INFLUENCE OF INVASIVE VEGETATION ON SALINITY IN SOUTHERN COAST WETLANDS, SRI LANKA

A Case Study of Bundala Wetland in Southern Coast, Sri Lanka

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Abstract: Invasive plants affect overall wetland quality. This study investigates how invasive species influence soil salinity processes in lagoon-based wetlands along the southern coast of Sri Lanka. A comprehensive literature review identified soil salinity, water contamination, & distance from contamination points, including proximity to the sea & to irrigation inlet connection points, as key parameters affecting wetland water quality. Invasive plant types & invasive plant density were identified as parameters influencing invasive vegetation patterns. Wetland water-quality data were collected through soil & water sampling at selected nodes, as well as distance measurements to the nearest sea-connecting point & irrigation inlet. Invasive-plant data were gathered through field observations, interviews, & recorded data sources. The data were analysed using soil & water quality assessments, spatial distance analysis, & vegetation–spatial analysis. The wetland water-quality analysis revealed that distance from the sea-connecting point & the irrigation inlet affects wetland salinity levels. The invasive-plant analysis demonstrated an inverse relationship between soil salinity levels & invasive plant type & density, indicating that specific invasive plant species & higher plant densities correlate with increased salinity concentrations. Overall, the study confirms that invasive vegetation plays a crucial role in regulating salinity levels in wetlands.

Keywords: *Invasive Vegetation, Invasive Plant-Salinity Interaction, Wetland management, Bundala National Park, Sri Lanka*

1. Introduction

1.1. OVERVIEW
The Bundala National Park in Sri Lanka, as the country's first Ramsar designated wetland, constitutes a unique mosaic of lagoons, salt marshes, & dry scrublands that support diverse bird & aquatic species. However, this ecosystem faces ecological instability primarily due to increasing salinity in water & soil, driven by upstream irrigation diversion, reduced freshwater flow, climate variability, & human-induced land use changes. Critically, the spread of invasive, salt-tolerant plants like Prosopis juliflora & Typha angustifolia is altering natural hydrological processes by affecting drainage, evapotranspiration, soil permeability, & reducing soil moisture retention, further exacerbating salinization & degrading native vegetation. These interactions between salinity fluctuations & invasive vegetation dynamics significantly influence wetland quality, but remain insufficiently studied, especially from integrative ecological & landscape architectural perspectives. This study aims to evaluate these impacts using remote sensing & field ecological monitoring to inform wetland conservation & management strategies in Bundala Lagoon.

1.2. PROBLEM STATEMENT
Despite the bundala lagoon ecosystem's national & international importance, there are limited understanding of how the invasive vegetation & salinity spread dynamics influence. The lack of integrated spatial assessments & temporal monitoring will lead to the development of effective landscape management strategies. Without such knowledge, restoration & conservation efforts can be risky without properly identifying the site patterns. According to that, the research will address the knowledge gap by exploring the relationship between invasive vegetation distribution & salinity using spatial analysis tools, salinity data, & landscape scale observations. The outcome will support evidence-based interventions in salt-affected wetlands. This study is contributing to resilient & ecologically balanced landscape development.

1.3. RESEARCH QUESTION
Is there an interconnection between the spread of invasive plants distribution & quality of the salinity based Bundala wetland margins?

1.4. RESEARCH AIM
To investigate how invasive vegetation influences the Bundala salinized lagoon-based wetland ecosystem, in order to support planning, design, & management approaches that help preserve the ecological durability of reserved wetland margins. This study aims to contribute to long-term preservation strategies that extend beyond protection status, ensuring the continued resilience & functionality of these valuable unique ecosystem ranges.

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1.5. OBJECTIVES

- Study & identify the physical quality of the salt-affected Bundala wetland, & the water & soil quality differentiations in the different nodes of the wetland.
- Identification of invasive plant types & native plant types & their distribution, in the salinity-based lagoon ecosystem.
- Identifying the interconnections between invasive plant distribution & native plant diversity, & how that affects the quality of the lagoon-based ecosystem.
- Identifying the connection between invasive plant types & distribution with the overall water & soil quality of the salt-affected Bundala wetland.

1.6. LANDSCAPE ARCHITECTURE RELATE SIGNIFICANCE

This study is significant for landscape architecture, as it addresses spatial & ecological challenges from invasive vegetation in the Bundala lagoon wetland, a Ramsar-protected site. Salt-tolerant invasive species cause salinity changes that threaten native vegetation & landscape structure. By analyzing interactions between invasive plant density & native vegetation affected by salinity, the research supports context-sensitive design & ecological planning. The findings aid in developing resilient buffer zones, restoration planting, & adaptive land-use frameworks tailored for saline-prone wetlands. This design-based preservation approach emphasizes continuous management & adaptation, strengthening long-term wetland conservation & ecological balance in fragile coastal lagoons.

1.7. SCOPE & LIMITATIONS

The study focuses on the physical quality of the salt-affected Bundala wetland, examining soil salinity levels, water contamination levels, distance from contamination points, including proximity to the sea & to irrigation inlet connection points, invasive plant species types & their diversity within five selected plots. It is confined to Southern coastal lagoon wetlands at Bundala & does not extend to other wetland types or address all plant species. The impact of invasive plants on wetland water & soil quality is explored, but ecological & ecosystem effects are not deeply investigated, & recommendations primarily suggest landscape design interventions to improve wetland quality. Limitations include restricted spatial & temporal scope, observer bias in vegetation cover estimates, limited faunal data, & shallow soil chemistry sampling. Future research should expand monitoring scope & frequency, include multifunctional biodiversity assessments, & explore invasive plant management & restoration impacts, with long-term monitoring & ecohydrological modelling to support adaptive management under environmental change.

