorus removal of 81 and 84% respectively (Roy, 1995).

The use of a nano-filtration membrane coupled with a bioreactor (NF-MBR) for 62 days at a flux rate of 16 l/m.h and hydraulic retention time of 2.9 h has been experimentally proven to be useful in the concentration reduction of COD (chemical oxygen demand), nitrogen-ammonia ($N\text{-}NH_3$), nitrogen-nitrite ($N\text{-}NO_2$), nitrogen-nitrate ($N\text{-}NO_3^-$) and phosphorus-phosphate ($P\text{-}PO_4^{3-}$) in wastewater. It was also reported that under optimum conditions a maximum reduction was observed on the final day of the research, and the process of eliminating pollutants from wastewater proceed effectively and the percentage removal for COD, $N\text{-}NH_3$, $N\text{-}NO_2$, $N\text{-}NO_3^-$ and $P\text{-}PO_4^{3-}$ were 95, 90, 89, 87 and 68% respectively (Juholin, 2016). Moreover, the occurrence of membrane fouling in nano-filtration is a setback that affects the removal of the efficiency of nano-filtration. However, the tendency of membrane fouling can be decreased by hybridizing a nanomembrane with a ZnO nanoparticle, which displays both catalytic and antibacterial properties. Therefore, the hybrid membrane gains advantageous properties of the catalytic and antibacterial material without losing the nanofiltration properties (Visvanathan and Roy, 1997).

A comparative study on the use of nano-filtration and reverse osmosis for wastewater treatment revealed that both treatment methods have similar retention efficiencies. However, the permeate flux obtained from nano-filtration was reported to be 7 times higher than that obtained from reverse osmosis. Furthermore, nano-filtration was reported to exhibit a higher permeate flux with lower energy consumption and fouling formation than reverse osmosis and can be obtained at a pH of 5. While a significant decrease in permeate quality is observed at a recovery rate above 40%, compared to reverse osmosis which displays 85% nitrate removal from wastewater (Matei and Racovitean, 2021; Shon *et al.*, 2013; Kootenae and Rad, 2013; Andrade *et al.*, 2017; Winter *et al.*, 2017). The major merit of reverse osmosis includes but is not limited to multi-contaminant removal, ease of operation, and high level of automation process in addition to the high quality of water produced, regardless of the quality of the untreated water fed into the reverse osmosis system. However, the setbacks of membrane separation technology include but are not limited to the high energy cost of pumping water through the membrane, and membrane fouling in addition to the high level of maintenance that has been associated with membrane separation technology as shown in Fig. 2 (Matei and Racoviteanu, 2021; Sulaiman and Shaari, 2016; Huno *et al.*, 2018; X. Li et al., 2021). Electrodialysis is a membrane separation technique that incorporates the use of electrodes for the migration of ions through selective semipermeable membranes on account of the electrically charged surfaces of the membrane. In an electrodialysis process, cathode and anode are utilized to charge the membrane, for instance, nitrate ions continuously move through the membrane to the anode, but are continuously rejected by the ion exchange impermeable cathode membrane thus trapping the nitrate ions in the recirculated concentrate stream as shown in Fig. 3. The deployment of electrodialysis has been recounted to produce 95% nitrate removal. However, this technique is impeded by a high cost of operation as well as unsuitability for large volume of untreated water (Matei and Racovitean, 2021).

3.2. Chemical techniques

3.2.1. Coagulation/Flocculation

Coagulation is a chemical treatment that results in the destabilization of anionically charged particles which are neutralized by collision with coagulants that are added to the solution, thereby leading to the agglomeration of particles. Flocculation is a primary bridging of particles by a polymer chain resulting in the formation of flocs (larger particles), which are either removed from the solution by floatation or sedimentation as shown in Fig. 4 (Akinnawo *et al.*, 2023; Ajala et al., 2023; Mahmudabadi et al., 2018). Coagulation and flocculation as shown in Table 1 are promising techniques in water treatment operations due to

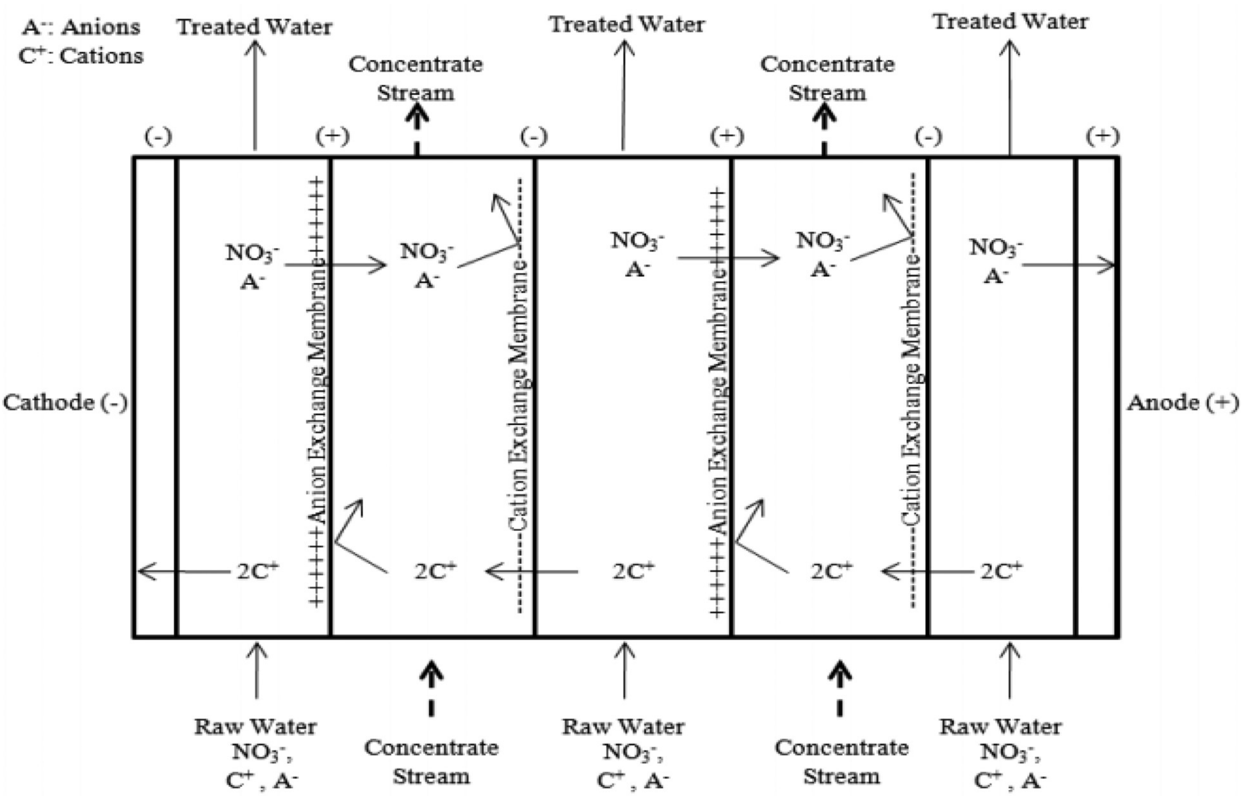

Fig. 3. Schematic diagram of Electrodiaysis process (Matei and Racovitean, 2021).

