Using the traditional $CaCl_2$ curing method, acridine orange dye was adsorbed onto synthesized SA and GO-based porous beads. The larger pore size enhanced the adsorption process, allowing for faster ion diffusion. Hydrogen bonds between the hydroxyl groups and carboxyl SA and those of GO were investigated. Improved adsorption kinetics and the macroporous nanocomposites (with $CaCO_3$) were found better by adding GO than using simple SA beads. A bioadsorbent was developed with a mix of calcium alginate and multi-walled carbon nanotubes (CA/MWCNTs) to adsorb ionic dyes like methyl orange (MO) and methylene blue (MB), and it was found that MO and MB have increased adsorption capacity and speed on the bioadsorbent [28]. The second-order pseudo model fit the equilibrium adsorption data well, and Langmuir and Freundlich's isotherms were used to study the adsorption kinetics. According to the results, adding MWCNTs increased the adsorption capacity of MOs by 3-fold and increased the adsorption rate of MBs compared to native CA. Li et al. [29] prepared a composite fiber of calcium alginate and multi-walled carbon nanotubes (CA/MWCNTs) by wet spinning to serve as a bioadsorbent.

Due to the large surface area, MWCNTs were able to increase the adsorption capacity on CA/MWCNT composite fibers by about 14.13 mg g^{-1} MO fibers, showing that the Langmuir adsorption isotherm fits experimental results better than the Freundlich isotherm. According to investigations by Gong et al., [30]. The complex centrifugal separation process can be a limiting factor. Therefore, adding magnetic properties to a multi-walled carbon nanotube system will aid in the separation process. Besides improving mechanical properties, the introduction of GO also ensured good adsorption capacities for cationic and anionic dyes. This is due to the covalent and non-covalent adsorption of the dyes to the resulting GO-based composite hydrogels. On the one hand, the cationic dyes have several active components, such as amino and azo groups, which interact with the carboxyl groups of the hydrogel. On the other hand, the aromatic units in the dye molecules have strong interactions. Similarly, it was found that the introduction of a zeolitic imidazolate framework (ZIF-8) showed extremely high adsorption performance for the cationic dyes crystal violet (CV) and malachite green (MG) with high adsorption capacity [31,32].

2.3 Alginate-Based Composites in Disinfection of Water

A new approach to water remediation combining biopolymers and nanoparticles has shown promise for treating water contaminated by bacteria. Although this type of conventional nanoparticle-based water disinfection faces numerous obstacles in terms of cost-effectiveness and application, it still has the potential to be used in water treatment applications. Point-of-use (POU) drinking water treatment systems have been developed since centralized drinking water treatment plants are not viable. Encapsulating sodium alginate with antimicrobial zinc oxide nanoparticles on bentonite and its bactericidal activity were prepared using surface water and artificial water containing Staphylococcus aureus [33]. The nanocomposites demonstrated excellent antimicrobial activity in just one minute, killing all bacteria in surface water with an initial bacterial concentration of 80 CFU 00mL^{-1}. In Table 2, it was shown that increasing the amount of nanocomposite and contact time improved inactivation. After 70 minutes of contact time with 0.5g of the nanocomposites and an initial bacterial concentration of 200 CFU ml^{-1} for synthetic water, no bacteria were found in the water [33].

The Nanocomposites can act as disinfectants and adsorbents to treat water loaded with bacteria. The bactericidal activity of nanocomposite is basically caused by bacteria adhering to its surfaces, probably due to their opposite charges. The leached Zn ions pierced the cell wall of the bacterium, resulting in cell lysis and death, and it was interestingly found that the amount of leached Zn^{2+} ions in water was within the permissible limits, which makes the nanocomposites suitable for disinfection. Nanocomposites are inexpensive to fabricate, making them suitable for point-of-use systems and enabling large-scale production. For portable alternative traditional water purification, silver nanoparticles (AgNPs)-alginate beads were successfully prepared for the dual purpose of disinfection and filtration by Lin et al., [34]. To test the antibacterial activity, the prepared composite beads were placed in a column of water containing Escherichia coli. Simultaneous Gelation Reduction (SGR), Adsorption Reduction (AR), and Nanoparticle Incorporation (NI) are three different methods for making composites, and all were found to have varying degrees of success in eradicating E.coli. disinfection [34].

