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ALGAE-BASED WASTEWATER TREATMENT: PHYTOREMEDIATION POTENTIAL OF MICROALGAE AND MACROALGAE

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Abstract

Algae play a crucial role in aqueous ecosystem by form the energy base of the food web for all aqueous organisms. As autotrophic organisms, algae convert aqua and carbon dioxide to sugar through the process of photosynthesis. The algae perform the wastewater treatment by interdictory nitrogen, phosphorus and decomposed organic carbon. Those evolution conditions destabilize noxious bacteria while yielding more energy-rich biomass than current treatment systems. Algal biosorption is used to recapture heavy metals from wastewater. The algal cells can then spend the heavy metals for their flourish and evolution. Diatoms have been calibrate for their role in heavy metal expulsion and as they represent 45% of the oceanic primary creativeness. Chlorophyta and Cyanophyta are hyper-absorbents and hyper-accumulators for Arsenic and Boron, intriguing and collect these essence from their atmosphere into their flesh. These algae can be hyper-phytoremediators and their arrival in water decrease Arsenic and Boron pollutant. Phytoremediation is the use of micro or macroalgae for the expulsion or biotransformation of pollutants, including nutrients and aconitic chemic from wastewater. Phytoremediation technology is an swell green outlook used to explore, demean and recapture various types of pollutants from the atmosphere. Different types of contaminants that cause bad effects on human health and other biotic systems are removed using plant nation. Phytoremediation an eco-friendly method utilizing plants for pollutant expulsion. Cost-effective, detract the need for vast infrastructure. Defiance comprise time-consuming procedure, site-specific efficacy and plant nation picking.

Key word: Algae, Phytoremediation, Wastewater management, Chlorophyta, Cyanophyta and Atmosphere.

Introduction

Wastewater management is a critical global concern due to increasing industrialization, urbanization and agricultural intensification. Large volume of untreated or inadequately treated wastewater are discharged into natural water bodies, resulting in nutrient enrichment, eutrophication, toxicity and severe ecological imbalance. Conventional wastewater treatment

methods, though effective are often energy-intensive and economically unsustainable. The pollutants can enter water bodies at various point and non-point and wastewater discharge remains a major pathway. Wastewater treatment effectively reduces contaminants, it is expensive and requires an eco-friendly and sustainable alternative approach to detract treatment costs (Bhatt *et.al* 2022). These problems of pollution can be partially solved by the application of phytoremediation technologies using algae or aquatic plants to recapture pollutants from the atmosphere (Chekroun and Baghour 2013). One of the consequences of this increase is the descent of larger quantities and varieties of wastewater contaminated with a wide range and concentrations of chemic. Besides utilizing several tons of pesticides per year, the agricultural sector also produces considerable amounts of biologic waste (Bockstaller *et.al* 2009), and is one of the most significant sprig of water contamination. These pollutants can have dire consequences for the atmosphere and for ecosystems into which they are discharged. Some pollutants mainly those of organic are generally degradable (either naturally or with the help of microorganisms) and therefore do not cause major problems for the atmosphere (Schwarzenbach *et.al* 2010). Algae are non-vascular plants that spectrum in magnitude from single-celled or colonial microalgae or “phytoplankton” such as diatoms and dinoflagllates, to large multicellular macroalgae such as seaweed or kelp. Every alga restrain chlorophyll but the many of them lack stems, vascular tissue, roots and leaves (Anbuchezhian *et.al* 2015). Microalgae are promising candidates for wastewater reclamation as they are competent of scarcity the congeries of nitrogen and phosphate as well as other aconitic compounds side by side heavy metals or pharmaceuticals (Plohn *et.al* 2020). Bioremediation by algae called “phytoremediation” has swell as a viable method for protection HMs from wastewater (Koul *et.al* 2022; Ahmad *et.al* 2020; Poo *et.al* 2018). Phytoremediation is the process of using plants to sequester aconitic chemic from soil and water (Yan *et.al* 2020; Tiwari *et.al* 2019). In the context, biological methods such as phytoremediation have gained increasing attention. Among biological agents, algae-both microalgae and macroalgae-have emerged as efficient, eco-friendly and cost-effective candidates for wastewater treatment. Their rapid growth, ability to absorb nutrients and toxic compounds and potential for biomass valorization make them particularly suitable for sustainable remediation strategies.

Source: Algae Live Science.

Types of wastewater

Wastewater is generated from a variety of domestic, industrial and agricultural activities and its composition depends largely on the source. The major categories of wastewater are as follows:

Domestic wastewater- Originates from households and residential areas. It contains organic matter, detergents, and minor chemical pollutants. In urban areas, this wastewater is usually transported to treatment plants through sewerage systems, whereas in rural regions it is often discharged untreated (Rangari *et.al* 2022).

Trade effluent- Liquid waste from industrial and commercial activities, including food processing, chemical manufacturing, and textile industries. It is often discharged into municipal systems or directly into environment (NI Water, 2021).

Grey water- Wastewater derived from sinks, showers, bathtubs, and washing machines. It has a lower contamination load than blackwater and can be reused for non-potable purposes after simple treatment (Global Water Group, 2019). Grey water that water food particles can validate tiller, it can also be applied for washing and flushing toilets (Admin 2019).

Black water- Wastewater from toilets and kitchens containing human excreta and food residues. Due to its pathogen load, it requires effective treatment before disposal (Global

Water Group, 2019). Black water is also indicated to as sludge or brown water and can carry illness and bacteria both of which could be injurious (Admin 2019).

