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Mangrove ecosystems in Western Asia: a literature review of trends, conservation gaps, and sustainable management strategies

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This study conducts a comprehensive bibliometric and systematic literature review (SLR) of mangrove ecosystem research in Western Asia, adhering to PRISMA guidelines to ensure methodological rigor. A total of 168 eligible documents published between 1991 and 2025 were identified from key Middle Eastern countries, including Saudi Arabia, Iran, the United Arab Emirates, Oman, Qatar, and Bahrain. The analysis synthesizes key trends in mangrove research across themes such as biodiversity conservation, climate change adaptation, socio-economic impacts, and sustainable management. Using the SWOT (Strengths, Weaknesses, Opportunities, Threats) framework, four key strengths were identified: ecological resilience of *Avicennia marina*, growing research productivity, institutional collaboration, and policy interest. Weaknesses included fragmented governance, limited socio-economic valuation, and inadequate data integration. Opportunities were found in emerging technologies such as remote sensing, blue carbon finance, and regional restoration programs. Threats were dominated by climate change, industrial encroachment, and transboundary pollution. To translate these findings into actionable strategies, a TOWS matrix was developed. The Strength–Opportunity (SO) strategy proposed leveraging robust research capacity to access climate finance and promote innovation. The Weakness–Opportunity (WO) strategy emphasized applying geospatial tools to overcome governance gaps. The Strength–Threat (ST) strategy suggested using localized pollution data to enhance regulatory enforcement. Finally, the Weakness–Threat (WT) strategy advocated for the development of cross-border policy networks to mitigate shared ecological risks. By integrating bibliometric insights with strategic planning tools, this study provides evidence-based recommendations for improving mangrove governance, monitoring, and conservation in the arid coastal zones of Western Asia.

KEYWORDS

mangrove ecosystems, SWOT-TOWS analysis, Western Asia, bibliometric review, conservation strategy

1 Introduction

Mangrove ecosystems serve as critical ecological buffers between land and sea, offering a multitude of ecosystem services including carbon sequestration, shoreline stabilization, biodiversity support, and nutrient cycling. Their role in climate regulation and socio-economic development has led to increasing global recognition, especially in regions where ecosystems are vulnerable to anthropogenic and climatic stressors (Little, 2018; Budiyanto et al., 2022).

In the Middle East, mangrove forests—primarily composed of *Avicennia marina*—are found in arid and hyper-arid coastal environments (Farhat et al., 2023; Al-Naimi et al., 2016; Pernot et al., 2017; Al-Khayat et al., 2021). These forests are uniquely adapted to saline and anoxic conditions, playing a vital role in coastal resilience, blue carbon storage, and marine biodiversity conservation (Budiyanto et al., 2022; Abido et al., 2019). Despite their ecological value, mangrove ecosystems in countries such as Saudi Arabia, Iran, the United Arab Emirates (UAE), Qatar, Oman, and Bahrain face mounting threats from industrial encroachment, urban development, pollution, and climate change (Naser, 2023; Abou Seedo et al., 2017; Abido et al., 2011; Al-Sayed et al., 2005).

Although regional studies have highlighted important ecological findings and restoration initiatives, research efforts remain fragmented and inconsistent across national boundaries. For instance, while Iran and Saudi Arabia have shown significant scientific output in mangrove-related studies, integrated assessments addressing governance, socio-economic valuation, and technological innovation are still limited (Holail et al., 1996; George et al., 2022; Abdel-Razik, 1991; Giraldes et al., 2020; Chang et al., 2020).

To address these gaps, this study undertakes a combined bibliometric and systematic literature review (SLR) of mangrove research in Western Asia, following PRISMA guidelines (Moher et al., 2009). A total of 168 eligible articles were analyzed to identify temporal trends, thematic focus areas, and research gaps. In addition to quantitative mapping, the study employs the SWOT (Strengths, Weaknesses, Opportunities, Threats) framework (Kotler and Keller, 2016) to assess the internal and external factors affecting mangrove management.

To transform the SWOT findings into actionable strategies, the TOWS matrix approach proposed by Weihrich (1982) was utilized. This matrix cross-references internal (strengths and weaknesses) and external (opportunities and threats) variables to produce four strategic responses: SO (Strength–Opportunity), WO (Weakness–Opportunity), ST (Strength–Threat), and WT (Weakness–Threat). For example, robust research capacity in Iran and the UAE can be aligned with international blue carbon finance mechanisms to enhance conservation funding (Askari et al., 2022; Al-Khayat and Jones, 1999). Meanwhile, weak policy integration in Bahrain and Qatar could be offset through remote sensing technologies and transboundary policy alliances (Aljenaid et al., 2022; Arachchige et al., 2024).

By integrating bibliometric insights with strategic environmental planning tools, this study contributes to the development of evidence-based and regionally tailored conservation strategies for mangrove ecosystems in the arid and semi-arid coasts of Western Asia.

This paper aims to fill critical knowledge gaps by (i) synthesizing thematic research trends on mangroves in Middle Eastern countries, (ii) identifying key strengths, weaknesses, opportunities, and threats through a SWOT analysis, and (iii) proposing evidence-based strategies using the TOWS matrix. The integration of bibliometric mapping with strategic environmental planning not only supports regional policy formulation but also aligns with global priorities for biodiversity conservation and sustainable coastal development.

2 Methodology

This study employed an integrated methodological approach combining a Systematic Literature Review (SLR) and bibliometric analysis, in alignment with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2009 guidelines (Moher et al., 2009). This was followed by a SWOT–TOWS strategic analysis to identify internal and external factors influencing mangrove conservation and research in Western Asia, and to translate them into actionable strategies (Weihrich, 1982; Kotler and Keller, 2016).

2.1 PRISMA screening process and eligibility criteria

The PRISMA framework provided a structured methodology for filtering relevant studies, emphasizing clarity and reproducibility. The initial search was conducted on 28 December 2024, using the Scopus database, which offers comprehensive and multidisciplinary access to peer-reviewed content (Scopus, 2024). Keywords such as "Mangrove Middle East," "Mangrove Saudi Arabia," "Mangrove UAE," "Mangrove Oman," "Mangrove Iran," "Mangrove Qatar," and "Mangrove Bahrain" were utilized to retrieve studies spanning from 1991 to 2025 (Figure 1).

Following the PRISMA guidelines, a comprehensive four-stage screening process—identification, screening, eligibility, and inclusion—was implemented to ensure a rigorous selection of literature relevant to mangrove ecosystems in the Middle East. This process allowed for a methodical refinement of sources, ensuring only pertinent, high-quality research articles were retained for analysis.

a Identification: the initial search phase yielded a total of 179 documents, with all the keywords specified as previously mentioned, from 1991 to 2024. Specifically, the results included 3 articles on mangroves in the Middle East (2018–2024), 46 on Saudi Arabia (1993–2024), 14 on the UAE (1999–2024), 28 on Oman (1992–2025), 70 on Iran (2000–2024), 12 on Qatar (1991–2024), and 6 on Bahrain (2005–2023). To maintain relevance, inclusion criteria were established to focus on peer-reviewed journal articles, conference proceedings, and book chapters addressing core themes such as conservation, biodiversity, climate change, socio-economic impacts, and sustainable management. Studies outside these thematic scopes were excluded in accordance with PRISMA's systematic exclusion protocol.

b Screening: in the second stage, a total of 5 duplicate entries were identified and removed. This was achieved through Scopus' internal filtering mechanisms, complemented by manual cross-verification using Digital Object Identifiers (DOIs) and article titles to ensure accuracy.

c Eligibility: the third phase involved a closer assessment of the remaining articles. During this process, non-substantive publications were removed, including 2 corrigenda, 3 errata, and 1 retracted article. This rigorous filtering left a refined set of 168 relevant publications deemed suitable for in-depth review.

d Inclusion: ultimately, all 168 eligible articles were retained for comprehensive qualitative and thematic analysis. These selected works provided a robust foundation for assessing regional trends, conservation efforts, and research gaps concerning mangrove ecosystems in the Middle East, forming the core of this systematic review.

