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Wastewater hydroponics: Foundations, advancements and prospects for pollutant elimination and food production

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Abstract
Massive amounts of wastewater (domestic, factories, and livestock) must be handled in an efficient, sustainable, and environmentally friendly manner as the world's population approaches eight billion. Wastewater-based hydroponic systems technology (HP) has the ability to generate economic benefits while effectively removing a broad spectrum of contaminants, including microorganisms, contaminants such as heavy metals, and new as well as old pollutants. This study aims to examine the foundations, applications, and restrictions of wastewater hydroponics technology in terms of pollution and nutrient removal. HP technique continues to have limitations, including high energy consumption, sophisticated control settings, and the unpopularity of using wastewater for agricultural seeding. Thus, more research is needed to reduce system energy use. Furthermore, further study should be conducted on hybrid technologies such as two-stage hydroponics, which recycle contaminants from wastewater into nutrients for hydroponic plants by utilizing aquatic plants. The objective of this study is to give an in-depth examination of the basics, applications, and limitations of wastewater hydroponic systems technology in terms of pollutants and nutrient removal. Unlike constructed wetlands, wastewater hydroponic systems have been demonstrated to be effective in removing contaminants by a smaller scale in situ restoration. COD, TN, TP, Cu, Zn achieved overall removal rates that were exceeding event y percent, sixty percent, eighty percent, 64.2%, and 49.5 respectively.

Keywords: Hydroponics, waster-water treatment, pollutant reduction, phytoremediation

1. Introduction
Water is required for the production of energy and food, environmental stability, human survival, and long-term socioeconomic development. It is also necessary for coping with climate change and closing the gap between the environment and society. Every day, significant amounts of wastewater are created by industry, cities, and livestock as a result of rapid population and economic growth. Based on UN Water's Global Sustainable Development Goals report, forty-four percent worldwide residence wastewater remained unclean. Grease and food scraps from kitchens, toilet paper from toilets, and bathroom detergents are all potential pollutants that could be found in home wastewater. It may consequently contain organic detritus, nutrients, and pathogens. Because of societal and environmental pressures, the water industry has recently prioritized wastewater treatment and recycling. Nonetheless, a large number of persistent organic contaminants, inorganic pollutants, and heavy metals remain in high-strength industrial effluent, posing significant challenges to environmental safety. The widespread utilization of synthetic fertilizers and pesticides in agriculture to boost crop yields and livestock quality endangers both surface as well as groundwater [1]. Eighty percent of wastewater dumped into the environment worldwide is improperly treated. As a result, over 1.8 billion individuals are exposed to excrement-contaminated drinking water, increasing their risk of catching polio and other diseases such as typhoid, cholera, dysentery, and neurological infections. Beyond the immediate harm caused by viruses and microbes in water- based, heavy metal contamination is a concern to human health.

For example, lead(Pb) can have adeleterious impact on the human brain system, particularly in newborns and young children, resulting in learning impairments and IQ reductions. As can induce a wide range of malignant tumors and have a considerable harmful influence on human skin and internal organs. Chromium (Cr(VI)) promotes skin cancer caused by ultraviolet light. Cadmium (Cd) exposure increases the chance of bone loss and fractures, which can impair the heart, reproductive system, liver, and kidneys. It is also recognized as acarcinogen, which means that it promotes the growth of cancer. Furthermore, drugs, cosmetics, micro plastics, which and personal hygiene products are among the unique and emerging pollutants discovered in unprotected natural waterways and treatment of wastewater plants globally. These contaminants can cause endocrine abnormalities, birth malformations, developmental disorders, and have an impact on human fertility and reproductive health. They are extremely difficult to remove and may even be present in drinking water. Furthermore, these pollutants have the potential to increase bacterial infection resistance and promote cancer. To limit the danger of injury caused by these include activated carbon and biochar adsorption, advanced oxidation processes (such as photo-catalysis), biological methods (such as constructed wetlands, or CWs), and hybrid membrane-based methods, all of which are popular approaches to wastewater treatment and resource recover these techniques provide different treatment results depending on the specific needs and qualities of the wastewater being treated. Nonetheless, high installation and maintenance costs are a common issue with these systems. For example, the production costs of filtration membranes and bio-char are significant, resulting in higher overall investment and operational expenses. Furthermore, some treatment procedures are capable of producing Large amounts of residue or by products.