2. Literature review

2.1 INVASIVE SPECIES IN TROPICAL WETLANDS

Tropical wetlands host complex ecosystems sustained by native flora & fauna interconnected under specific environmental conditions. These native species maintain ecological balance & wetland functions such as water filtration & habitat provision. However, invasive plant species disrupt this balance by outcompeting native vegetation for space, light, & nutrients, leading to habitat degradation, biodiversity loss, & reduced ecosystem quality(Suraweera et al., 2023),(Herbert et al., 2015).

Prosopis juliflora (Katu Andara/Vanni Andara)

Introduced in the 1950s in Sri Lanka's Bundala region to improve saline soils, Prosopis juliflora has become a highly invasive species in dryland wetland interfaces. Native to America, it thrives in saline, alkaline, & drought-prone soils through prolific seed dispersal aided by animals & water. It regenerates vigorously after cutting & produces allelopathic chemicals that inhibit native plants. Its deep taproot exploits saline groundwater, allowing expansion along lagoon margins with increasing salt intrusion. The species alters soil nutrients, hydrology, & increases surface & soil salinity, posing considerable ecological management challenges(Suraweera et al., 2023),(Bandara et al., 2022),(Lenjisa Diriba Balcha, 2022).

Typha angustifolia (Cattail Plant)

Originally from temperate regions, Typha angustifolia behaves invasively in tropical wetlands altered by nutrient enrichment & hydrological disruption. It forms dense monocultures in brackish lagoon margins, modifying soil-water interactions by reducing oxygenation & slowing water movement, thereby increasing evapotranspiration & affecting surface salinity dynamics. The plant spreads via seeds & extensive rhizomes, complicating control efforts. It thrives in low-salinity, stagnant waters with organic-rich substrates & alters sedimentation & microclimates by litter accumulation, further impacting native vegetation & wetland function(Chen, 2019),(DeBerry & Hunter, 2024),(Ling et al., 2023).

2.2 SALINITY DYNAMICS IN WETLAND SYSTEMS

Salinity is a key determinant of wetland structure & ecological function, influenced by precipitation, groundwater flows, evaporation, & vegetation. In the Bundala lagoon system, disrupted freshwater inflows due to irrigation & overgrown vegetation particularly dense invasive stands, reduce water flow & enhance salt concentration. Evapoconcentration in shallow tropical lagoons during dry seasons intensifies salinity. Invasive species like P. juliflora & T. angustifolia worsen these dynamics by obstructing natural water flow, increasing transpiration-driven water loss, & trapping salts, which raises both water & soil salinity levels(Peters et al., 2025),(Nachshon, 2018),(Kariyawasan Patabendige et al., 2023),(Xin et al., 2022)

Soil Salinity Influences
Runoff deposits dissolve salts into wetland soils, while poor infiltration & rapid evaporation contributing to surface & root-zone salinization. Saline groundwater interaction causes capillary rise of salts, especially in lagoon-edge wetlands. Invasive plants exacerbate soil salinity by blocking freshwater recharge & infiltration, allowing salt accumulation in upper soil layers, a persistent factor in salinization (Xin et al., 2022).

Water Contamination with Total Dissolved Solids (TDS)
High transpiration from Prosopis juliflora & Typha angustifolia elevates total dissolved solids (TDS) in stagnant lagoon waters by reducing flow & oxygenation, trapping salts during dry seasons. Invasive mats contribute to TDS buildup via litter decomposition & evapotranspiration, worsening contamination in nutrient-enriched systems. In Sri Lankan coastal wetlands, this dynamic intensifies with sea intrusion, degrading water quality.(Baltazar-Campos et al., 2025)

Sea Opening to Plot Distance
Plots nearer sea openings (<100 m) experience intensified salinity intrusion, boosting Prosopis juliflora dominance via salt tolerance & suppressing natives through capillary salt rise. Typha angustifolia densities increase in intermediate distances with brackish mixing, but extreme proximity limits growth via hypersalinity(Xin et al., 2022),(Bandara et al., 2022),(Peters et al., 2025). In Bundala lagoons, this gradient drives spatial invasion patterns, with sea-driven TDS elevating risks in wetland margins.

Irrigation Mouth to Plot Distance
Proximity to irrigation mouths delivers nutrient-rich runoff, promoting Typha angustifolia density through eutrophication while enabling Prosopis juliflora spread via seed flotation in disturbed plots. Shorter distances (<150 m) correlate with higher total dissolved solids (TDS) & higher invasive plant cover due to freshwater pulses amid saline backdrops, obstructing natural flushing. This hydrological alteration in Bundala creates invasion gradients, with control plots farther away showing lower densities.(Udadini & Bandara, 2017)

2.3 RESEARCH GAPS & RESTORATION STRATEGIES
Research largely separates vegetation patterns from hydrological salinity dynamics, lacking integrated landscape-scale studies on how specific invasives alter salinity at micro scales, particularly in tropical semi-arid lagoons like Bundala. Spatial & temporal variability in these interactions is underexplored. Restoration guidelines emphasize preserving buffer zones, controlling invasive vegetation to improve water infiltration & reduce salinization, & adaptive approaches that consider dynamic interactions between invasive species & salinity. For example, the Tamarix species is known to extract salts from deeper soils & deposit them on the surface, altering soil chemistry & microbial communities. Effective wetland conservation must integrate these complex feedbacks for successful ecosystem recovery (Suraweera et al., 2023),(Zedler & Kercher, 2004).