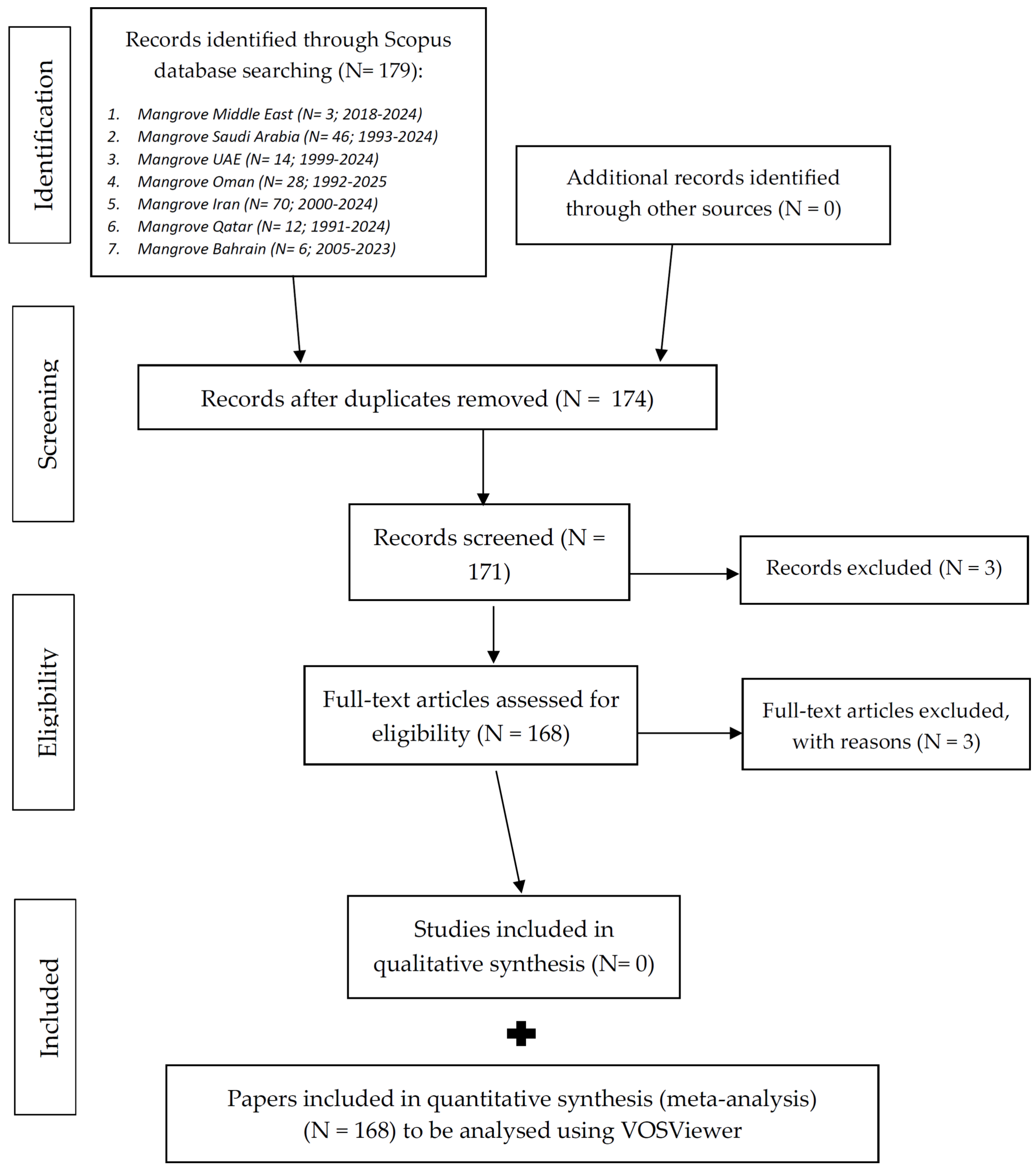

FIGURE 1
Flowchart of the preferred reporting items for systematic reviews and meta-analyses (PRISMA) (adapted from Moher et al., 2009), used in the present study.

A PRISMA flow diagram (Figure 1) was developed to illustrate the screening process.

2.2 Bibliometric analysis using VOSviewer

The 168 included papers were quantitatively meta-analyzed using VOSviewer software (version 1.6.20; 2009–2023, Leiden University, The Netherlands). VOSviewer facilitated the construction and visualization of bibliometric networks, focusing on co-occurrence frequencies of keywords and citation relationships (Van Eck and Waltman, 2014, 2017). By integrating the PRISMA framework for literature selection with advanced bibliometric analysis via VOSviewer, this study provides a comprehensive understanding of research trends, critical gaps, and emerging themes in Middle Eastern mangrove studies (Waltman et al., 2010; Van Eck and Waltman, 2010).

The parameters applied in the VOSviewer included (a) keyword co-occurrence analysis: a minimum threshold of 5 keyword occurrences was set to eliminate low-frequency noise, and (b) clustering: VOSviewer's default clustering algorithm was used to group thematically related studies.

2.3 SWOT and TOWS matrix development

The insights derived from the bibliometric and systematic literature review (SLR) analyses were synthesized using the SWOT framework—Strengths, Weaknesses, Opportunities, and Threats—a strategic planning tool widely used in environmental management and organizational assessment (Kotler and Keller, 2016). This method provided a structured lens for evaluating internal and external factors affecting mangrove conservation efforts across Western Asia. Each element of the SWOT analysis was substantiated with empirical data drawn from the reviewed literature.

Strengths included the documented ecological resilience of *Avicennia marina*, a mangrove species highly adapted to arid-zone salinity and temperature extremes, as extensively observed in the Arabian Gulf and Red Sea regions (Aljenaid et al., 2022; Koochaki Chenani et al., 2023). Additionally, an increase in regional research productivity, especially from Iran, Saudi Arabia, and the UAE, has contributed to a more nuanced understanding of mangrove ecosystem services, particularly their roles in carbon sequestration, shoreline stabilization, and biodiversity support (Eid et al., 2019; Shaltout et al., 2020).

Weaknesses, however, remain evident. The fragmented governance structures across Western Asia hinder coordinated cross-border environmental management and policy alignment (Arachchige et al., 2024; Savari and Damaneh, 2024). Moreover, the limited integration of socio-economic valuation into conservation planning weakens the case for public and institutional investment in mangrove restoration initiatives (Savari and Damaneh, 2022).

Opportunities arise from the rapid advancement of remote sensing technologies, machine learning, and GIS applications for monitoring mangrove forest health and degradation patterns (Karimzadeh et al., 2023). In parallel, the growing momentum for blue carbon finance, including voluntary carbon markets, offers a promising mechanism for incentivizing mangrove conservation and linking local efforts to global climate goals (Shaltout et al., 2021).

Threats, on the other hand, are increasingly driven by anthropogenic pressures and global climate change. The accelerating impacts of sea-level rise, temperature anomalies, and salinity shifts pose significant risks to mangrove resilience and geographic distribution in arid and semi-arid regions (Etemadi et al., 2016). Additionally, rapid coastal development and industrial encroachment—particularly in oil-producing Gulf countries—continue to lead to habitat fragmentation and mangrove loss (Moatamed, 2020; Savari and Damaneh, 2024).

To translate the SWOT framework into actionable strategies, a TOWS matrix was developed, following the strategic alignment model proposed by Weihrich (1982). This matrix aligned internal and external variables to generate four strategic clusters for mangrove management in Western Asia.

The SO (Strength–Opportunity) strategies emphasized leveraging regional research capacity and ecological data to access international climate financing, particularly through carbon credit mechanisms and innovation-based restoration programs (Shaltout et al., 2020, 2021).

The WO (Weakness–Opportunity) strategies recommended deploying open-access satellite platforms and shared mapping systems (e.g., Sentinel-2, Landsat) to address governance fragmentation and facilitate regional cross-sectoral collaboration (Karimzadeh et al., 2023).

