

Dryland wetlands in the global Ramsar network: aridity patterns, designation criteria and an evidence-to-action framework for Saudi Arabia

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Abstract

Dryland wetlands support distinctive biodiversity and critical ecological functions, yet their position within the global Ramsar network remains poorly quantified. We assessed the climatic composition of 2,533 Ramsar Sites, examined the frequency and aridity association of the nine designation criteria, and evaluated the evidence available for seven candidate wetlands in Saudi Arabia. Aridity classes were assigned to 2,506 sites, while 27 sites remained unclassified because no valid raster value was available. Criterion associations were tested using chi-square analysis with false-discovery-rate correction and Cramer's V. Humid environments contained 56.4% of classifiable sites, whereas arid and hyper-arid environments together accounted for 12.2%. Criteria 1 to 4, which address representative wetland types, threatened species, biodiversity and critical life-cycle functions, were used most frequently. Criterion profiles varied significantly across some aridity classes, but effect sizes were generally weak, indicating that aridity alone does not determine designation pathways. The Saudi assessment identified Tarut Bay and Jabal Qaraqir as priority candidates for detailed evaluation, although for different ecological reasons, and revealed widespread gaps in standardized abundance, and hydrological data. Because global wetland availability was not used as a denominator, the results describe network composition rather than proportional representation. We propose a conceptual adaptive evidence-to-action framework linking national screening, site assessment, nomination, monitoring and management. The approach provides a transferable basis for strengthening Ramsar implementation in Saudi Arabia and other data-limited dryland regions.

INTRODUCTION

Wetlands have declined more rapidly than many terrestrial ecosystems, despite their disproportionate contribution to biodiversity, water regulation, climate mitigation and human well-being (Zedler and Kercher, 2005; Davidson, 2014; Darrah et al., 2019; Gardner and Finlayson, 2018; Convention on Wetlands, 2021, 2025a). Their conservation is especially difficult in drylands, where water is intrinsically scarce and hydrological variability is high. Arid and hyper-arid wetland are therefore representing an ecological paradox. These ecosystems occur in the regions, where potential evapotranspiration greatly exceeds precipitation creating making water availability the principal ecological constraint (Zhang et al. 2022; Jolly et al. 2008). Because of their relative rarity in arid landscapes, some of these wetlands function as important biodiversity hotspots, ecological refugia, and provides essential ecosystem services (Abate et al., 2025).

Although precipitation is an important water source in may humid wetlands, arid wetlands often depend strongly on groundwater discharge, ephemeral surface flows, or irrigation return flows (Endter-Wada & Kettenring, 2014; Downard et al., 2014). Their ecology is shaped by extreme temporal and spatial variability, with "boom-and-bust" cycles of flooding and desiccation driving unique biological adaptations and ecosystem processes (Jenkins et al., 2005; Grenfell et al., 2022). These characteristics make arid wetlands vulnerable to anthropogenic disturbances and climate change, although some systems may recover when their natural hydrological regimes remain intact.

Despite their limited spatial extent, some arid and hyper-arid wetlands support high local and regional biodiversity and provide habitat for specialized wetland dependent taxa (Abate et al., 2025). In particular, geographically isolated and hydrologically persistent desert springs can support high levels of endemism and specialized biota adapted to distinctive physicochemical conditions (Murphy et al. 2015; Brim Box et al. 2023; Jenkins et al., 2005; Grenfell et al., 2022). The biodiversity patterns observed in arid wetlands often exceed those of permanent wetlands in more humid regions, driven by the presence of species uniquely adapted to temporary aquatic environments (Grenfell et al., 2022). Species inhabiting arid wetlands exhibit remarkable adaptations to cope with the "boom-and-bust" hydrological regime characteristic of these systems. Some arid provide important stopover, feeding, or breeding habitat for migratory water-birds along major flyways (Endter-Wada & Kettenring, 2014; Zhang, 2023). The importance of arid wetlands for avian biodiversity extends globally. Dryland wetlands in Sub-Saharan Africa provide breeding grounds for migratory birds and may support species adapted to arid environments (Abate et al. 2025). The biodiversity of arid wetlands is fundamentally dependent on maintaining natural hydrological variability. Studies demonstrate that water levels and vegetation cover are key determinants of wildlife habitat suitability, with different species requiring different hydroperiods and habitat structures (Alminagorta et al. 2016).

Despite their limited spatial extent, arid and hyper-arid wetlands can provide important ecosystem services to surrounding landscapes and human communities. These services include water storage and purification, flood regulation, groundwater recharge, carbon sequestration, nutrient cycling, and food production (Epele et al. 2022).

In desert regions, groundwater plays a critical role in sustaining wetlands during dry periods. Groundwater-surface water interactions are highly dynamic in arid wetlands, varying both temporally and spatially in response to changes in hydraulic gradients, local geomorphology, and wetland geometry (Jolly et al. 2008). Ephemeral surface flows are another critical water source for many arid wetlands as they depend on irregular flood events that deliver water, sediment, and nutrients from upstream catchments (Jenkins et al. 2005; Kingsford et al. 2001). In some arid regions, wetlands have become dependent on anthropogenic water sources, particularly irrigation return flows. While these anthropogenic water sources can sustain wetland habitat, they also create management challenges and vulnerabilities, as changes in agricultural practices or water allocation can threaten wetland persistence (Downard et al., 2014).

High atmospheric evaporative demand and limited precipitation strongly influence the water balance of arid and hyper-arid wetlands. Where surface water is available, evaporation and evapotranspiration can constitute major water-loss pathways and promote salt concentration, particularly in poorly flushed inland basins. In Saudi Arabia, studies of Al-Asfar Lake illustrate this process: relatively saline waters occur in isolated ponds around the main lake, where evaporation concentrates dissolved salts, while agricultural drainage supplies water to the main lake (Al-Dakheel et al. 2009). The magnitude of evapotranspiration in arid wetlands varies with vegetation type, water availability, and climatic conditions. Evapotranspiration rates are particularly high during summer months when temperatures

peak and vegetation is actively growing, creating critical periods when water demand exceeds supply (Lomeli-Banda et al., 2021).

Extreme temporal variability in water availability is a defining characteristic of arid and hyper-arid wetlands, with flood-drought cycles creating dynamic environmental conditions that shape ecosystem structure and function (Jenkins et al., 2005). Arid wetlands experience flood events that can be dramatic in magnitude yet highly irregular in timing. The ecological importance of flood-drought cycles extends beyond simply providing water. Flood events deliver sediment and nutrients to wetlands, allow fish and invertebrates to access floodplain habitats, and trigger breeding events for water-birds (Sandi et al., 2020). Freshwater pulses during floods also serve as the primary mechanism for flushing accumulated salts from both the water column and underlying sediments, temporarily reducing salinity and creating favorable conditions for salt-sensitive species (Jolly et al., 2008). Drought periods, while stressful for wetland biota, are a natural component of arid wetland ecology and can provide important ecological benefits. Periodic drying allows for sediment consolidation, nutrient mineralization, and control of invasive species. However, severe or prolonged drought can cause negative ecological consequences, including invasion by undesirable plant species and loss of aquatic habitat (Endter-Wada & Kettenring, 2014).

Climate change represents one of the most pervasive and severe threats to arid and hyper-arid wetlands, with projected changes in temperature, precipitation patterns, and evapotranspiration rates threatening to fundamentally alter wetland hydrology and ecology. Dryland wetlands are particularly vulnerable to climate change because they already exist at the margins of water availability, where small changes in water balance can have disproportionate impacts (Sandi et al., 2020; Abate et al., 2025). Reduced rainfall combined with increased evapotranspiration will critically increase pressure on dryland wetlands, which must compete with irrigation and human and livestock consumption for limited water resources. This intensification of water scarcity threatens to reduce wetland extent, increase desiccation frequency, and potentially push some systems beyond their capacity for recovery (Sandi et al., 2020). The impacts of climate change on arid wetlands extend beyond simple water scarcity. Increased water deficits from warming and reduced precipitation lead to decreased wetland stage and hydroperiod, particularly affecting shallow wetlands at high aridity (Fay et al., 2016).

In view of these ecological values and the threats facing arid and hyper-arid wetlands, international recognition and coordinated conservation are essential. The Convention on Wetlands of International Importance adopted in Ramsar, Iran, in 1971, provides the principal international framework for the conservation and wise use of wetlands (The Convention on Wetlands, 1971). Under the Ramsar Convention, wetlands are recognized for their ecological, hydrological, economic, cultural, and biodiversity values, and Contracting Parties are encouraged to designate sites of international importance, maintain their ecological character, and promote their wise use. The Convention is particularly relevant to arid and hyper-arid regions, where wetlands may be small, temporary, isolated, or groundwater-dependent, yet support biodiversity and ecosystem services that are disproportionate to

their spatial extent. Consequently, Ramsar designation can help strengthen the protection, monitoring, and sustainable management of these vulnerable ecosystems.