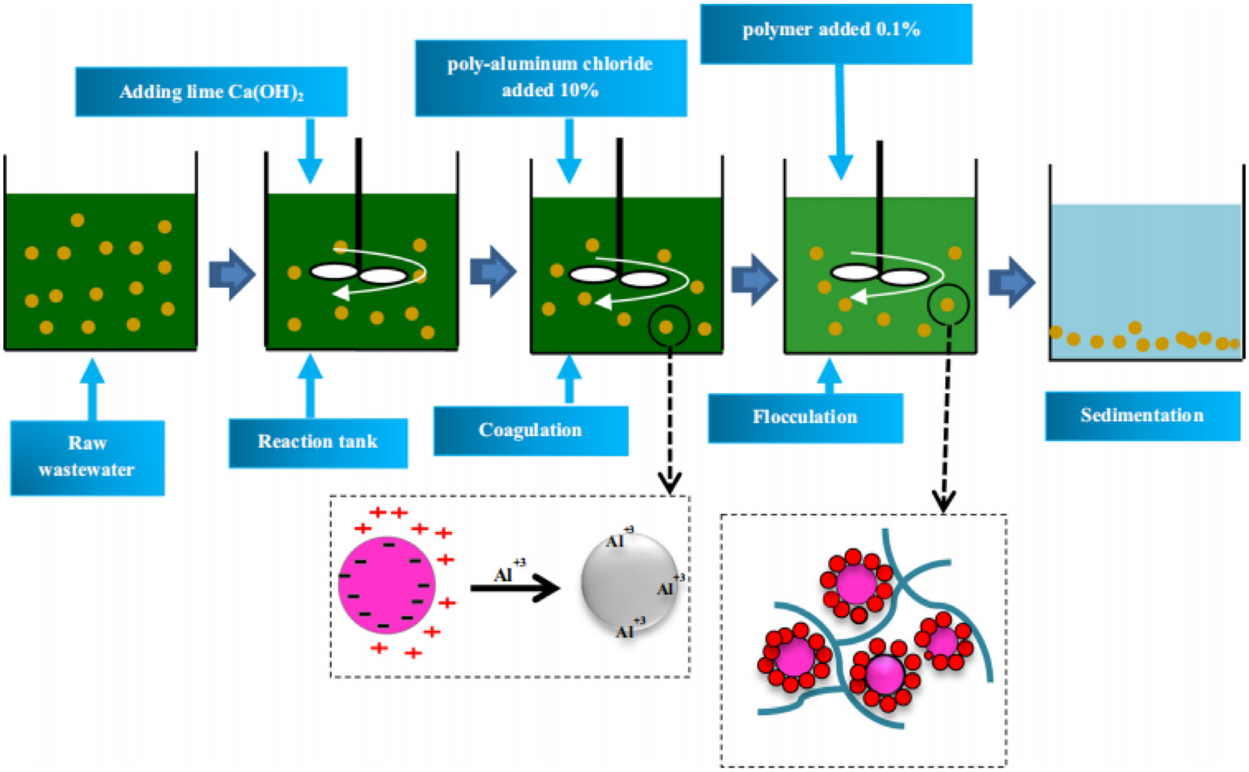

Fig. 4. Schematic diagram of Coagulation/Flocculation set up (Mahmudabadi *et al.*, 2018).

Table 1
The efficiency of coagulation/flocculation for nutrient removal.

Coagulant/Pollutants	Percentage removal	Ref
Iron sulphate (phosphorus removal)	80%	(Nassef, 2012)
Aluminium sulphate (phosphorus removal)	85%	(Nassef, 2012)
Calcium oxide		
1 phosphorus removal	90%	(Nassef, 2012; Dunets, 2014)
2 phosphate	99%	
Ferric sulphate (phosphorus removal)	95%	(Rich, 2005)
Ferric chloride		(Costa *et al.*, 2019)
1 nitrate-nitrogen	64%	
2 phosphate-phosphorus	87%	
3 total phosphorus	93%	
Magnesium sulphate		(Molahalli, 2011; Sutharand Chokshi, 2011; Morales *et al.*, 2013)
1 nitrate	99.3%	
2 phosphate	99.9%	
Magnesium chloride		(Molahalli, 2011; Suthar and Chokshi, 2011; Morales *et al.*, 2013)
1 nitrate	40%	
2 phosphate	50%	
Alum aided extended aeration		
1 total phosphorus	92%	(Martel *et al.*, 1997)
2 ammonia-nitrogen	97%	
Iron anode/Aluminium cathode electrodes		
1 total phosphorus	99%	(Aguilar-Ascon, 2020; Apshankar and Goel, 2020)
2 total nitrogen	27%	
3 nitrate	53%	

their desirable merits such as a high degree of reliability, low energy requirement, cost efficiency and simple operation process (Akinnawo *et al.*, 2023; Ajala *et al.*, 2023). The utilization of metal-base compounds such as iron sulphate, calcium oxide and aluminum sulphate have proved to be effective precipitating agents for phosphorus removal from aquaculture effluents. However, their removal efficiencies are reportedly reliant on the solution pH and precipitant doses premised on their respective 80, 85 and 90% phosphate removal by utilizing iron sulphate, aluminum sulphate and calcium oxide precipitant agents. However, a blend of two precipitants reportedly did not affect enhancing the percentage of phosphate removal from wastewater (Nassef, 2012). The deployment of tris hydroxyl methyl amino methane as a buffer for ferrous and ferric sulphate at solution pH of 7.3 and 7.6 experimentally yielded 95% phosphorus removal with complete precipitation time of 60 and 100 min correspondingly, but both precipitants attained the same settling time of 100 min (Rich, 2005).

Similarly, 99% phosphate removal has been reported with the deployment of lime at pH between 8.6 and 9.9 along with a 1.5 ratio of lime and phosphorus, nevertheless, it was posited that the utilization of cationic starch could enhance separation efficiency through flocculation (Dunets, 2014). In the same way, ferric chloride reportedly displayed N-NO_3^-, P-PO_4^{3-} and total phosphorus removal at 64, 87 and 93% efficiencies respectively. However, the utilization of ferric chloride reportedly exhibits an inhibitory effect on certain microbial activity (Costa *et al.*, 2019).

The deployment of 196 mg/L of $FeCl_3$ has been reportedly used in a peristaltic pump with a flow rate of 0.86 L/h in an SBR step-up for the treatment of raw sewage with high organic load ranging from 0.11 (phase I) to 0.66 (phase II) $kgCOD.m^{-3}.d^{-1}$. The performance of $FeCl_3$ coagulant reportedly attained a phosphorus removal from 0 to 1.2 mg/L, which corresponds to 93% removal efficiency, compared to a biological removal technique that exhibited a phosphorus removal from 15.6 to 9.0 mg/L, which corresponds to 42% of efficiency (Costa *et al.*, 2019). The utilization of magnesium sulphate and magnesium chloride has been reported to be efficient in the recovery of nitrate and phosphate from wastewater. Magnesium sulphate has been reported to yield 99.3 and 99.9% removal for nitrate and phosphate from wastewater with a pH of 9, while 45 and 25 mg/L doses of magnesium chlorine reportedly exhibit 40 and 50% removal of nitrogen and phosphorus from wastewater (Molahalli, 2011; Suthar and Chokshi, 2011; Morales *et al.*, 2013).

The employment of electrochemically induce calcium phosphate precipitation has been reported to yield 42.8, 62.1 and 71.5% for a duration of 24, 48 and 72 h correspondingly for phosphorus recovery from wastewater. However, conventional chemical precipitation has been reported to exhibit higher phosphate recovery compared to electrochemical precipitation. Furthermore, concurrent removal and separation reportedly occurs on the cathode surface in the electrochemical precipitation method compared to the conventional precipitation that requires separation follow-up after the precipitation process (Lie *et al.*, 2017). The employment of an extended aeration system to aid alum as a chemical precipitant has been reported to yield 92 and 97% removal of total phosphorus and NH_3-N respectively. Similarly, experimental findings have revealed that extended aeration aided with sodium aluminates yielded 92 and 97% removal of total phosphorus and NH_3-N respectively with a sludge volume index of 54 and solution pH below 4.5, lower than the required pH for phosphate precipitation. Consequently, lime is essential to buffer the solution to the required phosphate precipitation solution pH, thereby creating a cost implication (Martel *et al.*, 1997).

Electrocoagulation is an efficient electrochemical technique for the treatment of water and wastewater since it is capable of simultaneously eliminating a wide range of pollutants such as phosphate, nitrate, colloids, suspended particles, organic matter, turbidity, and colour as well as killing pathogens (Mollah *et al.*, 2001). A comparative study on the use of iron and aluminum-based coagulants for the removal of phosphorus from chemical and electrochemical coagulated wastewater revealed that the quantity of phosphorus adsorbed on colloidal micelles of aluminum or iron hydroxides depends on the applied coagulants or electrocoagulants. Moreover, it has been reported that aluminum ions from poly aluminum chloride and aluminum electrodes were equally effective in adsorbing phosphate, while the wastewater coagulated with ferric sulphate has adsorption maxima with a value nearly five times higher than that of the iron electrode. On the other hand, the aluminum electrode has been reported to have a higher maximum adsorption capacity over the iron electrode for the removal of phosphate from wastewater. Premised on this finding, poly aluminum chloride is more effective compared to iron electrocoagulant for the removal of phosphate from water (Butler *et al.*, 2011; Smoczynski *et al.*, 2014; Zidane *et al.*, 2014).

