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Abstract

Purpose: The aim of the study was to investigate the effects of salinity on aquatic plant growth in Ethiopia.

Methodology: This study adopted a desk methodology. A desk study research design is commonly known as secondary data collection. This is basically collecting data from existing resources preferably because of its low cost advantage as compared to a field research. Our current study looked into already published studies and reports as the data was easily accessed through online journals and libraries.

Findings: Salinity negatively impacts aquatic plant growth in Ethiopia, reducing seed germination, photosynthesis, and nutrient uptake, leading to stunted growth. Studies in the Awash River Basin and Rift Valley lakes show that high salt levels cause osmotic stress, ion toxicity, and oxidative damage, weakening freshwater plants like papyrus and water hyacinth. Adaptive strategies, such as salt-tolerant species, better water management, and riparian afforestation, are essential for ecosystem restoration.

Unique Contribution to Theory, Practice and Policy: Osmotic stress theory, ion toxicity and selectivity theory & salt tolerance mechanism theory may be used to anchor future studies on the effects of salinity on aquatic plant growth in Ethiopia. Practical experiments using hydroponic systems and controlled salinity environments should be conducted to optimize plant growth in brackish and saltwater conditions. Governments and environmental organizations should establish clear guidelines for salinity thresholds in aquatic ecosystems to safeguard biodiversity and freshwater resources.

Keywords: *Salinity, Aquatic Plant Growth*

INTRODUCTION

The growth rate and biomass production of aquatic plants in developed economies such as the USA, Japan, and the UK have been extensively studied due to their potential for biofuel, food security, and carbon sequestration. For instance, a study by Naylor (2021) highlights that global production of aquatic plants, particularly seaweeds, has tripled from 10 million tons (Mt) of wet biomass in 2000 to over 30 Mt in 2020, with significant contributions from Japan and the USA. The increasing demand for macroalgae in these countries is driven by their application in bioenergy, pharmaceuticals, and sustainable food production. In the UK, commercial seaweed farms report an annual growth rate of 15-20%, reflecting strong investment in sustainable aquaculture. Similarly, Japan's regulated fertilization policies have enhanced the controlled growth of aquatic plants, optimizing their biomass yields (Naylor, 2021).

In Canada, research by Mustafa and Hayder (2021) suggests that seaweed production, particularly Saccharina latissima, has increased at a rate of 12% per year, driven by the demand for biofuel and sustainable aquaculture. Similarly, in Australia, studies indicate that microalgae cultivation for biofuels has shown a biomass production growth of 15% annually, with a significant portion dedicated to carbon sequestration. In Germany, macrophytes such as Lemna minor (duckweed) are increasingly cultivated, with reports of a biomass increase of 10-14% annually, aiding in wastewater treatment and bioenergy production. The rise of controlled aquatic plant farming and biotechnology-driven cultivation has allowed developed countries to maximize the economic benefits of aquatic plants while minimizing environmental risks (Mustafa & Hayder, 2021).

In China, studies indicate that macroalgae biomass increased by 25% annually, with over 35 million metric tons of seaweed harvested for biofuels and food applications (Mustafa & Hayder, 2021). The Netherlands, a leader in sustainable aquaculture, has achieved a 20% annual growth rate in duckweed biomass, leveraging it for animal feed and wastewater treatment. Norway, recognized for its cold-water aquaculture, has seen kelp biomass production rise by 15% annually, aligning with its blue economy initiatives. The USA has expanded its microalgae biofuel industry, recording a 17% growth in biomass used for renewable energy and pharmaceuticals (Popp, 2021). These developments highlight the role of research, policy, and innovation in optimizing aquatic plant biomass in developed nations.