Saudi Arabia contains extensive Red Sea and Arabian Gulf coastal wetlands as well as inland lakes, springs, wadis, oases and human-made systems (Al-Obaid et al., 2017). These habitats support mangroves, seagrasses, coral-associated systems, migratory water-birds, endemic plants and freshwater-dependent communities, but face reclamation, pollution, groundwater depletion, altered runoff and climate stress (Price et al., 1998; Al-Dakheel et al., 2009; Almahasheer et al., 2016; Al-Obaid et al., 2017). The Convention entered into force for Saudi Arabia only on 2 August 2025, placing the country at the beginning of national implementation rather than at the end of a long designation history (Convention on Wetlands, 2025b). Its small initial Ramsar portfolio should therefore be interpreted in relation to this recent accession, rather than as evidence that few Saudi wetlands are internationally important. The timing creates an opportunity to establish a systematic national nomination pipeline instead of proceeding through isolated, documentation-driven site proposals.

This study has four objectives: (1) quantify the distribution of Ramsar Sites across global aridity classes; (2) evaluate the frequency and aridity association of the nine designation criteria; (3) conduct a preliminary, literature-based screening of selected Saudi wetlands; and (4) develop a practical assessment framework for future Saudi nominations and post-designation monitoring. The study is explicitly an assessment of network composition and evidence readiness.

MATERIALS AND METHODS

Global Ramsar dataset

The analysis used a tabular extract of the Ramsar Sites Information Service (RSIS), downloaded on September 21st from Home | Ramsar Sites Information Service. The dataset contained 2,533 sites. Geographic coordinates, country, region and the criteria recorded for designation were retained. Duplicate records and records lacking a valid site identifier were removed before analysis. Criterion fields were converted to nine binary variables. Sites may satisfy multiple criteria, so criterion frequencies are non-exclusive. The Ramsar Strategic Framework and current guidance were used to interpret the criteria and ecological-character obligations (Convention on Wetlands, 2012a, 2012b, 2024).

Ramsar designation criteria

For each Ramsar Site, the criteria recorded in the Ramsar Sites Information Service were extracted and coded as nine binary variables indicating the presence or absence of each criterion in the site record. The criteria are organized into two groups. Group A comprises Criterion 1, which identifies sites containing representative, rare or unique wetland types. Group B comprises Criteria 2 to 9, which identify sites of international importance for conserving biological diversity, including criteria relating to threatened species and ecological communities, regional biodiversity, critical life-cycle stages, water-birds, indigenous fish and other wetland-dependent animals (Convention on Wetlands 2024; Table 1).

Because a site may satisfy more than one criterion, the criterion variables were not mutually exclusive. Their individual frequencies and distributions were subsequently compared across the five aridity classes. The analysis examined the criteria documented in the Ramsar database and did not independently verify whether individual sites continued to meet the relevant ecological or numerical thresholds.

Table 1. Ramsar Criteria 1 to 9 used to identify Wetlands of International Importance, grouped according to their principal ecological basis.

Criteria	Criteria number	Criteria definition
Group A: Sites containing representative, rare or unique wetland types	Criterion 1	A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region.
	Criterion 2	A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities.
	Criterion 3	A wetland should be considered internationally important if it supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region.
	Criterion 4	A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions
	Criterion 5	A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds.
	Criterion 6	A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of waterbird.
	Criterion 7	A wetland should be considered internationally important if it supports a significant proportion of indigenous fish subspecies, species or families, life-history stages, species interactions and/or populations that are representative of wetland benefits and/or values and thereby contributes to global biological diversity.
	Criterion 8	A wetland should be considered internationally important if it is an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend.
Group B: Sites of international importance for conserving biodiversity	Criterion 9	A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of wetland-dependent non-avian animal species.

Source: *Convention on Wetlands (2024)*

Aridity classification

Site coordinates were intersected with the Global Aridity Index, expressed as mean annual precipitation divided by reference evapotranspiration (Trabucco and Zomer, 2019). UNEP thresholds were used: hyper-arid, $AI < 0.05$; arid, $0.05 \leq AI < 0.20$; semi-arid, $0.20 \leq AI < 0.50$; dry sub-humid, $0.50 \leq AI < 0.65$; and humid, $AI \geq 0.65$ (UNEP, 1992). For coordinates falling on no-data cells, the final workflow used a local valid-cell extraction around the reported point. Twenty-seven sites remained unclassified after this procedure and were excluded only from aridity-dependent analyses. Point assignment is a climatic screening device and not a delineation of within-site climatic heterogeneity, which may be substantial in large or coastal Ramsar Sites.

Criterion frequency and association analysis

For each criterion, we calculated the number and percentage of sites in the complete dataset. Among the 2,506 sites with valid aridity classes, Pearson chi-square tests evaluated independence between criterion occurrence and the five aridity classes. False-discovery rates were controlled across the nine tests with the Benjamini-Hochberg procedure (Benjamini and Hochberg, 1995). Cramér's V quantified effect size and was interpreted as evidence of practical association rather than relying on p-values alone (Agresti, 2019). Analyses were descriptive and cross-sectional.

Screening of candidate wetlands in Saudi Arabia

Seven wetland systems were selected to span coastal, island, inland-lake, wadi and spring-associated environments: Al Asfar Lake, Gayal, Gulf coral islands, Jabal Qaraqir, Jizan Bay, Tarut Bay and Wadi Lajab. Published literature and authoritative conservation sources were screened against Criteria 1 to 9. Evidence was coded as strong when a source directly documented a criterion-relevant attribute with site-specific quantitative or taxonomically explicit information; preliminary when the attribute was plausible or qualitatively documented but the applicable threshold or population context was incomplete; and no documented evidence when the review found no adequate source. The last category indicates an evidence gap, not ecological absence. For each site, a documented-evidence score summarized breadth and strength, while an evidence-gap score summarized the additional work required for a defensible nomination. This semi-quantitative prioritization is intended to direct surveys and dossier preparation, not to rank intrinsic conservation value.

Methodological scope and reproducibility

The global analysis uses reported site coordinates rather than Ramsar polygons because complete, consistent boundaries were not available for all records in the working dataset. Counts by aridity class therefore describe the climatic setting of reference points. A formal representation ratio would require the share of Ramsar sites or Ramsar area in each aridity class divided by the corresponding share of all global wetland availability; such a denominator was outside the present analysis. Future work should combine validated polygons with established inventory principles and global surface-water, wetland and groundwater-dependent ecosystem layers (Rebelo et al., 2009; Sieben et al., 2016; Fluet-Chouinard et al., 2015; Pekel et al., 2016; Murray et al., 2019; Chen et al., 2022).

RESULTS

Global distribution of Ramsar sites

Of the 2,533 Ramsar Sites included in the dataset, 2,506 sites (98.9%) received a final aridity classification, whereas 27 sites (1.1%) remained unclassified because no valid raster value was available. Among the classified reference points, 1,413 sites (56.4%) were humid, 535 (21.3%) semi-arid, 253 (10.1%) dry sub-humid, 223 (8.9%) arid, and 82 (3.3%) hyper-arid. Thus, 305 sites (12.2%) were associated with arid or hyper-arid classes.

Frequency of Ramsar criteria

Criterion 2 was the most frequently recorded criterion, applying to 2,147 sites (84.8%), followed by Criterion 1 (1,806 sites; 71.3%), Criterion 3 (1,774; 70.0%), and Criterion 4 (1,677; 66.2%). Criteria 6, 5, 8, and 7 occurred in 37.9%, 30.9%, 30.3%, and 21.8% of sites, respectively. Criterion 9 was least frequent, occurring in 67 sites (2.6%) (Fig. 3A). Because individual sites may satisfy multiple criteria, these percentages are not mutually exclusive.

The prevalence of criteria varied across aridity classes. Criteria 1 to 4 were generally common across classes, whereas Criteria 5 to 9 showed lower and more variable prevalence. The corresponding effect sizes were summarized using Cramér's V (Fig. 3B). Criteria with statistically significant associations should be interpreted together with their effect sizes, because the large global sample can produce small p-values even when the practical association is weak. The Cramér's V values were generally weak, indicating that aridity class explained only a limited part of the variation in criterion occurrence.

Preliminary evidence for selected Saudi wetlands

Saudi Arabia currently has two designated Ramsar Sites: the Farasan Islands Biosphere Reserve and Soudah Waterfall, designated in 2025 and 2026, respectively. Fig. 4 highlights the geographic distribution of the two designated sites together with selected wetland systems identified in this review as priorities for further Ramsar assessment.

