Building a Framework for Resilience Assessment and Monitoring: Integrating Human-Environment Interactions to Protect Anzali Wetland's Aquatic Ecosystems

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Abstract

Urban wetlands are critical socio-ecological systems that provide essential ecosystem services while facing increasing anthropogenic and environmental pressures. This study aims to develop a site-specific framework for assessing and monitoring the resilience of Anzali Wetland, a Ramsar Wetland of International Importance in northern Iran, by integrating ecological and social dimensions of resilience. A three-round Delphi process was conducted with 10 experts selected for their relevant expertise and direct experience with Anzali Wetland. Expert assessments were analyzed using descriptive statistics and Kendall's coefficient of concordance to examine the convergence of judgments across Delphi rounds. The results identified seven resilience factors spanning ecological and social dimensions. The overall resilience of the wetland was assessed at 2.7 on a five-point scale, with 50% of experts rating its resilience as weak or very weak. Water quality (mean = 4.9), biodiversity (mean = 4.7), and hydrological regime (mean = 4.6) were the three highest-priority factors, while human pressure was the highest-ranked social factor (mean = 4.3). Expert agreement increased across the Delphi rounds, with Kendall's W rising from 0.62 in Round 1 to 0.75 in Round 2 and 0.82 in Round 3 ($p = 0.001$). The prioritized factors were translated into an operational monitoring framework linking major threats with measurable indicators. These indicators included BOD, COD, nitrogen, and phosphorus concentrations for water pollution; annual sedimentation rate for hydrological and sediment-related pressures; and the abundance of indicator species for biodiversity changes. By linking expert-based prioritization of ecological and social resilience factors with measurable monitoring indicators, the framework provides a site-specific basis for repeated resilience assessment and adaptive management of Anzali Wetland. Its contribution lies in translating an integrated socio-ecological resilience assessment into an operational monitoring structure that can support evidence-based evaluation of management responses over time.

Keywords: Socio-ecological resilience, Anzali Wetland, Resilience assessment, Delphi method; Monitoring indicators, Adaptive management

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Introduction

Wetlands are among the most ecologically and socio-economically significant ecosystems globally, providing water purification, flood control, carbon storage, and habitat provisioning (Gardner et al., 2015; Gardner & Finlayson, 2018), yet they remain highly vulnerable to climate change, pollution, and urban expansion. These pressures are best understood through the lens of resilience, defined as the capacity of a social-ecological system (SES) to absorb disturbance while retaining its core structure, functions, and identity (Folke, 2006; Walker et al., 2004; Ostrom, 2009). SES framework formalizes this perspective by conceptualizing the interdependence between ecological subsystems and the human communities. This interdependence is particularly pronounced in urban-adjacent wetlands, where anthropogenic activity and ecological function are tightly coupled (Alberti & Marzluff, 2004). Within this framework, resilience operates along two interlinked dimensions: ecological resilience, referring to a system's capacity to sustain biodiversity and ecosystem services under stress (Folke et al., 2010). Social resilience, refers to the economic, institutional, and adaptive capacities of dependent communities to absorb and recover from shocks (Cutter et al., 2008; Folke et al., 2010). A central concept in resilience research is that of critical thresholds, beyond which incremental disturbances can trigger abrupt and potentially irreversible changes in system function (Scheffer et al., 2012) underscoring the practical stakes of timely resilience assessment. In this context, ecosystem services refer to the benefits humans derive from ecosystems, spanning provisioning, regulating, cultural, and supporting functions (Assessment, 2005).

Researchers have shown the importance of governance of SES in building resilience across various dimensions. (Evans, 2011) investigated how ecologists integrated adaptive experiments into urban governance to promote resilience against climate change. (Gotham and Campanella 2011) described urban ecosystems as containing both resilient and vulnerable elements.

Anzali Wetland, covering approximately 20,000 hectares, is a vital habitat for various aquatic and terrestrial bird species, fish, and other aquatic life, playing an important role in maintaining regional biodiversity (Fathi et al., 2010). Yet, this valuable ecosystem is threatened by multiple factors, including pollution due to industrial and agricultural activities, inflow of urban wastewater, illegal fishing, climate change, drought, and reduced precipitation (Ghazban & Zare Khosh Eghbal, 2011). These threats can undermine the resilience of Anzali Wetland by reducing its capacity to maintain essential ecological functions, biodiversity, and ecosystem services. Local communities surrounding the wetland also depend on its resources for their livelihoods through activities such as agriculture, fishing, and tourism. (Salehi & Qolamdoust, 2013). Therefore, understanding the social resilience of these communities to the threats and challenges associated with wetland degradation is as importance as ecological resilience.

In Iran, several studies have been conducted on the resilience of Anzali Wetland. (Ebrahimi and Kordevani 2014) evaluated the

ecological resilience of Anzali Wetland to climate change and showed that the wetland is at serious risk of reduced water levels and altered precipitation patterns. They suggested that enhancing resilience requires integrated management actions, including pollution control and vegetation protection. (Khosravi et al., 2021) examined the impact of human activities on the resilience of Anzali Wetland and found that urban and industrial development in the wetland's catchment area has significantly affected its water quality and biodiversity. Their findings emphasized the importance of considering human-natural system interactions in wetland management.

