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Behavioural Transformation of Mangrove and Halophytic Flora in the Gulf of Kutch: An Analytical Study of Salinity Stress, Coastal Disturbance and Ecological Resilience

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Abstract

The Gulf of Kutch is home to significant mangrove and halophytic vegetation and the only unique semi-arid coastal plant assemblage of India. There is interaction of hypersalinity, tidal exposure, sediment instability and coastal development which affect plant behaviour and community resilience. This paper uses a mixed-method ecological framework comprising secondary literature, official forest and coastal reports, proposed field sampling and geospatial interpretation, to examine the behavioural change of mangrove and halophytic flora. The study explores different plant responses which manifested at plant morphological, physiological, population and community levels again included salt secretion and osmotic adjustment, leaf succulence and root aeration, zonation shifts and dominance patterns, recruitment potential and recovery capacity. Since no fundamental field dataset was provided for this manuscript, the results section separates evidence-based analytical synthesis from simulated demonstration tables and figures that are merely intended to illustrate possible statistical and geospatial interpretation. The synthesis suggests that the main resilient mangrove species suitable for growing at river deltas and landward habitats exposed to acidity in the Gulf is Avicennia marina. Further, salt-marsh halophytes are an ecologically important transition belt species in higher salinity and disturbed habitats. The disturbance of coastal areas by port activities, salt-pan expansion, grazing, industry, sediment alteration and hydrology is likely to affect species diversity, regeneration, canopy continuity and resilience, testing of stress threshold. The manuscript presents a disturbance–resilience matrix, a salinity–vegetation response model and a management framework to ensure hydrological restoration, native species revival, GIS-based monitoring, legal enforcement and community participation. According to the study, one should

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not assess KCCT resilience in Kutch based on mangrove-cover expansion but functional diversity, regeneration, zonation integrity and stability over a long time.

Keywords: Gulf of Kutch; Avicennia marina; halophytes; salinity stress; coastal disturbance; ecological resilience; mangrove restoration.

1. Introduction

Mangrove and salt marshes are narrow but very critical areas at a land-sea interface. They moderate shoreline erosion, trap sediments, regulate nutrient exchange, support fisheries and coastal biodiversity, and provide natural buffering against storm surges and other hazards associated with rising sea levels (Bunting et al., 2022; FAO, 2023; IPCC, 2019). In terms of their size their ecological importance is more than their extent of areal coverage because the intertidal vegetation supports terrestrial and marine food webs and also sequesters carbon in biomass and waterlogged sediments (Bunting et al., 2022; FAO, 2023). These systems are some of the plant communities that are most exposed to stressors because they are rooted in saline, anoxic, periodically inundated and geomorphologically unstable habitats.

The Gulf of Kutch in Gujarat, the Gulf of Kutch is an important area to study the mangroves and halophytes transformation, as it has semi-arid conditions, saline soils, extensive tidal flats and creek networks, salt marshes and an industrial coastal belt under rapid construction. According to the 2023 state forest assessment, Gujarat has a mangrove cover of 1164.06 km² with the highest district-level mangrove cover being in Kachchh district. Gujarat has the second largest cover among the Indian states and also has the largest mangrove cover on the western coast. (Gujarat Forest Department, 2025a) Official presentations on conservation also highlight the dominance of A. marina in Gujarat's mangrove vegetation. Furthermore, the other two species namely Rhizophora mucronata, Ceriops tagal, and Aegiceras corniculatum are known to occur in much lesser patches, mainly in the Gulf of Kutch and associated protected areas (Gujarat Forest Department, 2025b; Gujarat Biodiversity Board, 2012).

The phrase ecological sense refers to human behaviour in the context of the paper. The word "plasticity" refers not to the behaviour of animals but to the observable ways in which plants modify their growth form, phenology, architecture, resource allocation, reproductive success, spatial distribution and community dominance in response to environmental pressure. Salinity tolerance in mangroves and halophytes manifests in a range of phenotypes. These include leaf succulence and lessened leaf area, salt glands or salt exclusion, osmotic regulation, root-zone aeration, altered seedling recruitment, dwarfing, zonation shifts and replacement of less tolerant species by more stress-tolerant taxa (Aljahdali et al., 2021; Grigore, 2023; Mann et al., 2023; Perri et al., 2023).

The transformation of gulf of kutch driven primarily by salinity stress The combination of low inflow of fresh water, high rates of evapotranspiration, limited drainage, tidal concentration of salts, and variation in sediment level can generate soil and pore water conditions that exceed the tolerance thresholds of many coastal plant species. Field observations from the Abdasa coast of

Kachchh show high salinity of creeks and pore-water. Forest structure is linked to low rainfall and poor runoff, with hypersalinity (Unny et al., 2022). Resilience does not just depend on the survival of mature trees but rather the recruitment, establishment of seedlings, development of the canopy, and persistence of the Associate halophytes under such conditions.

Coastal interference creates additional pressure layer. The ports, harbours, jetties, salt-producing landscapes, industrial estates, fishing activities, mining pressures, and shoreline infrastructure of the Gulf of Kutch. These disruptions could alter water connectivity, sedimentation, pollution exposure, grazing intensity, and spatial continuity of intertidal vegetation (Unny et al., 2022). Global assessments of mangrove ecosystems show that coastal development, pollution, hydrological alteration, and climate hazards are among the key threats (IUCN, 2024; IPCC, 2019). The present research thus provides an integrated analytical paper on salinity stress, coastal disturbance, plant transformation, and resilience in the Gulf of Kutch. The objective is to develop an ecological framework that can help future field studies, remote-sensing evaluation and conservation planning efforts. The study does not intend to provide new primary field measurements. In the results, any numerical table or chart appears labelled as simulated demonstration outputs and included to show how a real dataset could be analysed.

2. Review of Literature

2.1 Mangrove Ecosystems and Coastal Resilience

Recent studies on mangroves have transitioned from a mere forest-cover viewpoint to the understanding of mangroves as a socio-ecological system. According to the authors Bunting et al. (2022), global mangrove monitoring needs accurate, repeated mapping of mangrove change, as change involves loss and gain across tidal wetlands. According to FAO (2023), mangrove loss is slowing to some extent. However, mangroves are being converted for aquaculture and infrastructure. Cover figures must be interpreted along with structural and functional ones. For the Gulf of Kutch the implication is clear, the expansion in one creek need not imply compensation for loss of diversity, regeneration, and hydrological integrity elsewhere.

The resilience of the mangrove ecology is the ability of a system to withstand a stressor while keeping its core ecological functions intact and to recover from those stressors without changing into an alternative degraded state of the system. Resilience can be measured in different ways, such as regeneration, seedling survival, species diversity, canopy condition, sediment stability, hydrological connectivity and persistence of natural zonation. Successful mangrove restoration requires an understanding of local ecology. Ultimately, restoration should create the conditions for natural regeneration or self-replanting, not mass planting (Global Mangrove Alliance, 2023). It is particularly important in semi-arid coasts, where planting without hydrological correction results in poor survival.

2.2 Halophyte Species and Their Tolerance Mechanisms

Halophytes are plants that are capable of completing their life cycle in environments that have high salinity levels (saline environments). Most glycophytes cannot grow in saline environments.

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The basis of their tolerance involves a combination of osmotic adjustment, regulation of ion transport, vacuolar sequestration of sodium and chloride, antioxidant defence, succulence, tissue compartmentalisation and, in some taxa, salt excretion via specialised glands or bladders (Grigore, 2023; Mann et al., 2023). The mechanisms are not the same for all species. Some halophytes exclude salts, some accumulate toxic salts in a safe location in the tissues, and some utilize sodium for osmoregulation. Some mechanisms are effective in keeping the metabolites active (Mann et al., 2023).