Recent physiological studies reveal species-specific salinity tolerance mechanisms that explain observed distribution patterns in tropical wetlands. *Prosopis juliflora* employs proline accumulation, efficient Na^+/K^+ discrimination, & deep taproot salt exclusion to thrive in low-to-moderate salinity uplands, often reducing surface soil salinity through vertical redistribution(Shiferaw et al., 2021). Conversely, *Typha angustifolia* utilizes rhizomatous clonal growth, antioxidant defences, & ionic homeostasis to dominate nutrient-enriched, moderately saline wetland margins, where its dense mats exacerbate surface salt accumulation through reduced water flow & sediment trapping (Shrimali et al., 2025). These complementary tolerances create contamination-driven invasion gradients, where irrigation proximity favors nutrient-tolerant *Typha* & sea intrusion supports salt-excluding *Prosopis*, highlighting the need for spatially explicit management addressing both hydrological inputs & physiological feedback.

Controllable factors such as water flow regulation, vegetation removal, & land-use planning directly influence salinity dynamics & invasive plant spread. Proper management of irrigation canals & removal of invasive species can restore freshwater flow & reduce salt buildup, although clearance risks secondary invasions or erosion. Uncontrollable factors like sea-level rise, soil type, & fauna seed dispersal add complexity to management efforts. Understanding these interactive parameters helps in designing adaptive restoration strategies (Chen, 2019).

3. Research framework & methodology

The framework integrates invasive plant types (Prosopis juliflora, Typha angustifolia), densities, soil salinity, water TDS, irrigation mouth-to-plot distance, & sea opening-to-plot distance to examine their interactions across salinity gradients in Bundala lagoon margins. Parameters link via hydrological influences: irrigation proximity drives nutrient runoff favoring Typha dominance; sea proximity intensifies salinity boosting Prosopis; densities modulate salinity feedback through transpiration & flow obstruction.

3.1 SELECTION OF THE CASE STUDY SITE

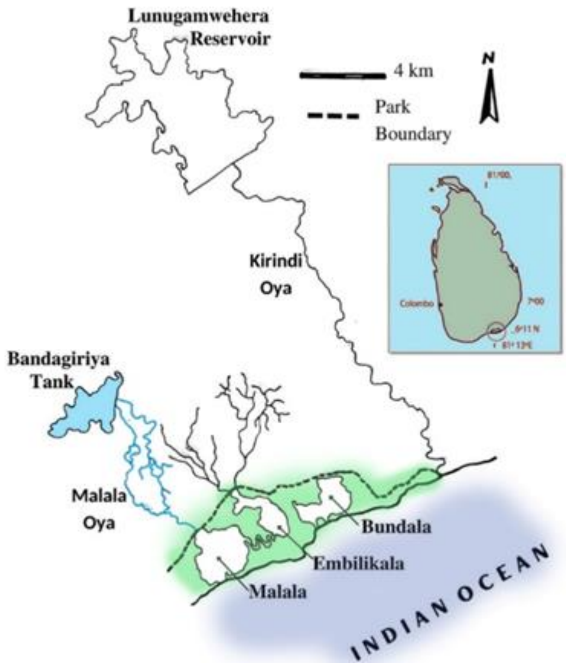


Figure 1, Hydrological map & flows around the Bundala Ramsar – Wetland
(Kariyawasan Patabendige et al., 2023) edited by the author.

Bundala National Park in Sri Lanka's southeastern dry zone was selected as the primary study site for this research due to its status as the country's first Ramsar wetland (designated 1990), encompassing 6216 ha of critical lagoon ecosystems including shallow brackish lagoons (e.g., Bundala, Malala, Embilikala, Koholankala) that support over 200 bird species, including migratory waterfowl, amid threats from invasive Prosopis juliflora covering >60% of the area. The site's diverse habitats dry thorny scrublands, salt marshes, sand dunes, & seasonal water bodies exhibit pronounced salinity gradients influenced by irrigation runoff, sea intrusion, & evapoconcentration, ideal for examining invasive plant densities (Prosopis juliflora & Typha angustifolia), soil salinity, TDS in water, & distances from irrigation mouths & sea openings. Ongoing degradation from hydrological disruptions & invasives, as documented in recent audits, underscores its representativeness for lagoon wetland management, with accessible plots (including Bitaway control) enabling safe, security-compliant sampling without deep wetland penetration

3.1.1 Selection of Specific Plots in Bundala Wetland

Data collection encompassed five strategically selected plots along an environmental gradient from water-exposed margins to drier upland sites (see figure 3). 20 m × 20 m plots were purposively selected along hydrological & salinity gradients.

Figure 2, Plot selection for the sampling within the wetland (google maps, edited by the author – Bundala wetland area)

Description of the selected plots

- Plot 01 (Figure 4) **-** lagoon margin, approximately 50% water coverage & moderate canopy cover, 25% dominated by mature invasive species *Prosophis juliflora* & *Typha augustifolia* with moderate soil & water salinity.
- Plot 02 (Figure 5) **-** transition zone, no standing water, canopy cover of 25%, with higher soil salinity & notable invasive species presence.
- Plot 03 (Figure 6) **-** Prosophis juliflora dominant zone, Upland plot with dense canopy (~87%), mostly dominated by Prosophis juliflora. Low soil salinity.
- Plot 04 (Figure 7) **-** Typha augustifolia dominant zone, Partial water presence, low canopy cover (0%), with high invasive Typha angustifolia coverage (~60%) & moderate to high soil & water salinity.
- Plot 05 (Figure 8) **-** Upland non-invaded zone/ as the controlled plot, dry upland with minimal canopy (10%) & no invasive species detected. Low soil salinity.