Despite this body of research, a closer examination reveals a specific and identifiable broad gap in the literature on Anzali Wetland and socio-ecological resilience assessment. With respect to Anzali Wetland itself, prior studies remain predominantly single-dimensional. (Ebrahimi and Kordevani, 2014) assessed ecological resilience to climate-driven hydrological change, while (Khosravi et al., 2021) examined the impact of urban and industrial development on water quality and biodiversity. However, both studies largely considered ecological degradation in isolation from the social dynamics of dependent communities. Conversely, (Salehi and Qolamdoust 2013) addressed community dependence on wetland resources but do not integrate these findings into a structured, quantifiable resilience assessment. To date, no existing study on Anzali Wetland has combined a systematic expert-based evaluation of ecological and social resilience factors within a single integrated instrument, or translated such an assessment into an operational set of site-specific monitoring indicators.

This gap is not unique to Anzali Wetland; it reflects a broader limitation in existing resilience assessment frameworks applied to similar urban-adjacent socio-ecological wetland systems. Frameworks such as (Ostrom, 2009) general SES model and subsequent applications in comparable contexts (e.g., Mosleh et al., 2023), in the context of urban stormwater infrastructure are largely diagnostic and typologic. They identify the categories of variables relevant to resilience but do not, in their standard form, generate a site-specific, empirically ranked set of factors or link that ranking to a concrete, ongoing monitoring structure. As a result, even where such frameworks have been applied to comparable wetland systems elsewhere, they have tended to produce conceptual maps of resilience determinants rather than operational tools that management authorities can directly use.

These limitations highlight the need for an integrated, site-specific framework for Anzali Wetland. The wetland has experienced substantial ecological degradation, including an estimated 30% reduction in area over three decades (Rahimi et al., 2019), while the resilience of communities dependent on its resources has not been systematically assessed alongside ecological conditions. This study addresses this gap by combining expert-based prioritization of ecological and social resilience factors with a set of operational monitoring indicators tailored to the wetland.

The novelty of the proposed framework can

be clarified along four distinct dimensions, relative both to standard SES models and prior empirical work on Anzali Wetland specifically. First, with respect to standard SES models, SES framework, and its subsequent applications in wetland research are predominantly diagnostic and typological in nature (Ostrom, 2009). They specify which categories of variables, including resource systems, resource units, governance systems, users should be considered, but do not themselves generate a ranked, empirically weighted set of factors for a specific site or translate directly into measurable monitoring indicators. The present framework differs from this standard usage in that it operationalizing the SES logic through a structured, three-round Delphi process. This process empirically ranks ecological and social resilience factors based on expert-assigned importance (Table 2) and statistically verified consensus (Kendall's W = 0.62 to 0.82), rather than treating the SES categories as a fixed conceptual checklist. Thus, the framework applies the SES perspective as a site-specific and quantifiable assessment approach rather than solely as a classificatory scheme.

Previous empirical studies on Anzali Wetland e.g., (Ebrahimi & Kordevani, 2014; Khosravi et al., 2021; Salehi & Qolamdoust, 2013) have primarily examined ecological and social dimensions separately. They have not integrated these dimensions into a single assessment instrument or developed a structured monitoring framework. The present framework addresses to advance this body by integrating ecological and social resilience into a consensus-based assessment (Table 2) and linking the findings to a second-stage monitoring framework (Table 3; Figure 2). The framework's theoretical contribution lies in how it treats the relationship between expert and lay knowledge rather than assuming its relative importance. Specifically, community participation was ranked alongside ecological and other social factors according to expert judgments. Its ranking (Table 2, rank 7) provides insight into how the expert panel prioritized this factor relative to other resilience factors. (Table 2, rank 7). this approach provides a basis for examining the relationship between the theoretical importance attributed to participatory governance in the literature (e.g., Ostrom, 2009; Berkes et al., 2008) and its comparatively low prioritization by the expert panel itself. This bridging of expert and lay perspectives, and the empirical exposure of the gap between them, constitutes a distinct theoretical contribution beyond simply asserting that participation matters.

A further contribution of the framework is its practical application of the Delphi consensus to wetland monitoring. Previous studies on Anzali Wetland have generally concluded with general policy recommendations, such as pollution control and integrated management. This framework identified BOD, COD, nitrogen (N), and phosphorus (P) levels for water pollution; annual sedimentation rates for hydrological loss; and the abundance of indicator species for biodiversity loss (Table 3). These indicators are associated with an explicit assessment-to-monitoring pipeline (Figure 2). Furthermore, its management authorities can operationalize directly, rather than a static diagnostic report requiring

further translation into practice.

Given the critical importance of Anzali Wetland and the communities that depended on it, this study seeks to answer three main questions: What is the current state of ecological and social resilience in Anzali Wetland? What factors influence the ecological and social resilience? What strategies can enhance the ecological and social resilience of Anzali Wetland, and how can their effectiveness be improved?

Materials and method

Study area and environmental setting

The Anzali Wetland complex (approximately 139 km^2) is located adjacent to the port city of Bandar Anzali in Gilan Province, northern Iran, along the southern shores of the Caspian Sea. This wetland is one of the closest wetlands to the city of Ramsar, the birthplace of the Ramsar Convention, and was registered in the Ramsar List of Wetlands of International importance on June 23, 1975 (Stroud et al., 2022). The Anzali Wetland is a large marsh fed by freshwater from numerous rivers and separated from the Caspian Sea by a sandy shoreline, featuring extensive reed beds and abundant floating vegetation. This permanent wetland is surrounded by seasonal marshes, agricultural fields (mainly rice), and fish farming ponds, and is of international importance for bird breeding and wintering (Aghsaei et al., 2020).