The salt-marsh vegetation of the Gulf of Kutch is ecologically important in occupying mudflats, marsh margins, creek banks and high intertidal areas where establishment of mangroves may be curtailed by elevation, salinity or inundation regime respectively. Salvi et al. (2017) reported the halophytic diversities recorded from coastal talukas and islands of Gulf of Kachchh and studied on the diversity indices of vegetation. While the work is earlier than the preferred evidence window of 2020–2026, it is still directly relevant as it provides region-specific halophyte information useful in designing updated field surveys.

2.3 Salinity Stress and Changes in Plant Behaviour

Salinity stress impacts plants in two wave, in the first wave, osmotic pressure causes reduced water uptake and in the second wave, the sodium and chloride accumulated in the plant through ionic toxicity and nutrient imbalance which exceeds their physiological tolerance. High salt concentration in mangroves members can lower the canopy height, slow down growth, modify leaf traits, limit seedling recruitment, and favour salt-tolerant taxa (Aljahdali et al., 2021; Perri et al., 2023). According to Perri et al. (2023), salinity may limit the height of mangrove canopies at broad spatial scales, which links salinity with tree stature, productivity and functional diversity. Avicennia marina is proven to show physiological stress to high salinity and temperature by Aljahdali et al. (2021), hence there is a need to couple vegetation observation with soil and water and physiological parameters.

According to some trajectories, in the Gulf of Kutch salinity driven transformation is expected to get expressed along a gradient from relatively taller or denser Avicennia stands in better-flushed creeks to sparse, shrubby or discontinuous stands in hypersaline mudflat and salt-pan-adjacent zones. Halophytes can spread or take over in areas where salinity and height exceed mangrove levels. In semi-arid intertidal mosaics, salt-marsh halophytes are natural and do not signal ecological degradation. Inundating large plots of mangrove propagation with empty mudflat or degraded halophyte patches could signal hydrological stress, grazing stress, or sediment disturbance.

2.4 Coastal Disturbance and Vegetation Degradation

Coastal disturbance affect inter-tidal vegetation through physical removal, alteration in sediment supply, restriction to tidal exchange, oil and other chemical pollution, trampling, grazing, dredging, embankment construction, salt-pan expansion, and port-related facilities. According to Unny et al. (2022), the industrial and coastal pressures which have impacted the mangrove belt

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at Abdasa in Kachchh include ports, jetties, mining, salt production, hydrological diversion, and pollution. These impacts can have a complicated relationship with salinity; a stand that can tolerate a naturally high salinity may suffer decline if tidal channels are blocked sediments compacted.

Rupture also creates edge effects. Fragmentation augments susceptibility to wave exposure, sediment dryness, and human access. When seedlings become removed by grazing, regeneration of communities may be altered even when adults live. Lateral tidal flow was altered by salt-pan bunds and road work which eventually creates hypersaline backwater pockets unsuitable for seedlings. Thus, a disturbance assessment must be spatially explicit, and include both field scores and stakeholder observation, and GIS-derived land-use change indicators.

2.5 Coastal Ecology and Conservation Challenges in the Gulf of Kutch

The Gulf of Kutch is an ecological sensitive area within which we can observe Mangroves, Coral Reefs, Seagrass associated habitats, Mudflats, creeks, Salt Marshes Islands. The official conservation documentation of Gujarat pays heed to the significance of mangrove and coral conservation in the landscape of the Marine National Park. Moreover, it states that Avicennia marina is the dominant mangrove species of the state (Gujarat Forest Department 2025b). The state forest time-series analysis indicates that the largest mangrove cover in Kachchh district makes it an important district for vegetation resilience and disturbance impact monitoring (Gujarat Forest Department 2025a).

Mangrove conservation in the country is linked to the forest monitoring system, Coastal Regulation Zone provisions, Mangroves Initiative for Shoreline Habitats and Tangible Incomes, biodiversity conservation, and climate change adaptation. According to a recent parliamentary response, the MISHTI programme has been launched in 2023 for mangrove restoration and promotion. The CRZ Notification, 2019 treats mangroves as ecologically sensitive areas. It also contains a buffer provision, which will apply where mangrove cover exceeds threshold areas. (Press Information Bureau, 2025) While these instruments can provide a policy base, their effectiveness in the field depends on a range of factors, including enforcement and hydrological restoration, local participation and adherence, and rigorous ecological monitoring and adaptation.

2.6 Research Gap

Current Information on Gulf of Kutch mangrove cover, Avicennia dominance, local stand structure, conservation initiative and diversity of halophytes (Gujarat Forest Department, 2025a; Gujarat Forest Department, 2025b; Salvi et al., 2017; Unny et al., 2022). Notwithstanding the fact that literature exists on forest reporting, species inventories, stand-structure studies, remote sensing and policy documents, the subject remains fragmented. The analysis of salinity stress in coastal ecosystems modification will require an integrated framework involving disturbance intensity, plant behavioural traits, community transformation and resilience indicators to develop a single design.

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A further gap is the lack of long-term plot-based data on soil salinity, pore-water salinity, pH, sediment texture, tidal inundation, species composition, seedling survival, canopy cover, and disturbance mapping. Without these coupled data, it is difficult to distinguish between natural semi-arid zonation and anthropogenic disturbance-induced degradation. The current document presents a potential framework for future empirical testing that is GIS compatible and field-ready.

Table 1. Review of key literature and institutional sources relevant to Gulf of Kutch mangrove–halophyte resilience.

Author/Year	Study area	Focus	Methodology	Key findings	Research gap
FAO (2023)	Global mangroves	Mangrove area change and drivers	Global assessment and reporting synthesis	Mangrove loss has slowed but conversion, erosion and hydrological change remain important drivers.	Needs finer local interpretation of ecological function and resilience.
Bunting et al. (2022)	Global	Mangrove extent change, 1996–2020	L-band SAR and Global Mangrove Watch mapping	Produced long-term mangrove extent and change products suitable for monitoring.	Remote-sensing cover must be linked to field indicators in local systems.
Perri et al. (2023)	Global	Salinity effects on mangrove canopy height	Large-scale ecological modelling	Salinity limits mangrove canopy height and influences community traits.	Needs site-specific application in semi-arid Indian coasts.
Aljahdali et al. (2021)	Rabigh Lagoon, Red Sea	Avicennia marina stress ecology	Field, water-quality and physiological assessment with PCA	High salinity and temperature were associated with stress responses in A. marina.	Comparable integrated stress studies are limited for the Gulf of Kutch.
Mann et al. (2023)	Global halophytes	Salt-tolerance strategies	Review of physiological, molecular and adaptive mechanisms	Halophytes use ion regulation, osmotic adjustment and anatomical adaptations to tolerate salinity.	Local halophyte functional traits need field testing.

Unny et al. (2022)	Abdasa, Kachchh	Mangrove stand structure and environmental factors	Transect and environmental assessment	High salinity, low rainfall and poor runoff influence Avicennia-dominated structure.	Requires integration with disturbance scoring and halophyte transitions.
Salvi et al. (2017)	Gulf of Kachchh	Halophyte diversity	Coastal survey and diversity indices	Recorded diverse halophyte flora across Gulf sites.	Needs updated floristic monitoring and remote-sensing linkage.
Gujarat Forest Department (2025a, 2025b)	Gujarat and Gulf of Kutch	Mangrove cover and conservation status	Official forest reporting and conservation documentation	Gujarat has major mangrove cover; Kachchh is the highest district; A. marina is dominant.	Cover reporting should be complemented by resilience indicators.

3. Study Area: Gulf of Kutch

The Gulf of Kutch is a semi-closed arm of the Arabian Sea along the northwestern coast of Gujarat. The region is located north of the Kachchh coast and south of the Saurashtra coast and has a varied landscape comprising a multitude of tidal creeks, mud flats, salt marshes, islands, patches of mangroves, coral-associated habitat, and industrial coastal zone. The Gujarat coastline is suitable for establishing mangrove, coral and seagrass-associated ecosystems due to the presence of important gulfs, although extreme conditions in this arid to semi-arid climate impose strong water and salinity constraints (Gujarat Forest Department, 2025b)

The climate area is characterized by low and variable rainfall, high evapotranspiration, high summer temperature and freshwater runoff. The rainfall in western Kachchh region is poor along with no perennial rivers and high tidal salinity endangering the mangrove stand structural attributes as per Unny et al. (2022). Salinity gradients formed between creek channels, mudflats, back marsh zones and salt pan margins. Sediment texture, tidal amplitude and elevation determine how often roots are flooded and how fast salt accumulates in the rhizosphere.