The literature-based evidence matrix showed marked differences among the seven selected wetlands (Fig. 5A). Tarut Bay and Jabal Qaraqir had relatively broad documentation across multiple criteria, whereas several sites had evidence concentrated in only a small number of criteria. Criteria 6 and 9 had no documented evidence in the supplied matrix. This result identifies information gaps for future assessment but does not indicate that these criteria are ecologically absent from the wetlands.

The distribution of evidence also differed among wetland types. Jabal Qaraqir and Wadi Lajab showed particularly strong relevance to the habitat- and biodiversity-related criteria (C1 to C4), whereas Tarut Bay exhibited the broadest combination of biodiversity, water-birds and fish-related evidence. Jizan Bay and the Gulf Coral Islands showed comparatively strong evidence associated with critical life-cycle functions (C4), while evidence for several other criteria remains preliminary. Across the seven wetlands, evidence

was sparse or absent for C6 and C9, identifying important targets for future quantitative population assessment.

The evidence-priority plot separates wetlands according to the strength and breadth of documented evidence and the remaining evidence requirements (Fig. 5B). Tarut Bay and Jabal Qaraqir occupy the high-evidence portion of the plot, while Gayal and Wadi Lajab have comparatively limited documented evidence. The plot is intended to guide research and documentation priorities rather than rank ecological importance.

DISCUSSION

Dryland wetlands in a climatically uneven Ramsar network

The global analysis demonstrates that Ramsar Sites are concentrated in humid environments and only 12.2% of Ramsar sites occur in arid or hyper-arid settings. This pattern is ecologically justifiable because persistent surface water and wetland extent are generally greater in humid climates, but it also reflects how readily wetlands can be detected, documented and recommended for designation. Dryland wetlands such as springs, episodically inundated playas and groundwater-dependent systems may be difficult to detect using single date imagery or short field campaigns (Fluet-Chouinard et al., 2015; Pekel et al., 2016; Gxokwe et al., 2022). Their ecological functions may become apparent only during flood pulses, seasonal migrations, or wet–dry transitions. Therefore, assessments based only on visible surface water may underestimate the occurrence and ecological importance of dryland wetlands. The comparatively modest share of arid and hyper-arid sites must also be interpreted in relation to the distinctive ecological dynamics of dryland wetlands. Many are temporary, saline or groundwater-dependent systems in which ecological character is expressed through episodic flooding, intervening dry phases and strong seasonal fluctuations rather than permanent inundation. These characteristics make dryland wetlands less conspicuous in conventional inventories and difficult to assess using single-date imagery or short field campaigns. Important functions may occur only during brief flood pulses or migratory windows, while dormant propagule banks, subsurface water connections and dry-phase processes remain poorly represented by assessments centered on visible surface water (Jenkins et al., 2005; Jolly et al., 2008; Grenfell et al., 2022; Gxokwe et al., 2022). Ramsar assessment and management in drylands therefore require multi-season observations, historical hydroclimatic information and explicit recognition that periodic drying can form part of the natural ecological character. This need becomes more urgent under climate change, because increased evaporative demand, altered flood frequency and groundwater abstraction can shorten hydroperiods and intensify salinity without causing an immediate or complete disappearance of the wetland (Fay et al., 2016; Sandi et al., 2020; Lomeli-Banda et al., 2021). Monitoring programs should consequently track groundwater levels, flood timing and duration, salinity, habitat condition and biological responses in addition to changes in open-water extent. Dryland wetlands frequently function as isolated nodes, so the loss of a small site can have effects disproportionate to its area. Their ecological character is also highly sensitive to upstream abstraction and groundwater drawdown outside nominal site boundaries (Jolly et al., 2008; Brim Box et al., 2023). Future network

planning should therefore consider hydrogeological connectivity, functional linkages and climate refugia, in addition to visible wetland boundaries.

Criterion-use patterns across the aridity gradient

The dominance of Criteria 1 to 4 indicates that Ramsar designation is usually supported by broad evidence of wetland-type representativeness, threatened species, biodiversity and critical life-cycle functions. These criteria can often be substantiated from habitat descriptions, species inventories and conservation status data. By contrast, the lower frequency of Criteria 5, 6 and 9 reflects their higher quantitative burden as they require credible abundance estimates, repeated counts and appropriate population thresholds. Criterion 9 is especially demanding because population estimates for many non-avian wetland-dependent taxa are incomplete or geographically coarse (Convention on Wetlands, 2012a).

The weak cramér's V values indicate that aridity is not a strong organizing variable for criterion use. This is important for Saudi Arabia as dryland status does not prescribe a narrow criterion pathway. Arid wetlands may qualify through representative hydrogeomorphic types, threatened taxa, refugial functions, congregatory water-birds, fish nurseries or other animal populations. Conversely, statistically significant global associations should not be turned into expectations that a Saudi site ought to satisfy a particular criterion.

The absence of strong aridity effects also suggests that institutional factors merit attention. Data-rich bird sites are more likely to meet numerical criteria, whereas botanically distinctive wadis or groundwater-dependent ecosystems may be better supported under Criteria 1 to 3. A balanced national program should therefore fund hydro-ecology, vegetation, fish and invertebrate surveys alongside water-bird monitoring. Otherwise, criterion selection will reproduce the distribution of existing expertise rather than the distribution of ecological importance.

Implications for Saudi Arabia

The country's accession is too recent for comparisons with long-standing Contracting Parties to be interpreted as a measure of national conservation performance. Instead, the global analysis provides an early baseline for building a representative portfolio and establishing the inventories, evidence standards and monitoring systems required under the Convention. The national review by Al-Obaid et al. (2017) documented coastal, inland and human-made systems and emphasized threats from development, pollution, altered hydrology and limited monitoring. The screened sites illustrate different types of evidence and assessment needs. Tarut Bay integrates intertidal flats, mangroves, seagrass-associated functions and water-bird habitat, but urban and industrial pressures make boundary design and ecological-character baselines critical. Jabal Qaraqir and Wadi Lajab provide examples of sites that may be evaluated using representative habitat, threatened species and biogeographic distinctiveness rather than through permanent open water alone (Llewellyn et al., 2010; Masrahi et al, 2017; Al-Namazi et al., 2021). Al Asfar Lake illustrates the conservation ambiguity of anthropogenic wetlands, where drainage

inputs sustain habitat but also create salinity and contaminant risks (Al-Dakheel et al., 2009; Al-Homaidan et al., 2011).

Tarut Bay's high evidence and high gap scores make it a logical candidate for an intensive assessment program. The immediate priorities are seasonal water-bird counts, habitat mapping, fish and nursery-function surveys, water and sediment quality assessment, pressure mapping and delineation of an ecologically meaningful boundary. Jabal Qaraqir appears closer to a defensible habitat and flora-led case, but hydrological dependence, threats and management feasibility still require explicit treatment. For Wadi Lajab and Gayal, foundational inventory and hydrological work should precede criterion claims.

Saudi nominations should be assembled as part of a coherent national wetland strategy aligned with biodiversity, water and protected-area planning. Designation alone does not guarantee favorable condition; evidence from the global network shows that ecological character can deteriorate even within listed sites (Davidson et al., 2020; Kingsford et al., 2021). Each nomination should therefore include measurable limits of acceptable change, named indicators, monitoring responsibility, data governance and response triggers. This shifts Ramsar designation from a recognition event to a long-term adaptive management commitment.

Practical assessment framework for future nominations

Saudi Arabia's recent accession to the Convention provides an opportunity to establish a nationally coordinated and evidence-based process for identifying wetlands of international importance. As summarized in Fig. 6, the proposed framework comprises three interconnected stages: national screening, site assessment, and nomination and management. Although presented sequentially for clarity, these stages form an adaptive cycle in which new ecological evidence and monitoring outcomes continually improve the national inventory and refine candidate-site priorities.

The first stage, national screening, establishes the evidence base required to identify and prioritize potential Ramsar Sites. It should begin with a comprehensive inventory and typology of natural and human-made wetlands using multi-season Sentinel-1 and Sentinel-2 imagery, historical records, digital elevation models, groundwater information and field verification. A hydrogeomorphic classification incorporating water source, geomorphic setting, salinity and hydroperiod would provide a consistent basis for distinguishing ecologically different wetland systems (Brinson, 1993; Tiner, 2017). Combining remote sensing with field verification is particularly important in arid environments, where many wetlands are small, temporary or groundwater-dependent and may not be detectable during a single observation period. The resulting inventory can support the development of a prioritized candidate portfolio based on ecological distinctiveness, biodiversity value, threat exposure, geographic coverage and the availability of supporting evidence.

The second stage, site assessment, determines whether a candidate wetland has the ecological characteristics and evidentiary support required for nomination. Hydrological assessment should identify surface-water inputs, groundwater dependence, abstraction pressures, residence time, salinity

and water-quality conditions because these factors determine both the functional site boundary and the wetland's vulnerability to external change. Biodiversity surveys should include seasonal vegetation assessments, standardized water-bird counts, fish and aquatic-fauna surveys, eDNA or conventional sampling, and targeted investigation of threatened, endemic or range-restricted taxa. Sampling must encompass wet and dry phases because assessments based on a single visit are likely to underestimate the ecological importance of episodic wetlands (Jenkins et al., 2005; Gxokwe et al., 2022).