The biodiversity of the Anzali Wetland is remarkable. The wetland is home to more than 100 bird species, 50 fish species, 230 plant species, and various mammals, reptiles, and amphibians. Specific animal species in this wetland include Gray Pelican, Mallard, Swan, White Stork, and fish species such as Pike-perch, Carp, and Pike. In terms of vegetation. The dominant species includes reed, cattail, and bulrush, which play important roles in the wetland's ecology (Amini et al., 2022).

However, the Anzali Wetland has faced serious challenges during recent decades. Water pollution from urban and industrial wastewater, excessive sedimentation, the invasion of exotic species such as water hyacinth, and climate change are among the most important threats to this valuable ecosystem. Studies have shown that over the past 30 years, the area of the Anzali Wetland has decreased by approximately 30 % (Rahimi et al., 2019).

Studies have shown that the Anzali Wetland ecosystem faces serious challenges. Increased sedimentation, water pollution, and declining biodiversity are among the issues that have affected the wetland's resilience (Jafari, 2009). Furthermore, changes in precipitation patterns and increasing temperatures due to climate change have affected the wetland's hydrological conditions (Khazaei et al., 2019). Research on the Anzali Wetland, has also shown that cooperation among various stakeholders, including local communities, government organizations, and researchers, can improve management and increase the ecosystem's resilience (Ebrahimi & Kordevani, 2014).

Finally, the resilience of social-ecological systems is a dynamic and continuous process. Continuous changes in environmental, social, and economic conditions require ongoing review and updates to our under-

standing of these systems' resilience. For the Anzali Wetland, this means the need for continuous monitoring of the wetland's ecological and socio-ecological status, evaluation of management action effectiveness, and adaptation of strategies based on new findings.

Data Collection

Delphi method

This research uses the Delphi method to collect and analyze expert opinions on the resilience of Anzali Wetland. The Delphi method is a structured and iterative process for gathering and converging expert opinions through a series of questionnaires with controlled feedback (Hsu & Sandford, 2007). This method originally introduced by (Linstone & Turoff, 1975), facilitates confidential group communication and collaboration. It is particularly effective for gathering insights from experts on complex issues where empirical data may be insufficient. The method aims to build a collective understanding of these issues and to reach consensus on viable solutions (Hasson et al., 2000; Linstone & Turoff, 1975). According to (Fletcher & Marchildon ,2014), the main objective of the Delphi method is to gather informed opinions on topics that are largely undefined, context-specific, or focused on future developments. This method has gained traction as a valuable technique in social and policy research, especially for decision-making in areas such as environmental governance, including forest management, public transportation, and energy transitions (Caglayan et al., 2021; Filyushkina et al., 2018; Hirschhorn, 2019; Makkonen et al., 2016; Revez et al., 2020; Waldron et al., 2020). In Indonesia, the Delphi method has been applied to identify interventions for addressing complex forest and land governance challenges (Toumbourou, 2020).

Process and participants

Data collection was conducted in identification, exploration, and consolidation. Experts were purposively selected using a set of formal inclusion criteria. These criteria were designed to ensure both depth of expertise and breadth of perspectives. Eligible candidates were required to have at least eight years of professional or research experience in wetland ecology, hydrology, natural resource management, or socio-ecological systems. They also needed demonstrated

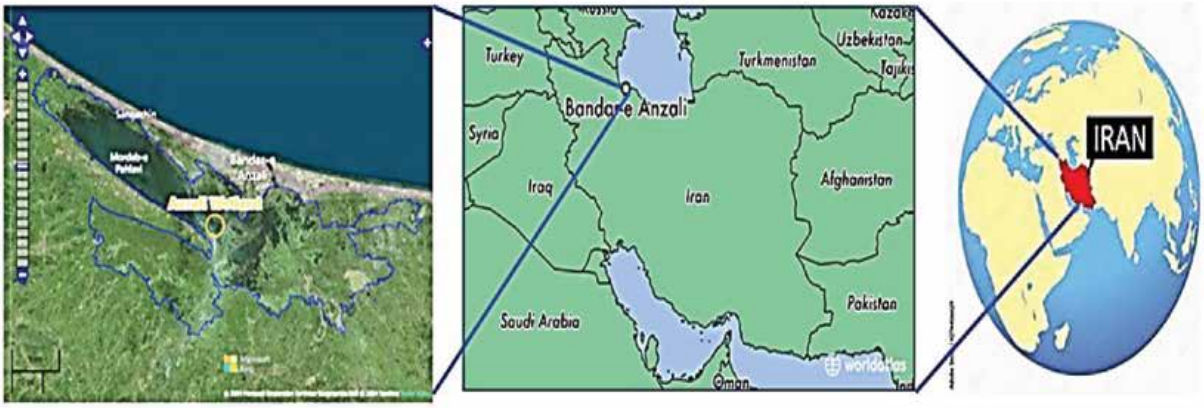


Fig. 1. Study area location- Anzali Wetland (Source: Google Maps, 2024)

experience with Anzali Wetland, through research, management responsibilities, or field-based work within its catchment area. In addition, candidates were required to hold an advanced academic degree (M.Sc. or Ph.D.) or have equivalent professional standing in a relevant discipline. Beyond these baseline criteria, the expert panel was deliberately balanced across institutional sectors to avoid the dominance of any single perspective. the final panel included four representatives from academic institutions, three from governmental environmental and water-management agencies, two from non-governmental organizations involved in wetland conservation, and a local institution with direct experience in local community engagement. This cross-sectoral structure was intended to capture both technical and scientific expertise and applied management experience. This structure is consistent with recommendations in the Delphi literature for panels addressing complex social-ecological problems (Hsu & Sandford, 2007). A summary of the anonymized panel composition is presented in Table 1. .