The Gulf holds great biodiversity significance as it represents the one of the major intertidal systems along the western coast of India. Most of the mangrove flora is found to consist of Avicennia marina and being found at localised patches and protected areas if Rhizophora mucronata, Ceriops tagal and Aegiceras corniculatum (Gujarat Biodiversity Board, 2012; Gujarat Forest Department, 2025b). Halophytic vegetation is located in salt marshes and (high-intertidal) flats, which transitions from a mangrove stand to salt scrub. This strip of vegetation plays an important ecological role in stabilising sediments, salt cycling, microhabitat formation and natural succession.

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Development pressure and ecological sensitivity overlap and this makes conservation more relevant. Stretches that are the Gulf involve ports, industrial estates, salt-production environments, fish-catch areas and protection sites. Both human and natural forces cause salinity stress to mangroves and halophytes. Due to this dual exposure, the Gulf is a suitable venue to test resilience-based conservation strategies that use field ecology, remote sensing, and regulatory planning.

4. Theoretical Framework

The conceptual framework of this paper relates to environmental stressors, coastal disturbance, plant behaviour transformation, and ecological resilience. The main natural stressors include salinity stress, tidal inundation, sediment texture, pH, temperature and shortage of freshwater. A second layer of stress is formed by disturbances such as ports, roads, salt-pans, grazing, dredging, pollution and shoreline modification. The pressures change how plant behaves with respect to their water uptake, ion balance, root aeration, leaf morphology.

At the level of the individual plant, transformation may occur through the mechanisms of salt secretion, salt exclusion, leaf succulence, reduced leaf area, thick cuticle, changed root-to-shoot allocation and development of aerial roots or pneumatophores. At population level, transformation can be manifested through changes in density, height class distribution, basal area, canopy cover, and seedling to adult ratio. On the community level, Avicennia marina dominance, contraction of less-tolerant mangroves, expansion of halophyte patches, loss of understorey diversity and bare saline mudflat formation may be observed.

Ecological resilience is seen as a composite outcome. A highly resilient site would be one that has native species with their ability to regenerate, natural zonation, a stable canopy and sediment, and one which would be able to recover after seasonal or episodic disturbance. A site with low resilience may still have mature trees, but it shows other features like poor recruitment, high fragmentation, low diversity, impeded tidal flow, or high die-off following the drought or pollution events. The framework thus proposes that the measures of resilience should rely on process indicators instead of cover alone.

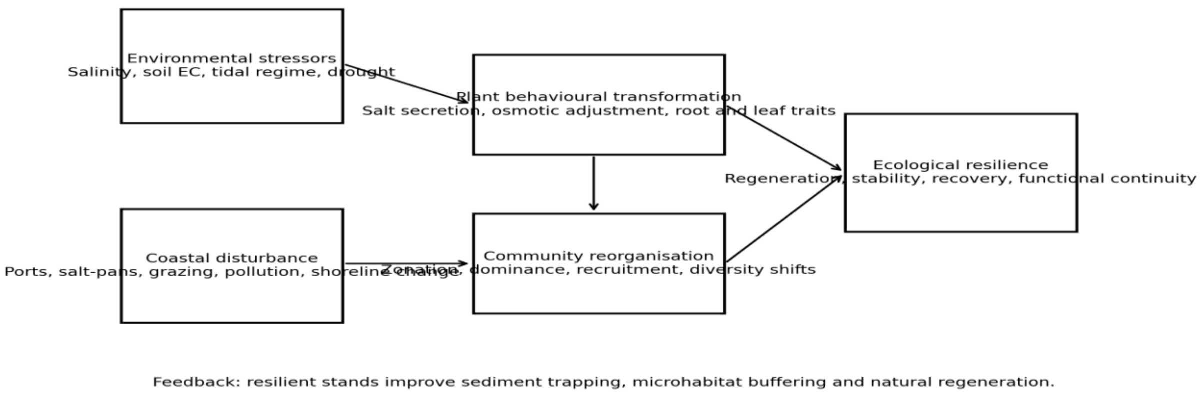

Figure 1. Conceptual resilience framework linking salinity stress, coastal disturbance, plant behavioural transformation and ecological resilience.

5. Research Methodology

5.1 Research Design

Mixed-method and ecological-analytical is the proposed research design. It takes use of secondary-data analysis, vegetation surveys, soil and water measurements, disturbance scoring, and GIS/remote-sensing interpretation. The design links field ecology with spatial analysis and conservation policy, thus making it appropriate for a Scopus-indexed or UGC-CARE journal article. Due to the absence of a primary dataset for the current manuscript, the empirical component is presented in the form of a replicable protocol reaching a designable primary dataset and the numerical examples provided in Section 6 are labelled simulated outputs.

The study will utilize stratified site selection across salinity disturbance gradient. Site categories should involve rather protected creek mangroves, restored mangrove plantations, creeks adjacent to a port or jetty, salt-pan margins, grazed mudflats, and natural salt-marsh transitions. The Gulf of Kutch vegetation is not homogenous that is why stratification is necessary. Stands differ on the basis of height, tidal flushing, proximity to creeks, sediment position, freshwater influence and anthropogenic pressure.

5.2 Method of Selecting Sample

Field sampling should consist of belt transects laid perpendicular to the shoreline or creek edge, from the low-intertidal mangrove edge through mid-intertidal stands to the high-intertidal halophyte or salt-marsh zone. In each transect, 10 m × 10 m quadrats may be placed for mature mangrove trees, 5 m × 5 m quadrats for saplings and shrub layers, and 1 m × 1 m quadrats for seedlings and herbaceous halophytes. Repetition must embrace the seasons as the monsoon freshwater entrance and pre-monsoon hypersalary impact can create different vegetation response.

The vegetation data must provide species identity, number of individuals in the height class, girth or stem diameter where applicable, canopy cover, seedling count, sapling count, mature tree count, leaf condition, number density of pneumatophores in Avicennia stand's leaves, and visible symptoms of stress such as chlorosis, leaf blackening, die-back, or dwarfing.

Because one cannot unambiguously define the salt-marsh taxa without the reproductive material, a voucher specimen or geo-tagged photographs are to be used for the confirmation of halophyte.

5.3 Ecological and Environmental Variables

Table 2. Proposed ecological and environmental variables for Gulf of Kutch field assessment.

Variable group	Indicators	Measurement method	Ecological relevance
Salinity / soil EC	Pore-water salinity, surface-water salinity and soil electrical conductivity	Portable salinity meter, EC meter, laboratory soil-water extract	Defines osmotic stress gradient and physiological pressure.
pH and sediment texture	Soil pH, sand–silt–clay proportion, organic matter	Soil sampling and laboratory analysis	Influences nutrient availability, root aeration and water retention.

Tidal inundation	Frequency, duration and creek connectivity	Field observation, tide tables, elevation/GIS layers	Controls salt flushing, propagule dispersal and seedling survival.
Vegetation structure	Density, canopy cover, height class, basal area, species composition	Quadrats, transects, canopy densiometer, GPS	Measures community condition and stand transformation.
Regeneration	Seedling, sapling and mature counts by species	Nested quadrats	Indicates recovery potential and future stand stability.
Disturbance intensity	Grazing, cutting, pollution, bunding, roads, ports, salt-pan proximity	Field score, land-use mapping, interviews where permitted	Links human pressure to vegetation decline or resilience.