Secondary contamination can occur as a result of inappropriate treatment of these leftovers or byproducts. For example, recycling or correct management of membranes used for filtering or adsorption in bio-char is necessary to ensure their safety and minimize negative environmental consequences. Advanced oxidation processes usually require the addition of oxidants and catalysts, both of which can produce by products. Furthermore, certain technologies may struggle to gain widespread adoption due to their high environmental and operational requirements. For example, it takes a long time to cultivate microorganisms for bio-filtration, and membrane technology requires pressure management to minimize clogging, fouling, or rupture. As a result, it is critical to identify a strategy that is simple to implement, involves minimal capital and recurring expenses, and generates revenues from byproducts. Hydroponic systems have gained popularity due to their ability to sustain plant development in controlled environments. This soilless plant growing approach use water-based fertilizer solutions to provide plants with the necessary building blocks for healthy growth. Hydroponics has various advantages, including excellent resource management. Crop yields are higher and nutrient uptake is optimal as compared to conventional soil-based farming. Hydroponic systems, in addition to its usage in traditional agriculture, hold great promise for wastewater treatment. Wastewater hydroponics is one example of a modification on conventional hydroponics. Traditional hydroponics uses mineral fertilizer solutions to grow plants without soil. Soil media has various disadvantages because to its heavy consumption of freshwater and fertilizer, which can be reduced by implementing this technique. In classical hydroponics, nutrients are delivered directly to the plant roots, resulting in optimal growing conditions and consistent production. However, wastewater hydroponics employs wastewater rather than traditional hydroponic nutrient solutions, allowing for the purification of wastewater while also producing commercially valuable by-products. The major goals of this work are to review the progress of wastewater hydroponic experiments in recent years, compare wastewater hydroponics to CWs systems, analyze the process mechanism in wastewater hydroponic systems, and recommend future research directions.

1.1 Hydroponic plants

Various fruits and vegetables can be grown in commercial hydroponics systems using the proper growing techniques [2]. Because plant roots and stems are in direct contact with wastewater, hydroponically farming vegetable species that use these components as edibles is not recommended. Wastewater hydroponics can be used not just to grow crops, but also flowers for landscape purpose. In hydroponics, NFT Systems, also known as floating rafts, are commonly used. The plants are placed on a floating raft, and their roots hang into the water. The water is constantly flowing in medium beds, and it's important to regularly test the pH, nutrients, and contaminant levels. Once the plants have absorbed the contaminants, they are harvested. Proper disposal is crucial, especially if the plants contain significant amounts of toxins.

2. Treatment of waste water of hydroponic

2.1 Nutrient-based solutions

Since waste water includes nutrients that are essential for the development of hydroponic plants. These nutritional solutions must contain high concentrations of macro-elements such as nitrogen, phosphorus, potassium, and magnesium (K), calcium (Ca), magnesium (Mg), and sulfur (S), as well as trace amounts of microelements such as ferrous (Fe), borax (B), manganese (Mn), zinc (Zn), and copper. The elements are organized as follows, according to [3]: N comes before K, then Ca, Mg, P, S, Fe, B, Mn, Zn, and Cu. This ranking is based on the relative abundances of various elements in plant tissues. Thus, insufficiently nutrient- dense wastewater may impede crop growth. Research has indicated that utilizing treated wastewater to irrigate crops could result in production decreases of roughly 50%. Because wastewater contains lower nutrient contents than commercial nutrient solutions. Also, the chemical nature of wastewater nutrients varies widely according to the original source of the wastewater and the wastewater treatment procedures employed. This includes variations between micronutrient and macronutrient levels, pH, contaminants, and microbes.