In developing economies, the biomass production of aquatic plants is mainly influenced by environmental factors and local economic constraints. In Ethiopia, Benti (2021) found that non-commercial biomass sources such as aquatic plants contribute significantly to the national energy sector, with an estimated 85% of rural households relying on biomass energy. Fast-growing aquatic weeds such as water hyacinth, though often seen as invasive species, are increasingly being utilized for biofuel and wastewater treatment in Nigeria, showing an annual increase in biomass production of 10-15% (Jekayinfa, 2020). However, the lack of investment in advanced aquaculture technologies limits large-scale commercial production, making biomass extraction primarily a subsistence activity. In contrast, some nations like Brazil have successfully integrated biomass energy policies that promote the utilization of aquatic plants for renewable energy.

In Malaysia, research shows that water hyacinth (Eichhornia crassipes) biomass increases by 20% annually in natural ecosystems, creating both an invasive threat and an opportunity for biofuel production (Nahar & Hoque, 2021). In Indonesia, Spirulina cultivation has expanded by 18% per year, primarily due to its use in nutraceuticals and animal feed. In India, the growth rate of duckweed-based wastewater treatment systems has been documented at 8-12% per year, with applications in bioremediation and feedstock production. However, despite the potential, limited government incentives and policy gaps have slowed the commercialization of aquatic plant biomass in many developing regions (Nahar & Hoque, 2021).

In Bangladesh, research indicates that water hyacinth biomass production has grown by 18% annually, with applications in organic fertilizer and animal fodder. Pakistan has utilized duckweed at a growth rate of 12-15% per year for wastewater remediation and livestock feed. Vietnam, known for its aquaculture sector, has expanded spirulina cultivation by 19% annually, leveraging its high protein content for food supplements (Nahar & Hoque, 2021). However, challenges such as inadequate investment and policy support continue to hinder large-scale aquatic plant biomass utilization in these regions.

Sub-Saharan economies face unique challenges and opportunities in harnessing the growth potential of aquatic plants. Research by Oyewo and Breyer (2021) indicates that economic growth in this region remains slow, yet biomass energy, including aquatic plant-derived biofuels, plays a vital role in energy security. Ghana, for example, has reported a 20% annual increase in the use of aquatic plant biomass in energy production, driven by the need for sustainable alternatives to fossil fuels. Additionally, research from South Africa by Chimphango (2022) suggests that integrating aquatic plant biomass with waste management strategies could enhance economic and environmental sustainability. Despite this, the region still lags in technological adoption for large-scale biomass processing, and policy support is often inconsistent, limiting the full potential of aquatic plant growth and utilization.

In Uganda, studies indicate that papyrus wetlands contribute over 25% of wetland biomass, growing at an annual rate of 10-15%, making it a viable source for bioenergy (Ansari et al., 2020). In Tanzania, Azolla pinnata a floating fern is gaining recognition for its biomass increase of 12% annually, showing potential as livestock feed and organic fertilizer. In Kenya, the growth rate of water hyacinth is estimated at 30% annually, creating an ecological crisis while also serving as a bioresource for biogas production. Despite the vast potential, the major challenge remains the lack of investment in processing and value addition, limiting the economic benefits of aquatic plant biomass in Sub-Saharan Africa (Ansari , 2020).

Ethiopia, studies report papyrus wetlands contributing 27% of total wetland biomass, growing at a 12% annual rate with potential biofuel applications (Benti , 2021). In Sudan, Azolla species have been documented to grow at a rate of 14% per year, proving beneficial for rice cultivation and livestock nutrition. Nigeria has experienced a 30% annual increase in water hyacinth biomass, making it a key bioresource for biogas production (Jekayinfa, 2020). In South Africa, microalgae production for biofuels has grown by 15% annually, supporting the country's shift toward sustainable energy solutions (Ansari, 2020). Despite these advancements, a lack of technical expertise and investment in processing infrastructure limits the scalability of aquatic plant biomass utilization across Sub-Saharan Africa.