Figure 3, Plot 01
(Captured image)

Figure 4, Plot 02
(Captured image)

Figure 5, Plot 03
(Captured image)

Figure 6, Plot 04
(Captured image)

Figure 7, Plot 05
(Captured image)

3.2 METHODOLOGICAL STEPS IN THE RESEARCH

The study has three stages. First stage encompasses data collection & analysis of soil & water quality of the wetland. Second stage encompasses data collection & analysis of invasive plants in the wetland, third stage encompasses cross analysing the relationship between soil & water quality of the wetland & the invasive plants.

Table 1, Data analysis stages.

Stage	Stage description	Methodological steps
Stage 1	Soil & water quality analysis	- Studying the soil & water quality related parameters plot wise.
		- Parameter comparison with each plot after the study.
Stage 2	Invasive plant analysis	- Studying invasive plant related parameters plot wise
		- Parameter comparison with each plot after the study.
Stage 3 - Final stage analysis	Cross analysis (Soil & water quality analysis with the invasive plant analysis).	- Evaluating the impact of invasive plants on the soil & water quality of the wetland, according to the research index evaluation.

Analysing soil & water quality parameters alongside invasive plant data, the study compares the selected plots to established salinity dynamics in soil with the invasive plant distribution, along with the different types of conditions of the wetland. This dual approach reveals how invasive vegetation-driven changes in salinity & soil quality vary spatially & temporally within the wetland landscape. Such integrated baseline data are essential for designing adaptive restoration strategies, including controlled invasive species removal, water flow regulation, & land use planning to mitigate salinity impacts.

3.2.1 stage 1 - methods relating to wetland soil & water quality study

Table 2, Methods Relating to Wetland Soil & Water Quality Study

<table>
<tr><th colspan="2">parameter</th><th>Data collection method</th><th>Data analysis method</th><th>Relatedness with the main factors</th></tr>
<tr><td colspan="2">Soil Salinity</td><td rowspan="2">All the plots do not have water surfaces inside the plots. Because of that, soil was used to extract the salty level using soil samples. The soil samples were soaked in a certain amount (24 grams) of water for 12 hours to fully dissolve. Then, the salinity levels were measured using an Electric Conductive meter.
Total dissolved solid (TDS) levels were measured using an EC meter with the water samples from plots .</td><td rowspan="2">Salinity levels & total dissolved solids (TDS) identified through Electric Conductive (EC meter), were categorised as high, moderate, low salinity levels & total dissolved solid (TDS) levels.</td><td rowspan="2">Using salinity quality & total dissolved solids (TDS) indexes will assess the salinity behavioural patterns in the lagoon-based wetland.</td></tr>
<tr><td colspan="2">Water Contamination (Total Dissolved Solids - TDS)</td></tr>
<tr><td rowspan="2">Distance from water contamination points</td><td>Distance to the closest point connecting to the sea</td><td rowspan="2">Google Earth Pro (accuracy ±5m)</td><td rowspan="2">Linear distance, regression, Salinity/TDS vs. distance (closer = higher contamination)</td><td>Distance from sea connecting point shows how marine salt is contaminating the wetland & the relationship between the contamination & distance from sea.
Shorter distances & marine salts promote or discourage certain types of invasive plants.</td></tr>
<tr><td>Distance to the closest point connecting to an irrigation inlet</td><td>Distance from an irrigation inlet connecting point shows how agricultural salt & other contamination materials are contaminating the wetland & the relationship between the contamination & distance from the irrigation inlets.
Proximal plots receive agricultural salts & nutrients, promoting or discouraging certain types of invasive plants.</td></tr>
</table>

Figure 8, Soaking the collected soil samples. (Captured image)

Figure 9, Filtering the soaked soil samples. (Captured image)

Figure 10, measuring the filtered soil samples. (Captured image)

3.2.2 Stage 2 - Methods Relating to Invasive Plant Study

Table 3, Methods Relating to Invasive Plant study

parameter	Data collection method	data analysis method	relatedness with the main factors
Invasive plant types	Questionnaires & interviews with park administration & stakeholders. From data records of invasive plants.	Plant type analysis	Independent of their density, invasive plant species can alter native plant communities & soil & water contamination levels, including salinity.
Invasive plant density	Denisity of Typha augustiflolia is collected by measuring shrub covered area. Prosophis juliflora is collected by measuring canopy covering area by the shade.	comparing the invasive plant covered area with the other plant covered area & taking ratios & percentages.	Independent of invasive plant types, their density can alter native plant communities & soil & water contamination levels, including salinity.

3.2.3 Stage 3 – Cross Analysis Method

Table 4, Methods Relating to cross analysis

Soil & water quality parameter	Invasive plant parameter
Soil salinity	invasive plant types
	invasive plant density
Total Dissolved Solids	invasive plant types
	invasive plant density
Sea Intrusion Distance	invasive plant types
	invasive plant density
Irrigation Distance	invasive plant types
	invasive plant density

Compared the soil & water quality parameter results with the invasive plant parameters to identify how soil & water quality parameters affect invasive plant types & density.