5.4 Ecological Indices and Statistical Tools

The Shannon-Wiener Diversity Index (H') is calculated by making use of the formula $H' = -\Sigma p_i \ln p_i$, where pi is defined as the proportion of individuals of species i. Simpson's Index can represent dominance and diversity as $1 - \Sigma p_i^2$. The species evenness can be evaluated as $J = H'/\ln S$, where S is total species richness. Importance Value Index for mangroves may be calculated by summing the values of relative density, relative frequency and relative dominance. A regeneration ratio can be computed as the number of seedlings plus saplings divided by mature individuals for each species or site.

Statistical analysis must include descriptive statistics, correlation analysis, regression analysis, ANOVA (or non-parametric equivalents), and principal component analysis. Using correlation you can test whether salinity and disturbance are related to density, diversity, regeneration, or resilience. The relative effects of salinity, disturbance, and tidal connectivity on vegetation density or resilience score can be estimated by regression. The following lines in PCA highlight the stress and vegetation gradient that can make salinity-stress axis, disturbance axis and, recovery axis.

5.5 GIS and Remote-Sensing Analysis

The geospatial part requires multi-temporal satellite imagery like Landsat and Sentinel-2 for the detection of mangrove cover and salt-marsh extent, bare mudflat, salt-pans, industrial land, roads and shoreline change. As a vegetation greenness proxy, NDVI may be calculated as (NIR − Red)/(NIR + Red). Water and built-up indices can help distinguish tidal water, mudflat and infrastructure. Bunting et al. (2022) show it is important to have consistent remote-sensing products for monitoring mangroves. However, local field validation is important as sparse Avicennia scrub, salt marshes and wet mudflats can spectrally confuse.

Change detection should ideally compare four time points, namely pre- and post-major development. Results need to be considered in the context of the tide stage, season, cloud conditions and image resolution. The geospatial output must contain corresponding maps showing mangrove-cover change, NDVI trend, land-use/land-cover conversion, salt-pan expansion, proximity to disturbance sources and shoreline modification.

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5.6 Hypotheses and Analytical Testing Plan

Table 3. Hypotheses and proposed analytical testing plan.

Hypothesis	Statement	Key variables	Testing approach
H1	Higher salinity stress significantly affects distribution, density and growth behaviour.	Pore-water salinity, soil EC, vegetation density, height, canopy cover	Correlation, regression and ANOVA across salinity classes.
H2	Coastal disturbance significantly reduces diversity, regeneration and ecological stability.	Disturbance score, Shannon index, regeneration ratio, canopy continuity	Regression, PCA and disturbance–resilience matrix.
H3	Native salt-tolerant species exhibit stronger resilience than disturbance-sensitive species.	Species-level survival, regeneration, stress symptoms, IVI	Species resilience ranking and trait-based comparison.
H4	Lower-disturbance sites show higher diversity, regeneration and resilience.	Site disturbance class, diversity, regeneration and resilience score	ANOVA/Kruskal–Wallis and post hoc comparison.

5.7 Ethical and Ecological Limitations

Research in mangrove and salt-marsh ecosystems should follow site permits, biodiversity regulations, and non-disturbance protocols. It is best to avoid unwanted cutting and trampling of seedlings, disturbance to nesting fauna, intertidal fauna, and removing plant material without permission. If community interviews or local ecological knowledge are used, retain consent and anonymity.

The absence of an available primary dataset limits the present manuscript. Consequently, it does not provide actual field measured statistical results. The tables and figures that were simulated in Section 6 are clearly specified as being methodological in character, and before the submission of the article to the journal as an empirical paper, these will be replaced with actual field and remote-sensing outputs.

6. Results and Analysis

This chapter is supplemented by evidence gathered from published sources and institutions of the such as government, NGO, and academic reports. Evidence is presented through simulated demonstration tables and graphs showing how actual data would be analysed. Simulated values are not field observations, satellite data, nor official statistics. These are included only for methodological illustration because no primary field dataset was provided.

6.1 Mangrove and Halophytic Flora

The most important species of the mangrove community of Gulf of Kutch is Avicennia marina. The prevalence of this species corroborates Gujarat's officially published mangrove information as well as the field studies conducted at Kachchh, where hypersalinity, low freshwater runoff, and arid coastal areas favour a very salt-tolerant mangrove species. (Gujarat Biodiversity Board, 2012; Gujarat Forest Department, 2025b; Unny et al., 2022). Rhizophora mucronata, Ceriops tagal, and Aegiceras corniculatum are ecologically important but comparatively localised indicating rather narrow habitat requirements and less tolerance of high aridity or salinity in parts of the Gulf.

Halophytic vegetation is the second major component of the intertidal flora. Salt marsh halophytes are represented by Salicornia, Suaeda, Sesuvium, Aeluropus, Sporobolus and other saline tolerant allied taxa. They occupy high salinity flats, creek margins and transition zones. In their investigation on the flora of salt marshes scientific knowledge base in the Gulf of Kachchh, Salvi et al. (2017) reported a large number of halophytes. Further, the authors reported that diversity indices could be effectively utilized to study the vegetation of salt marshes.

Surveys that are updated should confirm the present species composition as industrial development, salt-pan expansion, grazing, and climate variability may have altered local assemblages since earlier floristic work.

Table 4. Dominant and representative mangrove–halophyte flora relevant to Gulf of Kutch ecological assessment.

Species/group	Plant category	Likely habitat role	Adaptive behaviour	Relative resilience
Avicennia marina	Mangrove	Dominant mangrove in Gujarat and Kachchh; tolerant of hypersalinity and arid conditions	Salt secretion, pneumatophores, high physiological tolerance	High
Rhizophora mucronata	Mangrove	Localised patches in suitable creek/protected zones	Prop-root structure, propagule dispersal; prefers more stable inundation and sediments	Medium
Ceriops tagal	Mangrove	Patchy occurrence in parts of the Gulf/protected landscapes	Tolerance of intertidal stress but less dominant under extreme hypersalinity	Medium
Aegiceras corniculatum	Mangrove associate	Localised occurrence in the Gulf of Kutch region	Occurs in creek environments with suitable tidal flushing	Medium to low
Salicornia spp. / Salicornia brachiata complex	Halophyte	Salt-marsh and mudflat margins	Succulence, salt accumulation and seasonal growth	High
Suaeda spp.	Halophyte	High-intertidal salt marsh and saline flats	Succulence, osmotic adjustment, high salt tolerance	High
Sesuvium portulacastrum	Halophyte	Sandy or muddy saline margins	Creeping growth, succulence, rapid colonisation	High

Aeluropus / Sporobolus grasses	Halophytic grasses	Saline grassland and marsh edges	Salt tolerance, rhizomatous growth, sediment binding	Medium to high
Salvadora persica and saline scrub associates	Halotolerant shrub/scrub	Upper saline transition zones	Deep rooting and drought tolerance	Medium

6.2 Salinity Gradient and Vegetation Response

A salinity-gradient interpretation is necessary because plant response is not linear across all habitats. Moderate salinity with regular tidal flushing can support healthy Avicennia regeneration, whereas hypersalinity combined with poor drainage may reduce seedling establishment, canopy height, and stand density. Perri et al. (2023) provide broader support for the idea that salinity can limit mangrove canopy height, while Abdasa-specific evidence links high creek and pore salinity to Avicennia-dominated stand structure in Kachchh (Unny et al., 2022). The expected pattern is a shift from denser mangrove stands in better-flushed creek habitats to open scrub, halophyte patches, or bare saline mudflat where salinity is high and tidal exchange is restricted. Halophytes may show high survival under salinity but do not necessarily replace the ecological functions of structurally complex mangroves. Therefore, salinity response should be evaluated through both species identity and ecosystem function.

Table 5. Salinity–vegetation response matrix for Gulf of Kutch mangrove–halophyte habitats.