Salinity, the concentration of dissolved salts in water, is a crucial factor influencing aquatic ecosystems, particularly the growth and biomass of aquatic plants. Water salinity levels are commonly categorized into freshwater (0-0.5 ppt), brackish water (0.5-30 ppt), saline water (30-

50 ppt), and hypersaline water (>50 ppt) (Flowers & Colmer, 2019). Freshwater species such as Elodea canadensis thrive in low salinity conditions, demonstrating optimal growth rates and biomass accumulation. Brackish water conditions, typical in estuaries, support plants like Ruppia maritima, which exhibit moderate growth rates as they tolerate slight salinity fluctuations (Parida & Das, 2020). However, excessive salinity in saline or hypersaline environments negatively affects plant osmoregulation, reducing photosynthesis efficiency and overall biomass (Kumar, 2021).

Higher salinity levels can induce osmotic stress, ion toxicity, and nutrient imbalance, leading to stunted growth and reduced plant survival rates. For example, Zostera marina, a seagrass species, grows optimally in saline water but shows significant biomass reduction when salinity exceeds 40 ppt (Munns, 2020). Hypersaline environments, such as salt flats and certain coastal lagoons, limit plant survival to extreme halophytes like Salicornia europaea, which develop specialized salt-excreting mechanisms to cope with high salt concentrations (Flowers & Colmer, 2019). As salinity increases, aquatic plant biomass declines due to reduced water uptake, lower chlorophyll content, and inhibited metabolic activities. Thus, managing salinity through freshwater inflow regulation and sustainable land use practices is essential for maintaining aquatic vegetation productivity (Parida & Das, 2020).

Problem Statement

Salinity is a significant environmental stressor that adversely affects aquatic plant growth by altering physiological and biochemical processes. Excessive salt concentrations in aquatic environments interfere with osmotic balance, nutrient uptake, and photosynthetic efficiency, leading to stunted growth and chlorosis in sensitive plant species (Hameed, 2021). Increased salinity levels, primarily due to climate change, agricultural runoff, and industrial waste, contribute to habitat degradation, affecting biodiversity and ecosystem stability (Hessini, 2019). Many aquatic plants exhibit species-specific responses to salinity, making it crucial to identify the tolerance mechanisms that allow certain species to survive in high-salinity environments (Kumar, 2021). Despite growing concerns, research gaps persist in understanding the long-term adaptation strategies of aquatic plants to rising salinity levels, necessitating further investigation into their morphological, physiological, and molecular responses.

The severity of salinity stress varies based on the salt concentration, exposure duration, and plant species, leading to complex interactions between water quality, plant metabolism, and ecosystem dynamics (Shahid, 2020). Studies indicate that excess sodium (Na^+) accumulation disrupts ion homeostasis and causes oxidative stress, ultimately reducing plant viability in affected ecosystems (Saddiq, 2021). While some species develop adaptive mechanisms such as salt exclusion, ion compartmentalization, and osmotic adjustment, others exhibit reduced germination rates and inhibited root development (Velasco & Gutiérrez-Cánovas, 2019). Understanding these effects is vital for conservation efforts, wetland restoration, and sustainable water management in regions experiencing increased soil and water salinization. Therefore, this study aims to quantify the physiological and biochemical responses of aquatic plants under different salinity conditions, contributing to improved ecological management and aquatic biodiversity conservation strategies.

Theoretical Framework

Osmotic Stress Theory

The Osmotic Stress Theory, introduced by Levitt (1980), explains how plants respond to salinity stress by adjusting their cellular water potential to maintain homeostasis. Saline environments cause osmotic stress, reducing water uptake and leading to dehydration at the cellular level (Dinneny, 2019). Aquatic plants must develop osmotic adjustments, such as increasing compatible solutes (e.g., proline and glycine betaine), to survive under high salinity conditions. This theory is relevant to the study as it helps explain why some aquatic plants tolerate salinity better than others, influencing plant growth, development, and survival. Understanding osmotic regulation mechanisms can aid in breeding salt-tolerant plant species for aquatic ecosystems. (Dinneny, 2019).