The panel size of ten experts was determined based on established guidance in the Delphi literature rather than an arbitrary threshold. (Skulmoski et al. ,2007) and (Okoli and Pawlowski, 2004) note that Delphi panels composed of highly specialized, purposively selected expertise typically require fewer members than survey-based research. This is because validity of the method depends on the depth and relevance of expert knowledge rather than on statistical generalizability. A panel of 10–15 members is widely considered adequate when participants are selected based on their expertise and direct familiarity with the specific system under study (Hsu & Sandford, 2007). In this study, the panel was deliberately kept homogeneous in its focus on Anzali Wetland. While, remaining heterogeneous through the six relevant disciplines, including wetland ecology, water resource management, rural sociology, environmental economics, crisis management, and environmental sociology and across institutional sectors. This sectors allowed the

Table 1. Anonymized composition of the expert panel (n = 10)

Expert ID	Sector	Field of Expertise	Years of Experience	Degree
P1	Academia	Wetland Ecology	14	Ph.D.
P2	Governmental	Water Resource Management	18	Ph.D.
P3	NGO	Environmental Sociology	10	M.Sc.
P4	Academia	Rural Sociology	12	Ph.D.
P5	Governmental	Crisis Management	9	M.Sc.
P6	Local institution	Environmental Economics	8	M.Sc.
P7	Academia	Wetland Ecology	20	Ph.D.
P8	NGO	Wetland Conservation / Community Engagement	11	M.Sc.
P9	Governmental	Hydrology/Water Resource Management	15	Ph.D.
P10	Local institution	Rural Sociology / Local Governance	13	Ph.D.

Source: Authors

panel to reach a point of information richness. Additional experts within this narrow geographic and thematic scope were judged unlikely to introduce substantially new categories, given the convergence already observed by Round 3. This pattern is consistent with the concept of theoretical saturation in expert-based qualitative inquiry, where consensus stability across successive rounds serves as an empirical indicator that the panel size was sufficient for the scope of the study.

This assessment is further supported by the study's own data: Kendall's coefficient of concordance increased from 0.62 in Round 1 to 0.75 in Round 2 and 0.82 in Round 3, indicating that expert opinions converged toward a stable consensus well within the three-round process. This pattern suggest that the panel capture the relevant range of expertise for this specific, geographically bounded site. The process of implementing the Delphi method in this research is as follows.

Phase I: Anzali wetland resilience system Identification

The Identification phase aimed to gather information about the state of Anzali Wetland resilience system. We conducted biweekly meetings to discuss and refine our activities and methods. For the first Delphi Round interview, we developed a concise set of open-ended questions informed by an initial literature review. After collecting some basic background information with three introductory questions, the Phase 1 interview included five specific questions. At this stage, an open-ended questionnaire with general questions regarding the current state of resilience of Anzali Wetland, the main challenges, and opportunities for improvement was administered to the experts. The goal was to explore how participants from different disciplines perceived the resilience of Anzali Wetland, the factors influencing the social resilience of communities dependent on the wetland, their perceptions of its current condition, potential strategies for enhancing SES resilience, and actions needed to strengthen community resilience. The responses were examined using qualitative content analysis. The qualitative content analysis of Round 1 responses was conducted at the level of the individual statement or idea unit, that is, each distinct proposition or claim within an expert's response, whether expressed as a full sentence or as a clause within a longer sentence, was treated as a separate unit of analysis. This unit of analysis was chosen because expert responses frequently combined multiple distinct ideas within a single sentence, and coding at the sentence level alone risked conflating conceptually separate observations. The coding process was carried out by a single member of the research team, consistent with common practice in small-panel Delphi studies where the same researcher who conducts the interviews is best positioned to interpret contextual nuances in participants' responses (Hasson et al., 2000). To safeguard analytical consistency in the absence of a second independent coder, an intra-coder reliability check was performed. A random subsample of approximately 20 % of the Round 1 transcripts was re-coded by the same researcher after two-week interval without reference to the original coding decisions. The two sets

of codes were then compared, and the level of agreement between the original and re-coded labels was used as an indicator of coding stability. Any discrepancies identified through this process were reviewed and resolved by refining the coding definitions before the scheme was finalized and applied consistently across the full dataset. Following open coding, axial coding was used to group related open codes into broader sub-categories based on shared conceptual meaning. These sub-categories were subsequently consolidated into the final resilience factors reported in Table 2. To illustrate this analytical pathway, consider the following coding path, which traces a raw expert statement through to a final resilience factor.

Raw statement (illustrative excerpt) → Open code → Sub-category → Final factor

" Untreated wastewater from the surrounding cities keeps flowing into the wetland, and it's clearly affecting the water" → Open code: "untreated wastewater inflow" → Sub-category: "urban and industrial pollution loading" → Final factor: Water Quality

This same pathway was applied consistently across all Round 1 transcripts: idea units were first assigned open, descriptive codes; conceptually related open codes were then grouped into sub-categories through axial coding; and sub-categories were finally consolidated into the seven resilience factors presented in Table 2, spanning both the ecological and social domains. This structured coding pathway underlies the questionnaire items subsequently distributed to experts in the Round 2 (Explore) phase. Based on this analysis, a list of factors influencing the resilience of Anzali Wetland was compiled, including factors affecting ecological resilience and social resilience.