Salinity condition	**Likely habitat**	**Expected vegetation response**	**Management implication**
Low to moderate salinity / well flushed	Creek margins, restored channels, lower intertidal flats	Higher mangrove density, better seedling establishment, greater canopy continuity	Maintain tidal exchange and protect regeneration zones
Moderate to high salinity	Mid-intertidal Avicennia belts and salt-marsh transitions	Avicennia dominance, reduced height, salt-tolerant halophyte expansion	Monitor regeneration and soil EC seasonally
High salinity with seasonal desiccation	Salt-pan margins, blocked back-marsh flats	Sparse mangrove recruitment, dominance of succulents or halophytic grasses	Hydrological correction before plantation
Hypersaline and disturbed	Bunds, industrial margins, poorly flushed mudflats	Low diversity, seedling mortality, bare patches or stress-tolerant annual halophytes	Restoration should prioritise drainage, creek reconnection and disturbance control

6.3 Morphological and Physiological Adaptation Patterns

The most visible morphological response in Avicennia-dominated mangroves is the development of pneumatophores, which enable gas exchange in waterlogged and oxygen-poor sediments. High salinity and aridity may also produce smaller leaves, thicker leaf texture, reduced canopy height, and altered growth allocation. At the physiological level, Avicennia marina uses salt regulation mechanisms that allow persistence under conditions that restrict many other mangroves (Aljahdali et al., 2021; Unny et al., 2022).

Halophytes show a broader set of salt-tolerance strategies. Succulent halophytes dilute internal salts by storing water in tissues, while other taxa regulate ion transport, accumulate compatible solutes, or sequester sodium and chloride in vacuoles. Mann et al. (2023) explain that halophytes combine selective ion uptake, vacuolar compartmentalisation, osmotic adjustment, and anatomical specialisation to survive saline habitats. Grigore (2023) similarly highlights halophytes as important models for understanding salt tolerance under climate change and soil salinisation.

Table 6. Adaptive behaviour indicators for mangrove and halophytic flora.

Adaptive response	Representative taxa	Ecological function	Suggested measurement
Salt secretion/exclusion	Avicennia marina and some halophytes	Reduces toxic salt accumulation in active tissues	Leaf-level salt crystals, tissue ion analysis
Osmotic adjustment	Halophytes and mangroves	Maintains water uptake under low external water potential	Proline, soluble sugars, leaf water potential
Succulence	Suaeda, Salicornia, Sesuvium and allied halophytes	Dilutes salts and stores water in tissues	Leaf thickness, water content, anatomical sections
Pneumatophore development	Avicennia stands	Improves root aeration in anoxic sediments	Pneumatophore density and sediment redox
Dwarfing / reduced canopy	Mangroves under hypersalinity	Reduces transpiration demand but signals growth limitation	Height class distribution and canopy cover
Seasonal growth and dieback	Annual or short-lived halophytes	Avoids peak stress or responds to monsoon salinity dilution	Seasonal biomass and phenology monitoring

6.4 Impact of Coastal Disturbance on Plant Communities

Disturbance modifies mangrove–halophyte systems by changing the physical template on which plants establish. Port construction, dredging, roads, bunds, and salt-pan embankments can alter sediment elevation and tidal circulation. Grazing and wood extraction directly reduce regeneration. Pollution can affect root-zone chemistry, while chronic trampling compacts sediments and damages seedlings. Unny et al. (2022) identify high and increasing pressures from salt production, mining, urban and industrial development, hydrological diversion, and coastal pollution in the Kachchh mangrove context.

The most damaging disturbance combinations are those that intensify salinity and simultaneously reduce recovery pathways. For example, a blocked tidal channel can increase salt concentration, prevent propagule movement, and reduce sediment moisture. Plantation in such a site may fail unless hydrological conditions are corrected first. This supports a restoration philosophy based on diagnosis of causes rather than only planting of seedlings.

Table 7. Disturbance intensity classification for Gulf of Kutch field assessment.

Class	Indicative site type	Disturbance features	Expected ecological signal
Low	Protected creek or remote salt-marsh edge	Minor grazing or seasonal access only	Natural regeneration visible, stable sediments, mixed age classes
Moderate	Restored or community-use zone	Controlled grazing, nearby road, small-scale extraction	Some seedling loss, fragmented canopy, partial recovery possible
High	Salt-pan margin, fishing/landing access, dredging influence	Bunds, trampling, altered drainage, waste deposition	Low recruitment, bare patches, halophyte dominance, stressed Avicennia
Very high	Port/industrial edge or severely blocked creek	Hydrological disruption, pollution risk, sediment alteration, heavy traffic	Severe fragmentation, poor regeneration, possible conversion to bare mudflat

6.5 Diversity, Density and Regeneration Analysis

Table 8 is a simulated demonstration that illustrates how diversity, density and regeneration may be presented after field sampling. The values are not measured data. They should be replaced with actual quadrat, transect and soil results before submission as a primary-data research article.

Table 8. Simulated demonstration of site-wise diversity, density, regeneration and resilience indicators.

Site	Site category	Salinity proxy	Disturbance score	Species richness	Shannon H′	Density ha⁻¹	Regeneration ratio	Resilience score
S1	Protected creek	36	1.2	9	1.92	2850	1.35	82
S2	Restored patch	39	2.0	8	1.74	2480	1.15	74
S3	Port-adjacent creek	48	4.4	5	1.05	1220	0.48	38
S4	Salt-pan margin	55	4.1	4	0.82	760	0.31	31
S5	Grazing mudflat	44	3.2	6	1.28	1580	0.72	53
S6	Natural salt marsh	52	2.4	7	1.46	1120	0.86	61

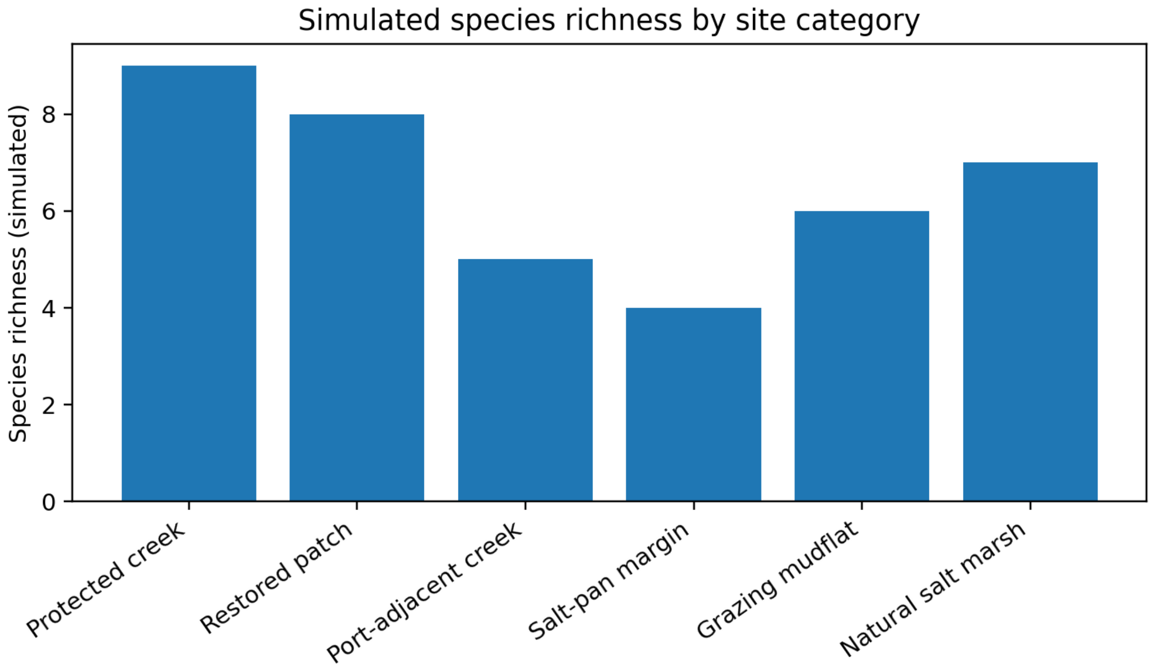

Figure 2. Simulated bar chart showing species richness by site category. These values are illustrative and not field-measured.