The utilization of an acrylic reactor with iron and aluminium as cathode and anode electrodes respectively as shown in Fig. 5 has been re-

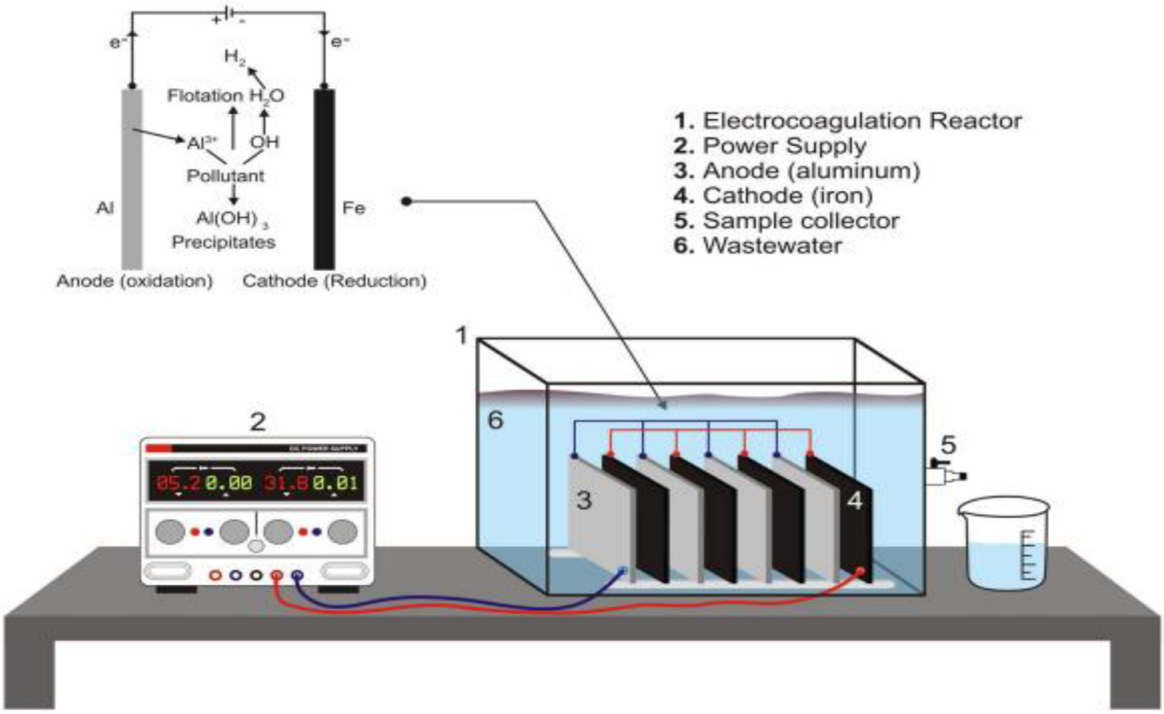

Fig. 5. Schematic diagram of electrocoagulation reactor set up (Aguilar-Ascon, 2020).

counted to yield 99 and 27% removal of phosphate and nitrogen respectively (Aguilar-Ascon, 2020). The 99 and 27% removal of phosphorus and nitrogen were obtained at a solution pH of 6, current intensity of 3 amps and a contact time of 40 min. This outcome indicates a high efficiency of electrocoagulation for phosphorus removal compared to nitrogen removal (Aguilar-Ascon, 2020).

The deployment of 22 DC power supply after electrocoagulation and settling has recorded a maximum nitrate removal efficiency of 38.21%. Further study on coupling solar energy with electrocoagulation has been recounted to display 53% nitrate removal efficiency in electrolysis time of 3 h, at respective pH and voltage of 10.8 and 14 V, thus recommending the effectiveness of coupling solar energy with electrocoagulation for nitrate removal from wastewater (Apshankar and Goel, 2020). However, chemical and electrocoagulation techniques exhibit shortcomings that involve the relatively high procurement cost for developing countries, alteration of the pH of the treated water, technical skills and training as well as the production of a large volume of sludge. In addition, aluminum-based coagulants have been linked to the development of Alzheimer's disease in humans (Akinnawo *et al.*, 2023).

3.2.2. *Adsorption and ion exchange method*

Adsorption is a phenomenon in which a substance (adsorbate) is accumulated and deposited on the outer surface of a solid material (adsorbent) as shown in Fig. 6 (Ademiluyi et al., 2009). Research on the use of plant-based material for the removal of nitrate and phosphate has been successfully carried out as shown in Table 3. It was observed that the use of sugar cane bagasse was found to be effective in removing nearly 100% of nitrate at an initial concentration of 5 mg/L at 25 °C for 30 min (Schwantes *et al.*, 2015). Similarly, research on nitrate removal using palm kernel shell-based lignocellulose anion resins has been reported under various nitrate concentrations, pH, and adsorbent dosages. The nitrate adsorption capacity displayed by the biomaterial-based resins was 53.18 mg/g (Bashir *et al.*, 2017). The adsorption efficiency of *Cymodocea rotundata* in removing nitrate and phosphate is reported to be dependent on the adsorption experimental condition of pH, dose, initial concentration and contact time. *Cymodocea rotundata* adsorbent was noted to exhibit 62 and 71% adsorptive nitrate and phosphate removal at optimum adsorption parameters (Soumya *et al.*, 2015).

A comparative study on phosphorus removal efficiency using sequencing batch reactors (SBRs) and conventional activated sludge (CAS) revealed a respective maximum removal of 88 and 99% for CAS and SBR with a respective decrease to 1.2 and 3.5 mg/L effluent concentration from an initial average influent total phosphorus concentration of 4.2–9.2 mg/ L (Denisova *et al.*, 2020).

The deployment of ion exchange (IEX) processes as shown in Table 2 has been reported to be an effective technique for the removal and recovery of nutrients from wastewater. The utilization of IEX process has been reported used at a low cost and reduction in the emission of greenhouse gas for the recovery of nitrate and phosphate to an annual recovery of an approximated 98 and 3.4 tons of nutrients in the form of $(NH_4)_2SO_4$ and $Ca_3(PO_4)_2$ respectively (Huang *et al.*, 2020). The coupling of nanotechnology and ion exchange process to develop a hybrid ion exchange nanotechnology (HIX-Nano) has been recorded to produce a 21.92 mg/g adsorption capacity for phosphorus-phosphate per gram for wet resin at an adsorption time of 168 h (Foste and Vaneeckhaute, 2021).

Additionally, the utilization of WBA-2 and SBA-1 as a version of HAIX-Nano ion exchange resin have been recorded to yield 62 and 43% phosphate removal with desorption efficiency of 78 and 24% respectively, with the WBA-2 displaying 32% adsorption capacity than SBA-1 compare to the predicted 44% with the Avrami equation as well as 63% higher with the PSO model. Further, desorption study on the recovery of the adsorbed phosphate from the hybridized HAIX-Nano resin-iron oxide nanoparticle reportedly displayed a high percentage recovery (Foste and Vaneeckhaute, 2021; Ownby and Vaneeckhaute, 2021).

The fabrication of hydrated iron-alum oxides-contained cation exchange resin (HIAO/225H) has been reportedly synthesized and applied for the removal of phosphate from water. The synthesized HIAO/225H was reported to display a maximum phosphate adsorption capacity of 69.16 mg/g at a pH value of 6, compared to hydrated ferric oxide/225H material, anion exchange resin (Akualite A420), as well as amphoteric ion exchange resin (MB6SR) which were respectively less by values of 1.12, 11.15, and 2.11 (Tran *et al.*, 2022).

Table 2
The efficiency of ion exchange resins for nutrient removal.

Ion exchange resin/pollutants	Percentage removal	Adsorption capacity	Ref
hybrid ion exchange nanotechnology (HIX-Nano)	NA	21.92 mg/g	(Foste and Vaneeckhaute, 2021)
i. phosphorus-phosphate			
hydrated iron-alum oxides-contained cation exchange resin	NA	69.16 mg/g	(Tran *et al.*, 2022)
i. phosphate			
Auchlite A101D anion exchange resin			(Shende and Main, 2014)
i. nitrate	NA	68.08 mg/g	
ii. phosphate	NA	50.8 mg/g	
zeolite Na-A	60%	NA	(Mohamed *et al.*, 2015)
Duolite A7	80%	NA	(Nujić *et al.*, 2017)
i. nitrate			
Relite A490	60%	NA	(Nujić *et al.*, 2017)
i. nitrate			

NA= not applicable.

Table 3
The efficiency of adsorption for nutrient removal.