Evidence generated during site assessment should then be evaluated explicitly against Ramsar Criteria 1 to 9. A claim-evidence-threshold matrix could provide a transparent means of linking each proposed criterion to the ecological claim, supporting dataset, applicable threshold and level of confidence. For quantitative criteria, particularly Criteria 5, 6 and 9, abundance estimates should be accompanied by information on sampling effort, detectability, temporal replication and the population estimate used as the denominator. The assessment should also characterize major pressures and changes in ecological character, including alterations in hydroperiod, inundated area, groundwater level, salinity, water quality, habitat condition, connectivity, invasive species and focal-taxon abundance. Such indicators can subsequently form the basis for defining limits of acceptable change and designing long-term monitoring (Convention on Wetlands, 2012b; Kingsford et al., 2021).

The third stage, nomination and management, converts ecological evidence into an implementable conservation commitment. Independent expert review should verify the sufficiency of the evidence, appropriateness of the proposed boundary and validity of the criteria claimed before preparation of the Ramsar Information Sheet. Nomination readiness should therefore reflect not only ecological significance but also the availability of baseline information, governance arrangements, responsible institutions, financing, monitoring capacity and feasible management responses. Stakeholder participation is particularly important where wetland condition depends on groundwater abstraction, irrigation returns, grazing access or upstream water allocation (Finlayson et al., 2011; Downard et al., 2014).

The readiness decision produces three possible pathways. Candidates supported by adequate evidence and management arrangements may proceed directly to nomination. Sites with clear potential but specific information deficiencies should undergo targeted hydrological, biodiversity or criterion-focused investigation. Poorly documented sites of possible strategic importance should remain within the national research portfolio rather than being rejected solely because current evidence is limited. Structured citizen science can supplement professional surveys, particularly for water-birds and seasonal wetland occurrence, but should operate through standardized protocols and quality-control procedures (McInnes et al., 2020).

Importantly, the readiness decision does not represent the end of the assessment process. Information generated through additional research, preparation of nomination documentation and post-designation monitoring should be incorporated into the national wetland inventory. Newly detected wetlands, revised boundaries, changing threats and management outcomes may consequently alter the relative priority of

existing candidates or reveal previously unrecognized gaps in the national Ramsar network. Sites requiring additional evidence may re-enter the site-assessment stage, whereas accumulated evidence from all candidates and designated sites feeds back into national screening. The framework therefore functions as a continuous learning cycle that supports periodic reprioritization, strengthens future nomination dossiers and enables Saudi Arabia's Ramsar network to develop systematically as national knowledge improves.

Methodological limitations and research priorities

Several methodological considerations define the scope of the present findings. Climatic conditions were assigned using the reported coordinates of individual Ramsar Sites. Although this approach provides a consistent basis for global comparison, a single reference point may not adequately represent large, elongated or coastal sites that encompass substantial environmental heterogeneity. The resulting classifications should therefore be interpreted as the dominant climatic context of each site rather than a complete characterization of within-site aridity. Future analyses based on validated site boundaries could apply polygon-level zonal statistics to quantify dominant conditions, climatic variability and the proportion of each site occurring within different aridity classes. Similarly, the site-count approach treats each designation as an equivalent unit regardless of its spatial extent. This is appropriate for evaluating the frequency and climatic distribution of Ramsar designations, but it does not measure the total area of wetland habitat represented within the network. Complementary area-based analyses would require harmonized site boundaries and separation of actual wetland habitats from marine waters, terrestrial buffer zones and other non-wetland components included within some Ramsar polygons. The literature-based assessment of Saudi wetlands is also influenced by variation in research and publication effort. Consequently, the absence of documented evidence for a criterion should be interpreted as an information gap rather than evidence that the criterion is ecologically absent.

Further global assessment should integrate validated Ramsar boundaries with consistent wetland-extent, surface-water and hydroperiod datasets and examine patterns separately by geographic region and Ramsar wetland type. Sensitivity analyses using alternative aridity datasets, coastal-cell assignment procedures and polygon-summary statistics would help quantify uncertainty in climatic classification. In Saudi Arabia, priority should be given to developing a standardized national wetland inventory; establishing long-term monitoring of water-birds and other wetland-dependent fauna; mapping groundwater-dependent ecosystems; and implementing seasonal assessments of hydroperiod, habitat condition and water quality. A centralized evidence repository linking field observations, spatial datasets and published records to individual Ramsar criteria and ecological-character indicators would further improve transparency and consistency. Together, these developments would provide the evidence base required to progress from preliminary screening to a nationally coordinated system for Ramsar nomination, ecological-character monitoring and adaptive wetland management.

CONCLUSIONS

The Ramsar network is climatically dominated by humid sites, while arid and hyper-arid environments account for 12.2% of classifiable sites. The network relies primarily on broad habitat- and biodiversity-based criteria, and criterion profiles vary only weakly with aridity. These findings do not establish proportional under-representation of dryland wetlands, because global wetland availability was not used as a denominator, but they reveal the limited size of the dryland evidence base and the quantitative demands that constrain use of population-threshold criteria. For Saudi Arabia, the global analysis supports a portfolio approach encompassing coastal, island, wadi, spring and human-made wetlands. Tarut Bay and Jabal Qaraqir emerge as high-priority assessment candidates for different reasons, while gaps in standardized abundance, hydro-ecological and pressure data remain widespread. A staged framework linking inventory, hydrology, biodiversity, criterion testing, ecological-character baselines and adaptive governance provides a practical route from preliminary screening to defensible nomination and sustained management.

Declarations

Competing interests

The authors report there are no competing interests to declare

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Author Contribution

N.K.V., M.I.N., M.A., A.A.M., A.K., T.I., and M.O.A .contributed to the study conception and design. Material preparation, data collection and analysis were performed by NK Veettil, MI Naikoo, and MO Abouelresh. The first draft of the manuscript was written by NK Veettil and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

1. Abate SG, Mekonnen YG, Ambaye BA, Habtie DG, Tadesse KB, Ayalew MG, Alamirew T (2025) Ecological insights of dryland wetlands for climate resilience and its challenges in Sub-Saharan Africa. *Discover Environment* 3:79. <https://doi.org/10.1007/s44274-025-00379-4>
2. Agresti A (2019) *An introduction to categorical data analysis*, 3rd edn. Wiley, Hoboken
3. Al-Ali AM, Del Campo AG, Rocha C (2015) Environmental assessment of mangrove communities in Tarut Bay, Eastern Arabian Peninsula, based on multidisciplinary approach. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XL-7/W3:269-276. <https://doi.org/10.5194/isprsarchives-XL-7-W3-269-2015>
4. Al-Dakheel YY, Hussein AHA, El Mahmoudi AS, Massoud MA (2009) Soil, water chemistry and sedimentological studies of Al Asfar Evaporation Lake and its inland sabkha, Al Hassa area, Saudi Arabia. *Asian Journal of Earth Sciences* 2:1-21. <https://doi.org/10.3923/ajes.2009.1.21>
5. Al-Homaidan AA, Al-Ghanayem AA, Alkhalifa AH (2011) Green algae as bioindicators of heavy metal pollution in Wadi Hanifah Stream, Riyadh, Saudi Arabia. *International Journal of Water Resources and Arid Environments* 1:10-15
6. Al-Namazi AA, Al-Khulaidi AWA, Algarni S, Al-Sagheer NA (2021) Natural plant species inventory of hotspot areas in Arabian Peninsula: Southwest Al-Baha region, Saudi Arabia. *Saudi Journal of Biological Sciences* 28:3309-3324. <https://doi.org/10.1016/j.sjbs.2021.02.076>
7. Al-Obaid S, Samraoui B, Thomas J, El-Serehy HA, Alfarhan AH, Schneider W, O'Connell M (2017) An overview of wetlands of Saudi Arabia: values, threats, and perspectives. *Ambio* 46:98-108. <https://doi.org/10.1007/s13280-016-0807-4>
8. Almahasheer H, Aljowair A, Duarte CM, Irigoien X (2016) Decadal stability of Red Sea mangroves. *Estuarine, Coastal and Shelf Science* 169:164-172. <https://doi.org/10.1016/j.ecss.2015.11.027>
9. Alminagorta O, Rosenberg DE, Kettenring KM (2016) Systems modeling to improve the hydro-ecological performance of diked wetlands. *Water Resources Research* 52:7070-7085. <https://doi.org/10.1002/2015WR018105>
10. Benjamini Y, Hochberg Y (1995) Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society Series B* 57:289-300
11. Brim Box J, Davis J, Howard J, Work K (2023) Editorial: threatened aquatic gems: freshwater springs and groundwater-dependent ecosystems. *Frontiers in Environmental Science* 11:1270348. <https://doi.org/10.3389/fenvs.2023.1270348>
12. Brinson MM (1993) *A hydrogeomorphic classification for wetlands*. US Army Corps of Engineers, Waterways Experiment Station, Vicksburg