4. Data Analysis & Research Results

4.1 WETLAND SOIL & WATER QUALITY ANALYSIS

Table 5, Wetland soil & water analysis

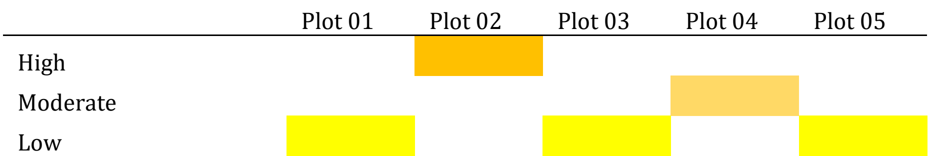
Parameter	Site conditions	Index value description	Analysis
1. Soil Salinity	Plots 02 & 04 (2/5) have high salinity levels (>3 ppt), & Plots 01, 03, 05 (3/5) have lower salinity levels.	Salinity above 3-5 ppt is considered as high salinity levels. These levels often stress freshwater-adapted plants; salt tolerant species dominate at higher salinities. (Sui et al., 2022)	Among the considered plots, the two high plots have more than 3 ppt values, & the other three plots have comparatively much lower ppt values than the high salinity plots.
2. Water Contami- -nation (TDS)	Only plot 01 & 04, have surface water levels. From these plots, plot 04 has a drastic difference in the soil TDS level.	Index Description: HDI = (TDS_Plot04 / TDS_Plot01) × Stagnation Factor (1.5). HDI >3.0 indicates critical contamination risk from hydrological stagnation & inlet flushing	Plot 04 exhibited substantially elevated TDS levels, while Plot 01 showed minimal TDS accumulation with consistently low values.

3. Sea Intrusion Distar	Plot 01: 3075m, Plot 02: 2726m, Plot 03: 5547m, Plot 04: 5046m, Plot 05: 5827m	More than 5000m distance - long distance Between 2000m to 5000m distance - moderate distance Less than 2000m distance - short distance	Plot no. 3, 4 & 5 have more than 5000m distance (long distance) from the sea connecting point. Plot no. 1 & 2 have between 2000m to 5000m distance (moderate distance) from the sea connecting point.
4. Irrigation Distance	Plot 01: 0m, Plot 02: 111m, Plot 03: 2135m, Plot 04: 1656m, Plot 05: 2523m	More than 5000m distance - long distance Between 2000m to 5000m distance - moderate distance Less than 2000m distance - short distance	Plot no. 5 has between 2000m to 5000m distance (moderate distance) from an irrigation outlet. All other plots (1,2,3,4) have less than 2000m distance (short distance) from an irrigation outlet.

4.1.1 Soil & Water Quality Analysis

Soil Salinity levels – plot 02 & 04, exhibited high salinization (>3 ppt), remaining 01,03 & 05 plots showed comparatively low salinity levels.

Table 6, Salinity variation along with the plots



Water Contamination - Total Dissolved Solids (TDS) - Only Plots 01 & 04 contained a water surface, which can be taken for data collection & analysis. Plot 04 displayed substantially elevated TDS level, while Plot 01 maintained low values.

Sea Intrusion Distance - Plot 01 (3075 m), Plot 02 (2726 m), Plot 03 (5547 m), Plot 04 (5046 m), Plot 05 (5827 m). Plot no. 3, 4 & 5 have more than 5000m distance (long distance) from the sea connecting point. Plot no. 1 & 2 have be-tween 2000m to 5000m distance (moderate distance) from the sea connecting point.

Irrigation Distance - Plot 01 (0 m), Plot 02 (111 m), Plot 03 (2135 m), Plot 04 (1656 m), Plot 05 (2523 m). Plot no. 5 has between 2000m to 5000m distance (moderate distance) from an irrigation outlet. All other plots (1,2,3,4) have less than 2000m distance (short distance) from an irrigation outlet.

4.1.2 Relationship Between the Distance from Water Contamination Points & Soil & Water Quality

Sea intrusion distances ranged from 2726 m (Plot 02) to 5827 m (Plot 05). It was expected that shorter distances from sea connecting point to the wetland plot should result in high salinity levels in wetland water quality, & longer distances from sea connecting point to the wetland plot should result in high salinity levels in wetland water quality. But data analysis showed that contrary to the expectations, longer distances unexpectedly correlate with higher salinity due to localized stagnation overriding marine gradients. Plot 04 displayed substantially elevated TDS despite greater sea distance (5046 m), while Plot 01 maintained low values (3075 m sea distance).

Irrigation distances ranged from 0m (Plot 01) to 2523m (Plot 05). It was expected that shorter distances from irrigation outlet connecting point to the wetland plot should result in high salinity levels & high total dissolved solids (TDS) levels in wetland water quality, & longer distances from irrigation outlet connecting point to the wetland plot should result in high salinity levels & total dissolved solid levels in wetland water quality. Data analysis also showed that, shorter distances have a direct negative correlation with salinity/TDS as irrigation outlets streams flush irrigation salts & dissolved solids into the stagnant lagoon, depositing both agricultural runoff & sea intrusion salts under limited water movement.

4.2 WETLAND INVASIVE PLANT ANALYSIS

Invasive Plant Types

Plots 01 & 02 contain both Prosopis juliflora and Typha angustifolia, reflecting mixed invasion pressure. Plots 03 & 04 are dominated by a single invasive species matching site conditions (Prosopis juliflora in Plot 03 dry/low-salinity, Typha angustifolia in Plot 04 wet/moderate-salinity). Plot 05 contains no invasive species. Prosopis juliflora acts as the primary dominant species across the wetland, particularly in distant sea plots (03, 05), while Typha angustifolia prevails near irrigation mouths (Plots 01–02) due to nutrient.