Adsorbents/pollutants	Percentage removal	Adsorption capacity	Ref
Sugar cane bagasse (nitrate removal)	100%	NA	(Schwantes *et al.*, 2015)
Palm kernel shell-based lignocellulose anion resins (nitrate removal)	NA	53.18 mg/g	(Bashir *et al.*, 2017)
Cymodocea rotundata			
1 nitrate removal	62%	NA	(Soumya *et al.*, 2015)
2 phosphate removal	71%	NA	
Virgin almond shell activated carbon (nitrate removal)	40%	NA	(Dehestaniathar and Rezaee, 2014)
$Fe_2(SO_4)_3$ modified virgin almond shell activated carbon (nitrate removal)	70%	NA	(Dehestaniathar and Rezaee, 2014)
Clay			
1 nitrate removal	92.72%	NA	(El Ouardi *et al.*, 2015; Idris and Ahmed, 2012)
2 phosphate removal	97.77%	NA	
Red mud (phosphate removal)	98%	NA	(Al-Fatlawi and Neamah, 2015)
Wastewater sludge (phosphate removal)	95%	NA	(Al-Fatlawi and Neamah, 2015)
Acid-heat red mud (phosphate removal)	NA	202.9 mg/g	(Chang-jun *et al.*, 2007; Wang *et al.*, 2009)
Heat-activated red mud (phosphate removal)	NA	155.2 mg/g	(Chang-jun *et al.*, 2007; Wang *et al.*, 2009)
Phoslock (lanthanum-modified bentonite) (phosphate removal)	93%	NA	(Sato, 2003)
Granular ferric hydroxide (phosphate removal)	80%	24 mg/g	(Wolfgang, 2010)
Layer double hydroxides (LDHs) of Mg-Al-Cl (nitrate removal)	NA	87%	(Islam, 2008).
magnesium hydroxide (phosphate removal)	na	90%	(xie *et al.*, 2014)
aluminum-doped magnetic nanoparticles (phosphate removal)	na	102 mg/g	(xu *et al.*, 2017)
carboxymethyl konjac glucomannan loaded with lanthanum (phosphate removal)	NA	16.06 mg/g	(Zhang *et al.*, 2018)
Immobilization of lanthanum (III) onto 1,6- hexamethylenediamine-functionalized copper ferrite (phosphate removal)	NA	32.59 mg/g	(Gu *et al.*, 2018)
Iron/Cobalt chitosan modified nanoparticles (phosphate removal)	58.7%	NA	(Issaian and Reyes, 2020)
Zinc oxide	51%	NA	(Cepan *et al.*, 2021)
Titanium dioxide	71%	NA	
Cobalt ferrite	80%	NA	
Magnetite	88%	NA	
Mordenite zeolite (phosphate removal)	96%	NA	
Unmodified chitosan	NA	44.38 mg/g	(Filipkowska *et al.*, 2014)
Glutaraldehyde cross-linked chitosan	NA	139.4 mg/g	
Epichlorohydrin cross-linked chitosan (phosphate removal)	NA	108.24 mg/g	
$MgFe_2O_4$/biochar magnetic composite (phosphate removal)	80.4%	163.02 mg/g	(Jung *et al.*, 2017)
Zirconium-encapsulated chitosan quaternized beads			
1 nitrate removal	NA	138.40 mg/g	(Banu *et al.*, 2021)
2 phosphate removal	NA	142.95 mg/g	
Zirconium hydroxide/MgFe layered double hydroxide composite (phosphate removal)	91.7%	25.15 mg/g	(Nuryadin and Imai, 2021)
Organic-modified aluminum-manganese bimetal oxide (phosphate removal)	NA	33.16 mg/g	(Wu *et al.*, 2019)
Silver nanoparticles (phosphate removal)	NA	156.12 mg/g	(Trinh *et al.*, 2020)
Silver nanoparticles-loaded tea-activated carbon (phosphate removal)	NA	13.62 mg/g	(Akram *et al.*, 2021)
Iron/pomegranate peel	NA	13.91 mg/g	(Akram *et al.*, 2021)
Lanthanum/pomegranate peel	NA	44.5 mg/g	
Iron-lanthanum pomegranate peel (phosphate removal)	NA	38.86 mg/g	
Micro emulsion-prepared magnetic nanoparticles			
1 phosphate removal	100%	NA	(Khodadadi *et al.*, 2017)
2 nitrate removal	33%	NA	
Lamellar alumina (phosphorus removal)	NA	588.2 mg/g	(Sun *et al.*, 2020)
Copper smelter slag (phosphorus removal)	97%	0.16 mg/g	(Letshweny and Sima, 2020)
Conventional activated sludge (CAS) (phosphorus removal)	99%	NA	(Denisova *et al.*, 2020)
Particulate adsorbent (La-CZ) (phosphorus removal)	NA	18.2 mg/g	(Y. Zhang et al., 2022)
Sodium bentonite (nitrate removal)	45%	NA	(Hamouda *et al.*, 2016)
Lime bentonite (nitrate removal)	96%	NA	(Hamouda *et al.*, 2016)
Coal mining waste (phosphate removal)	79%	NA	(Mekonnen *et al.*, 2021)
alginate-calcium carbonate bead (phosphate removal)	83%	NA	(Mahmood *et al.*, 2015; Liu *et al.*, 2012)

NA= not applicable.

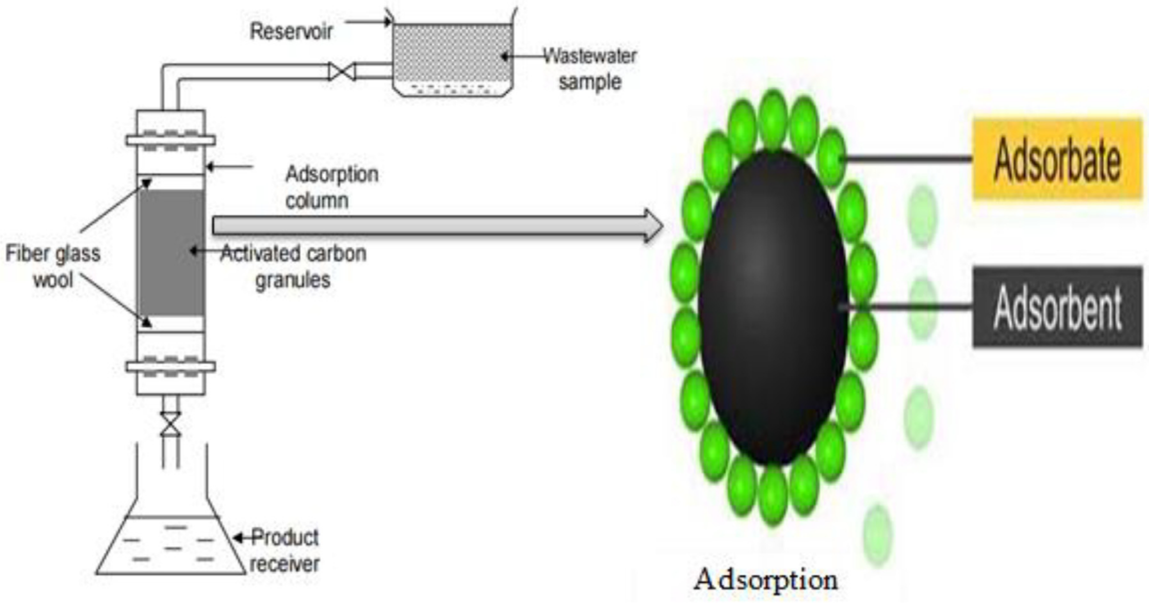

Fig. 6. Schematic diagram of Adsorption set up (Ademiluyi *et al.*, 2009).

The utilization of Auchlite A101D anion exchange resin has been posited to exhibit higher adsorption capacities of 68.08 and 50.8 mg/g with equilibrium times of 100 and 140 min for the removal of nitrate compared to phosphate for wastewater treatment (Shende and Main, 2014). Reports on the employment of zeolite Na-A at optimum pH of 4, 5 mg/L initial concentration and contact time of 3 h, have pointed out the optimum removal efficiency of 60% for the removal of phosphate from aqueous solution (Mohamed *et al.*, 2015). A comparative study on the adsorptive nitrate removal using clinoptilolite zeolite and HCl/heat-modified zeolite has revealed that the modified zeolite exhibited higher nitrate removal compared to the unmodified clinoptilolite zeolite (Azari *et al.*, 2014). Moreover, unmodified clinoptilolite zeolite reportedly yields higher adsorptive removal of ammonium in a column scale with a corresponding increase in contact time and adsorbent dose. Conversely, a decrease from 95 to 85% and 50 to 35% was reported when there was an increase in initial concentration (Murkani *et al.*, 2015). Comparatively, a study revealed that Duolite A7 and Relite A490 exhibit 80 and 60% nitrate removal at the optimum dose of 4 and 6 g respectively. In addition, for both Duolite A7 and Relite A490 at higher initial nitrate concentration, the percentage of nitrate removal declined from 81.26 to 40.39% and 92.23 to 80.78% respectively (Nujić *et al.*, 2017).

A comparative analysis has been reported on the efficiency of modified and unmodified virgin almond shell activated carbon for the removal of nitrate from aqueous solution at the optimum conditions of 20 mg/L initial concentration, 20 °C temperature and a pH of 6.2 in equilibrium time of 30 min. The findings revealed a respective 40 and 70% nitrate removal for unmodified virgin almond shell activated carbon and $Fe_2(SO_4)_3$ modified virgin almond shell activated carbon (Dehestaniathar and Rezaee, 2014). In addition, there has been report on the decline in the adsorption removal of nitrite and nitrate by using activated carbon derived from corncobs, rice husk and groundnut shells, consequent to the presence of electrolytes in the aqueous solution. It was posited that the presence of alkaline salts, neutral chloride salts, neutral sulphate salts and acidic salts respectively resulted in 95.5, 90.4, 67.8 and 52.2% nitrate removal. Moreover, acetic acid modification of adsorbent has been reported to increase the adsorption removal of nitrite by a factor of 26% but decrease the adsorptive removal of nitrate by 30% (Motosic *et al.*, 2000; Mir, 2010). There has been a series of findings on the utilization of clay as an adsorbent for nitrate removal, resulting in the attainment of 86% nitrate removal at the optimum experimental condition of dose (1.4 g), pH (6.5) and contact time (130 min) (Mise and Bashetty, 2013; El Ouardi *et al.*, 2015). Similarly, the effect resulting from the increase in the range of pH (2 to 10) and initial concentration (100 to 450 mg/L) on nitrate and phosphate removal using clay as a low-cost adsorbent revealed a decrease in the percentage removal of nitrate and phosphate from 92.72 to 38.96% and 97.77 to 53.40% respectively (Idris and Ahmed, 2012; El Ouardi *et al.*, 2015). On the other hand, the nitrate removal was reported to increase from 9.84 to 72.9%, with an increase from 0.2 to 1 g adsorbent dose (Idris and Ahmed, 2012; El Ouardi *et al.*, 2015).