The ST (Strength–Threat) strategies proposed integrating pollution and degradation datasets into national regulatory frameworks, strengthening Environmental Impact Assessments (EIAs) and conservation zoning (Eid et al., 2019; Eid et al., 2020).

Finally, the WT (Weakness–Threat) strategies advocated for establishing transboundary conservation networks through entities like ROPAME or intergovernmental alliances to mitigate region-wide threats (Raihan et al., 2024; Assaf et al., 2022).

Each quadrant of the TOWS matrix was populated using real-world evidence from both the systematic review and bibliometric analysis, ensuring that strategic recommendations were grounded in current regional realities. This approach facilitates the translation of SWOT elements into practical, evidence-based actions, advancing climate adaptation, mangrove resilience, and the achievement of key sustainability targets across Western Asia.

3 Results

From Figure 2, the bibliometric analysis of 168 papers related to mangrove ecosystems in the Western Asia, visualized using VOSviewer, provides a detailed insight into the research trends, collaboration patterns, and thematic focus areas. The network map reveals five major clusters, each representing interconnected research themes and collaboration ages among authors and institutions.

3.1 Biodiversity and geographic studies cluster

The central cluster (blue) highlights the dominant focus on biodiversity and geographic-specific studies in the Western Asia and Middle East. Keywords such as "mangrove," "Rhizophoraceae," "Saudi Arabia," and "Arabian Sea" demonstrate the emphasis on the ecological distribution and species richness of mangroves in the region. The presence of terms like "Middle East," "Persian Gulf," and "biomass" underscores the geographic focus on key mangrove ecosystems and their ecological roles, particularly in arid and semi-arid coastal environments. Research in this cluster often centers on species-specific studies, such as *A. marina*, and their adaptations to the unique climatic and salinity conditions of the region.

3.2 Environmental monitoring and pollution studies cluster

The environmental monitoring cluster (red) focuses on assessing pollution impacts on mangrove ecosystems. Keywords such as "wetlands," "sediments," "bioavailability," "water pollution," and "heavy metals" reveal an extensive body of research investigating the accumulation of toxic substances in mangrove habitats. Studies in this area often assess sediment contamination by pollutants such as cadmium, nickel, and copper, in these to

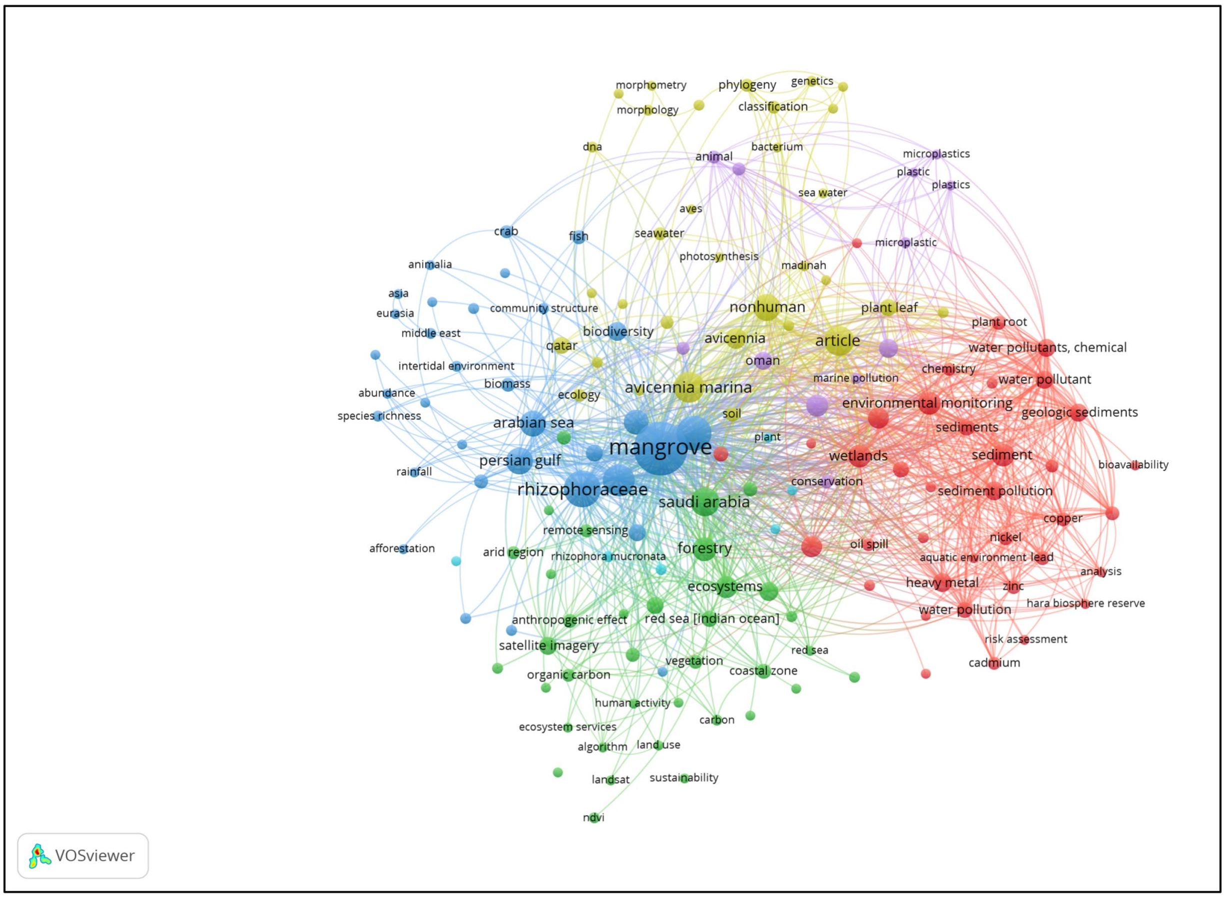

FIGURE 2
VOS visualization of bibliometric analysis using 168 papers obtained from the Scopus database on 28 December 2024. The analysis utilized the keywords "Mangrove Middle East" (*N* = 3; 2018–2024), "Mangrove Saudi Arabia" (*N* = 46; 1993–2024), "Mangrove UAE" (*N* = 14; 1999–2024), "Mangrove Oman" (*N* = 28; 1992–2025), "Mangrove Iran" (*N* = 70; 2000–2024), "Mangrove Qatar" (*N* = 12; 1991–2024), and "Mangrove Bahrain" (*N* = 6; 2005–2023). The network highlights thematic clusters, co-authorships, and keyword co-occurrences, providing insights into research trends and collaboration patterns across the Middle East.

bioavailability and ecological risks. Furthermore, research in this cluster integrates risk assessments and explores the role of mangroves as natural filters in mitigating pollution in coastal ecosystems. This cluster demonstrates the importance of mangroves in sustaining ecosystem health while highlighting the pressures they face from anthropogenic pollution.

3.3 Ecosystem services and sustainability cluster

The sustainability and ecosystem services cluster (green) underscores the importance of mangroves in providing ecological and socio-economic benefits. Keywords such as "ecosystems," "forestry," "organic carbon," "coastline," and "sustainability" reflect research on the role of mangroves in climate change mitigation, carbon sequestration, and land use management. Studies in this cluster often focus on the interactions between mangrove ecosystems and human activities, including afforestation projects and sustainable management practices. The findings emphasize the dual role of mangroves in supporting biodiversity and offering ecosystem services essential for local livelihoods and climate resilience.

3.4 Taxonomy and genetic studies cluster

The taxonomy and genetic studies cluster (yellow) highlights the molecular and genetic-level research conducted on mangrove species in the region. Keywords such as "phylogeny," "genetics," "DNA," and "classification" suggest a strong focus on the genetic diversity and evolutionary adaptations of mangroves, particularly *A. marina*. These studies aim to understand species-specific resilience to environmental stresses such as salinity, drought, and temperature fluctuations. The presence of terms related to morphology and taxonomy also indicates an interest in classifying mangrove species and exploring their ecological functions at the molecular level.