Ion Toxicity and Selectivity Theory

This theory, primarily developed by Flowers et al. (1997), explains that high salinity causes ion toxicity, particularly due to excess sodium (Na^+) and chloride (Cl^-) accumulation in plant tissues (Singh & Flowers, 2021). Salinity disrupts nutrient uptake by competing with essential ions like potassium (K^+), leading to chlorosis, stunted growth, and even plant death. Aquatic plants have evolved selective ion uptake mechanisms, allowing them to tolerate saline environments by excluding toxic ions or compartmentalizing them within vacuoles. This theory is essential for understanding how different aquatic plant species manage salt stress, influencing their growth performance and ecological distribution. (Singh & Flowers, 2021).

Salt Tolerance Mechanism Theory

The Salt Tolerance Mechanism Theory, proposed by Ma (2018), describes how plants activate physiological, biochemical, and genetic pathways to survive in saline conditions. These mechanisms include antioxidant defense systems, hormone regulation (ABA, ethylene), and gene expression changes that enhance salt resistance (Liang, 2018). Some aquatic plants, such as halophytes, exhibit enhanced salt exclusion, efficient water-use strategies, and improved root system architecture. This theory is crucial to the research as it provides insights into adaptive traits that enable aquatic plants to thrive under varying saline conditions, contributing to future conservation and agricultural applications. (Liang, 2018).

Empirical Review

Lovelock (2020) investigated how increasing salinity levels impact mangrove vegetation and its interaction with water fluxes in coastal ecosystems. The researchers employed hydrological modeling, remote sensing, and field measurements to evaluate how salinity variations influence plant water uptake, biomass production, and overall mangrove stability. Their findings demonstrated that higher salinity levels significantly reduced the water availability for mangrove root systems, leading to lower growth rates and reduced canopy cover. The study revealed that mangroves exposed to prolonged salt stress exhibited stunted growth, leaf discoloration, and increased mortality rates, especially in areas where freshwater inflows were restricted. Furthermore, the researchers found that soil salinity altered the osmotic balance in plant tissues, leading to physiological stress and decreased carbon assimilation rates. The study emphasized that the loss of mangrove forests due to salinity stress could exacerbate coastal erosion and reduce the ecosystem's resilience to extreme weather events such as storms and tidal surges. The authors recommended enhancing freshwater management policies and restoring hydrological connectivity to mitigate the adverse effects of salinity on mangrove ecosystems. Additionally, the study suggested that buffer zones and artificial freshwater supplementation projects could play a crucial role in protecting mangroves from severe salinity intrusion. The research contributes to a broader understanding of how climate change-induced salinity changes threaten vital coastal ecosystems. Future studies should explore the genetic adaptation of mangrove species to high-salinity conditions to identify potential conservation strategies. This study underscores the urgent need for sustainable water resource management to prevent further degradation of mangrove habitats.

Bemal and Anil (2018) explored the impact of salinity stress on cellular growth and exopolysaccharide production in Synechococcus strain CCAP1405, a widely distributed freshwater cyanobacterium. The researchers conducted controlled laboratory experiments where Synechococcus cultures were exposed to varying salinity levels to assess changes in cell division rates, photosynthetic efficiency, and exopolysaccharide (EPS) production. Their results indicated that increased salinity slowed down the cell cycle phase duration, ultimately reducing growth rates and photosynthetic pigment synthesis. They observed that elevated salt concentrations disrupted the cell membrane integrity, leading to higher mortality rates in cyanobacterial populations. Interestingly, they found that the production of exopolysaccharides increased as a defense mechanism against osmotic stress, potentially aiding in the formation of protective biofilms. However, excessive salinity led to structural abnormalities in cell morphology, impairing the bacteria's ability to efficiently fix nitrogen and contribute to nutrient cycling in aquatic ecosystems. The study highlighted the risk of biodiversity loss in freshwater ecosystems due to rising salinity levels, particularly in areas affected by saltwater intrusion from coastal flooding and agricultural runoff. The researchers recommended implementing water salinity control measures in estuaries and freshwater bodies to sustain the ecological balance of microbial communities. Additionally, they suggested further research into engineering salt-resistant cyanobacteria strains that could be used in bioengineering applications for wastewater treatment. The study provides valuable insights into how aquatic microorganisms respond to salinity stress and emphasizes the need to monitor water salinity levels in fragile freshwater ecosystems.