A relative study on the use of acid-heat and heat-activated red mud for the adsorptive removal of phosphate revealed that phosphate removal efficiency was considerably pH dependent, and the adsorption isotherm best fits the Langmuir isotherm model with respective maximum phosphate adsorption capacities of 202.9 and 155.2 mg/g for the acid-heat activated red mud and the heat activated samples (Fuleky and Tolner, 2006; Chang-jun *et al.*, 2007; Wang *et al.*, 2009). The employments of sodium bentonite and lime bentonite as adsorbents have been reported to exhibit 45 to 96% nitrate removal respectively. However, the presence of organic matter (organic ligand and humic acid), carbonate and competing ions such as silicate compete with the phosphate for the binding sites on the adsorbents, thereby reducing the percentage of phosphate removal (Lee, and Kim, 2007; Tani *et al.*, 2010; Hamouda *et al.*, 2016; Marco, 2017; Maluf *et al.*, 2018). Experimental findings on the use of phoslock (lanthanum-modified bentonite) for phosphate removal have been suggested to be dependent on the solution pH. The maximum phosphate removal of 93% on phoslock adsorbent has been reported when the solution pH increases from 5 to 9. However, the percentage of phosphate removal decreases to 81%, when the solution pH exceeded 9 (Sato, 2003).

Furthermore, a comparative study on the use of wastewater treatment sludge and red mud for removing phosphate showed that at a pH of 4, a dosage of 50 g and an initial concentration of 4 mg/L, the phosphate sorption efficiency of 95 and 98% were observed for the wastewater treatment sludge and red mud respectively (Al-Fatlawi and Neamah, 2015). The effectiveness of goethite as an adsorbent has reportedly exhibited an increase in phosphate sorption removal with an increase in adsorption parameters, with both phosphate and phosphonates competing for binding sites. Moreover, granular ferric hydroxide exhibited increased nitrate removal with a corresponding increase in the adsorption parameters with the maximum adsorption capacity attained within 2 to 3 min. Conversely, an increase in adsorbent dose and a decrease in adsorbent particle size resulted in a decrease in the adsorptive removal of nitrate from wastewater (Torrent *et al.*, 1992; Ruan and Gilkes, 1996; Nowack and Stone, 2006; Rahimi *et al.*, 2016). On the other hand, the adsorptive removal of phosphate on granular ferric hydroxide is reportedly dependent on the solution pH, with the highest adsorption capacity of 24 mg/g obtained at a pH of 6. In addition, the presence of calcium ions in the solution is observed to enhance the adsorption of phosphate from wastewater with the regeneration of granular ferric hydroxide yielding 80% phosphate recovery (Wolfgang, 2010).

The use of layer double hydroxides (LDHs) of Mg-Al-Cl at an initial concentration of 10 mg/L has been reported to display 87% removal of nitrate. LDHs were observed to have a demerit of not being useable at a pH below 6 because they are usually unstable in an acidic medium, a low desorption and reusability percentage of the adsorbents was observed, Moreover, it was also noted that the presence of anions such as phosphate, carbonate, sulphate and chloride reduces the adsorption of nitrate appreciably (Islam, 2008). The utilization of magnesium hydroxide has been reported to exhibit 90% phosphate removal at 300 mg/L of initial concentration. However, the adsorption removal of phosphate by using metal oxide and hydroxide is reportedly influenced by the presence of competing ions and organic matter (Altundogan and Tumen, 2001; Zheng *et al.*, 2012; Xie *et al.*, 2014; Li *et al.*, 2016).

A comparative study on the phosphate adsorption removal from wastewater using aluminum-doped magnetic nanoparticles and carboxymethyl konjac glucomannan loaded with lanthanum have been recounted to yield 102 and 16.06 mg/g respectively at a pH of 4 (Xu *et al.*, 2017; Zhang *et al.*, 2018). Similarly, at optimum contact time and adsorbent dose, the immobilization of lanthanum (III) onto 1,6-hexamethylenediamine-functionalized copper ferrite to develop an adsorbent has been reported to produce 32.59 mg/g adsorption capacity for the removal of phosphate in the presence of competition ions (Gu *et al.*, 2018). Further findings on utilizing iron/cobalt chitosan modified nanoparticles as adsorbent has been proposed to yield percentage phosphate removal of 52.7 and 58.7% from synthetic wastewater and real water samples collected from river water (Issaian and Reyes, 2020). Furthermore, a comparative adsorption study on the efficiency of magnetite, cobalt ferrite, titanium dioxide, zinc oxide, and zeolite for the removal of phosphate from wastewater has been reported to record 51, 71, 80, 88, and 96% respectively for zinc oxide, titanium dioxide, cobalt ferrite, magnetite and mordenite zeolite (Cepan *et al.*, 2021). Further studies on comparative analysis on the use of modified and unmodified chitosan have been recorded on removing phosphate from wastewater with the modified and unmodified chitosan exhibiting their highest adsorption capacities at respective pH of 3 and 4 but at same equilibrium contact time of 60 min. Glutaraldehyde cross-linked chitosan exhibited the highest adsorption capacity of 139.4 mg/g, while epichlorohydrin cross-linked chitosan exhibited 108.24 mg/g adsorption capacity but the lowest adsorption capacity of 44.38 mg/g was exhibited by the unmodified chitosan (Filipkowska *et al.*, 2014). The use of chitosan- zinc (II) complex as bio-sorbents has been posited to be efficient at low pH for phosphate removal at an optimum dose of 1.5 mg. However, competing ions of sulphate, nitrate and chloride reduce the efficiency of the bio-sorbent for removing phosphate (Yazdani *et al.*, 2018).

The modification of biochar by using magnesium ferrite ($MgFe_2O_4$) to develop a $MgFe_2O_4$/biochar magnetic composite has been successfully utilized for the removal of phosphate from wastewater. The adsorption study at a pH of 3 revealed an adsorption phosphate removal of 80.4% and an adsorption capacity of 163.02 mg/g at optimum operating conditions (Jung *et al.*, 2017). Research studies on the encapsulation of zirconium into chitosan to fabricate zirconium-encapsulated chitosan quaternized beads have been comparatively reported on the removal of nitrate and phosphate from wastewater. The recounted outcome revealed an optimum adsorption capacity of 138.40 and 142.95 mg/g for respective adsorption removal of nitrate and phosphate from wastewater (Banu *et al.*, 2021). Comparatively, the utilization of a zirconium hydroxide/MgFe layered double hydroxide composite for phosphate removal in a column adsorption study has been recounted to display a high adsorption capacity of 25.15 mg/g and percentage removal of 91.7% for phosphate adsorption recovery. In addition, the zirconium hydroxide/MgFe layered double hydroxide composite display a high level of regeneration usage (Nuryadin andImai, 2021).

Similarly, the adsorptive phosphate removal capacity of organic-modified aluminum-manganese bimetal oxide and silver nanoparticles has been reportedly compared. The silver nanoparticle displayed an adsorption capacity of 156.12 mg/g, which is reportedly higher than the adsorption capacity of 33.16 mg/g displayed by the organic-modified aluminum-manganese bimetal oxide (Wu *et al.*, 2019; Trinh *et al.*, 2020). In the same way, the incorporation of silver nanoparticles into the structural network of activated carbon synthesized from tea tree precursor to yield a composite adsorbent of silver nanoparticles-loaded tea-activated carbon (AgNP-TAC) has been detailed for the adsorption removal of phosphate from wastewater. The composite adsorbent of silver nanoparticles-loaded tea-activated carbon exhibited an optimum phosphate adsorption capacity of 13.62 mg/g with a possible phosphate adsorption mechanism of a surface complex silver ion formation and ligand exchange at an acidic pH (Nguyen *et al.*, 2020).

The utilization of a modified solvothermal synthetic method for the synthesis of pomegranate peel co-doped with ferric chloride and lanthanum hydroxide nanoparticles for the adsorption removal of phosphate has been investigated. The synthesized iron-lanthanum pomegranate peel (Fe-La/Peel) displayed an irregular rough surface with a surface area of 93.18 m^2 /g. However, it was reported that the presence of iron and lanthanum on the surface of the prepared adsorbent increases the adsorption removal of phosphate. The prepared iron/pomegranate peel (Fe/Peel) and lanthanum/pomegranate peel (La/Peel) recorded a maximum phosphate adsorption capacity of 13.91 and 38.86 mg/g respectively, compared to iron/lanthanum/pomegranate peel (Fe-La/Peel), which recorded the highest phosphate adsorption capacity of 44.5 mg/g at a pH of 2 (Akram *et al.*, 2021). Thus indicating that, the co-doping of pomegranate peels with iron-lanthanum nanocomposite increases the adsorption capacity of pomegranate peels for phosphate recovery (Akram *et al.*, 2021).