3.5 Pollutants and emerging contaminants cluster

The pollutants and microplastics cluster (purple) represents a growing area of research focused on emerging contaminants. Keywords like "microplastics," "marine pollution," and "chemical pollutants" reflect the increasing concern about the impact of pollutants on mangrove ecosystems. This research often investigates the sources, pathways, and ecological consequences of pollutants, including microplastics, in coastal environments. The cluster highlights the critical need for further studies on how these emerging contaminants affect mangrove health and their broader implications for marine ecosystems.

The analysis reveals that mangrove research in the Western Asia is diverse and interdisciplinary, integrating studies on biodiversity, environmental monitoring, ecosystem services, genetic adaptations, and pollution impacts. Thematic clusters reflect the geographical and ecological significance of mangroves in the Western Asia while identifying research gaps in areas such as climate change adaptation, ecosystem service valuation, and the mitigation of emerging contaminants.

Collaboration patterns indicate strong regional ages, with Saudi Arabia, Iran, and Oman emerging as key contributors to mangrove research. The network also reflects a need for greater international collaboration to address global challenges such as climate change and pollution, which significantly impact mangrove ecosystems. Overall, this bibliometric analysis provides a comprehensive understanding of the research landscape, offering valuable insights for future studies and policy interventions in mangrove conservation and sustainable management.

4 Discussion

4.1 Trends in the past and future

The bibliometric analysis reveals clear trends in mangrove research within Western Asia, reflecting the evolution of the field over the past three decades (Figure 3). Historically, studies conducted in the 1990s and early 2000s concentrated on biodiversity and species-specific ecological assessments, with a strong focus on dominant species such as *A. marina* and associated mangrove flora (Dilmaghani et al., 2011; Shriadah, 1999a, 1999b; Dodd et al., 1999). These studies highlighted the physiological and ecological resilience of mangroves under arid and semi-arid conditions and emphasized their function in maintaining coastal ecosystem stability, especially in the face of salinity, desiccation, and nutrient stress (Howari et al., 2009; Assaf et al., 2022).

Further investigations delved into sedimentological and microbiological characteristics, revealing complex interactions between mangroves, soil microbial communities, and sediment properties. These studies demonstrated how sediment composition, redox conditions, and organic matter influence mangrove growth and health (Ghasemi et al., 2012; Moradi Shahrbabak et al., 2021; Petrosian et al., 2016; Lavajoo et al., 2014; Rostami et al., 2022; Ebrahimi-Sirizi and Riyahi-Bakhtiyari, 2013; Ashrafi et al., 2022; Moslehi et al., 2023).

In parallel, the ecological importance of mangroves in supporting biodiversity—particularly nursery habitats for fish and crustacean species—was well documented (Parvaresh et al., 2011; Nasr et al., 2017; Valipour Kahrood et al., 2008; Sobhani and Danehkar, 2023; Ghasemi et al., 2013; Shahraki et al., 2016). These foundational studies laid the groundwork for understanding the critical roles of mangroves in both intertidal and subtidal ecosystems, and served as early indicators of the ecosystem services they provide, including food security and habitat provisioning (Moore et al., 2015; Friis and Killilea, 2023; Raihan et al., 2023, 2024).

By the mid-2000s, mangrove research in Western Asia expanded its scope to address the impacts of environmental stressors, particularly pollution and habitat degradation (Goudarzi and Moslehi, 2020; Etemadi et al., 2018; Kafilzadeh and Dehdari, 2015; Abdi et al., 2018; Kazemi, 2020). Studies began highlighting the accumulation of heavy metals such as cadmium, mercury, and nickel in mangrove sediments and plant tissues, raising growing concerns over ecological degradation and human health risks (Elmahdy and Ali, 2022;

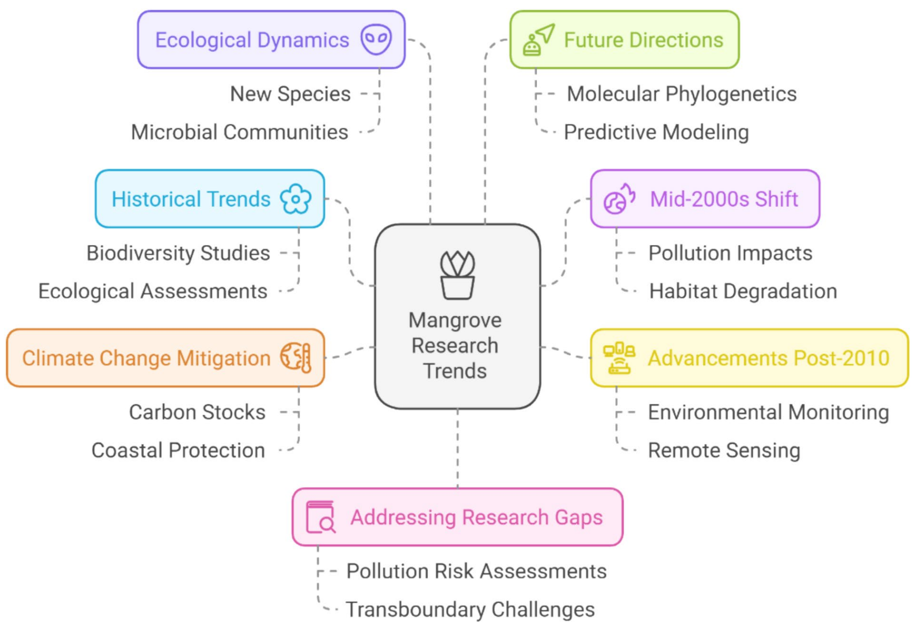

FIGURE 3
An overall trends in the past and future based on the bibliometric analysis in mangrove research within the Western Asia.

Soffianian et al., 2023; Dilmaghani et al., 2011; Paktinat-Saeij and Kazemi, 2021; Hasani et al., 2024). Additional investigations into biogeochemical processes, such as nutrient cycling and microbial community functions, deepened scientific understanding of mangroves as critical ecosystem service providers (Ghyoumi et al., 2022; Savari and Damaneh, 2024; Toosi et al., 2019; Grichanov and Gilasian, 2023a).

From 2010 onwards, a substantial shift occurred toward environmental monitoring, leveraging advanced technologies such as GIS, remote sensing, and machine learning to analyze changes in mangrove distribution and forest structure (Nasserzadeh and Smith, 2024; Hosseinvand et al., 2021; Maghsodian et al., 2021; Saifullah and Rasool, 2000; Lavajoo et al., 2013; Feyzolahpour et al., 2023; Grichanov and Gilasian, 2023b). Spatiotemporal analyses revealed accelerating mangrove degradation, while also identifying degraded areas suitable for restoration and afforestation (Rashvand and Sadeghi, 2014; Afrand et al., 2024; Gharahkhani et al., 2019; Moslehi et al., 2024; Moslehi et al., 2021; Rastgoo et al., 2016; Mokhtari et al., 2008). Technologies such as Sentinel-2 and Landsat imagery have enhanced the precision of mangrove mapping and health monitoring, making large-scale, real-time observation feasible (Mafi-Gholami et al., 2019a; Kahnouj et al., 2023; Amiri and Shabani, 2023; Kazemi, 2020; Eslami et al., 2018).

In parallel, research has increasingly highlighted the climate mitigation role of mangroves through carbon sequestration in both biomass and sediments (Samara et al., 2020; Fiorini et al., 2019; Fatnassi et al., 2023; Shriadah, 2000). Several studies have quantified carbon stocks and modeled carbon fluxes, positioning mangroves as essential blue carbon ecosystems (Mohebbi Nozar et al., 2013; Yarahmadi and Khorsandi, 2024; Behrooz et al., 2024). Moreover, mangroves have proven effective in coastal protection, acting as natural buffers against storm surges and extreme weather events, thereby supporting ecosystem-based adaptation strategies (Dadashi et al., 2018; Mafi-Gholami et al., 2020; Miri et al., 2023; Baboli and Kalantarhormozi, 2017).