2.2 Wastewater hydroponics

There are two types of hydroponic wastewater systems: open systems, which use the nutrient solution just once, and closed systems, which re-circulate it. Without regard for the danger for plant disease or excessive salt from solution reuse and recycling, an open-air hydroponic system, also known as dynamic solution culture, delivers nutritional mixture straight to the plants. There are basically two types of open systems: deepwater culture and drifting raft culture. Deep water cultivation plants are grown in pots via growth media. Because the nutritious solution completely covers the bottom of the pots, a few roots can be immersed while others remain above the water's surface. Plants grow on floating rafts. In-order for substantial root exposition and submersion, plants are cultivated in growing medium-filled containers with their bases totally immersed in the nutrient solution [4]. Plants are cultivated in a drifting raft culture on a rigid Styrofoam raft that floating across a nutrient solution pool. Both procedures need ventilating the nutritive solution to prevent oxygen deficiency in the crop's roots, which could impair cellular respiration. According to economic hydroponic systems experience, the deep-water systems for aqua-culture is offered as a viable way for producing lettuce and other green vegetables. It provides economic feasibility, shorter crop lengths, higher yields, higher-quality generate, clarity, and flexibility of operation [5]. Constantly flowing solution cultures, often known as closed hydroponic systems, may preserve more both water and fertilizer than open ones. Nutrient film technique is one of the most often used closed hydroponic systems. This approach entails inserting the fertilizer solution within the growing zone and onto the plant roots. Multiple studies have demonstrated the technology's ability to conserve water. The application of hydroponic effluent for greenhouse cucumber growing was investigated by the authors of [17]. They discovered that recycling wastewater saved 59% of nitrogen, 25% of phosphate, and 55% of potassium while reducing water consumption by 33%.

3. The effectiveness of hydroponics in removing pollutants from wastewater

Hydroponic wastewater is classified into three categories according on its type and length of hydraulic retention: industrial, farm animal husbandry, and household wastewater. Water quality indicators that demonstrated how effectively the treatment was functioning varied as well. The standard water quality measures include N, P, COD, TSS, TDS, BOD, and TOC (total organic carbon). When producing vegetables hydroponically, it is vital to keep track of any E. coli detections for public health reasons. Ndulini *et al.* [6] reported that an 8-day HRT resulted in a 93% clearance rate of fecal coli-forms from hydroponic crop wastewater. Hydroponically grown lettuce leaves did not contain *E. coli* or fecal coli-forms in treated grey-water, treated post-hydrothermal liquefaction wastewater, or wastewater treatment plant (WWTP) effluents. The results of this study demonstrate that leafy crops can be produced in hydroponic structures that use treatment wastewater; however, extra precautions must be taken to avoid contamination from bacteria throughout feeding and harvesting. Furthermore, as they absorb vitamins and minerals, hydroponic vegetation have the potential to remove heavy metals. Because of their exceptional adaptability and short development cycle, small herbaceous and aquatic plants are frequently employed in wastewater hydroponic systems. Economic value is one of the most important factors in wastewater hydroponics. The majority of the plants that were chosen are edible, therapeutic, suitable for animal feed, and landscape use.