The employment of micro emulsion-prepared magnetic nanoparticles has been reported to yield 100 and 33% phosphate and nitrate removal in a contact time of 60 min. Comparatively, iron nanomagnetic particles coated with powder-activated carbon exhibit 100% phosphate removal at pH 4 and 90 min contact time. However, the percentage of phosphate removal is reportedly affected by the presence of competing anions, cations and dissolved organic matter (Khodadadi *et al.*, 2017). The use of an alginate-calcium carbonate bead as adsorbent has been reported to have 83% removal efficiency of phosphate at a pH of 10, contact time of 150 min, agitation speed of 100 rpm and adsorbent dose of 1.5 g. However, it has been posited that the presence of sulphate significantly influences the removal of phosphate using calcite. A low concentration of sulphate ions in an acidic medium could enhance the removal of phosphate, but a high sulphate ion concentration could inhibit phosphate removal. Under strong basic conditions, phosphate removal increases with an increase in the concentration of sulphate ions (Mahmood *et al.*, 2015; Liu *et al.*, 2012).

The utilization of cheap adsorbents such as alumina with granular material as adsorbents for phosphorus removal has been recounted to display low adsorption capacity as a result of their low surface area. However, the synthesis of alumina lamellar material has been recorded to display a large surface area with a requirement of 0.8 g/L of lamellar alumina adsorbent to exhibit a maximum phosphorus adsorption capacity of 588.2 mg/g at an initial concentration of 100 mg/L phosphorus solution (Sun *et al.*, 2020). Adsorption study on the use of industrial waste for nutrient removal from wastewater has reportedly produced desirable results. For instance, an adsorption study on the use of waste material such as waste from coal mining as an adsorbent has been reported to yield 79% adsorptive removal of phosphate from wastewater (Mekonnen *et al.*, 2021). Further studies have been reported on the utilization of industrial waste as adsorbent has been recounted with the employment of copper smelter slag as adsorbent for the removal and recovery of phosphorus from wastewater. The study outcome produces 97% phosphorus adsorption removal at an equilibrium dose of 160 g/L, with the adsorption isotherm best described by the Langmuir model with a maximum adsorption capacity of 0.16 mg/g. Moreover, the adsorption kinetics followed the pseudo-second-order with the adsorption mechanism of phosphorus on copper smelter slag reported controlled by multilinearity of intraparticle diffusion model with 11.7% recyclability of the copper smelter slag recounted for the period of the first regeneration (Letshweny and Sima, 2020).

The utilization of activated carbon, lanthanum and zeolite as precursors for the synthesis of particulate adsorbent (La-CZ) has been employed for the removal of phosphorus from wastewater. A batch adsorption study on using La-CZ adsorbent in an equilibrium time of 2 h has been recounted to yield an optimum phosphate adsorption capacity of 18.2 mg/g with the adsorption isotherm and kinetics best fitted into the Langmuir and pseudo-second-order model respectively, in addition, the chemisorption mechanism was recounted to dominate the adsorption removal of phosphate in a pH range from 3 to 7 (Zhang et al., 2022). Additionally, the presence of competing ions such as nitrates, and carbonates reportedly decreases the percentage of phosphate removal, while the presence of coexisting ions that include chloride, fluoride and sulphate exhibited no significant effect on the percentage removal of phosphate which recorded 77.68% at optimum conditions (Zhang et al., 2022).

The adsorption technique has been considered to exhibit less cost and energy requirement without the production of by-products (chemicals or sludge) that require secondary treatment after application in nitrate removal, unlike other treatment techniques. However, the adsorption technique has been associated with low adsorption capacity for nitrate and phosphate removal with continuous adsorbent replacement cost. In addition, the regeneration of adsorbent has been recounted to produce a certain degree of sewage thereby constituting a shortcoming for the application of adsorption technique for nutrient removal (Huno *et al.*, 2018; Li et al., 2021). On the other hand, the ion exchange resins have been recounted to maintain a high capacity for phosphate removal after regeneration. However, the shortcomings of ion exchange resins have been reported to include high regeneration cost and poor selectivity. In addition, resin drugs have been reportedly susceptible to poisoning thereby impeding the application of ion exchange technique (Li et al., 2021).

3.3. Biological treatment technique

Research outcomes on the use of lotus (*Nelumbo nucifera*) and cane shoot (*Zizania latifolia*) for the recovery of nutrients from aquaculture wastewater reveal that under surface flow operation, the removal efficiency on N-NO_2, N-NH_4^+ (nitrogen-ammonium), TN (total nitrogen), TP (total phosphorus) and chemical oxygen demand (COD) from pond wastewater was 11.30–26.27, 8.30–26.60, 1.87–20.60, 11.0–19.70 and 23.00–30.65% respectively with the influent flow rate of 0.08 m^3/h and 0.13 m^3/h as shown in Table 4. Moreover, it was reported that the recycling rate of cane shoot and lotus test pit on TN, TP and COD increases with an increase in retention time, in which TN and TP were significant when the retention time was longer than 24 h (Tao *et al.*, 2015).

Report on the removal of nitrogen and phosphorus from wastewater via bacterial sulphate reduction in an anoxic bioreactor packed with wood and iron revealed that the denitrification and phosphate removal rates in the bioreactor packed with aspen wood and iron were higher than those in the bioreactor packed with cedar wood and iron. It was also reported that the bioreactor packed with aspen wood and iron removes nutrients for a higher number of operation days than the bioreactor packed with cedar wood and iron (Yamashita and Yamamoto-Ikemoto, 2014). In addition, at a temperature below 15 ˚C, an average nitrification rate of 0.17 kg N/m^3.day and uptake of 0.11 kg N/m^3.day was reported in the trickling filter. However, a nitrate removal activity of 0.42 g NO3$^-$-N/kg dry weight wood• day was reported in the biofilm attached to the aspen wood from the bioreactor after 748 days of operation and there was no report of an increase in the amount of dissolved organic matter in the outflow from the bioreactors (Yamashita and Yamamoto-Ikemoto, 2014). The major advantage of membrane bioreactor has been reported to include the high quality of the treated water with the generation of low volume of sludge however the high cost of operation has been a pitfall for the application of membrane bio-reactor for nutrient removal from wastewater (Li et al., 2021).

From the experimental findings on utilizing microalgae at initial phosphate and nitrate concentrations of 0.25, 0.35 as well as 0.45 g/L for a growth period of 1, 4, 6 as well as 8 days, microalgae has been reported to be effective in the removal of phosphate and nitrate from aqueous solution. It was posited that the maximum nitrate removal of 89.80 and 81.49% was recorded for *Chlorella vulgar and Spirulina platensi* respectively at an initial concentration of 0.25 g/L and a period of 8 days (Larsdotter, 2006; Sayadi *et al.*, 2016). In addition, it was reported that *Chlorella vulgar* recorded 98.81 and 100 % for ammonia-nitrogen and phosphorus-orthophosphate removal respectively as shown in Table 4. Statistical analyses revealed that the concentration removal of phosphate and nitrate at the different periods by *Chlorella vulgaris* portrayed a significant difference at $P<0.01$, whereas *Spirulina platensis* validated a significant difference at $P<0.05$ (Larsdotter, 2006; Sayadi *et al.*, 2016). The use of an optimized bioretention system has been reported to show the possibility of obtaining a nitrate removal of 71% for the mesocosms with a saturation zone, while 80% phosphate removal can be obtained for the mesocosms without a saturation zone as shown in Table 4 (Palmer, 2012).

The application of mixed bacterial culture of *Pseudomonas and Paracoccus* sp. strain in the removal of nitrate from wastewater has been effectively carried out. It was reported that at a temperature of 25 ˚C and duration of 5.5 h, the mixed bacterial culture reduces 200 mg/L nitrate to 0.11 mg N-NO_2/L. A precise denitrification rate of 21 mg N-NO_3/g was observed to proceed under anoxic conditions, following a zero-order reaction for nitrate concentration and the first-order reaction for biomass concentration (Foglar *et al.*, 2004). Furthermore, it was reported that complete nitrate removal was attainable after 45 days at 25 ˚C when the hydraulic retention time (HRT) declined from 62 to 28 h with the nitrate and methanol loading rate of 4.35 mg N-NO_3/lh and 23 mg O_2/l h respectively (Foglar *et al.*, 2004).

The deployment of a biofilter for the removal of nitrogen and phosphorus has been reportedly conducted using multi-variant simulations of the combined system of fixed-film-activated sludge performance. The nitrification process was reportedly performed in the fixed film, while the removal of nitrogen and phosphorus from sewage was carried out in an anoxic chamber operating in an activated sludge method. In addition, the process of denitrifying the dephosphotation reportedly exhibited 42 and 81% for phosphorus and nitrogen reduction as shown in Table 4. However, the success of this technique depends on the ability of the microorganisms to consume the decomposable substrate in the anoxic chamber (Wałęga *et al.*, 2019).