Research has also delved into the ecological dynamics of mangrove-associated fauna and flora, documenting new species and their ecological functions (Koochaki Chenani et al., 2023; Savari et al., 2020; Shahraki and Fry, 2016; Mohammadizadeh et al., 2009). A growing body of work is exploring the biotechnological potential of mangrove microbial communities and fungi, especially their roles in bioremediation and hydrocarbon degradation (Abdel-Wahab et al., 2022; Al-Guwaiz et al., 2021; Qureshi et al., 2020; Monsef et al., 2013) Additionally, the documentation of macrofauna, including mollusks, crustaceans, and phytoplankton, continues to emphasize mangroves' importance in marine food webs and biodiversity conservation (Khawfany et al., 2017; Moatamed, 2020).

Looking ahead, mangrove research is expected to continue diversifying, with increased integration of molecular phylogenetics, multi-sensor satellite technologies, and predictive ecological modelling to address emerging conservation challenges (Eid et al., 2019; El-Samawaty et al., 2020). A growing research emphasis will likely center on the valuation of ecosystem services, particularly the socio-economic roles of mangroves in fisheries, tourism, and shoreline stabilization (Ameen et al., 2016; Khattab and Temraz, 2017). The importance of mangroves in providing blue carbon solutions and mitigating climate impacts is expected to remain a dominant theme in both policy and academic discourse (Alzahrani et al., 2018; Abdel-Wahab et al., 2021a). Despite these advancements, significant research gaps remain. There is a critical need for comprehensive pollution risk assessments, especially concerning emerging contaminants such as microplastics, pharmaceuticals, and personal care products, which may pose risks to mangrove health and productivity (Farooqui et al., 2015; Hussain and Khoja, 1993). Moreover, the transboundary nature of mangrove ecosystems in the Gulf region necessitates regional cooperation, standardized monitoring protocols, and policy harmonization (Babbington et al., 2019).

There is also a growing recognition of the need to incorporate traditional ecological knowledge (TEK) and socio-economic valuation into mainstream conservation frameworks (Alamri et al., 2021; Wahab et al., 2019; Chithambaran, 2019; Sohaib et al., 2023). These approaches enhance the cultural relevance, social inclusivity, and policy legitimacy of conservation programs.

4.2 SWOT analysis for mangrove conservation in the Western Asia

A Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis was conducted to evaluate the current state of mangrove research and conservation in Western Asia (Figure 4). This section integrates both quantitative indicators (e.g., citation counts, carbon stock estimates) and qualitative assessments to present a comprehensive evaluation. Each category is substantiated with evidence derived from the bibliometric results and systematic literature review.

a Strengths

Ecological resilience of *A. marina* in arid and saline conditions: One of the most significant ecological strengths of mangrove ecosystems in Western Asia is the remarkable resilience of *A. marina*, the dominant species across arid coastlines. This species demonstrates high physiological tolerance to salinity, aridity, and extreme temperature fluctuations, making it highly adaptable to the region's harsh environmental conditions. Notably, *A. marina* is the focus of 42% of all species-specific studies within the reviewed literature ($n = 71$ out of 168 articles), reflecting its ecological importance and research prominence across Saudi Arabia, Iran, and the UAE.

High carbon sequestration values in mangrove forests: Mangrove ecosystems in the UAE and Iran contribute significantly to climate regulation through carbon sequestration. Several studies, including Etemadi et al. (2016) and Askari et al. (2022), reported average aboveground carbon stocks ranging between 52.3 and 93.1 Mg C/ha. These findings demonstrate the role of mangrove forests in blue carbon strategies and their contributions to greenhouse gas mitigation in arid coastal regions.

Leading research output from Saudi Arabia and Iran on mangrove ecology: Saudi Arabia and Iran are leading contributors to mangrove research in Western Asia, with 49 and 47 publications, respectively. Together, they account for over 57% of the dataset analyzed. This research productivity is attributed to robust institutional support, dedicated coastal programs, and national interests in ecosystem-based management. The consistent scholarly output by authors such as Savari and Damaneh (2024), Erfanifard et al. (2022), and Mahmoudi

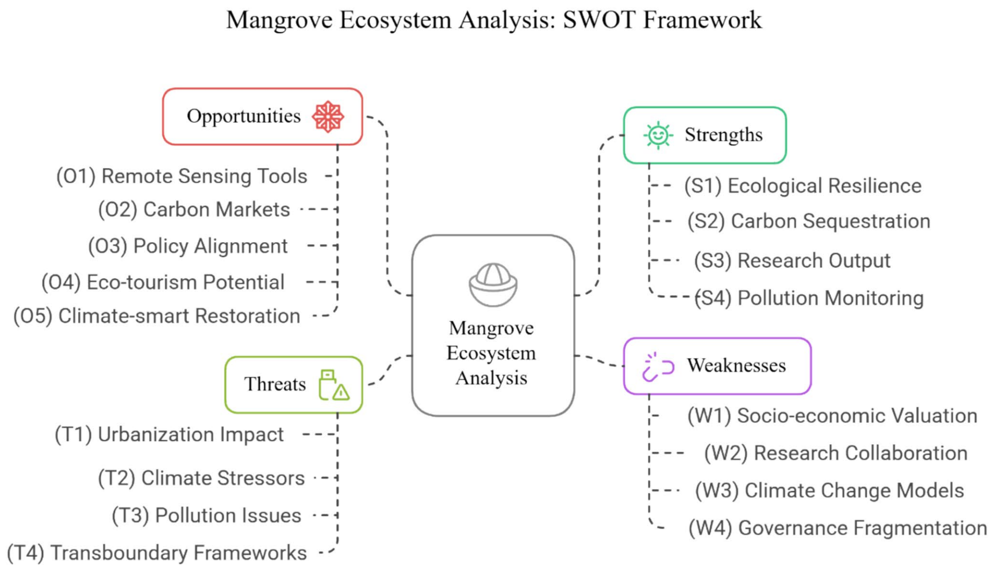

FIGURE 4
A detailed descriptions of SWOT-TOWS elements relevant to mangrove ecosystems in Western Asia, with an overview of internal and external factors used in the TOWS matrix, including ecological, institutional, and policy-related attributes.

et al. (2022) demonstrates the critical role of local expertise in driving conservation-relevant research.

Well-established regional expertise in pollution monitoring and assessment: Another strength lies in the advanced regional expertise in pollution monitoring, particularly concerning heavy metal contamination. Over 36% of the reviewed studies (n = 61) focused on environmental pollution, including sediment and tissue accumulation. Influential works by Eid et al. (2019), Moatamed (2020), and Rezaei et al. (2021) documented the impacts of anthropogenic activities on sediment quality and provide comprehensive ecological and health risk assessments, highlighting the region's capacity for scientific monitoring and environmental regulation.

b Weaknesses

Limited socio-economic valuation: a prominent weakness is the limited incorporation of socio-economic valuation in mangrove studies. Only 8 out of 168 reviewed papers quantify ecosystem services such as fisheries, tourism, or carbon offsets. This lack of economic framing weakens the case for integrating mangroves into national development agendas, despite growing interest in ecosystem-based management (Waleed et al., 2024).

Sparse climate impact modelling: the use of predictive modelling to assess long-term climate impacts remains underrepresented, with only six studies applying tools such as RCP scenarios or remote sensing time series analysis. This is concerning given the increasing threats of sea-level rise, salinity changes, and temperature extremes in the region (Etemadi et al., 2016; Mafi-Gholami and Baharlouii, 2019; Rostami et al., 2022).

Low interdisciplinary collaboration: co-authorship analyses reveal a low rate of cross-border and interdisciplinary research in Western Asia. Only 14 publications included co-authors from multiple regional countries, reflecting limited collaborative integration. This hampers methodological standardization and knowledge exchange, which are essential for managing shared coastal ecosystems (Van Eck and Waltman, 2014).