Phase II: Explore

At this stage, a questionnaire was designed based on the results of the first round. The Round 2 questionnaire items were derived directly from the categories and sub-categories identified through the open and axial coding of Round 1 responses, ensuring content validity by grounding each item in expert-generated language rather than researcher-imposed categories. Prior to distribution, the questionnaire was reviewed internally for clarity and item redundancy, and minor wording adjustments were made to ensure that each factor was phrased as a single, unambiguous evaluative statement appropriate for scoring on a 5-point Likert scale. Experts were asked to evaluate the importance of each identified factor on a 5-point Likert scale, ranging from 1 (not important) to 5 (very important). The responses were analyzed, and the mean, median, and standard deviation for each factor were calculated. Kendall's coefficient of concordance was used to assess the level of agreement among the experts.

Phase III: Consensus consolidation

At this stage, the results of the second round, along with a new questionnaire, were sent to the experts. They were asked to reassess their evaluations based on the collective feedback. Experts were given the opportunity to adjust their opinions if they wished or to maintain their previous opinions. After receiving the responses from the third round, the final analysis was conducted. The mean, median, and standard deviation for each factor and solution were calculated.

The Kendall's coefficient of concordance was also recalculated to determine the final level of agreement among the experts. To analyze the data obtained from the Delphi process, descriptive and analytical statistical methods were employed. SPSS version 26 was used to perform the statistical analyses.

Results

The results obtained from the Delphi process can be presented in several main sections, including the current state of the resilience of Anzali Wetland and the main factors and indicators influencing its resilience. According to the experts' assessment, Anzali Wetland is currently facing serious challenges regarding its resilience. The mean score of overall resilience of the wetland (on a scale of 1 to 5) was 2.7, indicating a below-average and declining status. This assessment was based on a combination of ecological and socio-economic indicators. In the ecological dimension, experts pointed to declines in water quality and biodiversity, as well as changes in the hydrological regime of the wetland.

Specifically, increased pollution from urban and industrial wastewater, a decline in the population of native species, and changes in water-flow patterns were identified as major indicators of reduced ecological resilience. In the socio-economic dimension, experts reported declining incomes among communities dependent on the wetland and increased migration from surrounding villages, which may have reduced local participation in wetland management. These factors indicate reduced in social resilience in the region. 50% of the experts assessed the resilience of the Anzali Wetland as weak or very weak. Only 10% of the experts rated the wetland's resilience as good, whereas none rated it at the highest level of the assessment scale.

Indicators identified to assess resilience of Anzali Wetland

The factors influencing the resilience of Anzali Wetland were divided into two categories, Ecological Resilience and Social Resilience. The identified factors primarily comprised ecological aspects, including water quality, biodiversity, hydrological regime, human pressure, climate change effect, integrated management, and of local community participation. Based on the experts' assessments of the importance of these indicators, the first three ranked highest within ecological domain. However, factors within the social domain were received lower rankings than those within the ecological domain (Table 2). Further details of interview findings are presented in Table 2.

In the first round, there was moderate disagreement among experts (n = 10) regarding the relative importance of the factors (score range: 2-5, Kendall's coefficient of concordance= 0.62). In the second round, the level of disagreement decreased (score range: 3-5, Kendall's coefficient of concordance:0.75), and by the third round, it had decreased further (score range: 4-5, Kendall's coefficient of concordance:0.82). A Kendall's coefficient of concordance of 0.82 being close to one, indicates a high level of agreement among the experts. Higher values of the coefficient indicate greater agreement among the experts. The Delphi process facilitated the collection of diverse expert perspectives and supported rthe development of

consensus regarding the main factors influencing the resilience of Anzali Wetland. It also enabled the identification of potential strategies to improving the resilience of this ecosystem.

After identifying the indicators, experts assessed the current status of the wetland by gathering comprehensive data on both ecological and social factors. This evaluation involves looking at various ecological indicators, such as the vegetation health, water quality, and species diversity, which provided insights into the overall condition of the ecosystem. Simultaneously, social indicators are considered, examining how local communities interact with and depend on the wetland, as well as their awareness of and involvement in conservation efforts. Once the current status was established, experts identified specific threats to the wetland, including pollution, habitat destruction, or the impact of climate change. Understanding these threats was crucial for developing effective solutions. Based on a comprehensive analysis, the experts then proposed potential strategies to address these issues. These included restoration measures, such as replanting native species or improving water management practices, as well as policy recommendations aimed at regulating harmful activities. Additional strategies are presented in Table 3. A critical aspect of this process is establishing a monitoring framework that allows for the ongoing assessment of the proposed strategies. By tracking relevant indicators over time, experts can determine whether their interventions are effective or if adjustments are needed. At this stage, monitoring indicators were also initially identified. Overall, this holistic approach combines scientific evaluation with community engagement to support the sustainable management of the wetland.

Analytical interpretation of the ranking pat-

Table 2. Ranking factors affecting the social-ecological resilience of Anzali Wetland after three rounds of Delphi