The utilization of filler filled with rockfos (acquired by calcination of carbonate-silica rock at a temperature of 900 ˚C) and employed as components of hybrid constructed wetlands exhibiting 2.0 m^3/L average capacity has been recounted on the evaluation of total-phosphorus removal from domestic wastewater (Pytka-Woszczyło *et al.*, 2022). The outcome of the finding confirmed the suitability of using rockfos filters for the removal of total phosphorus from domestic wastewater by recording 40 and 80% total phosphorus removal by filter 1 and filter 2 in the first and second years. However, the total phosphorus removal efficiency of the filters reportedly declined to zero in the subsequent years of operation (Pytka-Woszczyło *et al.*, 2022). Further studies on us-

Table 4
The efficiency of biological methods for nutrient removal.

Biological Methods	Percentage Removal	Ref
Lotus (*Nelumbo nucifera*)	11.30–26.27% nitrogen-nitrite, 8.30–26.60% ammonium-nitrogen, 1.87–20.60% total nitrogen, 11.0–19.70% total phosphorus	(Tao *et al.*, 2015)
Chlorella vulgar	89.80% nitrate, 98.81% ammonia-nitrogen 100% phosphorus-orthophosphate	(Sayadi *et al.*, 2016; Zhang *et al.*, 2012)
Spirulina platensi	81.49% nitrate	(Sayadi *et al.*, 2016)
Bioretention system with mesocosms	71% nitrate, 80% phosphate	(Palmer, 2012)
Biofilter with fixed-film-activated sludge	42% phosphorus, 81% nitrogen	(Wałęga *et al.*, 2019)
Duckweed	75% phosphate, 60.62% nitrate, 75.04% ammonia	(Vanitha *et al.*, 2013)
Macrophyte species		
1 *A. calamus*	97.7% total nitrates	(Fu and He, 2015)
2 *M. korsakowii*	96.4% total nitrates	
3 L. *salicaria*	94.9% total nitrates	
4 *A. orientale*	91.2% total nitrates	
Macrophyte species		
1 *A. calamus*	96.1% total phosphorus	(Fu and He, 2015)
2 L. *salicaria*	83.4% total phosphorus	
3 *M. korsakowii*	79.9% total phosphorus	
4 *A. orientale*	75.8% total phosphorus	
Gloeocapsa gelatinosa	93% nitrate	(Kumar and Saramma, 2012)
Polyphosphate accumulation organism (PAO)	78% phosphate	(Bajekal and Dharmadhikari, 2007)
Wetlands	86–98% ammonium-nitrogen 99% nitrogen-nitrite 82–99% nitrogen-nitrate 95–98% total inorganic nitrogen 71.2–31.9% phosphate	(Turcios and Papenbrock, 2014; Hu *et al.*, 2015)

ing the filler filled with rockfos for the treatment of sewage samples for 5 years displayed a removal efficiency in the range of 30.2 to 31.5% total phosphorus removal (Pytka-Woszczyło *et al.*, 2022).

The use of duckweed for the recirculation of pond water quality has been posited to exhibit removal efficiency of 75.0, 60.62, 18.86 and 75.04% for phosphate, nitrate, turbidity and ammonia respectively as shown in Table 4 (Vanitha *et al.*, 2013). Furthermore, it was reported that a reduction in the pH values from 8.74 to 7.8 was recorded in the treated water. However, the presence of glyphosate at dosages of 0.12, 0.25 and 0.5 mg/L was observed to reduce the percentage removal efficiency of duckweed for phosphate from 75 to 37.5%, thereby indicating that glyphosate is a toxicant which inhibits the duckweeds removal efficiency for phosphate uptake (Vanitha *et al.*, 2013). Report on using *chollera sp* for the removal of ammonia-nitrogen (N-NH$_4{}^+$) and phosphorus-orthophosphate (P-PO$_4{}^{3-}$) from wastewater has recorded the influence of key factors such as cell density, starvation time and cell viability that affects the removal rate of nutrients by *chollera* sp. It was reported that *chollera sp* recorded an N-NH$_4{}^+$ removal efficiency of 81% after 1.25 h and 98.81% after 4 h, while P-PO$_4{}^{3-}$ removal efficiency of 77.4% after 1.25 h and 100% after 4 h was obtained as shown in Table 4 (Zhang *et al.*, 2012).

A report from a scientific study on nitrogen and phosphorus removal abilities of different species of macrophyte has been recounted to vary from one to another depending on the macrophyte species. A significant finding from the report revealed that *A. calamus, M. korsakowii,* L. *salicaria* as well as *A. orientale* displayed high removal efficiency of 97.7, 96.4, 94.9 and 91.2% respectively for the removal of total nitrates, while the other macrophyte species recorded low ability to remove total nitrate in the order *A. calamus* > *M. korsakowii* > L. *salicaria* > *A. plantago-aquatic* > *S. sagittifolia* as shown in Table 4 (Fu and He, 2015). On the other hand, the following order of *A. calamus* > L. *salicaria* > *M. korsakowii* > *A.orientale* > *S. sagittifolia* has been reportedly recorded for the removal of total phosphorus exhibiting varying degree of reduction in concentration with rapid decline in 14 day to a relatively stable reduction after a period of 21 days. Moreover, the total phosphorus removal ability of macrophyte species was recorded to be as high as 96.1, 83.4, 79.9 and 75.8% respectively for *A. calamus,* L. *salicaria, M. korsakowii* and *A. orientale as shown in* Table 4 (Fu and He, 2015).

The laboratory experimental outcome on the usage of *Gloeocapsa gelatinosa* for nutrient removal from wastewater has been successfully carried out. It was reported that 93% of nitrate was absorbed by employing immobilized cells within 24 h whereas algae-free beads and free algal cells absorbed 46 and 70% respectively as shown in Table 4. Also, the immobilized cells were able to absorb 80% of phosphate within 24 h (Kumar and Saramma, 2012). Research on phosphate removal from wastewater by the use of a moving bed biofilm reactor (MBBR) reported that the highest aerobic phosphate uptake achieved was 0.13 g/(m^2•d) after 76 days, while the highest anaerobic phosphate removal achieved was 0.35 g/(m^2•d) at a release rate of 0.2 g/(m^2•d) after 91 days. Moreover, It was reported that the anaerobic COD uptake was 6.4 g/(m^2•d) after 76 days and the microscopic study of MBBR revealed that polyphosphate granules found in the biomass were assimilated and used for growth (Arvidsson, 2015). Polyphosphate accumulation organism (PAO) has been reported to achieve 78% phosphate removal efficiency and 57% reduction of the mass of phosphate sludge produced during water treatment as shown in Table 4. It has been posited that key factors such as temperature, phosphorus to organic carbon ratio and dissolved oxygen affect the removal efficiency of phosphate by PAO (Mulkerrins *et al.*, 2004; Bajekal and Dharmadhikari, 2007). The usage of wetlands in the treatment of aquaculture wastewater as shown in Fig. 7 has been successfully reported to have percentage removal efficiencies of 86–98% (N-NH$_4{}^+$), 99% (N-NO$_2$), 82–99% (N-NO$_3{}^-$), 95–98% (total inorganic nitrogen), 71.2–31.9% (phosphate), 25–55% (COD) and 47–86% (suspended solids) as shown in Table 4. However, the hydraulic loading rate was observed to have a slight effect on the efficiency of wetlands in the treatment of aquaculture wastewater (Turcios and Papenbrock, 2014; Hu et al., 2015; Setiawan and Hardiani, 2020).

The advantages that have been associated with microbial phosphate removal include simplicity of operation without the use of chemicals. Therefore, there is no resultant secondary pollution and the amount of sludge produced is less, thus making microbial application an economic and environmentally friendly technique (Li et al., 2021). On the other hand, biological methods have been associated with setbacks that include a high quantity of operation time and environmental conditions required for the survival of biological organisms as well as the requirement to disinfect the biologically treated water. In addition, the oc-

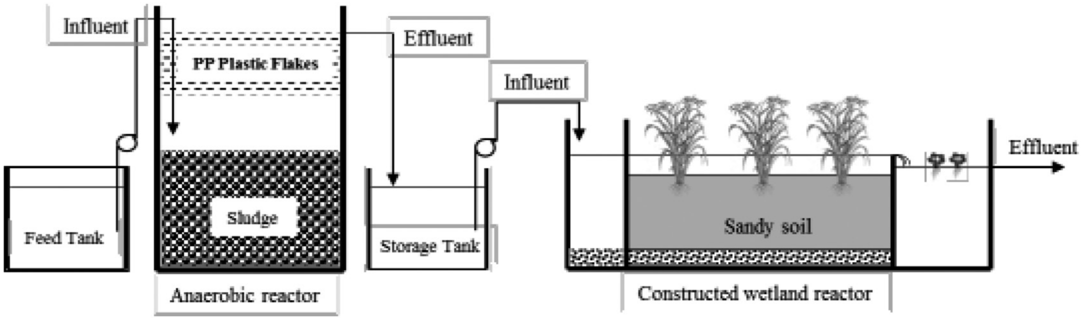

Fig. 7. Schematic diagram of wastewater treatment with anaerobic reactors-constructed wetlands system (Setiawan and Hardiani, 2020).

currence of insufficient organic carbon as substrates for heterotrophic bacteria, affects their required energy and cell synthesis, thus limiting their denitrification rate in an organic carbon-deficient environment (Matei and Racoviteanu, 2021; Fu and He, 2015). Lastly, autotrophic bacteria are reported to produce less amount of biomass and reduce the cost of post-treatment by making use of HCO_3^- and CO_2 as a carbon source for energy and cell synthesis compared to heterotrophic bacteria, however autotrophic bacteria utilization constitute a very slow process for nutrient removal (Fu and He, 2015).