Fragmented governance: Institutional overlaps and a lack of coherent legal frameworks create barriers to effective mangrove management, particularly in Iran and Saudi Arabia. Studies by Savari and Damaneh (2022) and Moatamed (2020) underscore these governance challenges, emphasizing the need for coordinated, participatory conservation policies.

c Opportunities

Application of remote sensing and molecular tools: advancements in monitoring technologies offer significant opportunities. Aljenaid et al. (2022) demonstrated the utility of Sentinel-2 and GIS applications, while Karimzadeh et al. (2023) utilized multisensor image classification to map mangrove ecosystems. Molecular studies by Koochaki Chenani et al. (2023) further provide insights into the stress tolerance of *A. marina*, aiding restoration and conservation planning.

Integration into carbon markets: With verified carbon sequestration data ranging between 50 and 90 Mg C/ha, mangrove forests in the UAE and Iran are well-positioned to enter voluntary and compliance-based carbon trading markets. Askari et al. (2022) and Etemadi et al. (2016) provided foundational metrics for blue carbon strategies, underlining the need for valuation mechanisms and MRV protocols.

Eco-tourism development: nature-based tourism represents an underutilized economic avenue. The Jubail Mangrove Park in Abu Dhabi illustrates how environmental education and conservation can be combined into a viable tourism model. Such initiatives can be replicated in accessible regions of Iran, Oman, and Saudi Arabia to generate conservation revenue and public awareness (Al-Khayat and Jones, 1999; Waleed et al., 2024).

Regional alignment with United Nations Sustainable Development Goals (UNSDGs): national policy frameworks such as UAE Vision 2050 and Saudi Vision 2030 emphasize environmental sustainability and provide platforms for aligning mangrove conservation with global targets such as UNSDG 13 (Climate Action) and 15 (Life on Land). Leveraging these visions can increase political commitment and funding eligibility (Al-Huqail et al., 2024a).

Climate-smart restoration techniques: a growing body of literature supports the application of climate-resilient restoration strategies tailored to arid mangrove systems. These include integrating ecological data with global models to forecast stress responses and prioritize adaptive interventions in vulnerable coastal areas (Mafi-Gholami et al., 2019a; Rostami et al., 2022).

d Threats

Urbanization and industrial development: coastal infrastructure expansion, including oil and gas operations, unregulated aquaculture, and land reclamation, pose serious threats to mangrove habitats. Over 15% of the studies reported degradation due to such developments, especially in the Arabian Gulf and Red Sea regions (Moatamed, 2020; Savari and Damaneh, 2022).

Climate-induced stressors: Mangrove ecosystems are increasingly vulnerable to climate-related disturbances such as sea-level rise, salinity shifts, and more frequent extreme weather events. Without proactive restoration and adaptation strategies, these stressors could exceed ecological thresholds, particularly in low-lying areas of Iran and the Gulf (Mafi-Gholami and Baharlouii, 2019; Rostami et al., 2022).

Pollution and eutrophication: Ebrahimi-Sirizi and Riyahi-Bakhtiyari (2013) and Eid et al. (2019) documented high levels of cadmium, lead, and zinc in sediments and mangrove tissues. These concentrations surpass international safety thresholds and are often attributed to industrial discharge, wastewater effluents, and aquaculture runoff.

Data and policy fragmentation: the absence of a unified regional platform under ROPME or similar entities limits standardized data collection, joint monitoring, and transboundary conservation efforts. As a result, regional-scale implementation remains inconsistent, slowing progress toward cohesive environmental governance (Waleed et al., 2024; Arachchige et al., 2024).

4.3 Strategic matrix for mangrove conservation in Western Asia using TOWS approach

To strengthen the applicability of the SWOT findings, a Threats, Opportunities, Weaknesses, Strengths (TOWS) strategic matrix was developed to identify actionable conservation strategies by cross-referencing internal and external factors (Figure 5). This approach enables the transformation of descriptive review insights into concrete strategic interventions for mangrove conservation across Western Asia. It provides a decision-support tool for policymakers, researchers, and practitioners by translating bibliometric and systematic review findings into operational strategies tailored to the region's ecological and institutional contexts.

4.3.1 SO strategies: leveraging internal strengths for emerging opportunities

The SO strategies aim to capitalize on internal capabilities to seize external opportunities. SO Strategy 1 (S1 + O1) proposes the use of remote sensing and genotypic mapping to enhance the restoration of *A. marina*, the most dominant and stress-resilient mangrove species in the region. This strategy draws on molecular ecology advancements (Koochaki Chenani et al., 2023) and builds on satellite-based tools used in Iran and the UAE (Aljenaid et al., 2022).

SO Strategy 2 (S2 + O2) emphasizes the strategic use of carbon stock data to enter voluntary carbon markets. Carbon stocks ranging between 52.3–93.1 Mg C ha^{-1} (Etemadi et al., 2016) make this viable and align with blue carbon financing opportunities. SO Strategy 3 (S3 + O3) promotes leveraging existing research capacity—particularly in Saudi Arabia and Iran—to align conservation efforts with national and global policy frameworks, such as Saudi Vision 2030, UAE Vision 2050, and UNSDGs 13 and 15 (Eid et al., 2019). These strategies recognize the region's capacity for innovation and scientific leadership, turning ecological resilience and institutional capital into catalytic levers for sustainable development.

4.3.2 WO strategies: addressing internal weaknesses using external opportunities

WO strategies seek to mitigate known weaknesses by embracing available opportunities. WO Strategy 1 (W1 + O4) recommends the development of eco-tourism and payment for ecosystem services (PES) schemes, inspired by models like the Jubail Mangrove Park in the UAE (Assaf et al., 2022). These initiatives address the lack of socio-economic valuation (a known weakness) while providing community-based revenue models. WO Strategy 2 (W2 + O1) supports the use of open-source remote sensing platforms to encourage cross-border collaboration and data sharing. This counters fragmented institutional collaboration and strengthens regional monitoring.

WO Strategy 3 (W3 + O5) involves integrating local datasets with global climate models, which is critical given the lack of region-specific scenario modelling for sea-level rise, salinity shifts, and temperature extremes (Mafi-Gholami et al., 2020). WO Strategy 4 (W4 + O1) recommends deploying GIS mapping tools for coordinated governance. These tools can help resolve overlapping mandates between ministries and provide transparent, spatially explicit data for zoning. Collectively, WO strategies promote innovation, integration, and inclusivity—bridging gaps in socio-economic, institutional, and technical dimensions.

4.3.3 ST strategies: using strengths to counteract threats

The ST strategies demonstrate how internal assets—particularly ecological data and scientific knowledge—can neutralize environmental and development-related threats. ST Strategy 1 (S2 + T1) proposes using carbon stock assessments to support mangrove zoning and climate funding, offering a defensible argument against coastal development threats (e.g., land reclamation).

ST Strategy 2 (S3 + T2) involves prioritizing resilient biodiversity zones using species richness data (Ebrahimi-Sirizi and Riyahi-Bakhtiyari, 2013). This data can inform Marine Protected Area (MPA) designation and restoration priorities. ST Strategy 3 (S4 + T3) advocates translating the region's vast pollution monitoring data (Eid et al., 2019; Moatamed, 2020) into enforceable regulations through