Invasive Plant Density

Plots 03 & 04 exhibit high invasion (>30% cover), Plots 01 & 02 show low density (<10%), and Plot 05 remains invasives-free. High-density plots align with extreme conditions: Prosopis-dominated dry zone (Plot 03) and Typha-dominated wet margin (Plot 04). Low-density plots reflect transitional conditions (Plot 02) or native recovery (Plot 05). Density, rather than species diversity, drives invasion pressure, with >30% cover causing significant hydrological obstruction and salinity feedback amplification.

Table 7, Wetland invasive plant analysis

Parameter	Site conditions	Index value description	Analysis
1. Invasive plant types	plot 01 & 02 contain two invasive species, plot 03 & 04 are dominated by a single species depending on site conditions, & plot 05 has no plant species	Count number of invasive species varieties present; higher numbers indicate more complex invasion pressure (Zedler & Kercher, 2004)	This invasive plant community is primarily composed of two main species, with Prosopis juliflora acting as the dominant species & a key driver within the wetland ecosystem
2. Invasive plant density	plot 03 & 04 are highly invaded, plot 01 & 02 exhibit low invasive plant density, & plot 05 contains no invasive species	density categories <10% low 10-30% moderate >30% high invasion (Khan et al., 2023)	Among the considered plots, the invasiveness is highest in two plots, & the other two have lower levels of invasive density. Looking at the plant varieties, the invasiveness depends on the invasive plant density within each particular plot.

4.3 OVERALL ANALYSIS

Across Bundala's five plots, soil salinity varied distinctly with two plots exhibiting high salinization (>3 ppt) stressing freshwater plants while favoring salt-tolerant species, & three showing lower levels; this gradient strongly controlled invasive vegetation distribution. Water TDS analysis from Plots 01 & 04 revealed elevated levels in Plot 04 (5046 m sea distance) versus low values in Plot 01 (3075 m), driven by inlet streams flushing irrigation salts into stagnant lagoon conditions depositing both agricultural runoff & sea intrusion salts under limited water movement. Invasive plant analysis confirmed two plots contained both Prosopis juliflora & Typha angustifolia, two were dominated by single invasive matching site conditions, & one remained invasive-free, with Prosopis juliflora as the primary dominant species; density categories showed two plots with high invasion (>30%), two with low (<10%), & one invasives-free, confirming density as the key invasion pressure indicator.

These patterns demonstrate clear species-salinity partitioning: Prosopis juliflora achieved highest cover in low-salinity dry plots (e.g., Plot 03), declining in higher-salinity transition zones (Plot 02 >2 ppt), reflecting moderate salt tolerance limits; conversely, Typha angustifolia dominated moderate-salinity wet plots (Plot 04 ~1.29 ppt) with shallow submersion, thriving where water salinity & nutrient-rich stagnation prevail. Hydrological distance gradients reinforced these dynamics, irrigation proximity (Plot 01: 0 m, Plot 02: 111 m) washed salts lagoon-ward diluting proximal TDS while promoting Typha via nutrient runoff, whereas longer sea distances unexpectedly correlated with higher salinity due to stagnation overriding marine dilution (Plot 05: 5827 m).

Invasive plants fundamentally alter salinity dynamics through biophysical mechanisms: Prosopis juliflora's deep taproots access saline groundwater for bioremediation (reducing surface salinity via vertical redistribution), while Typha angustifolia's dense rhizomatous mats impede flow, reduce oxygenation, & trap sediments, exacerbating surface salt accumulation via evapoconcentration. Uniform temperatures (~30-31°C) across plots indicate microclimate played minimal role, positioning salinity-hydrology gradients & invasive density as primary vegetation determinants. These interactions create reinforcing feedback loops where elevated salinity selects invasives, which further modify hydrology to intensify salinization, posing profound challenges to wetland resilience & native biodiversity conservation.

Environmental gradient analysis further confirmed distinct clustering based on salinity, water presence, & species dominance, low-salinity dry plots forming Prosopis clusters, & wetter moderate-salinity zones forming Typha-dominated clusters. These gradients act as ecological filters, showing how invasive species' physiological tolerances shape vegetation–salinity relationships across the wetland.

Distant/sea plots favor Prosopis density due to salt tolerance; irrigation-proximal plots boost Typha density via nutrients; high salinity selects dense invasives while low salinity limits establishment.

Runoff, water depth, & hydrological connectivity shape salinity–vegetation interactions, with obstructed flow from sediment, invasive root mats, or physical barriers increasing salt retention. *Typha* slows water movement & traps salts through dense rhizomes, while *Prosopis* deep rooting lowers water tables & promotes upward salt movement. These mechanisms intensify salinity in both wet & dry zones, creating a feedback loop where salinity drives invasive spread & invasives further modify salinity patterns.

Table 8, Overall analysis.