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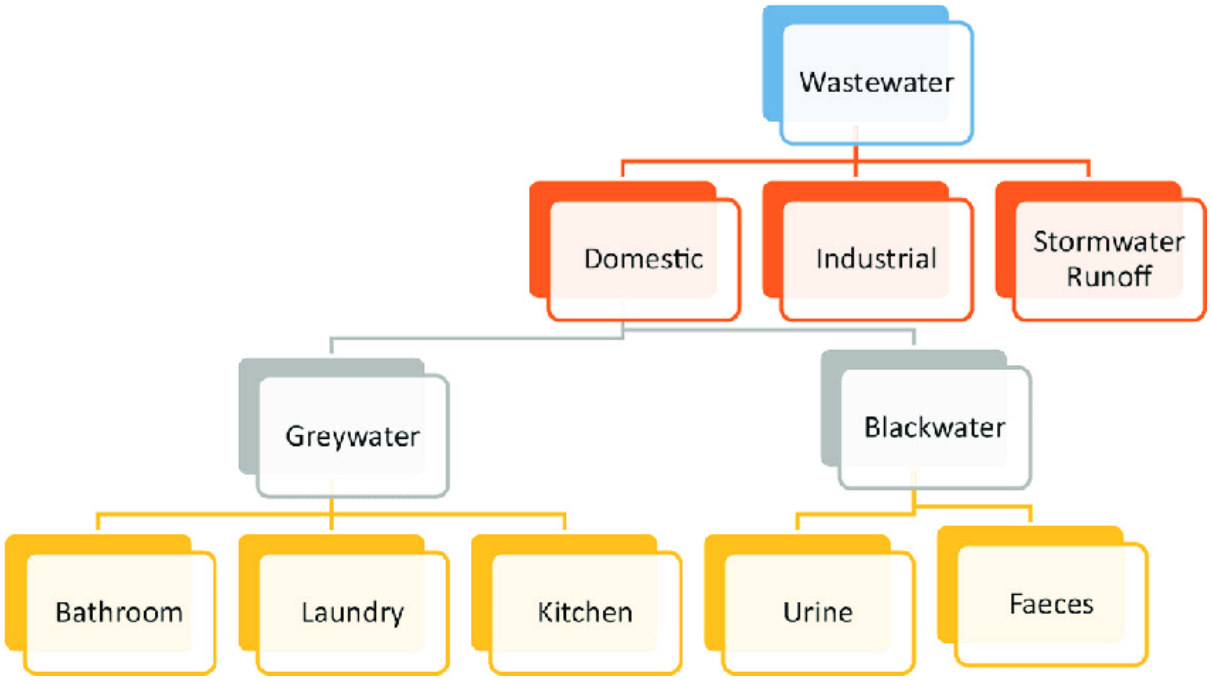
Sewage wastewater- Broadly refers to wastewater containing human excreta and municipal discharges. It typically includes domestic, commercial and industrial waste streams (UNEP, 2008)

Industrial wastewater- Highly variable in composition depending on the industry. It may contain dyes, heavy metals, organic matter and toxic chemicals. Industries such as textiles, tanning and mining are major contributors (Alturkmani, 2013).



Sources: Types of waste water| Download scientific diagram by Joshua Nosa Edokpayi (2017).

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Role of microalgae and macroalgae in wastewater

Microalgae can utilize wastewater as a nutrient-rich medium and remove pollutants through biosorption, bioaccumulation and biodegradation. They are effective in treating agricultural runoff, textile effluents and pharmaceutical wastewater (Abdelfattah *et.al* 2023). Microalgae-based systems are cost-effective, sustainable and capable of sequestering carbon dioxide. The biomass generated can be used to produce biofuels, animal feed, and fertilizers.

Macroalgae also absorb nutrients and toxicity compounds efficiently due to their large bioass and rapid growth. They are particularly effective in removing dyes and synthetic pollutants. For instance, macroalgae have shown over 98% efficiency in removing crystal violet from wastewater (Bibi *et al*., 2023). Additionally, macroalgae biomass can be used in agriculture, phatmaceutical and biofertilizer production, integrating pollution management with resource recovery (Zrimec *et al*., 2022).

Phytoremediation of heavy metals by algae

Phytoremediation employs plants and algae to detoxify polluted environments. Algae demonstrate high efficiency in removing heavy metals because of their fast growth and tolerance to harsh conditions.

Mechanisms of Heavy Metal Removal:

- Biosorption- binding of metals to functional groups on algal cell surfaces.
- Bioaccumulation-active uptake into algal cells.
- Biotransformation- conversion of toxic ions into less harmful forms.

Microalgae such as chlorella vulgaris and Scenedesmus obliquus remove cadmium, lead, chromium and arsenic effectively (Sudha *et al*., 2019). Their extracellular polymeric substances enhance metal-binding.

Macroalgae like Ulva, Sargassum and Gracilaria are also efficient, with brown algae (Sargassum spp.) showing high capacity for lead, copper, and nickel removal (Kumar and Gaur, 2020).

Advantages include low cost, eco-friendliness, simultaneous nutrient removal and biomass valorization for fertilizers and bioenergy.

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Conclusion

The increasing discharge of untreated wastewater poses serious risks to ecosystems and human health. Algae-based phytoremediation provides a sustainable and cost-effective

solution for wastewater management. Both microalgae and macroalgae efficiently remove nutrients, heavy metals and organic pollutants while generating biomass for biofuels, fertilizers and other value-added products.

However, large-scale applications face challenges such as wastewater variability, biomass harvesting and seasonal growth fluctuations. Future research should focus on integrated algal-bacterial systems, immobilized bioreactors and genetically engineered strains to enhance pollutant uptake and resilience.

By coming phytoremediation with circular economy strategies, algae-based systems can contribute significantly to sustainable wastewater management, energy security, and environmental protection.

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