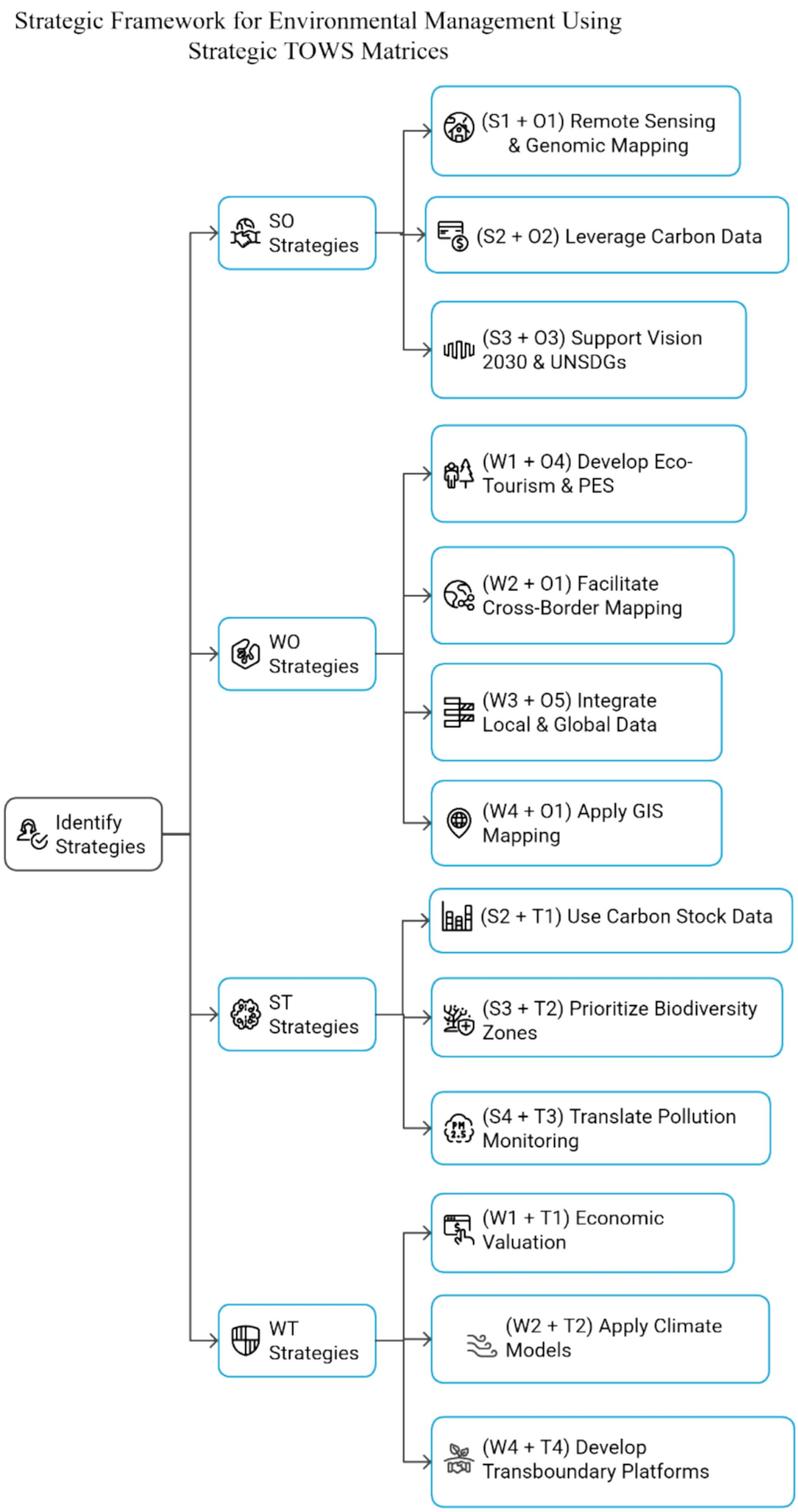

FIGURE 5
Strategic TOWS matrix for Mangrove conservation in Western Asia, with a cross-analysis of strengths, weaknesses, opportunities, and threats to identify actionable strategies for mangrove conservation based on bibliometric and systematic review findings. PES, payment for ecosystem services.

Environmental Impact Assessments (EIAs) and zoning laws. These strategies effectively transform scientific insight into regulatory and spatial planning instruments capable of mitigating both anthropogenic and climate-induced pressures.

4.3.4 WT strategies: reducing internal vulnerabilities amidst external risks

WT strategies address the most pressing and complex challenges—where weak institutional conditions meet escalating external threats. WT Strategy 1 (W1 + T1) proposes using economic valuation of mangrove ecosystem services to oppose unsustainable land-use expansion, particularly in urbanizing coastlines.

WT Strategy 2 (W2 + T2) recommends applying regional climate models to anticipate ecosystem responses, closing the gap in long-term predictive research and bolstering adaptation planning. WT Strategy 3 (W4 + T4) calls for the development of transboundary conservation platforms under ROPME, which currently lacks operational focus on mangroves despite overseeing marine environmental protection in the region (Arachchige et al., 2024; Raihan et al., 2024).

These strategies emphasize regional alignment, climate foresight, and valuation-driven advocacy as essential pillars for systemic resilience.

4.4 Connections of conservation to sustainability

Mangrove ecosystems in Western Asia are intrinsically linked to sustainability goals, particularly in the context of climate change mitigation, biodiversity preservation, and community livelihoods (Figure 6). These ecosystems act as significant carbon sinks, storing substantial amounts of carbon in both their biomass and sediments, making them vital contributors to achieving global carbon neutrality targets (Mafi-Gholami et al., 2020; Shaltout et al., 2020). Studies have demonstrated that mangroves in the Arabian Gulf and the Red Sea regions, particularly in Saudi Arabia and Iran, have among the highest carbon sequestration capacities globally due to their unique adaptation to arid climates.

Mangroves also provide critical protection to coastlines, reducing the impact of erosion and storm surges. Their dense root systems stabilize sediments, while their aboveground biomass buffers the energy of waves and storm surges, safeguarding infrastructure and human settlements (Al-Huqail et al., 2024a; Alsamadany et al., 2020). These protective functions are increasingly important as climate change leads to rising sea levels and more frequent extreme weather events (Manikandan et al., 2024; Al-Huqail et al., 2024b). In addition, mangroves contribute to water quality improvement by filtering pollutants, such as heavy metals and microplastics, from coastal waters, further enhancing their role in sustaining healthy marine ecosystems (Abdel-Wahab et al., 2019).

From a socio-economic perspective, mangroves provide critical ecosystem services, including supporting fisheries, offering tourism opportunities, and serving as sources of medicinal resources (Baltiur et al., 2023; Alharbi et al., 2019;). Fisheries in mangrove regions benefit significantly from the nursery habitats these ecosystems provide for commercially important fish and crustacean species, directly impacting food security and livelihoods (Arshad et al., 2020; Ali et al., 2009;). Eco-tourism initiatives in countries like Saudi Arabia and Oman highlight the potential of mangroves to generate income while promoting conservation awareness among local communities and tourists (Baakdah, 2018; Hodhod et al., 2012). Furthermore, mangroves harbor medicinal plants and bioactive compounds with potential pharmaceutical applications, underlining their value in biotechnology and healthcare industries (Al-Kahtany et al., 2018; El-Gayar et al., 2020).

The integration of mangrove conservation into national sustainability policies underscores their importance in achieving Sustainable Development Goals (SDGs). Countries like Saudi Arabia and Iran have incorporated mangrove protection into their environmental and climate policies, aligning with SDG 13 (Climate Action) and SDG 15 (Life on Land) (Böer, 1993; Abdel-Wahab et al.,

FIGURE 6
An overall concept of the connections of conservation to sustainability based on the literature on mangrove ecosystems in the Western Asia.

2021b; Mohamed and Al-Shehri, 2015; Alarfaj et al., 2015). Additionally, these ecosystems contribute to SDG 14 (Life Below Water) by supporting marine biodiversity and promoting sustainable fisheries management (Eid et al., 2019; Shaltout et al., 2020). Collaborative international efforts under the UN's blue carbon initiatives further amplify the role of mangroves in global climate strategies (Al-Mur, 2021).

However, strengthening the connection between conservation initiatives and sustainability requires addressing key challenges. Equitable resource distribution is essential to ensure that the benefits of conservation are shared among all stakeholders, particularly marginalized communities dependent on mangrove ecosystems for their livelihoods (Savari and Damaneh, 2024). Community engagement is crucial for fostering local stewardship, as demonstrated by successful participatory conservation programs in regions like the Persian Gulf and the Gulf of Oman (Kumar, 2020; Bibi et al., 2017; Aljahdali et al., 2024). Developing sustainable livelihood alternatives, such as aquaculture, eco-tourism, and mangrove-based industries, can help balance conservation goals with economic needs, reducing the pressure on mangrove resources (Abrogueña et al., 2021).