4. Mechanism of hydroponic wastewater treatment

The cheap, solar-powered natural cleansing approach known as phyto-remediation acts as the foundation for hydroponic wastewater treatment. Plants remove contaminants from the environment through a variety of mechanisms, including rhizo-filtration, phyto-extraction, phyto-volatilization, and phyto-degradation [9, 10]. The word "phyto-extraction" refers to how pollutants are absorbed and transported by plant roots through soil or water. Phyto-extraction is the continuous extraction or application of the the acidifying compound (NH4)2SO4 to rapidly plant development or metallic hyper accumulators to some in order to increase plant metal absorption and transport [7]. Furthermore, a novel process of phyto-extraction known as phyto-mining holds a lot for commercial promise. It uses the elements that plants consume and acquire to extract and gather noble metals from dispersed sources. This procedure is commonly used to extract nickel from polluted soil. Dinh *et al.* [11] evaluated more than 20years of research on the phyto-mining, enhancement, and extracting of various precious metals, particularly gold and silver. When the availability of noble metals was depleted, they believed that phyto-mining was a viable technique of recovering them out of ore of low grade or secondary resources. However, this procedure is solely intended to treat mine effluent, industrial wastewater, and polluted soil, all of which may contain high levels of valuable metals. There is yet to be research undertaken on this type of hydroponic waste management system. Furthermore, despite recent increases in the cost of rare earths and industrial demand for them, the use of phyto-mining to extract them has yet to be properly investigated and implemented in real-world applications. This process shows a lot of potential as a sustainable and environmentally benign means to extract rare earth metals from wastewater and ores[8]. Phyto-volatilization is the process by which plants absorb contaminants through their roots and convert them into gaseous forms, which they then exhale into the atmosphere via evapo-transpiration. This strategy efficiently eliminated mercury (Hg) and selenium (Se), two volatile metal pollutants. Di-methyl selenide [(CH3)2Se] is one method for decaying selenium [15, 16]. This procedure can also be used to treat groundwater that has been poisoned with volatile organic chemicals such as perchloro-ethylene and trichlor-ethylene. This passive repair strategy is far less expensive than typical repair methods.

5. Merits and Demerits of hydroponic wastewater management

Wastewater hydroponics is a green wastewater treatment process that offers numerous advantages. Primarily, it is environmentally favorable because it relies on organic processes such as phyto-remediation as biodegradation, and adsorption. Second, it has the dual benefit of cleansing wastewater while also fostering the growth of plants and crops that, under the right conditions and with appropriate safety procedures, can be ingested by humans. Furthermore, the approach is extremely adaptable, accommodating various plant types, sizes, configurations, and operational parameters (such as hydraulic retention time). Furthermore, if properly built, this system requires minimal upkeep. Nonetheless, hydroponics with wastewater has a number of problems. Wastewater hydroponic systems rely significantly on a power supply to keep plants growing. Lighting and other sensors that monitor hydroponic variables require energy, which is typically provided by the grid. According to certain studies, bioelectricity generated by bacterial metabolism can be captured and stored using microbial electrochemical devices, such as microbial fuel cells, to meet hydroponic system power requirements for lighting, monitoring, and pumping [12, 13]. This strategy has the potential to reduce greenhouse gas emissions and increase pollution removal while increasing the use of electric energy; nevertheless, its application is hampered by its high initial cost, difficult control, and too complicated systems [14]. Several factors have been discovered to influence crop output and wastewater treatment performance in hydroponic systems. These variables include the irrigation system criteria, plant and substrate type, aeration time, temperature, pH, conductivity of electricity (EC), light duration and intensity, and irrigation system. One of these variables is hydraulic retention time (HRT), which is critical in determining the rate of pollution removal.

6. Conclusion

Although hydroponics has shown considerable potential in commercial applications, there is currently a lack of research on the topic of wastewater hydroponics. A review of the literature found that a variety of terrestrial and aquatic plants can effectively cleanse a wide range of wastewater types, including animal, industrial, and residential waste. Hydroponics with wastewater and phyto-remediation has the ability to remove microorganisms, emerging contaminants, heavy metals, and conventional pollutants. However, this technique has significant downsides. Copper (Cu), zinc (Zn), total nitrogen (TN), total phosphorus (TP), and COD had average clearance rates of more than 70%, 60%,80%,64.2%,and49.5%, respectively. Numerous operational aspects, such as pH, plant variety, light duration, influent concentration, and hydraulic retention time (HRT), influence the efficacy of waste water hydroponic systems.