Factor	Domain	Mean	STD	Rank	Details
Water quality	Ecological	4.9	0.16	1	Pollution from urban and industrial wastewater, agricultural runoff, and sedimentation has significantly harmed water quality, leading to diminished biodiversity, altered aquatic communities, and reduced ecosystem services.
Biodiversity	Ecological	4.7	0.24	2	Experts note that a decrease in the diversity of native plant and animal species undermines the ecosystem's ability to cope with environmental changes, highlighting the need to preserve genetic diversity in existing populations.
Hydrological regime	Ecological	4.6	0.26	3	Experts highlight that changes in water flow patterns, precipitation, evaporation, and Caspian Sea levels can impact resilience, stressing the need to maintain a natural hydrological regime to support the wetland's ecological functions.
Human Pressure	Social	4.3	0.27	4	Human pressures include urban and industrial development in the watershed, increased agricultural activities, overfishing, and uncontrolled tourism. Experts noted that these activities can lead to habitat destruction, pollution, and overexploitation of the wetland's resources.
Climate change	Ecological	4.2	0.39	5	Experts noted that rising temperatures, changes in precipitation patterns, increased occurrence of droughts and floods, and rising sea levels can affect the wetland's resilience. They emphasized that the effects of climate change may be exacerbated by other stressors, creating complex challenges for wetland management.
Integrated management	Social	4.0	0.41	6	Experts believe that the absence of a comprehensive and integrated management approach can reduce the resilience of the Anzali Wetland. They highlighted the importance of coordination among various organizations, the integration of scientific and local knowledge, and considering the entire watershed in decision-making to enhance resilience.
Participation of local communities	Social	3.9	0.44	7	Experts emphasized that active involvement of local communities in the management and conservation of the wetland can enhance the overall resilience of the system. They noted that local knowledge, a sense of ownership, and community responsibility can significantly contribute to the preservation and restoration of the wetland.

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The ranking pattern in Table 2 provides information not only about factor priority but also about the degree of agreement among experts. The three top-ranked factors-water quality, biodiversity, and hydrological regime-cluster together not only in their mean scores (4.6–4.9) but also in the narrow range of their standard deviations (0.16–0.26), indicating related high degree of agreement among experts regarding their importance and close conceptual relationship. This is not a coincidence of ranking; rather, it reflects an underlying ecological sequence evident in the factor descriptions themselves in Table 2. Pollution and sedimentation degrade water quality, which in turn contributed to the biodiversity loss described by the experts. While, both are influenced by hydrological disruptions reduced flow, altered precipitation, sedimentation, captured by the third-ranked factor. Taken together, these three top ranked factors describe a connected sequence of ecological pressures rather than three separate problems. This finding has implications for management, suggesting that interventions targeting water quality may also contribute to improved biodiversity outcomes, rather than relying solely on biodiversity-focused interventions. The patterns change noticeably for factors in the social domain. Integrated management and local communities' participation, ranked sixth and seventh, respectively. These factors showed the highest standard deviations in Table 2 (0.41 and 0.44), approximately twice those of the top-ranked ecological factors. This difference in agreement is itself a noteworthy finding. While the expert panel showed strong agreement on the biophysical drivers of wetland decline, agreement was considerably weaker regarding the relative importance of governance and participation, even after three rounds of Delphi feedback designed to reduce disagreement. Human pressure, ranked fourth, occupies an instruc-

Table 3. Threats, solutions, and monitoring indicators mentioned by experts for SES resilience enhancement

Threats	Details	Solution	Monitoring indicator
Water pollution from urban and industrial wastewater	Experts noted that the inflow of untreated wastewater leads to increased nutrient levels (eutrophication), reduced dissolved oxygen, and contamination with heavy metals and chemicals, all of which can have detrimental effects on the wetland's biological communities.	Improvement of wastewater treatment systems in cities and industries around the wetland.	BOD, COD, N, P
Hydrology flow loss, Sedimentation and reduction of wetland depth	It is caused by soil erosion in the watershed and the inflow of sediments into the wetland. This process leads to decreased wetland depth, changes in hydrology and morphology, and reduced water retention capacity, all of which can diminish the ecosystem's resilience.	Restoration of vegetation cover along the wetland and control of soil erosion. Execution of dredging projects and sediment management.	Rate of annual sedimentation
Loss of biodiversity due to habitat destruction	Experts noted that habitat destruction and fragmentation, particularly in the fringe areas of the wetland, have led to a decrease in biodiversity. This includes the loss of native plant species, a decline in aquatic bird populations, and a reduction in fish diversity, all of which play crucial roles in the functioning of the wetland ecosystem.	Establishment of protected areas to preserve biodiversity	Diversity and abundance of indicator species (such as aquatic birds and native fish).
Land use change, particularly the conversion of natural areas to agricultural and residential lands	These changes lead to increased soil erosion, alterations in runoff patterns, and an increase in non-point source pollution, all of which can diminish the resilience of the wetland.	Formulation and implementation of an integrated management plan.	Percentage of wetland vegetation cover
Increased pressure from tourism without proper management	Experts noted that the rise in visitor numbers without adequate infrastructure can lead to habitat destruction, pollution, and disruption of wildlife activities.	Development of sustainable tourism and ecotourism.	The level of local community participation
Climate change and the increasing frequency of droughts	Experts noted that these changes can lead to alterations in the wetland's hydrological regime, increased temperatures and evaporation, and shifts in species composition, all of which can impact the resilience of the ecosystem.	Implementation of educational and participatory programs for local communities	Water level and its seasonal variations

tive midpoint between these two groups. Although human pressure, is classified as a social factor, its fourth-place ranking positions it between the two clusters It encompasses overfishing, unmanaged tourism, agricultural expansion into wetland margins describes human behavior with direct ecological consequences. This illustrates that the boundary between the ecological and social categories used in this study is itself somewhat porous in practice.