Soil & water quality parameter	Invasive plant parameter	Comparative Analysis
1.Soil salinity	invasive plant types	High salinity plots (>3 ppt, 2 plots) = P. juliflora dominance; low salinity (3 plots) = Typha/mixed
	invasive plant density	High salinity = high density (>30%, 2 plots); low salinity = low density (<10-30%, 3 plots)
2.Water contamination	invasive plant types	Plot 04 (high TDS) = Typha dominant; Plot 01 (low TDS) = mixed/low invasives
	invasive plant density	High TDS (Plot 04) = high density (>30%); low TDS (Plot 01) = low density (<10%)
3.Sea Intrusion Distance	invasive plant types	Distant plots (03,05) =P. juliflora bioremediation; closer plots =Typhasalt trapping via rhizome mats
	invasive plant density	Distant plots (03,05) = high P. juliflora (>30%); closer plots = moderate Typha (10-30%)
4.Irrigation Distance	invasive plant types	Negative correlation with salinity/TDS; proximal plots (01-02) =T. angustifoliahotspots due to nutrient-saline synergy
	invasive plant density	Proximal plots (01-02) = high Typha (>30%); distant plots (03-05) = low (<10%)

Study limitations include restricted spatial & temporal coverage, reliance on visual cover estimates, & shallow soil sampling, which may miss deeper salinity processes relevant to invasive root systems. The absence of faunal data also limits understanding of ecological interactions. Broader, multi-season sampling & deeper soil analyses are needed to better quantify invasive effects on soil chemistry & hydrology.

Management focuses on controlling salinity-altering invasives & restoring hydrological connectivity. Adjusting freshwater inflows, drainage, & nutrient inputs can reduce salinity & invasive advantage, while water-level regulation helps limit Typha. Mechanical removal of Prosopis & Typha, supported by cautious herbicide use, remains essential, along with long-term biological control options that require ecological risk evaluation.

Effective restoration requires re-establishing native species suited to local salinity regimes, maintaining buffer zones, & continuous monitoring of vegetation, salinity, & water levels to support adaptive management. Community engagement is critical for sustaining invasive control in Bundala.

4.4 RECOMMENDATIONS

- Maintain mature Prosopis juliflora cover at steady densities (20-30% optimal) to leverage bioremediation while preserving native vegetation access to water, sunlight, & core habitat requirements.
- Deploy remote sensing/GIS monitoring for real-time wetland condition assessment to enable timely intervention decisions.
- Install salinity-responsive irrigation barriers/regulators based on periodic soil-water assessments to control nutrient runoff & Typha proliferation.
- Implement distance-targeted mechanical thinning near irrigation/sea interfaces (<150 m) combined with hydrological restoration for natural flushing.

5. Conclusion

This study successfully investigated how invasive species influence soil salinity processes in Sri Lanka's southern coastal lagoon wetlands by systematically examining *Prosopis juliflora* & *Typha angustifolia* through soil salinity, water TDS, sea opening-to-plot distances, irrigation mouth-to-plot distances, invasive plant types, & their densities.

The research achieved the following objectives: invasive plant types & distributions were identified across Bundala wetland's five selected 20 m × 20 m plots along salinity gradients; invasive plant densities were quantified, revealing inverse correlations with surface soil salinity; & spatial influences of irrigation proximity (favoring *Typha* via nutrient runoff) & sea proximity (boosting *Prosopis* via salt intrusion) were analyzed. Soil & water quality feedback was demonstrated through transpiration-driven salt accumulation.

A comprehensive literature review identified soil salinity, water contamination, & distance from contamination points, including proximity to the sea & to irrigation inlet connection points, as key parameters affecting wetland water quality. Invasive plant types & invasive plant density were identified as parameters influencing invasive vegetation patterns. Wetland water-quality data were collected through soil & water sampling at selected nodes, as well as distance measurements to the nearest sea-connecting point & irrigation inlet. Invasive-plant data were gathered through field observations, interviews, & recorded data sources. Data analysis included descriptive statistics, density–salinity correlations, & spatial gradient comparisons. Key findings include, higher invasive densities were generally linked to elevated salinity, except in mature *Prosopis* stands showing bioremediation through salt redistribution to deeper horizons; irrigation distances <150 m promoted *Typha* dominance; sea distances <100 m intensified *Prosopis* cover; & TDS rose in stagnant zones under dense vegetation.

These findings demonstrate that invasive vegetation critically regulates salinity dynamics in lagoon wetlands. Distribution patterns directly modulate soil & water salt levels via hydrological–spatial interactions.

Effective management strategies include: maintaining mature *Prosopis juliflora* cover at steady densities (20–30%) to leverage bioremediation benefits while ensuring native vegetation access to water, sunlight, & core habitat; deploying remote sensing & GIS monitoring systems for real-time wetland assessment to guide timely interventions on invasive spread & salinity fluctuations; installing salinity-responsive irrigation barriers & regulators, calibrated through periodic soil-water assessments, to control nutrient runoff & limit *Typha angustifolia* proliferation near irrigation mouths (<150 m); & implementing targeted mechanical thinning at critical irrigation/sea interfaces, combined with hydrological restoration measures to promote natural flushing & reduce salt accumulation.

Future Research Directions
Future studies should examine climate-driven changes in Prosopis suitability, long-term ecohydrological monitoring, & experimental manipulation of hydrology & salinity to refine restoration thresholds. Additional research on allelopathy, soil microbial dynamics, & safe biological control methods is needed, alongside socioeconomic studies to integrate local community participation in invasive management.