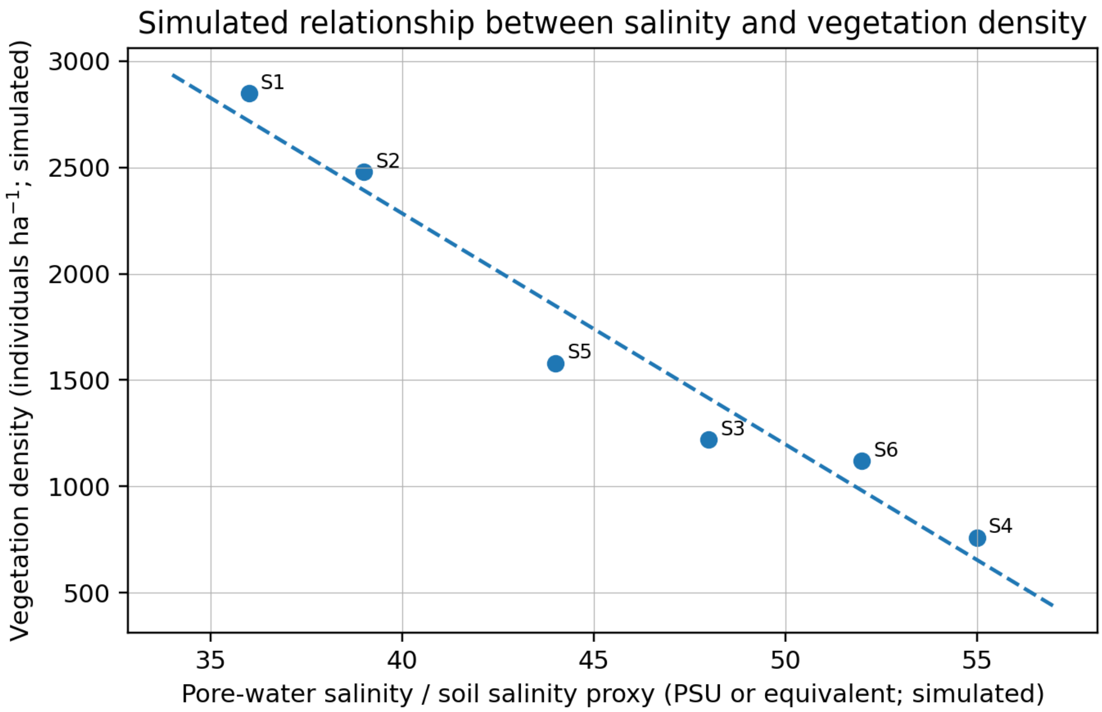

Figure 3. Simulated scatter plot showing a negative salinity–density relationship for demonstration only.

6.6 Ecological Resilience Assessment

A resilience assessment should combine species-level tolerance with community-level recovery indicators. Avicennia marina can be classified as highly resilient under hypersaline Gulf conditions because it is dominant, salt tolerant, and capable of occupying arid intertidal flats. However, a landscape composed only of sparse Avicennia scrub should not automatically be

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treated as highly resilient if seedling recruitment is low, canopy continuity is weak, or tidal hydrology is degraded. Resilience is therefore both a trait property and a system property.

Halophytes such as Salicornia, Suaeda, and Sesuvium can maintain vegetation cover in high-salinity zones where mangrove seedlings fail. Their presence may stabilise sediments and indicate natural salt-marsh function. Yet expansion of halophytes into formerly regenerating mangrove zones may also indicate disturbance-driven salinisation. Interpretation must therefore consider elevation, historical vegetation, salinity, hydrology, and land-use history.

Table 9. Species/group resilience interpretation for Gulf of Kutch vegetation assessment.

Taxon/group	Resilience traits	Expected resilience	Interpretation caution
Avicennia marina	High salinity tolerance, wide dominance, pneumatophores, salt regulation	High	Can mask functional degradation if regeneration is poor.
Rhizophora mucronata	Requires suitable sediment and tidal conditions; important for structural diversity	Medium	Vulnerable in hypersaline or exposed flats.
Ceriops tagal	Moderate intertidal tolerance and patchy occurrence	Medium	Useful indicator of habitat heterogeneity.
Aegiceras corniculatum	Localised creek-associated species	Medium to low	Sensitive to extreme aridity and disturbance.
Salt-marsh succulents	Rapid colonisation and salt tolerance	High for cover maintenance	May indicate natural marsh or disturbed salinisation depending on context.
Halophytic grasses	Sediment binding and upper-marsh persistence	Medium to high	Grazing pressure can alter dominance.

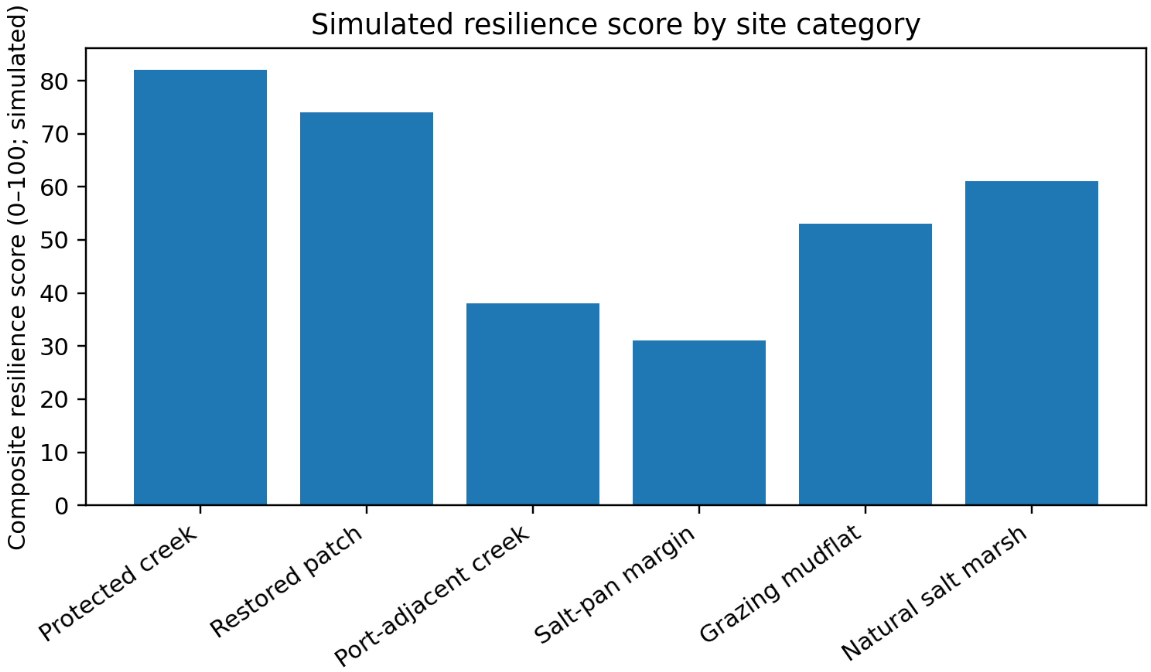

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Figure 4. Simulated composite resilience score by site category. Scores are illustrative and not field-derived.

6.7 GIS-Based Interpretation of Vegetation Change

GIS interpretation should avoid treating all green pixels as equivalent. Dense mangrove canopy, sparse Avicennia scrub, salt-marsh halophytes, algal wet mud, and seasonal vegetation can produce overlapping spectral signals depending on tide and season. Therefore, NDVI should be combined with field validation, high-resolution imagery, land-use classification, and tidal-stage metadata. Global Mangrove Watch products are valuable for long-term mangrove monitoring, but site-scale research in the Gulf of Kutch should use local ground control points and class-specific accuracy assessment (Bunting et al., 2022).

Figure 5 illustrates the type of NDVI trend that may be compared between protected or restored vegetation and disturbed margins. The figure is simulated and does not represent an actual satellite time series. In a real study, NDVI and mangrove-cover change should be extracted from atmospherically corrected imagery and compared with field-measured canopy cover, salinity, and disturbance scores.