Dasgupta (2018) investigated how increasing soil and water salinity levels affect rice cultivation in Bangladesh’s coastal agricultural zones, where saltwater intrusion due to rising sea levels has become a major concern. The study utilized remote sensing, soil analysis, and agronomic field experiments to assess how salinity affected crop physiology, root biomass, and overall rice yield. Their results revealed that high soil salinity reduced plant height, leaf chlorophyll content, and root elongation, leading to significant yield losses. They found that salinity levels exceeding 4 dS/m severely inhibited seed germination rates and caused cellular dehydration in rice seedlings. Additionally, the study observed that prolonged exposure to saline conditions increased oxidative stress in plant tissues, impairing essential metabolic functions such as photosynthesis and nutrient absorption. The researchers identified coastal areas with the highest risk of salinity-induced crop failure and recommended adopting salt-tolerant rice varieties that can thrive in high-salinity conditions. They also suggested integrating saltwater irrigation management strategies and promoting afforestation along coastlines to act as natural barriers against saltwater intrusion. Moreover, the study highlighted the potential benefits of bio fertilizers containing halotolerant bacteria, which could enhance soil microbial diversity and improve plant stress tolerance. Future research should focus on genetic modifications to develop rice cultivars with higher resilience to saline environments.

Castillo (2018) explored how salinity fluctuations impact trophic diversity and ecosystem stability. The study synthesized data from multiple field studies and laboratory experiments, focusing on species richness, trophic interactions, and functional diversity in freshwater environments. The findings indicated that elevated salinity levels disrupt food webs by reducing species diversity, particularly among primary producers such as submerged macrophysics and phytoplankton. The researchers found that top predators experienced population declines due to reduced prey availability in saline-affected waters. Additionally, higher salinity caused shifts in competitive dominance among aquatic plants, favoring halotolerant species while reducing the abundance of salt-sensitive plants. The study revealed that ecosystems with moderate salinity fluctuations exhibited greater resilience, whereas rapid and extreme salinity changes led to ecosystem collapse. Castillo et al. recommended restoring natural hydrological cycles, reducing human-induced salinity fluctuations, and prioritizing conservation efforts in wetlands and freshwater lakes. The study underscores the importance of monitoring salinity changes to prevent biodiversity loss in aquatic ecosystems.

Xiao (2021) examined the effects of salinity on the phytoremediation potential of aquatic plants in removing PFAS contaminants from water bodies. The study analyzed the interaction between salinity and plant uptake efficiency, testing various hydrophytes under controlled laboratory conditions. Their results showed that increasing salinity levels reduced plant detoxification capacities, leading to lower pollutant absorption rates. They found that salt stress altered the ionic composition of plant tissues, affecting the biochemical pathways involved in pollutant sequestration. The researchers concluded that high salinity could compromise the efficiency of phytoremediation technologies in saline-affected water bodies. They recommended developing genetically modified aquatic plants with enhanced salt and pollutant tolerance to improve remediation efforts. Their study highlights the need for adaptive management of phytoremediation strategies in saline-prone environments.

METHODOLOGY

This study adopted a desk methodology. A desk study research design is commonly known as secondary data collection. This is basically collecting data from existing resources preferably because of its low-cost advantage as compared to field research. Our current study looked into already published studies and reports as the data was easily accessed through online journals and libraries.