4. Comparison between the efficiency of physical, chemical and biological techniques

Comparatively, physical, chemical and biological techniques have been reported to produce good quality of treated water for nutrient removal and recovery from wastewater. Chemical coagulation technique that involve the utilization of magnesium sulphate and ferric sulphate as coagulants have been documented to produce 95% removal of nitrate and phosphate from wastewater but with the generation of sludge. Comparatively, the deployment of nano-filtration membrane coupled with bioreactor has been reportedly effective in removing $N\text{-}NH_3$, $N\text{-}NO_2$, $N\text{-}NO_3^-$ and $P\text{-}PO_4^{3-}$ at a percentage nutrient removal of 90, 89, 87 and 68% respectively, which is obviously lower than the percentage removal recorded by magnesium sulphate and ferric sulphate coagulants. The use of biological technique has reported a close range of percentage nutrient removal of 86–98% ($N\text{-}NH_4^+$), 99% ($N\text{-}NO_2$), 82–99% ($N\text{-}NO_3^-$), 95–98% (total inorganic nitrogen), 71.2–31.9% (phosphate), which is comparatively close to the percentage nutrient removal recorded by nano-filtration membrane with bioreactor. The utilization of biological organisms such as macrophyte species and *chollera sp* have been studied to produce percentage nutrient removal that are in close range to the hyphenated technique of nano-filtration membrane coupled with bioreactor.

On the other hand, the deployment of electrocoagulation for nutrient removal has been reported to be highly successful for phosphate removal but exhibiting little success for nitrate removal with the use of acrylic reactor with iron and aluminum as anode and cathode electrodes yielding 99 and 27% removal of phosphate and nitrogen respectively. This comparatively agrees with the adsorption technique on using micro emulsion-prepared magnetic nanoparticles which produced 100 and 33% phosphate and nitrate removal in a contact time of 60 min.

Comparatively, ion resin exchanger and reverse osmosis have been recounted to respectively yield 97 and 85% removal of nitrate within minutes of operation, while biological denitrification has recorded approximately 100% nitrate removal for a duration of days/months. Similarly, the used of sugar cane bagasse for adsorption removal of nitrate has reportedly yield 100% nitrate removal. On the other hand, pretreatment and automation is required in both ion resin exchanger and reverse osmosis, also difficulty is encountered in managing concentrate and solution from regeneration from reverse osmosis and ion exchangers respectively. Electrodialysis has been recounted to exhibit similar conditions of pretreatment, post-treatment and operation time but with higher nitrate removal of 95%, compared to reverse osmosis. Further, biological process is reportedly dependent on the quality of raw water and associated with the potential of nitrites formation, coupled with heavy installation process and the requirement for additional carbon source for cell synthesis. In addition, ion resin exchangers and reverse osmosis require filtration without pH adjustment for pre-treatment compared to biological dentrification. On the part of post-treatment, pH adjustment is required for ion exchangers compared to biological dentrification that require disinfection as well as reverse osmosis that require pH adjustment as well as demineralization.

5. Cost estimation

Cost estimation is a crucial aspect to be considered in sustaining the process of nutrient removal and recovery from wastewater. The deployment of aeration technique for water treatment deals with an oxygenation process, especially with the release of phosphorus that has been linked with low level of dissolved oxygen. Additionally, the preliminary cost of installing an aeration pump as well as the yearly cost for maintenance has been reported to range from $50 to $800/acre (Rathore *et al.*, 2016).

Comparatively, the investment cost, operation cost and waste storage cost for reverse osmosis, have been recorded to range from, 0.12–0.23, 0.29–0.79 and 0.11–0.69 $\$/m^3$, while the cost for ion exchangers ranges from 0.06 to 0.31, 0.12–0.20 and 0.01–0.08 $\$/m^3$ respectively (Matei and Racoviteanu, 2021). On the other hand, the investment cost, operation cost and waste storage cost for biological dentrification, have been detailed to range from, 0.11–0.24, 0.13–0.21 and 0.003–0.005 $\$/m^3$. Similar comparative assessment revealed that reverse osmosis exhibit the highest total cost estimation in the range of 0.41–1.71 $\$/m^3$, compared to ion exchangers and biological dentrification with total cost estimation in the ranges of 0.18–0.57 and 0.24–0.45 $\$/m^3$ respectively (Matei and Racoviteanu, 2021).

In addition, a 40-year whole life cost of ions exchangers coupled with traditional activated sludge processes has been reportedly estimated to be approximately £7.4 M, and whole life cost of ions exchangers coupled with anaerobic membrane process has been estimated to be £6.1 M. Thus both hyphenated techniques are respectively, 17% and 27% less expensive compared to the traditional biological nutrient removal (Huang *et al.*, 2020). The cost of coagulants such as $FeCl_3$, and MgO has been reported to range between 4 and 120 USD m^{-3} respectively for wastewater treatment. Similarly, the cost of commercial activated carbon has been estimated to be 259.5 US$ per kg but the preparation of low cost activated carbon could be as low as 42.96 US$ per kg.

6. Future perspective

It is of principal scientific interest to put into consideration, factors such as the ecological vulnerability of receiving water bodies in addition to hydro-biogeochemical as well as climate hazards, which is needed in constructing the analytical framework associated with the risk of eutrophication. Thus, to prevent the consequences of eutrophication, it is important to perform regular physicochemical and biological analyses of receiving water bodies as well as the acquirement of relevant data to develop an effective model and efficient nutrient removal technique that does not contribute to secondary pollution. amongst the promising technique for nutrient removal that has received a paucity of information is dredging, which is performed by excavating nutrient enriched bottom sediment of a lake. The excavated nutrient-enriched bottom sediment of lakes may be mixed with farm soil thereby acting as a source of fertilizer for agricultural food production, however dredging is faced with the challenge of operational cost. Further, electrodialysis is another promising technique with a paucity of information on the removal of nutrients from wastewater and the prevention of eutrophication. The electrodialysis technique retains the advantage of lower pressure requirement and higher durability of membrane compared to reverse osmosis. However, the pitfalls of the electrodialysis technique include the pre-treatment of untreated water with a high contamination level of Fe, H_2S and Mn. Furthermore, emphasis should be placed on desorption studies for the recovery of nutrients from the various materials that can be used to remove nutrients from wastewater, to engineer the recovered nutrient for the production of fertilizer.

Lastly, both dredging and electrodialysis techniques have been associated with high operational cost, such as the costs of excavating the bottom sediment of water bodies and the energy cost of operating an electrodialysis instrument. However, advances should be made in the utilization of renewable energy sources such as wind and solar energy for the operation of electrodialysis for nutrient removal from wastewater.

7. Conclusion

The utilization of physical, chemical and biological techniques as mitigation strategies for combating eutrophication has been acknowledged to be effective and thus producing desirable results. Nevertheless, the use of the chemical technique as a mitigation strategy for combating eutrophication has been associated with cost implications as well as the generation of undesirable waste in the form of sludge as in the state of the coagulation method. Similarly, the use of membrane separation as a physical technique has been linked with cost implications, in addition to membrane fouling which reduces the efficiency of the membrane separation technique for removing nutrients from wastewater. On the other hand, the biological treatment technique, which has been considered to be cost-effective and environmentally friendly, has been posited to exhibit certain setbacks, which could hamper the efficiency of biological treatment techniques for combating eutrophication. These setbacks include key factors such as temperature, nutrient-to-organic carbon ratio and dissolved oxygen, which affect the removal efficiency of nutrients by microorganisms, in addition, hydraulic loading rate has been observed to have a slight effect on the efficiency of wetlands in the treatment of aquaculture wastewater.

Declaration of Competing Interest

I declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere. I know of no conflicts of interest associated with this publication, and there has been no significant financial support for this work that could have influenced its outcome. As corresponding author, I confirm that the manuscript has been read and approved for submission.

Thank you for your understanding

Data availability

Data will be made available on request.

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