This structure carries a direct implication for how the overall resilience score of 2.7 out of 5 should be interpreted and acted upon. Because the highest-priority factors also show the strongest expert-consensus and are concentrated in the biophysical domain. Te results suggest that near-term interventions with the clearest expert backing wastewater treatment upgrades, sediment control, hydrological restoration have relatively strong expert support. These interventions may therefore be implemented without first resolving the comparatively unsettled question of how participatory governance should be structured. At the same time, the lower ranking and greater disagreement surrounding community participation should not be mistaken for evidence that it matters less. they indicate that expert consensus on this factor remains limited. To keep this issue visible over time. the monitoring framework proposed in Table 3 includes the level of local community participation as an explicit, ongoing indicator. This approach allows participations to be monitored consciously over time rather than assessed only once, reducing the risk that it will be less attention as more immediately measurable ecological interventions are underway.

Discussion

The results of this study show that Anzali Wetland is currently facing serious challenges in terms of resilience and that could be a situation that may also characterize for numerous wetlands within the urbanized watershed. Similar challenges have been reported for aquatic ecosystems worldwide (Folke et al., 2010), particularly, in relation to the factors influencing their resilience. However, water quality received the highest mean score in this study (4.8 out of 5), indicating the severity of water-related challenges in Anzali Wetland. Similarly, (Jamshidi Zanjani & Saeedi, 2014) reported unfavorable conditions in Anzali wetland based on several ecological indicators. Water quality, biodiversity and hydrological regime were identified as the most important factors affecting wetland resilience. This finding is consistent with global studies emphasizing the importance of these factors in the resilience of wetland ecosystems. The consistency between the present study and earlier assessments also suggests that key ecological challenges in Anzali Wetland have remained over time and continue to require sustained the management attention.

The proposed solutions for improving the resilience of Anzali Wetland encompass several approached, including technical measure to improve treatment systems, ecological measures to restore vegetation, and social measures to educate and engage communities). This comprehensive approach is aligned with the principles of resilience of coupled human–natural systems proposed

by (Berkes et al. ,2000). However, implementing of these solutions in practice may present challenges that require further investigation. The general framework from the result of the results of this paper (Figure 2). Such a resilience assessment and monitoring can support the development of strategies to enhance the ecosystem resilience, s particularly in aquatic ecosystems such as wetlands (Figure 2). Understanding Knowing the main function of an ecosystem and the potential threats plays an essential role for assessing and strengthening its resilience. After identifying the current condition, we need to develop indicators. The proposed indicators for assessing resilience include a combination of ecological and socio-economic indicators. This comprehensive, in line with the resilience assessment presented by (Folke et al., 2010), can help capture the dynamics of the complex system of Anzali wetland. Nonetheless, identifying indicators have to be done by monitoring and communicating the results with local communities and stakeholders. This integrated monitoring can help identify practical solutions and adaptive planning.

The role of local community participation in the proposed strategies highlights the importance of human–environment interactions for ecosystem resilience. This finding is consistent with studies on the role of participatory management in enhancing the resilience of social–ecological systems (Ostrom, 2009). Although the literature generally emphasizes the role of civil society and local participation in strengthening social and ecological resilience, community participation received the lowest ranking among the seven factors assessed in this study (mean =3.9; rank=7). This finding suggests that the expert panel assigned greater priority to ecological factors than to community participation. However, the relatively low ranking of com-

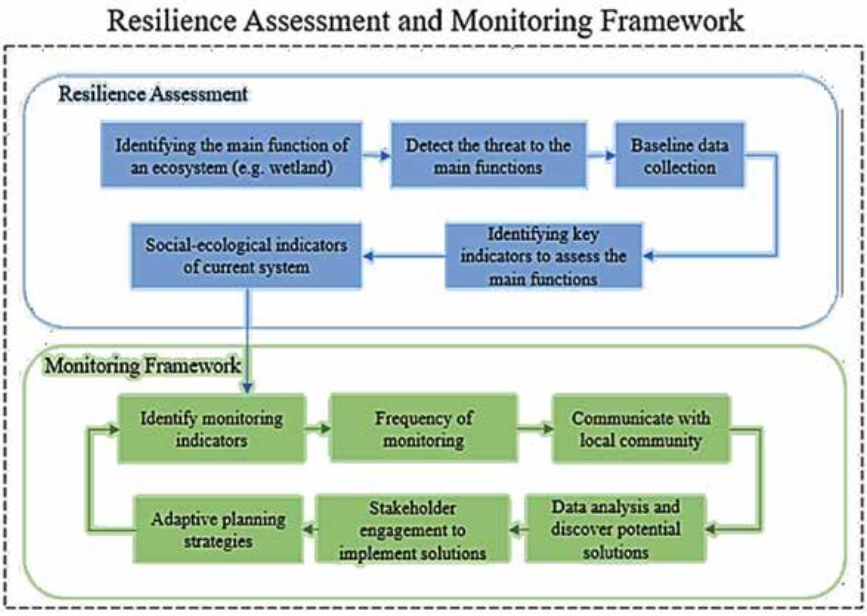


Fig. 2. Resilience assessment and monitoring framework for aquatic ecosystem

Source: Authors

munity participation highlights the need to consider this factor more explicitly in future planning and resilience strategies. This issue warrants greater attention because several ecological pressures, including agricultural water use and changes in wetland depth, are closely connected to local practices, awareness, and participation (Vera-Herrera et al., 2022; Zhao et al., 2021). The finding may also indicate a gap between the perspectives of academic experts and governmental and non-governmental organizations and the requirements of local communities and the wetland environment. Similar tensions have been reported in other environmental governance contexts (Basu et al., 2024; Zebardast et al., 2021).