13. Chen W, Cao C, Liu D, Tian R, Wu C, Wang Y, Qian Y, Ma G, Bao D (2019) An evaluating system for wetland ecological health: case study on nineteen major wetlands in Beijing-Tianjin-Hebei region, China. *Science of the Total Environment* 666:1080-1088.
<https://doi.org/10.1016/j.scitotenv.2019.02.325>
14. Convention on Wetlands (1971, as amended) Present text of the Convention on Wetlands. Ramsar Convention Secretariat, Gland. <https://www.ramsar.org/document/present-text-convention-wetlands>
15. Convention on Wetlands (2012a) Strategic framework and guidelines for the future development of the List of Wetlands of International Importance. Ramsar Convention Secretariat, Gland
16. Convention on Wetlands (2012b) An integrated framework for avoiding, mitigating and compensating for wetland losses. Ramsar Convention Secretariat, Gland
17. Convention on Wetlands (2021) Global wetland outlook: special edition 2021. Secretariat of the Convention on Wetlands, Gland
18. Convention on Wetlands (2024) The Ramsar Sites criteria. Secretariat of the Convention on Wetlands, Gland
19. Convention on Wetlands (2025a) Global wetland outlook 2025. Secretariat of the Convention on Wetlands, Gland
20. Convention on Wetlands (2025b) Contracting Parties to the Convention on Wetlands: annotated list. Secretariat of the Convention on Wetlands, Gland
21. Darrah SE, Shennan-Farpon Y, Loh J, Davidson NC, Finlayson CM, Gardner RC, Walpole MJ (2019) Improvements to the Wetland Extent Trends index as a tool for monitoring natural and human-made wetlands. *Ecological Indicators* 99:294-298
22. Davidson NC (2014) How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research* 65:934-941
23. Davidson NC, Dinesen L, Fennessy S, Finlayson CM, Grillas P, Grobicki A, McInnes RJ, Stroud DA (2020) Trends in the ecological character of the world's wetlands. *Marine and Freshwater Research* 71:127-138
24. Downard R, Endter-Wada J, Kettenring KM (2014) Adaptive wetland management in an uncertain and changing arid environment. *Ecology and Society* 19:23. <https://doi.org/10.5751/ES-06412-190223>
25. Elsheikh MA, Al-Gahtani SM, Al-Solaimani SG (2016) Ecological characteristics of plant species at Alasfar Lake in Al-Ahsa Region, Saudi Arabia. *International Journal of Agricultural Innovations and Research* 5:41-48
26. Elsohaby I, Samy A, Elmoslemany A, Alorabi M, Alkafafy M, Aldoweriej A, Al-Marri T, Elbehiry A, Fayez M (2021) Migratory wild birds as a potential disseminator of antimicrobial-resistant bacteria around Al-Asfar Lake, Eastern Saudi Arabia. *Antibiotics* 10:260.
<https://doi.org/10.3390/antibiotics10030260>
27. Epele LB et al (2022) Patagonian wetlands: vertientes, vegas, mallines, turberas, and lagunas. In: Mataloni G, Quintana RD (eds) *Freshwaters and wetlands of Patagonia*. Springer, Cham.

https://doi.org/10.1007/978-3-031-10027-7_10

28. Fay PA, Guntenspergen GR, Olker JH, Johnson WC (2016) Climate change impacts on freshwater wetland hydrology and vegetation cover cycling along a regional aridity gradient. *Ecosphere* 7:e01504. <https://doi.org/10.1002/ecs2.1504>
29. Finlayson CM, Davidson NC, Pritchard D, Milton GR, MacKay H (2011) The Ramsar Convention and ecosystem-based approaches to the wise use and sustainable development of wetlands. *Journal of International Wildlife Law and Policy* 14:176-198
30. Fluet-Chouinard E, Lehner B, Rebelo LM, Papa F, Hamilton SK (2015) Development of a global inundation map at high spatial resolution from topographic downscaling of coarse-scale remote sensing data. *Remote Sensing of Environment* 158:348-361. <https://doi.org/10.1016/j.rse.2014.10.015>
31. Gardner RC, Finlayson CM (2018) Global wetland outlook: state of the world's wetlands and their services to people. Ramsar Convention Secretariat, Gland
32. Gopi J, Joydas TV, Manokaran S, Abouelresh MO, Jayachandran PR, Dixit S, Rafeeq M, Almusabeh AH, Nazal MK, Manikandan KP, Hala S, Pulido B (2025) Profiling the microeukaryote diversity in arid sabkha soils in NEOM, Saudi Arabia, using 18S rRNA-based eDNA metabarcoding. *Ecological Frontiers* 45:1814-1822. <https://doi.org/10.1016/j.ecofro.2025.07.013>
33. Grenfell SE, Grenfell M, Tooth S, Mehl AE, O'Gorman E, Ralph TJ, Ellery WN (2022) Wetlands in drylands: diverse perspectives for dynamic landscapes. *Wetlands Ecology and Management* 30:607-622. <https://doi.org/10.1007/s11273-022-09887-z>
34. Gxokwe S, Dube T, Mazvimavi D (2022) Leveraging Google Earth Engine platform to characterize and map small seasonal wetlands in semi-arid environments. *Science of the Total Environment* 803:150139
35. Hall M, Miller AG, Llewellyn O et al (2010) A conservation assessment of *Douepea arabica* (Brassicaceae): a critically endangered plant species from Saudi Arabia. *Oryx* 44:547-550. <https://doi.org/10.1017/S0030605310000955>
36. Jenkins KM, Boulton AJ, Ryder DS (2005) A common parched future? Research and management of Australian arid-zone floodplain wetlands. *Hydrobiologia* 552:57-73. <https://doi.org/10.1007/s10750-005-1505-6>
37. Jolly I, McEwan K, Holland K (2008) A review of groundwater-surface water interactions in arid/semi-arid wetlands and the consequences of salinity for wetland ecology. *Ecohydrology* 1:43-58. <https://doi.org/10.1002/eco.6>
38. Kingsford RT, Bino G, Finlayson CM et al (2021) Ramsar wetlands of international importance-improving conservation outcomes. *Frontiers in Environmental Science* 9:643367. <https://doi.org/10.3389/fenvs.2021.643367>
39. Kingsford RT, Thomas RF, Curtin AL (2001) Conservation of wetlands in the Paroo and Warrego River catchments in arid Australia. *Pacific Conservation Biology* 7:21-33. <https://doi.org/10.1071/PC010021>

40. Llewellyn OA, Hall M, Miller AG, Al-Abbasi TM, Al-Wetaid AH, Al-Harbi RJ, Al-Shammari KF (2010) Important Plant Areas in the Arabian Peninsula: Jabal Qaraqir. *Edinburgh Journal of Botany* 67:37-56
41. Lomeli-Banda MA, Ramirez-Hernandez J, Rodriguez-Burgueno JE, Salazar-Briones C (2021) The role of hydrological processes in ecosystem conservation: comprehensive water management for a wetland in an arid climate. *Hydrological Processes* 35:e14013. <https://doi.org/10.1002/hyp.14013>
42. Masrahi YS, Remesh M, Sayed OH (2017) Enumeration of the flora of Wadi Lajab, Saudi Arabia. *Ecology, Environment and Conservation* 23:115-123
43. McInnes RJ, Davidson NC, Rostron CP, Simpson M, Finlayson CM (2020) A citizen science state of the world's wetlands survey. *Wetlands* 40:1577-1593. <https://doi.org/10.1007/s13157-020-01267-8>
44. Murphy NP, Guzik MT, Cooper SJB, Austin AD (2015) Desert spring refugia: museums of diversity or evolutionary cradles. *Zoologica Scripta* 44:693-701. <https://doi.org/10.1111/zsc.12129>
45. Murray NJ, Phinn SR, DeWitt M, Ferrari R, Johnston R, Lyons MB, Clinton N, Thau D, Fuller RA (2019) The global distribution and trajectory of tidal flats. *Nature* 565:222-225
46. Pekel JF, Cottam A, Gorelick N, Belward AS (2016) High-resolution mapping of global surface water and its long-term changes. *Nature* 540:418-422. <https://doi.org/10.1038/nature20584>
47. Price ARG, Jobbins G, Shepherd ARD, Ormond RFG (1998) An integrated environmental assessment of the Red Sea coast of Saudi Arabia. *Environmental Conservation* 25:65-76
48. Rabaoui LJ, Hamza F, Arossa S et al (2026) Responses of coastal bird communities to habitat types and anthropogenic factors along the Saudi Red Sea coast. *Estuarine, Coastal and Shelf Science* 337:109907. <https://doi.org/10.1016/j.ecss.2026.109907>
49. Rebelo LM, Finlayson CM, Nagabhatla N (2009) Remote sensing and GIS for wetland inventory, mapping and change analysis. *Journal of Environmental Management* 90:2144-2153
50. Sandi SG, Rodriguez JF, Saintilan N, Wen L, Kuczera G, Riccardi GA, Saco PM (2020) Resilience to drought of dryland wetlands threatened by climate change. *Scientific Reports* 10:13232. <https://doi.org/10.1038/s41598-020-70087-x>
51. Sea Alarm (2025) Country wildlife response profiles: Saudi Arabia. Sea Alarm, Brussels
52. Sieben EJJ, Kotze DC, Job N, Muasya AM (2016) A review of wetland classification and inventory in South Africa. *Wetlands Ecology and Management* 24:141-158
53. Tiner RW (2017) Wetland indicators: a guide to wetland formation, identification, delineation, classification, and mapping, 2nd edn. CRC Press, Boca Raton
54. Trabucco A, Zomer RJ (2019) Global aridity index and potential evapotranspiration database, version 3. CGIAR Consortium for Spatial Information
55. Turk KGB (2025) Wetlands in Saudi Arabia: review and assessment of the environmental hazards in Al-Asfar Lake. *Polish Journal of Environmental Studies*. <https://doi.org/10.15244/pjoes/209835>
56. UNEP (1992) World atlas of desertification. Edward Arnold, London
57. Youssef AM, Al-Fredan MA, Fathi AA (2009) Floristic composition of Lake Al-Asfar, Alahsa, Saudi Arabia. *International Journal of Botany* 5:116-125