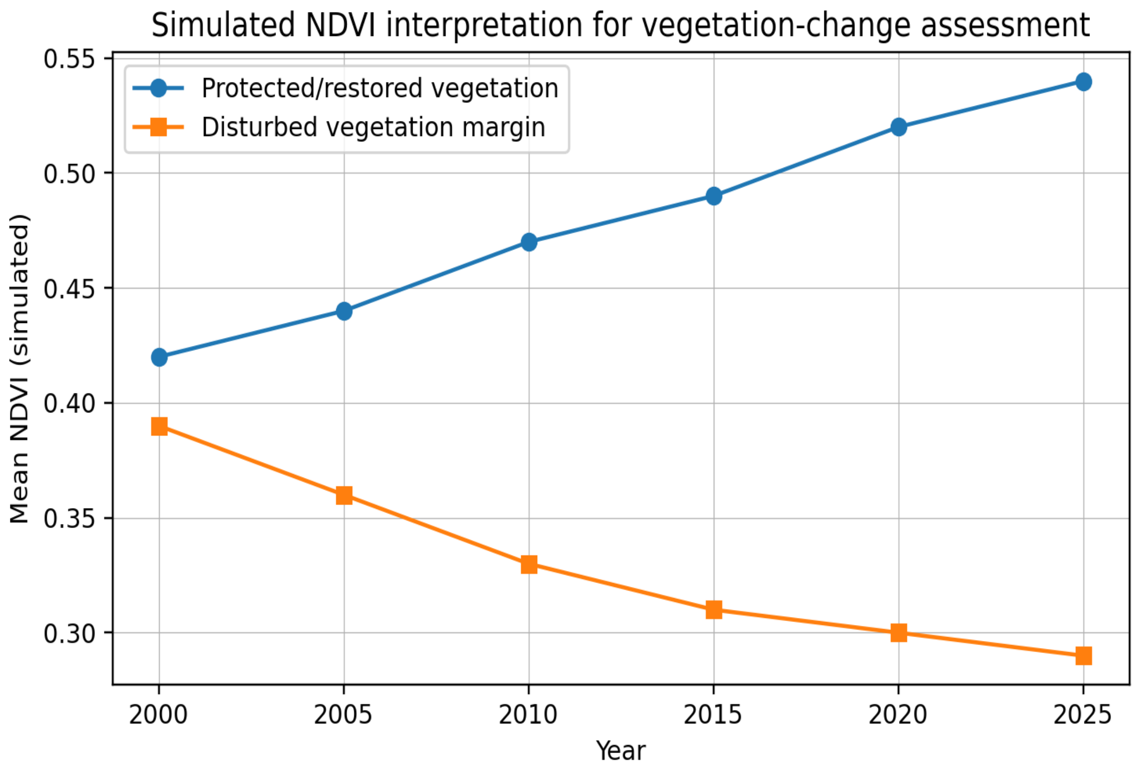

Figure 5. *Simulated NDVI trend for vegetation-change interpretation. These values are illustrative only and are not satellite-derived results.*

6.8 Statistical Relationship Between Stress, Disturbance and Resilience

The following correlation and regression outputs are simulated demonstrations. They show the analytical pattern expected if salinity and disturbance negatively influence density, diversity and regeneration, but they must not be cited as empirical findings for the Gulf of Kutch.

Table 10. Simulated correlation matrix for stress, vegetation and resilience indicators.

Variable	Salinity	Disturbance	Richness	Density	Regeneration	Shannon H′	Resilience
Salinity	1.00	0.64	-0.81	-0.86	-0.73	-0.78	-0.76
Disturbance	0.64	1.00	-0.90	-0.88	-0.84	-0.91	-0.93
Richness	-0.81	-0.90	1.00	0.89	0.82	0.96	0.92
Density	-0.86	-0.88	0.89	1.00	0.86	0.87	0.91
Regeneration	-0.73	-0.84	0.82	0.86	1.00	0.83	0.88
Shannon H′	-0.78	-0.91	0.96	0.87	0.83	1.00	0.94
Resilience	-0.76	-0.93	0.92	0.91	0.88	0.94	1.00

Table 11. Simulated regression demonstration: resilience score as dependent variable.

Predictor	Coefficient	SE	t	p	Interpretation
Intercept	96.40	8.25	11.68	<0.001	Baseline resilience where stress scores are low.
Salinity proxy	-0.82	0.21	-3.90	0.030	Higher salinity is expected to reduce resilience.
Disturbance score	-10.35	2.42	-4.28	0.023	Disturbance is expected to have a strong negative effect.
Tidal connectivity score	5.70	1.96	2.91	0.062	Better flushing is expected to improve resilience.

If a real dataset showed this general pattern, then H1 and H2 would be supported by negative associations of salinity, disturbance, and vegetation performance. H3 would demand evidence of survival and regeneration at the species level; not only site level correlations. In the study, low-, mid-, and high-disturbance sites would be assessed via ANOVA (or non-parametric tests) for H4. It is important, however, that such statistical inference must be based on measured and actual field data, and not simulated examples.

A disturbance-resilience matrix can help (or assist in) interpretation. It sorts sites into four categories: low disturbance–high resilience; low disturbance–low resilience; high disturbance–moderate resilience; and high disturbance-low resilience. The sites that experience high disturbances and low resilience are the most urgent sites for restoration activities. These include also sites where there is hydrological blockage and poor regeneration. Hypersaline sites with low disturbance but also low resilience likely represent harsh natural habitats, which should be protected not planted.

7. Discussion

Synthesis of literature review supports the observation that Gulf of Kutch mangrove and halophyte communities are outcomes of natural semi-arid stress and anthropogenic coastal disturbance interaction. Because of its adaptive characteristics, Avicennia marina dominates the mangrove vegetation cover. This pattern is in line with the official mangrove documentation of Gujarat and is also consistent with Abdasa field evidence that rainfall, runoff and salinity affect stand structure (Gujarat Forest Department, 2025b; Unny et al., 2022). The presence of a tolerant species should not be mistaken as high ecosystem diversity or full resilience.

Salinity stress causes changes through both physiological and structural pathways. According to Grigore 2023 and Mann et al 2023 salt-tolerant plants at the physiological level regulate ions, adjust osmotic balance and shield cellular metabolism while some excrete or compartmentalise salts. At structural level, salinity may reduce canopy height, limit seedling establishment and favour dwarf or open stand forms (Perri et al., 2023). In the Gulf of Kutch, it implies that if a low-stature Avicennia scrub might be indicative of natural stress adaptation, then its sudden reduction or lack of regeneration may indicate an additional disturbance.

We must consider halophytes as ecological agents instead of degradation indicators. Halophytes that grow in salt marshes are capable of stabilising sediments, tolerating extreme salinities, creating microhabitat and occupying ecotonal or transitional areas in which mangroves may not be able to establish naturally. According to Salvi et al. (2017), there is extensive halophyte diversity residing in the Gulf of Kachchh which calls to add these taxa in coastal monitoring. A perspective that focuses solely on mangroves for conservation may be overlooking the ecological significance of salt marshes, potentially inappropriate plantations in naturally halophytic zones, in and around mangrove forests.

Coastal disruption alters the significance of salinity. The naturally high salinity of a back-marsh in an arid region may be part of the ecological character of the Gulf. In contrast, high salinity resulting from bunding, drainage obstruction, or salt-pan expansion is a management issue. The difference is critical for restoration. Growing mangrove seedlings in hypersaline, poorly drained, or compacted sites may not succeed if the cause of this disturbance is not rectified. Recent guidance on restoration emphasises hydrological restoration, natural regeneration and avoidance of maladaptive mass monoculture planting (Global Mangrove Alliance, 2023; UNEP, 2020).

The proposed hypotheses cannot be accepted unconditionally and require field testing. H1 is conceptually supported by salinity physiology and canopy-height literature. H2 draws support from disturbance ecology and specific evidence from the Gulf regarding industrial and hydrological pressures. H3 is most likely for Avicennia marina and salt-marsh halophytes. Species-level recruitment and survival data required. The reference H4 may be tested from protected, restored, industrial, salt-pan, and grazing sites. The simulated analysis shows the workflow but does not prove its significance.