The comparatively low ranking of local community participation (mean = 3.9; rank 7 and its highest standard deviation observed among all factor in this study (0.44) provide the empirical anchor for the following interpretation. The numerical pattern indicates that the panel reached stronger agreements on the main ecological drivers of wetland decline namely water quality, biodiversity, and hydrological regime, each of with showed a standard deviation below 0.27. In contrast, agreement on the governance and participatory dimensions of resilience remained weaker. despite three full rounds of structured feedback specifically designed to reduce disagreement.

This gap between technical and participatory consensus can be interpreted through broader critical perspectives on knowledge and power in environmental governance. These perspectives are applied here explicitly as interpretive lenses rather than as conclusions demonstrated by the study, since the Delphi design was not considered to test these theoretical propositions. (Gordon and Foucault ,1980) concept of power-knowledge relations offers one such interpretive lens: according to this context, the panel's strongly agreement on measurable technical indicators than on participatory ones raises the possibility that is perceived technical expertise as more "legitimate" than community-based knowledge in environmental decision-making. This reading is consistent with (Li's, 2007) observation that development experts often favor technical solutions over socio-cultural considerations. A similar pattern can be observed in the present study, where technical factors were both higher-ranked and associated with lower variance, while participatory factors were lower-ranked and associated with higher variance. (Spivak's, 2023) notion of epistemic violence and (Bourdieu, 1991) related concept of symbolic violence extend this interpretation by providing a theoretical basis for understanding how experiential and local knowledge may be structurally devalued relative to technical expertise in environmental governance. Dean (2009) and Agrawal (2005) provide complementary perspectives on governmental rationality, while Dryzek, (2022) demonstrated that technocratic discourse can obstruct environmental democracy and Swyngedouw (2011) similarly examines the "depoliticization" of environmental issues. Together, these perspectives suggest that the disagreement documented in this study regarding community participation may reflect a broader structural pattern in how socio-ecological governance values

and prioritizes technical and participatory forms of knowledge.

However, the present study does not directly test any of these frameworks. The collected data cannot determine which framework is more appropriate or confirm which specific mechanism of exclusion or symbolic devaluation operate in the management of Anzali Wetland. A more immediate and methodologically grounded explanation is also available and should be weighed alongside these theoretical interpretations. The Delphi method employed in this study aggregates the judgment of technically and scientifically trained experts. Consequently, the resulting rankings may reflect the perspective of these experts more strongly than those local residents, whose direct evaluation of the same factors might allocate greater weight to community participation. Distinguishing between a structural, governance-level explanation and this narrower methodological one would require research that directly engages local community members. We identify it as a clear and necessary priority for future work building on the present framework. Regardless of which interpretations proves correct, present data support anarrower, practical implication with the greatest confidence. Drawing on Ostrom (2009), participatory mechanisms warrant deliberate strengthening in future governance strategies. Given the disconnect, this study identifies between the theoretical weight typically assigned to community participation in the wetland-resilience literature and its comparatively low, less-consensual ranking by this study's own expert panel.

This study has several limitations and the expert panel was relatively small (n = 10). Although the panel size was appropriate for the specialized Delphi design and the defined study area, the findings may not be generalizable beyond Anzali Wetland. A larger or more geographically diverse panel might have identified additional resilience factors or assigned different weights resilience to the assessed factors. The assessment was based primarily on expert judgment rather than longitudinal field data. Expert assessment is useful for complex and data-limited socio-ecological systems, but it cannot replace direct measurements of ecological and social conditions over time. The proposed monitoring indicators (Table 3) have not yet been field-validated. Their sensitivity, feasibility, and cost-effectiveness therefore remain to be evaluated. Future research should pilot the framework in collaboration with local management authorities and compare its indicators with independently observed ecological and social outcomes.

Conclusions

Anzali Wetland is facing significant resilience challenges that mirror what is happening to urbanized aquatic ecosystems more broadly around the world. The factors identified in this study as most consequential water quality, biodiversity, and hydrological regime echo findings from previous research. (Folke et al, 2010) reinforcing that what is happening in Anzali is part of a larger, familiar pattern rather than an isolated case. The technical, ecological, and social strategies proposed here align with established principles of resilience in coupled human-natural systems, though translating any

of them from expert consensus into effective practice may present challenges that call for further exploration. The resilience assessment and monitoring framework developed in this study provides a systematic basis for identifying ecosystem functions, potential threats, and relevant indicators. These indicators bring together ecological and socio-economic dimensions of the wetland's condition.

Local community participation remains an important component of wetland resilience. Yet one of this study's more striking findings is precisely how little that importance was reflected in practice. While civil society's role was expected to weigh heavily, the results reveal a real disconnect between how significant experts believe local participation to be and how much weight they actually assigned to it. This gap deserves serious attention in future planning, since local actions bear directly on the wetland's health. It also points toward a broader and more difficult question: whether technocratic approaches to Anzali Wetland's management may be quietly overshadowing local knowledge. We raise this possibility as an interpretation this the study's findings make plausible, rather than one they directly prove. Confirming it would require research that engages local communities on their own terms. Future assessments should therefore consider both scientific and local knowledge and include community members directly in evaluating resilience priorities.

The resilience and monitoring framework proposed for Anzali Wetland offers a structured basis for understanding how ecological and socio-economic factors interact to shape the resilience of aquatic ecosystems more broadly. The proposed framework provides a structured basis for linking resilience assessment with ongoing monitoring. It integrates ecological and socio-economic factors and connects identified threats with measurable indicators and potential management responses. However, the framework should be regarded as a starting point rather than a fully validated management tool, field testing and longitudinal monitoring are required to assess the performance of the proposed indicators. They are also needed to determine whether the framework can be adapted to other wetland systems.

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