58. Zedler JB, Kercher S (2005) Wetland resources: status, trends, ecosystem services, and restorability. *Annual Review of Environment and Resources* 30:39-74
59. Zhang L, Sun T, Fei K, Deng L, Song N, Wang X, Yang X, Wang L, Chen L (2022) Soil moisture variations of wetland at different altitudes in desert regions, China. *International Journal of Environment, Agriculture and Biotechnology* 7:41-51. <https://doi.org/10.22161/ijeab.75.5>
60. Zhang W (2023) Evaluating abiotic and biotic factors affecting plant succession processes at Malheur Lake. Dissertation, Louisiana State University. https://doi.org/10.31390/gradschool_theses.5788

Figures

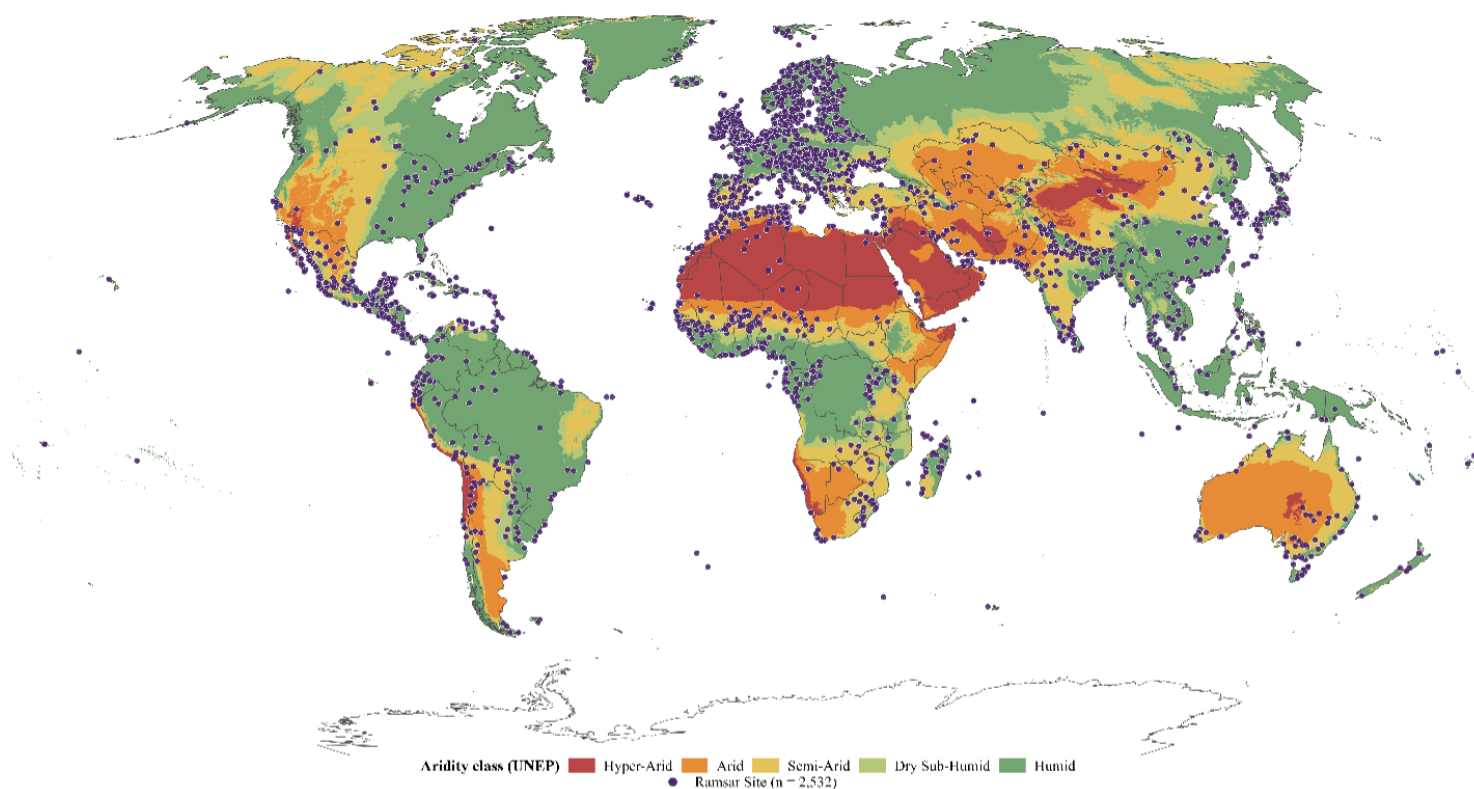


Figure 1

Global distribution of Ramsar Sites across UNEP aridity classes. Reported site locations are superimposed on five classes derived from the Global Aridity Index: hyper-arid, arid, semi-arid, dry sub-humid and humid. Aridity-dependent summaries include 2,506 of the 2,533 sites in the dataset; 27 sites remained unclassified after exact-cell and local valid-cell extraction. Basemap boundaries: Natural Earth