According to the results, SGR beads are superior to the other two, shown in Figure 4. and demonstrated acceptable bactericidal performance with a relatively low material consumption rate. Beak et al. [35] created ZnO NP-alginate beads to kill antibiotic-resistant bacteria. The research findings of this experiment showed significant effectiveness. Alginate biopolymer serves as a dispersant and improves the electrostatic and repulsion in the process of inactivation bacteria. Also, it assists in maintaining a larger surface area while preventing nanoparticle aggregation. Therefore, ZnO NP-alginate beads have been demonstrated to be a versatile material for the disinfection and filtration of antibiotic-resistant bacteria [35].

Table 2: Bactericidal activity of alginate nanocomposites

Nature of water	Initial Bacterial concentration	Nanocomposite amount	Time of contact	Status
Surface water	80 cfu/100 ml	0.2g/100ml of surface water	1 min	Inactivation of bacterial growth
Synthetic water	200 cfu/1 ml	0.2g/100ml of synthetic water	120 mins	,,
		0.5g/100ml of synthetic water	70 mins	,,
		1g/100ml of synthetic water	1 min	,,

2.4 Alginate- Ionic Liquid Composite for Water Treatment

For the removal of Hg(II) from contaminated water, a novel solid-phase extractant media was prepared by using ionic liquid and PVA-alginate matrix gel beads and found an adsorptive removal rate of 99.98%, the maximum Hg(II) ion adsorption capacity measured was 49.89 (0.11) mg/g at pH 5.8. Hg was preferred over Pb and Cu regarding the PVA/IL beads' selectivity for those ions [36]. The results of the second-order model following kinetic data indicated that PVA/IL beads could be effectively used as novel extractants to remove divalent mercury from aqueous solutions under simpler operating conditions. Tetra-alkylphosphonium dicyanamide, or Cyphos IL-105, was biopolymerized and immobilized in alginate capsules to bind Cd(II) to HCl solutions effectively. Between Cd(II) and the phosphonium cation, there was a 1:2 ratio, and the sorption capacity was found to increase proportionally with ionic liquid content. The chemical reaction rate equation, or pseudo-second order [37], and Crank's equation, which measures resistance to intraparticle diffusion, accurately describe the uptake kinetic data. Rufato et al. [38] created chitosan/alginate and N, N-dimethyl chitosan/alginate-based adsorbents for removal of Pb(II) ions from wastewater and found it performed effectively at significant levels and it was also possible to recover and repurpose the used ionic liquid [38].

Cyphos Phosphonium ionic liquids and Cyphos ionic liquids (IL-111, IL-109, IL-105, and IL-101) were immobilized in alginate/gelatin composite capsules and tested for sorption of Cd(II). Since Cyphos IL-111 is typically solid at room temperature, the phase change makes the resin particle form large vesicles [39]. It was also found that the anionic components of the IL, like chloride, tetrafluoroborate, and dicyanamide, did not affect the sorption isotherms. Diffusion properties of adsorbents were improved by taking advantage of their intraparticle diffusion kinetic equation and creating highly porous foams as an alternative to resin beads. Alginate was immobilized using alkylphosphonium IL to bind Pd(II) from HCl solutions.

The batch hydrogenation of nitro phenols (NPs) and 4-nitroaniline (4-NA) was tested on the composite material using sodium formate/formic acid as the hydrogen donor (HD) post-chemical reduction of Pd(II). For 2-NP, 3-NP, 4-NP, and 4-NA, the effects of agitation, particle type, size, concentration, and pH on lead adsorption have been assessed. A polymer composite with a blend of gelatin and alginate by using resins immobilized with Cyphos IL-101, resins, which range in size and ionic liquid content (IL), have been used to remove mercury from HCl solutions irrespective of their concentration, it no effect on extraction. Thus, the ion exchange was used to recover metal (binding of HgCl42-). The effectiveness of the resins for recovering Hg(II) was demonstrated by sorption isotherms and uptake kinetics that adhered to pseudo-second order [40]. Tetraalkylphosphonium IL was used to strengthen the gel in highly porous discs by being immobilized in cellulose fibers and alginate as composites. These biopolymer composite discs have been used to immobilize Pd(II) by adsorption from HCl solutions. The metal reduction makes it possible to create a catalytic material that can successfully hydrogenate 4-nitroaniline into p-phenylene diamine while using formic acid. For eight consecutive catalytic runs, the kinetics of hydrogenation were achieved by the IL and compared with methanol-washed material (without the IL). Pd micro/nanoparticles can be stabilized by the composite's presence, preventing their release into the solution.