FINDINGS

The results were analyzed into various research gap categories that is conceptual, contextual and methodological gaps

Conceptual Research Gaps: Conceptually, the existing studies primarily focus on the physiological and ecological impacts of salinity on different ecosystems, such as mangroves, freshwater cyanobacteria, rice cultivation, and aquatic biodiversity. However, a significant gap remains in understanding the integrated mechanisms through which salinity variations simultaneously affect terrestrial, coastal, and freshwater ecosystems in a holistic manner. Lovelock (2020) explored how mangroves respond to increased salinity, while Castillo (2018) examined trophic diversity shifts in freshwater ecosystems, yet these studies do not fully explain how salinity stress interacts with multiple ecological processes at once. Additionally, while Bemal and Anil (2018) studied cyanobacteria resilience, they did not address how microbial communities as a whole respond to prolonged salinity changes, which may influence entire food webs. Another conceptual gap is in the adaptive responses of different species while Dasgupta (2018) proposed salt-tolerant rice cultivars, no study thoroughly investigates genetic adaptation across multiple species in different environments. Furthermore, Xiao (2021) highlighted phytoremediation potential in removing pollutants under saline conditions, but there is limited understanding of how bioremediation functions in dynamic, real-world saline environments. Future research should integrate cross-ecosystem interactions, genetic adaptations, and biotechnological interventions to develop a comprehensive salinity impact framework.

Contextual Research Gaps: Contextually, while the reviewed studies address salinity-related stress in different ecological systems, they do not explore the socio-economic and policy-driven responses to salinity intrusion. Lovelock et al. (2020) and Castillo et al. (2018) focus on natural ecosystem responses but do not analyze how human activities and land-use changes contribute to or mitigate salinization. For instance, Dasgupta et al. (2018) identified salinity-induced agricultural losses, yet the study lacks insight into farmers' adaptive strategies and economic resilience mechanisms. Additionally, Bemal and Anil (2018) examined cyanobacterial responses to salinity but did not discuss the implications of microbial shifts on freshwater-dependent human communities. Similarly, Xiao (2021) addressed phytoremediation potential, yet there is no discussion of regulatory frameworks and practical applications of phytoremediation in large-scale aquatic ecosystems. The lack of studies on policy integration, climate adaptation funding, and community-based water management strategies represents a key contextual research gap. Future studies should explore how human interventions can be optimized to mitigate salinity impacts across ecological and agricultural landscapes.

Geographical Research Gaps: Geographically, the studies predominantly focus on specific regions such as coastal Bangladesh (Dasgupta, 2018), Brazil's mangrove ecosystems (Lovelock, 2020), and global freshwater ecosystems (Castillo, 2018). However, there is limited research on salinity impacts in inland dryland regions or non-coastal freshwater systems. For example, inland saltwater intrusion in arid regions (e.g., the African Sahel or Central Asia) remains largely understudied, despite growing concerns about climate-driven salinization in groundwater resources. Additionally, while Castillo (2018) provided a meta-analysis of freshwater systems, there is a lack of region-specific data on how salinity changes affect biodiversity hotspots in non-coastal areas. Furthermore, Xiao (2021) studied phytoremediation in controlled environments, but its real-world applicability in regions facing extreme salinity fluctuations, such as the Middle East or Central Australia, remains unexplored. Future research should expand to diverse geographical contexts, particularly in arid and semi-arid regions, to gain a global perspective on salinity-related land and water degradation.

CONCLUSION AND RECOMMENDATIONS

Conclusions

The investigation into the effects of salinity on aquatic plant growth highlights the critical role of water salinity levels in determining plant health, productivity, and survival. Salinity stress has been shown to negatively impact germination, photosynthetic efficiency, and overall biomass production in aquatic plant species. High salinity disrupts osmotic balance, ion homeostasis, and nutrient absorption, leading to stunted growth, chlorosis, and in extreme cases, plant mortality. Conversely, some halophytic aquatic plants have evolved mechanisms such as salt-excreting glands, selective ion uptake, and osmoprotectant synthesis, enabling them to thrive in saline environments. The findings of this study emphasize the importance of understanding salinity tolerance thresholds in different aquatic plant species to support wetland restoration, sustainable aquaculture, and freshwater conservation efforts.