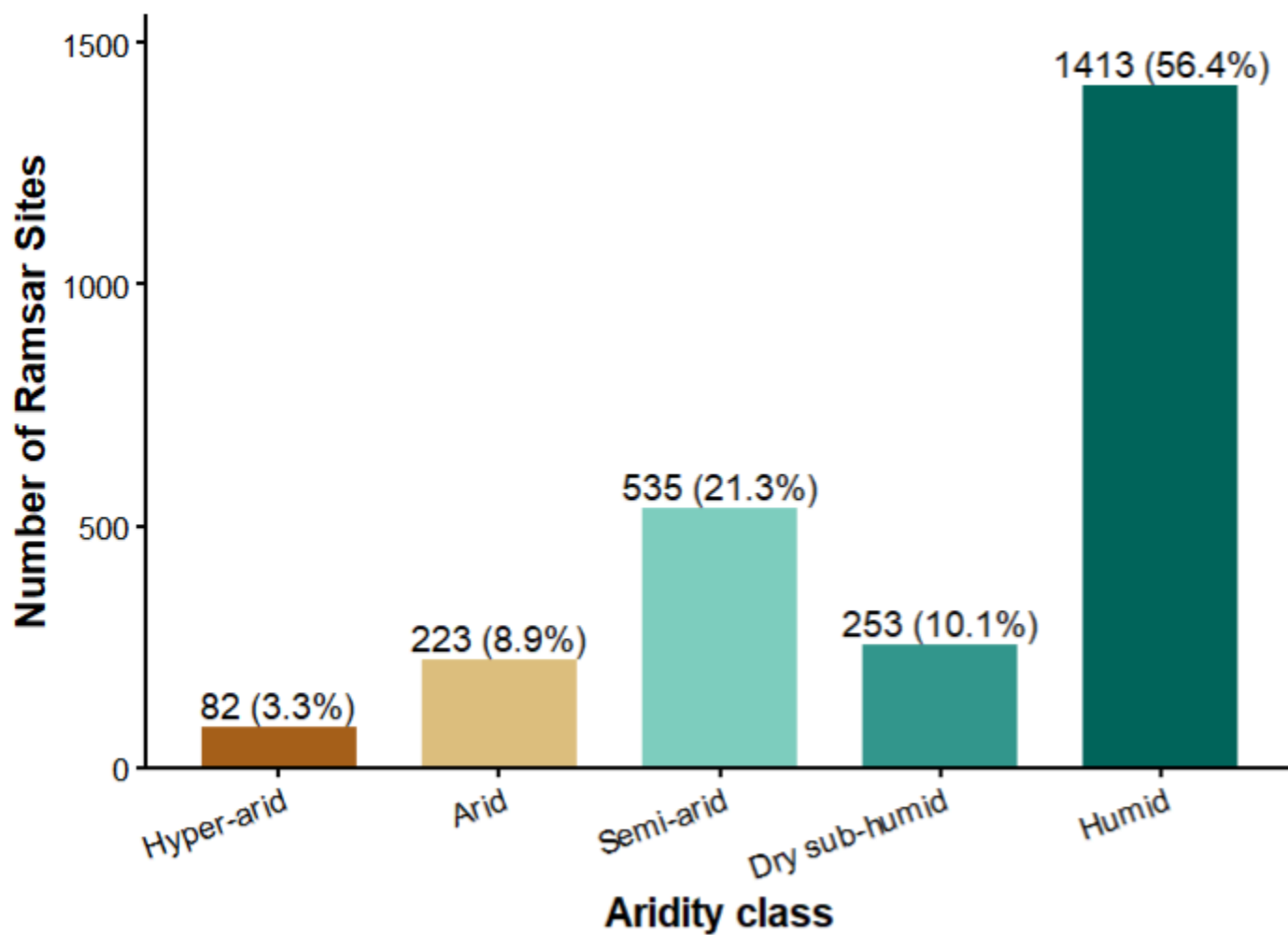


Figure 2

Distribution of Ramsar Sites among the five global aridity classes. Percentages were calculated among the 2,506 sites with valid final aridity classifications; 27 sites remained unclassified.

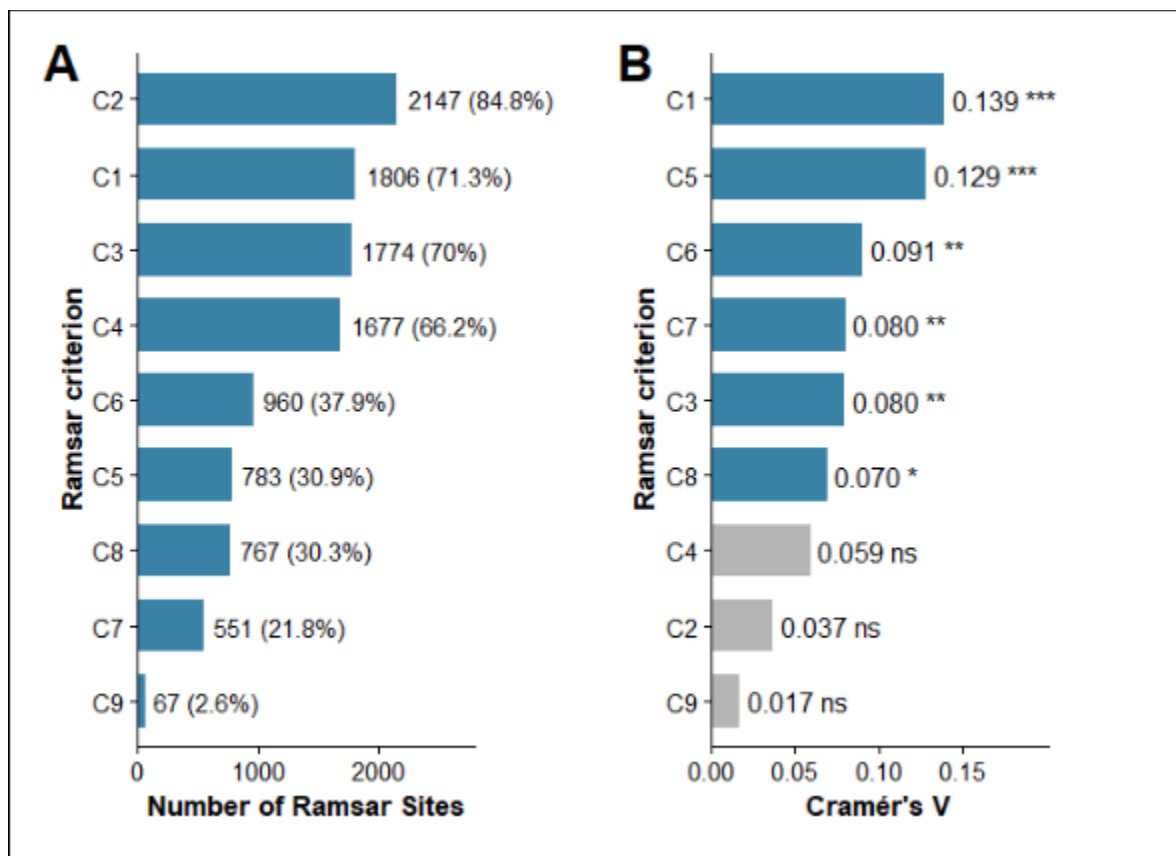


Figure 3

Global frequency and aridity-related associations of Ramsar Criteria 1-9. (A) Number and percentage of Ramsar Sites designated under each of the nine criteria. (B) Strength of association between criterion occurrence and the five aridity classes, expressed as Cramér's V. Statistical significance was assessed after Benjamini–Hochberg adjustment. Effect sizes were calculated using the 2,506 sites with valid aridity classifications.

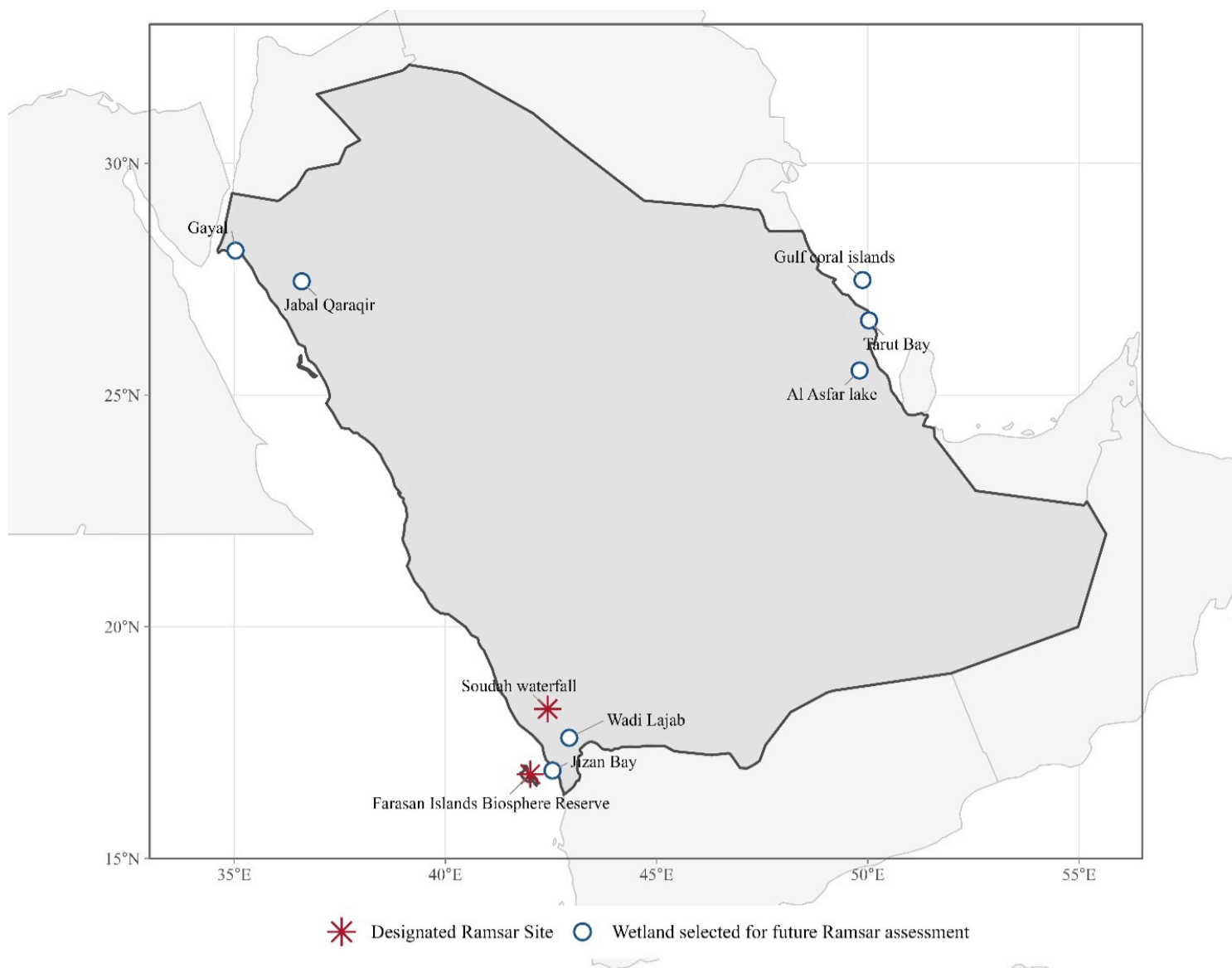


Figure 4

Spatial distribution of designated Ramsar Sites and wetlands selected for future Ramsar assessment in Saudi Arabia. Red stars indicate the two designated Ramsar Sites, and open blue circles represent the seven wetlands identified through literature-based screening for further assessment against Ramsar Criteria 1 to 9. Base map data: Natural Earth.