Alginate beads immobilized with ionic liquid function as sustainable and biodegradable adsorbent material. Separation Lead(II) ion from contaminated water was separated by using alginate (Alg) beads with ILs of [Bmim][PF6], [Bmim][DCA] and [Bmim][NTf2] and $CaCl_2$ as a cross-linker, the adsorption Pb(II) depends on the type and loading of the ionic liquid used and initial pH of the water contaminated with the Pb (II). The results of the experiments also showed that 25% Bmim DCA-impregnated alginate beads have the highest capacity for adsorption at pH 5.5. The research on alginate ionic liquid composites is still in the early stage and should be encouraged for a clean and sustainable environment [41].

The high adsorption performance was ascribed to the mesoporous/macroporous network-like structure and the availability of many active adsorption sites in the alginate-based hydrogel. The role of GO in creating the specific surface area and porosity has improved the removal of pollutants at higher levels. It has been reported that GO improved adsorption using NaAlg-acrylamide with high specific surface area (6.983 m^2/g) and porosity (average pore diameter: 24.62 nm) as it was proven by comparison of the adsorption capacity of acrylamide/graphene NaAlg system with and without GO [42]. Inorganic nanomaterial-based NaAlg hydrogels have also increased the capability of removing pollutants. For instance, a nanocomposite hydrogel consisting of acrylic acid, NaAlg, and tetraammine copper (II) sulfate was developed by in-situ cross-linking for the adsorption of CV and malachite green (MG) due to improving the chemical interaction with the dye molecules while enlarging the surface area for adsorption, the NPs incorporated in the hydrogel facilitated dye adsorption [43]. Similarly, Maqbool et al. [44] reported that Congo red dye could be adsorbed and removed by sodium alginate and polypyrrole composites blended with algal biomass. Fluoride is a major water contamination and is often associated with fluorosis of teeth. Kumari et al. [45] proposed Fe_3O_4/graphene/alginate hydrogels for removing fluoride (F) ions from water. Alginate-based hydrogel was proven to be an excellent material for removing heavy metals. Santoso et al., [46] developed calcium alginate-exfoliated clay sponge composites to remove Cu^{2+} and Cr^{6+} ions from an aqueous solution.

3. Conclusion and Perspectives

From the literature reports, it can be concluded that an alginate-based hydrogel can be one of the candidates for effectively removing pollutants like heavy metal ions, dye, and microbes from water. Further, incorporating nanomaterials like GO, ZnO, TiO_2, etc., greatly improves the adsorption performance of the hydrogel because the nanoparticles significantly improve the surface area and porosity of the hydrogel. Alginate-based hydrogels can incorporate a large amount of water due to their hydrophilic nature and unique structural forms like flat membranes, hollow fibers, microspheres, gels, foams, nanofibers, etc. Alginate, a green biopolymer extracted renewal seaweed, could provide an edge over synthetic fossil fuel-based materials and has huge potential to manage water pollution.

However, the main challenge in applying alginate-based hydrogel in water treatment is carrying out experimental procedures in practical applications and variable environmental conditions. The research that has been carried out is mostly at the laboratory scale. Therefore, research must be carried out at a large scale and develop pollutant-based application procedures. Though environmental conditions significantly impact adsorption behavior, it is rare to find the testing of the hydrogels for real water samples in the literature. The effectiveness of hydrogels under challenging environmental conditions must, therefore, be prioritized. Also, considerable efforts still need to be employed in the context of the circular economy, a market analysis of the alginate markets, and the production capacity of alginate-bearing seaweeds.

Author contributions

Conceptualization, D. Lakshmi**,** K. Radha, T. Azeez and Sh. Munisamy; writing—review and editing, D. Lakshmi, K. Radha, T. Azeez and Sh. Munisamy. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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