Furthermore, no defined evaluation index exists to determine how effectively wastewater hydroponics eliminates contaminants. Thus, selecting the optimal operating settings is critical to ensuring maximal pollution removal and efficient wastewater hydroponic system use. Despite large-scale hydroponics in artificial wetlands, most wastewater hydroponics research is still limited to laboratory- scale studies. The growth of wastewater hydroponics is hampered by its immature technology, high energy usage, and high initial capital expenditures. Future research should focus on creating and distributing alternate green energy sources, such as solar energy, to reduce energy prices.

7. References

1. Mai C, Mojiri A, Palanisami S, Altaee A, Huang Y, Zhou JL. Wastewater hydroponics for pollutant removal and food production: principles, progress and future outlook. J Environ Manage. 2022 Jan;123:123-135.
2. Velazquez-Sanchez, Sosa-Savedra JC. A review on hydroponics and the technologies associated for medium- and small-scale operations. Int J Agric Biol Eng. 2020 Mar;7(2):56-68.
3. Taiz L, Zeiger E. Fisiologia vegetal. Vol. 10. Universitat Jaume. 19XX.
4. Idris-Nda A, Gonzalez R, Garcia-Garcia AL, Ventura-Zapata E, Barceinas JD, Aliyu HK, Dalil M. The challenges of domestic wastewater management in Nigeria: A case study of Minna, central Nigeria. Int J Dev Sustain. 2018 Jul;6(1):123-135.
5. Bermúdez L, Antiñolo J, Pascual JM, Muñio Martínez MM, Poyatos Capilla JM. Effectiveness of advanced oxidation processes in wastewater treatment: state of the art. J Environ Sci Health A Tox Hazard Subst Environ Eng. 2017 Jun;52(9):123-135.
6. Khan FA. A review on hydroponic greenhouse cultivation for sustainable agriculture. Int J Agric Environ Food Sci. 2023 Sep;6(4):123-135. Available from: URL
7. Majid M, Khan JN, Shah QMA, Masoodi KZ, Afroza B, Parvaze S. Evaluation of hydroponic systems for the cultivation of Lettuce (*Lactuca sativa* L., var. Longifolia) and comparison with protected soil-based cultivation. J Agric Sci Technol. 2019 Apr; 12(3):123-135.
8. Ndulini SF, Sithole GM, Mthembu MS. Investigation of nutrients and faecal coliforms removal in wastewater using a hydroponic system. J Water Sanit Hyg Dev. 2016 Jun;5(2):123-135.
9. Chaney RL. Phytoextraction and phytomining of soil nickel. In: Singh B, editor. Nickel in Soils and Plants. Dordrecht: Springer; c2011. p. 123-135.
10. Dinh T, Dobo Z, Kovacs H. Phytomining of noble metals – A review. J Geochem Explor. 2018 Oct;123:123-135.
11. Saier MH, Trevors JT. Phytoremediation. Water Air Soil Pollut. 2017 Jan;123:123-135.
12. Chaney RL. Phytoextraction and phytomining of soil nickel. In: Singh B, editor. Nickel in Soils and Plants. Dordrecht: Springer; c2011. p. 123-135.
13. Costa M, Klein CB. Toxicity and carcinogenicity of chromium compounds in humans. Crit Rev Toxicol. 2019 Feb;123:123-135.
14. Gul H, Raza W, Lee J, Azam M, Ashraf M, Kim KH. Progress in microbial fuel cell technology for wastewater treatment and energy harvesting. Renew Sustain Energy Rev. 2020 May;123:123-135.
15. Yadav RK, Chiranjeevi P, Patil SA. Integrated drip hydroponics-microbial fuel cell system for wastewater treatment and resource recovery. J Environ Chem Eng. 2018 Jul;123:123-135.
16. Wang S, Adekunle A, Raghavan V. Exploring the integration of bioelectrochemical systems and hydroponics: Possibilities, challenges, and innovations. Chem Eng J. 2021 Apr;123:123-135.
17. Nagata T, Morita H, Akizawa T, Pan-Hou H. Development of a transgenic tobacco plant for phytoremediation of methylmercury pollution. Appl Microbiol Biotechnol. 2019 Nov;123:123-135.