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7. References

Baltazar-Campos, H., Orona-Tamayo, D., & Arcibar-Orozco, J. A. (2025). Short-term removal of pollutants from tanning wastewater-impacted river by Typha domingensis. *Science of The Total Environment*, *982*, 179651. https://doi.org/10.1016/j.scitotenv.2025.179651

Bandara, W. A. R. T. W., Ranasinghe, O., Perera, P., Vlosky, R., & Kizha, A. R. (2022). Potential to use invasive plants in biomass energy production: A case study Prosopis juliflora in coastal wetlands of Sri Lanka. *Trees, Forests and People*, *10*, 100330. https://doi.org/10.1016/j.tfp.2022.100330

Chen, L. (2019). Invasive Plants in Coastal Wetlands: Patterns and Mechanisms. In S. An & J. T. A. Verhoeven (Eds.), *Wetlands: Ecosystem Services, Restoration and Wise Use* (Vol. 238, pp. 97–128). Springer International Publishing. https://doi.org/10.1007/978-3-030-14861-4_5

DeBerry, D. A., & Hunter, D. M. (2024). Impacts of Invasive Plants on Native Vegetation Communities in Wetland and Stream Mitigation. *Biology*, *13*(4), 275. https://doi.org/10.3390/biology13040275

Herbert, E. R., Boon, P., Burgin, A. J., Neubauer, S. C., Franklin, R. B., Ardón, M., Hopfensperger, K. N., Lamers, L. P. M., & Gell, P. (2015). A global perspective on wetland salinization: Ecological consequences of a growing threat to freshwater wetlands. *Ecosphere*, *6*(10), 1–43. https://doi.org/10.1890/es14-00534.1

Kariyawasan Patabendige, K. M., Amarasinghe, M. D., Ratnayake, R. M. C. S., & Dahanayaka, D. D. G. L. (2023). Impact of climate and irrigation practices on hydrological aspects of Bundala wetlands in Sri Lanka. *Irrigation and Drainage*, *72*(3), 696–705. https://doi.org/10.1002/ird.2797

Khan, N., Ullah, R., Okla, M. K., Abdel-Maksoud, M. A., Saleh, I. A., Abu-Harirah, H. A., AlRamadneh, T. N., & AbdElgawad, H. (2023). Spatial distribution of the four invasive plants and their impact on natural communities' dynamics across the arid and semi-arid environments in northwest Pakistan. *Frontiers in Plant Science*, *14*, 1207222. https://doi.org/10.3389/fpls.2023.1207222

Lenjisa Diriba Balcha. (2022). ProsopiIs juliflora Distribution, Impacts, and Control Methods Available in Ethiopia. *Natural Resource Ecology and Management*, *7*, 14. https://www.researchgate.net/publication/366191429_ProsopiIs_juliflora_Distribution_Impacts_and_Control_Methods_Available_in_Ethiopia

Ling, J. E., Powell, M., Wen, L., & Pinto, U. (2023). Soil seed bank can complement restoration efforts in a coastal freshwater creek. *Wetlands Ecology and Management*, *31*(6), 825–852. https://doi.org/10.1007/s11273-023-09954-z

Nachshon, U. (2018). Cropland Soil Salinization and Associated Hydrology: Trends, Processes and Examples. *Water*, *10*(8), 1030. https://doi.org/10.3390/w10081030

Peters, R., Reis, Â. C. A., Mehlig, U., Wimmler, M.-C., Vollhüter, J., Pimple, U., Tietjen, B., & Berger, U. (2025). Modelling the dynamics of soil moisture and soil water salinity in tropical saltmarshes. *Ecological Modelling*, *504*, 111089. https://doi.org/10.1016/j.ecolmodel.2025.111089

Shiferaw, W., Demissew, S., Bekele, T., Aynekulu, E., & Pitroff, W. (2021). Invasion of Prosopis juliflora and its effects on soil physicochemical properties in Afar region, Northeast Ethiopia. *International Soil and Water Conservation Research*, *9*(4), 631–638. https://doi.org/10.1016/j.iswcr.2021.04.003

Shrimali, C., Tandan, H. N., Khemeshwari, Patel, M., Tuleshwari, Roshani, Kiran, & Sahu, B. (2025). Ecological Significance of Typha angustifolia Dominated Wetlands: A Case Study of Avian Biodiversity in Chhattisgarh, India. *UTTAR PRADESH JOURNAL OF ZOOLOGY*, *46*(2), 103–114. https://doi.org/10.56557/upjoz/2025/v46i24767

Sui, H., Chen, D., Yan, J., Li, B., Li, W., & Cui, B. (2022). Soil Salinity Estimation Over Coastal Wetlands Based on Random Forest Algorithm and Hydrological Connectivity Metric. *Frontiers in Marine Science*, *9*, 895172. https://doi.org/10.3389/fmars.2022.895172

Suraweera, C., Gallo, J., Vacek, Z., Cukor, J., Vacek, S., & Baláš, M. (2023). Silvicultural Practices for Diversity Conservation and Invasive Species Suppression in Forest Ecosystems of the Bundala National Park, Sri Lanka. *Plants*, *13*(1), 121. https://doi.org/10.3390/plants13010121

Udadini, K. M. E., & Bandara, W. A. R. T. W. (2017). Community and Industry Attitude Towards Using Prosopis juliflora as a Dry Matter Energy Source: A Case Study in Hambantota. *Proceedings of International Forestry and Environment Symposium*, *21*(0). https://doi.org/10.31357/fesympo.v21i0.3084

Xin, P., Wilson, A., Shen, C., Ge, Z., Moffett, K. B., Santos, I. R., Chen, X., Xu, X., Yau, Y. Y. Y., Moore, W., Li, L., & Barry, D. A. (2022). Surface Water and Groundwater Interactions in Salt Marshes and Their Impact on Plant Ecology and Coastal Biogeochemistry. *Reviews of Geophysics*, *60*(1). https://doi.org/10.1029/2021rg000740

Zedler, J. B., & Kercher, S. (2004). Causes and Consequences of Invasive Plants in Wetlands: Opportunities, Opportunists, and Outcomes. *Critical Reviews in Plant Sciences*, *23*(5), 431–452. https://doi.org/10.1080/07352680490514673