The dialogue also discloses a policy challenge. As per official cover statistics, Gujarat is still a major mangrove state whereas Kachchh is important for state-level mangrove cover (Gujarat Forest Department, 2025a). However, resilience-focused conservation demands more than just the increase in mapped area. To conserve biodiversity, it is important to maintain functional diversity and mixed age classes along with natural zonation, hydrological exchange, and lower disturbance pressure. A cover-rich but diversity-poor or regeneration-poor system may be vulnerable to future salinity extremes, storms, sea-level rise, or development shocks.

8. Implications for Conservation and Management

Conservation planning for the Gulf of Kutch should be resilience based in which mangrove cover halophyte diversity hydrology and disturbance are considered together. The first, is that hydrology should lead restoration. In cases where there has been hydrological disruption, large-scale planting should not be done until the creek is reconnected, obstruction bunds are removed or modified, tidal flushing is restored and sediment level correction is done. This is consistent with international restoration guidance advocating against a plantation without performing a site constraint diagnosis (Global Mangrove Alliance, 2023; UNEP, 2020).

The second implication is that halophyte conservation has to be integrated into mangrove management. The salt marshes and halophytic transition zones have the eco function and may show natural resilience to extreme salinity. Every patch of saline vegetation, which is not a mangrove, should not be designated as a degraded land in the management plans. Restoration must be habitat appropriate. For example, mangroves should be encouraged where hydrology and elevation are suitable; salt marshes should be protected where they are the natural high-intertidal vegetation.

The third implication in industrial and port monitoring. It is proposed that the ecosystem-based indicators of vegetation – seedling density, canopy continuity, pneumatophore damage, soil EC, sediment contamination and disturbance source proximity be included in environmental clearances and coastal-zone plans. Monitoring done over a long term should be independent, georeferenced and publicly auditable. According to the Daily Press Information Bureau, the implementation of mangrove buffer rules and CRZ provisions must not just remain limited to policies. They should ideally find their way into the field as well. And most essentially, the local hydrology and regeneration must be safe from interference.

Participation in the community is the fourth implication. Mangrove–halophyte landscapes are home to daily life, work and cultural processes. Monitoring by the community can detect cutting, grazing pressure, pollution, bunding and seedling mortality early. The restoration can reduce conflict if conservation is associated with livelihood-compatible benefits like fisheries support, shoreline protection and regulated access to ecosystem services.

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Table 12. Conservation and management framework for resilient Gulf of Kutch mangrove–halophyte ecosystems.

Action area	**Specific measures**	**Responsible stakeholders**	**Expected resilience outcome**
Hydrological restoration	Reopen blocked creeks, improve tidal exchange, avoid planting in stagnant hypersaline basins	Forest department, CRZ authority, local administration	Pore salinity reduction, improved seedling survival
Native regeneration protection	Fence seedling zones where required, control trampling and grazing during regeneration windows	Forest department, communities, panchayats	Higher seedling-to-adult ratio and mixed age classes
Halophyte conservation	Map salt-marsh vegetation and avoid converting natural marsh into unsuitable plantations	Biodiversity boards, researchers, coastal planners	Protected salt-marsh diversity and ecotonal integrity
Industrial monitoring	Mandate vegetation-health, sediment and water-quality monitoring near ports, jetties and salt-pans	Regulators, industries, independent auditors	Reduced pollution, transparent compliance and early warning
GIS surveillance	Annual NDVI/LULC and mangrove-cover change with ground truthing	Forest department, universities, remote-sensing agencies	Spatially explicit disturbance and recovery database
Community stewardship	Train local observers, integrate livelihood concerns and restoration work	Local communities, NGOs, government agencies	Higher compliance, local ownership and rapid reporting

9. Conclusion

The Gulf of Kutch presents a unique example of how mangrove and halophytic vegetation change in response to salinity stress, coastal perturbation and ecological uncertainty. The synthesis indicates behaviour is characterised by salt tolerance, changed growth form, dominance within the community, regeneration, and zonation in vegetation. Avicennia marina is the dominant and the most visibly resilient mangrove while Ehalophytic salt-marsh flora provides an essential transition system in hypersaline and high-intertidal habitats.

Furthermore, the paper illustrates that resilience is not synonymous with mangrove cover. A resilient mangrove–halophyte ecosystem must maintain functional diversity, natural zonation and viable regeneration with hydrological connectivity, stable sediments and recovery after disturbances. The resilience of a coastal community may be hindered by disturbance created by ports, salt-pans and grazing and pollution and physical modification. This is so when disturbance enhances salinity and/or blocks pathways of recruitment. The above analytical framework may guide future primary data-based research, GIS monitoring and conservation planning for the Gulf of Kutch.

Since no primary field dataset is provided, the quantitative outputs in this paper are merely simulated examples. For journal submission as an empirical article, measured quadrat data, soil and water analysis, remote sensing outputs and statistically tested results must replace them. On the other hand, the framework provides a sound basis for designing such a study and orienting mangrove conservation towards ecological resilience rather than plantation targets.

10. Suggestions

1. Establish permanent plots across protected, restored, port-adjacent, salt-pan and grazing-affected sites. The monitoring work will cover salinity, regeneration, canopy condition and species composition.

2. Salt marshes that support halophytes should be regarded as valuable ecosystems and not merely as unutilised land for mangrove planting.

3. Restoration of hydrology should be given priority on sites affected by blocked creeks, blocked bunds, salt-pan embankments or poorly flushed with tides, before planting.

4. Plant only native species and microhabitat-specific species in field diagnosis where elevation, salinity and sediment conditions are suitable.

5. Integrate NDVI, land use/land cover change shoreline mapping and ground truthing in annual surveillance of vegetation in Gulf of Kutch.

6. independent and thorough ecological monitoring of mangrove health, sediment condition, pollution indicators and regeneration status be conducted through requirement on industrial and port operators.

7. Create community monitoring with fishers, pastoralists, coastal villages and salt-worker communities to detect early on grazing pressure, illegal cutting and pollution.

8. Government restoration reporting should include resilience indicators such as seedling survival, regeneration ratio, diversity index, tidal connectivity and disturbance score.

9. Form a database that comprises information on mangroves, halophytes, herbarium records, field plots, satellite imagery, and conservation interventions of Gulf of Kutch.

10. It is suggested to foster cooperation between universities and forest departments in conducting physiological studies on Avicennia marina and the dominant halophytes under seasonal salinity gradients.

11. The Future and Imminent Threats

The lack of primary field data is the first limitation. The methodology, analytical synthesis and simulated demonstration outputs from this paper do not claim any measured field statistics. Putting up quadrat, transect, soil, pore-water, canopy and remote-sensing data round the year must be done in future research. The second concern is time scale. Mangrove and halophyte reactions during the pre-monsoon, monsoon and post-monsoon periods differ; therefore, single-season sampling may misrepresent the salinity stress and regeneration stages.

The third limitation has to do with the resolution of remote-sensing. The sparse Avicennia shrub, halophytic vegetation, algal mudflat and wet sediment may not be reliably separated using medium resolution imagery. Use high-resolution imagery, drone surveys, and field validation whenever possible. The fourth constraint pertains to taxonomic certainty. The identification of halophytes requires floristic verification, especially in cases where the species in question are seasonal, similar in morphology or present without flowers and fruits.

The field plots and coupled salinity–vegetation datasets should be used in future tests of hypotheses. Physiological measures of leaves like osmotic potential and chlorophyll fluorescence along with antioxidant activity, tissue sodium and potassium and water-use traits will add strength to their behavioural interpretation. Long-term studies should also investigate how climate change, sea level rise, cyclones, sediment dynamics and industrial expansion will influence the future resilience of the Gulf of Kutch's mangrove–halophyte mosaic.

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