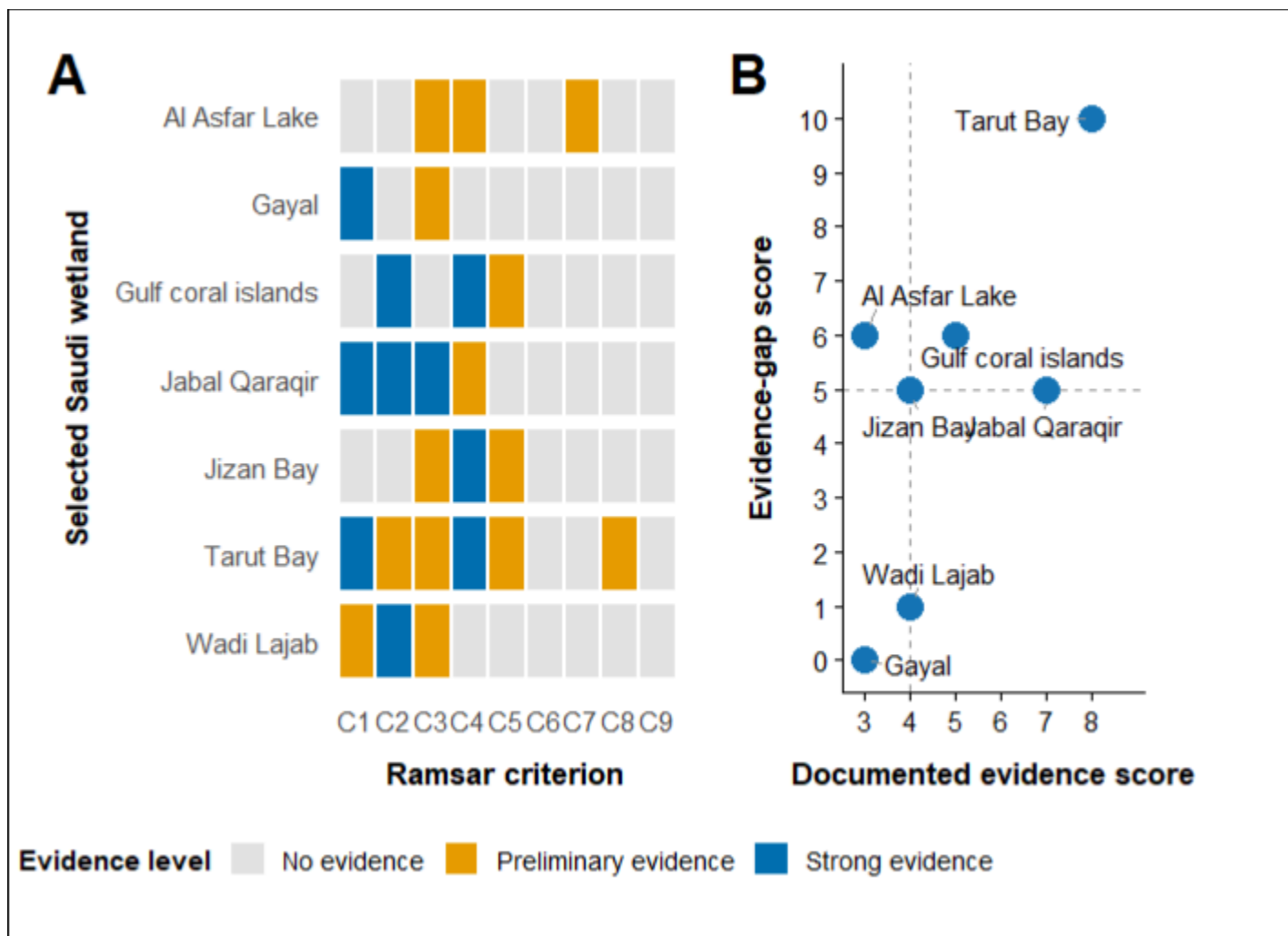


Figure 5

Evidence matrix and evidence-gap profile for selected Saudi wetlands. (A) Literature-based evidence matrix showing the level of available evidence for the selected wetlands against Ramsar Criteria 1 to 9. Grey cells indicate no documented evidence, orange cells indicate preliminary evidence, and blue cells indicate strong evidence. (B) Relationship between the documented evidence score and evidence-gap score for each wetland. Dashed lines indicate the median scores. The plot identifies sites combining substantial documentation with important remaining evidence needs.

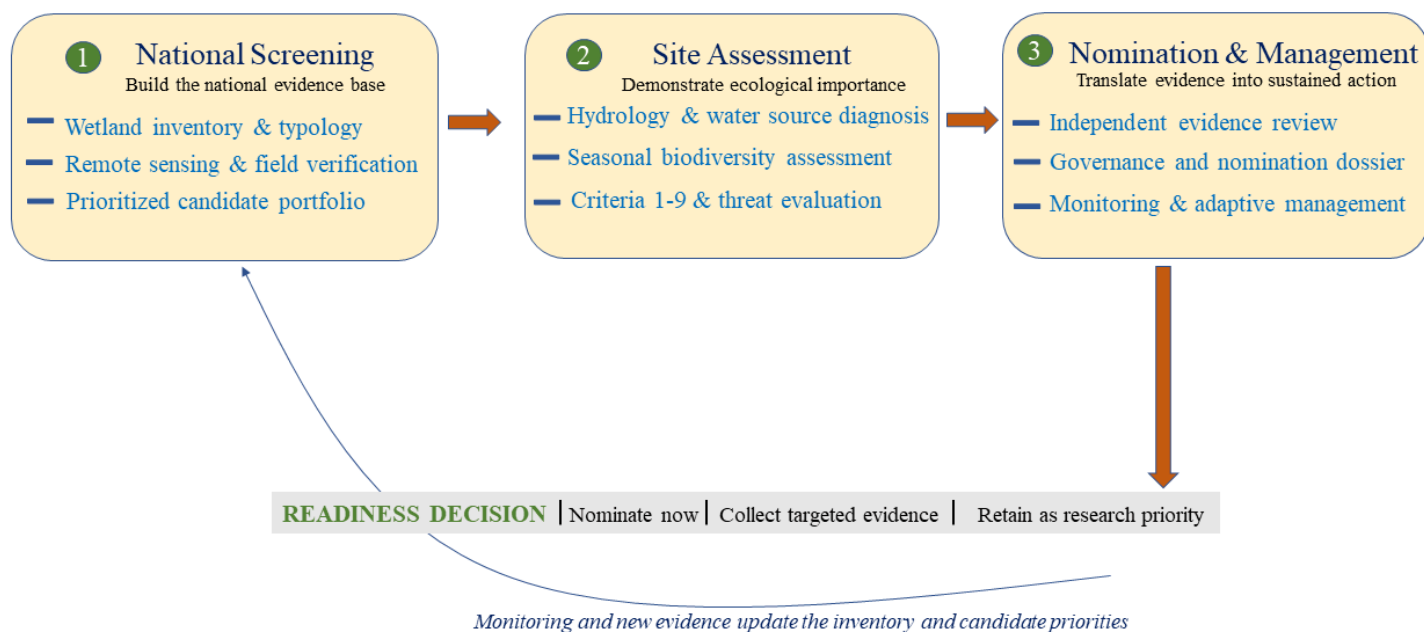


Figure 6

Adaptive evidence-to-action framework for identifying, assessing and nominating wetlands of international importance in Saudi Arabia. National screening establishes a field-validated wetland inventory and candidate portfolio; site assessment evaluates hydrological functioning, seasonal biodiversity, Ramsar criteria and threats; and the final stage integrates independent evidence review, nomination preparation, governance and adaptive management. Readiness decision distinguishes sites suitable for nomination from those requiring targeted evidence or longer-term investigation. Monitoring results and new evidence feed back into national screening and periodic reprioritization.