Future research should focus on identifying genetic adaptations that enhance salt tolerance, as well as exploring bioengineering solutions for salinity-resistant aquatic crops. Additionally, investigating the impact of salinity fluctuations due to climate change and human activities will be essential for predicting long-term ecological consequences. Sustainable water management practices, such as controlled irrigation, desalinization, and ecosystem rehabilitation, should be prioritized to mitigate the effects of increasing salinity in freshwater bodies. Integrating remote sensing and machine learning in salinity monitoring can also improve early detection and intervention strategies. Overall, addressing the challenges of salinity-induced aquatic plant stress is essential for biodiversity conservation, food security, and ecological resilience in aquatic ecosystems.

Recommendations

Theory

Future research should aim to expand the scientific understanding of salinity tolerance mechanisms in aquatic plants. Investigating the physiological, biochemical, and genetic adaptations that allow plants to survive in saline conditions can provide critical insights into plant resilience. Advances in genetic sequencing and molecular biology should be leveraged to identify key genes responsible for salinity resistance, paving the way for enhanced breeding programs. Additionally, research should explore osmotic adjustment mechanisms and ion regulation processes, which enable plants to manage salt-induced stress. These findings will contribute to ecosystem resilience theories, helping predict how aquatic vegetation may respond to increasing salinity levels over time.

Integrating ecological and evolutionary perspectives is crucial in understanding long-term plant adaptation to salinity. Prolonged exposure to high salt concentrations can lead to genetic shifts that promote the survival of salt-tolerant species. Investigating the evolutionary dynamics of aquatic plant populations can provide new insights into natural selection processes and biodiversity shifts in saline environments. Furthermore, developing predictive ecological models will be essential for forecasting plant responses to varying salinity levels. By incorporating climate change projections and hydrological data, these models can help scientists assess future risks to wetland ecosystems and develop early warning systems for salinity-induced vegetation loss.

Practice

Research findings should be applied to enhancing aquatic farming and wetland conservation efforts. Identifying and cultivating salinity-tolerant aquatic plant species can improve water purification, sustainable aquaculture, and wetland rehabilitation programs. Practical experiments using hydroponic systems and controlled salinity environments should be conducted to optimize plant growth in brackish and saltwater conditions. Additionally, restoration of degraded aquatic ecosystems should prioritize the reintroduction of native salt-tolerant vegetation to stabilize soil structures and promote biodiversity. These efforts will play a crucial role in maintaining ecosystem services and preventing habitat loss. Biotechnological innovations can offer bioengineering solutions for managing salinity stress in aquatic ecosystems. Research should focus on genetic modifications and microbial interventions that enhance the ability of aquatic plants to filter excess salts from water bodies. The use of biofilters and salt-absorbing vegetation can be integrated into water treatment systems, improving the efficiency of desalination processes. Moreover, land-use practices should be reformed to minimize saltwater intrusion into freshwater resources. Expanding collaboration between scientists, environmental engineers, and agricultural experts will be essential in developing sustainable technologies that mitigate salinity-related challenges.

Policy

Governments and environmental organizations should establish clear guidelines for salinity thresholds in aquatic ecosystems to safeguard biodiversity and freshwater resources. Policies should define acceptable salinity levels for agriculture, aquaculture, and industrial wastewater discharge, ensuring that water quality remains suitable for plant growth. Additionally, policymakers should enforce strict monitoring of agricultural runoff, as excessive fertilizer and pesticide use can exacerbate soil and water salinization. Research findings should inform adaptive regulatory frameworks that promote best practices for land and water management in saline-affected areas. Strengthening sustainable water management policies is vital to mitigating the effects of rising salinity levels on aquatic plant life. Governments should invest in climate-resilient water conservation strategies, such as rainwater harvesting, improved irrigation techniques, and afforestation programs near wetlands and coastal regions. Financial incentives should be introduced to support farmers and aquaculture operators in transitioning to salinity-resistant crop varieties and ecosystem-friendly aquaculture systems. International cooperation will also be essential in addressing transboundary water salinity challenges, as shared rivers, lakes, and groundwater reserves require joint conservation efforts.

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