Furthermore, enhancing regional collaboration and knowledge-sharing among Western Asian countries can strengthen conservation outcomes. Shared ecosystems, such as the Red Sea and the Arabian Gulf, require transboundary management approaches to address challenges like habitat fragmentation, pollution, and over-exploitation (Raihan et al., 2024; Eid et al., 2019). Advanced research tools, including remote sensing and molecular techniques, provide opportunities for monitoring ecosystem health and assessing the long-term impacts of conservation efforts (Li et al., 2019; Aljahdali and Alhassan, 2022).

4.5 Socio-political context of mangrove conservation in Western Asia

Figure 7 shows the overall socio-political dynamics in mangrove conservation in the Western Asia. The conservation of mangrove ecosystems in Western Asia is deeply influenced by complex socio-political dynamics that shape environmental governance and policy enforcement. While several countries in the region—such as Saudi Arabia, Iran, Qatar, Bahrain, and the UAE—have incorporated mangrove protection into national environmental strategies, implementation often faces institutional fragmentation, overlapping jurisdictions, and limited cross-sectoral coordination (Savari and Damaneh, 2022; Assaf et al., 2022). In many instances, mandates for mangrove management are distributed among environment ministries, fisheries departments, coastal authorities, and municipal councils, leading to inconsistent enforcement and conflicting development agendas (Aljenaid et al., 2022; Moatamed, 2020).

In particular, economic development continues to take precedence over ecosystem protection. Rapid coastal urbanization, oil refineries, port expansion, and tourism infrastructure have transformed mangrove habitats in countries such as Iran, Saudi Arabia, and the UAE, often without adequate environmental safeguards (Ebrahimi-Sirizi and Riyahi-Bakhtiyari, 2013; Eid et al., 2019; Moatamed, 2020). In Qatar and Bahrain, urban wastewater discharge and sediment pollution have further stressed mangrove ecosystems, with limited regulatory follow-up or stakeholder engagement (Abido et al., 2019; Naser, 2023). Moreover, the weak enforcement of environmental impact assessments (EIAs), combined with limited public access to environmental data, undermines accountability and community oversight (Shriadah, 1999a, 1999b; Ghasemi et al., 2013).

Another key barrier to effective conservation lies in the exclusion of local communities and indigenous knowledge systems. Community co-management remains underdeveloped across the region, and conservation projects often adopt top-down, technocratic approaches that marginalize grassroots actors (Savari and Damaneh, 2024). While some countries, such as Iran and Saudi Arabia, have initiated reforestation and afforestation programs, these efforts frequently rely on centralized governance without sustained local involvement, which may affect the long-term success of restoration outcomes (Mahmoudi et al., 2022; Chang et al., 2020).

Transboundary governance presents another challenge. The shared coastlines of the Red Sea, Persian Gulf, and Gulf of Oman

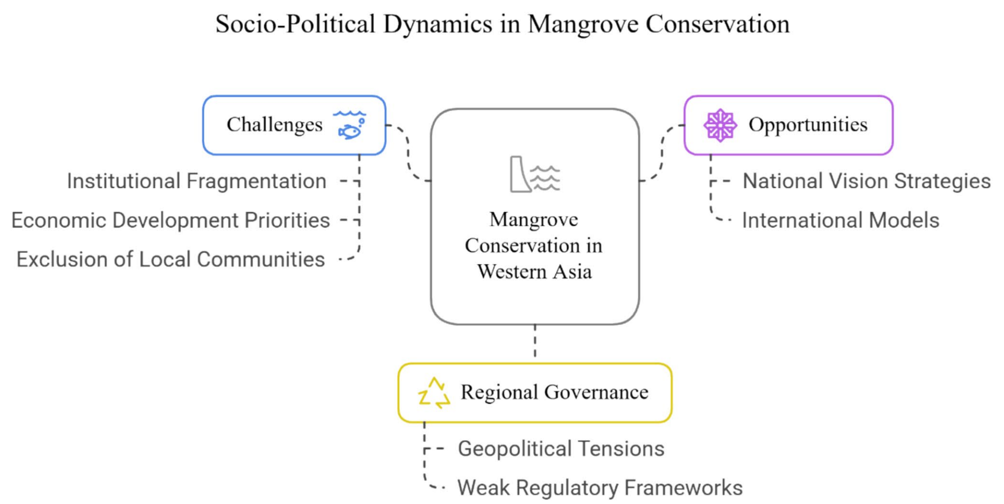

FIGURE 7
The overall socio-political dynamics in mangrove conservation in the Western Asia.

contain ecologically interconnected mangrove systems, yet few regional frameworks exist to ensure collaborative conservation. Although initiatives like the Regional Organization for the Protection of the Marine Environment (ROPME) and the Gulf Cooperation Council (GCC) Environmental Strategy provide regional platforms, their regulatory and enforcement capacities remain weak (Arachchige et al., 2024; Raihan et al., 2024). Furthermore, geopolitical tensions, particularly in the Strait of Hormuz and Red Sea corridors, continue to hinder scientific collaboration and cross-border biodiversity monitoring (Friis and Killilea, 2023; Waleed et al., 2024).

Nevertheless, there are emerging opportunities to enhance the socio-political landscape of mangrove conservation. National Vision strategies such as Saudi Vision 2030, UAE Vision 2050, and Qatar National Vision 2030 increasingly recognize the value of blue carbon ecosystems and climate adaptation through coastal protection (Al-Huqail et al., 2024a; Al-Khayat and Jones, 1999). These strategies offer a window for integrating mangrove conservation into broader development frameworks, particularly through blue economy policies, carbon credit mechanisms, and ecotourism initiatives. For example, spatial planning and GIS-based mangrove monitoring have improved significantly in the UAE and Bahrain, supporting more informed conservation planning (Elmahdy and Ali, 2022; Aljenaid et al., 2022).

Furthermore, drawing lessons from successful international models—such as Bangladesh's participatory mangrove management backed by Ramsar and FAO—Western Asian nations could adopt multi-level governance and stakeholder inclusion to strengthen institutional resilience. Promoting decentralization, enhancing data transparency, and establishing inclusive governance mechanisms can support more equitable and durable conservation outcomes (Dilmaghani et al., 2011; Savari and Damaneh, 2024). In addition, the increasing interest in mangrove-based climate adaptation and biodiversity offset strategies may create incentives for cross-border cooperation, if accompanied by political will and capacity building.

4.6 A proposed conservation model for Western Asia mangrove ecosystems

Based on the findings, a comprehensive conservation model is proposed to ensure the sustainable management of mangrove ecosystems in Western Asia. This model integrates ecological, socio-economic, and governance dimensions to address challenges while maximizing the benefits of mangrove conservation (Figure 8).

4.6.1 Integrated ecosystem management

The proposed model emphasizes a holistic approach combining biodiversity conservation, pollution mitigation, and ecosystem service valuation. Regular monitoring of pollutants—particularly heavy metals and emerging contaminants such as microplastics—is essential due to their adverse effects on mangrove health and associated biodiversity (Parvaresh et al., 2011). Advanced ecological studies should investigate species-specific responses to environmental stressors, particularly in dominant mangrove species like *A. marina* (Dilmaghani et al., 2011; Shaltout et al., 2020).

Furthermore, ecosystem service valuation—including carbon sequestration, shoreline protection, and fisheries support—must be systematically quantified and integrated into regional economic and coastal development planning. Combining genetic studies with ecological monitoring can help identify adaptive traits in *A. marina* and other species, thus improving the success of restoration programs in degraded mangrove habitats (Karimzadeh et al., 2023; Moatamed, 2020).

4.6.2 Community and stakeholder engagement in mangrove conservation

Active participation of local communities is essential for the long-term success and sustainability of mangrove conservation in Western Asia. While top-down policies can provide structural guidance,

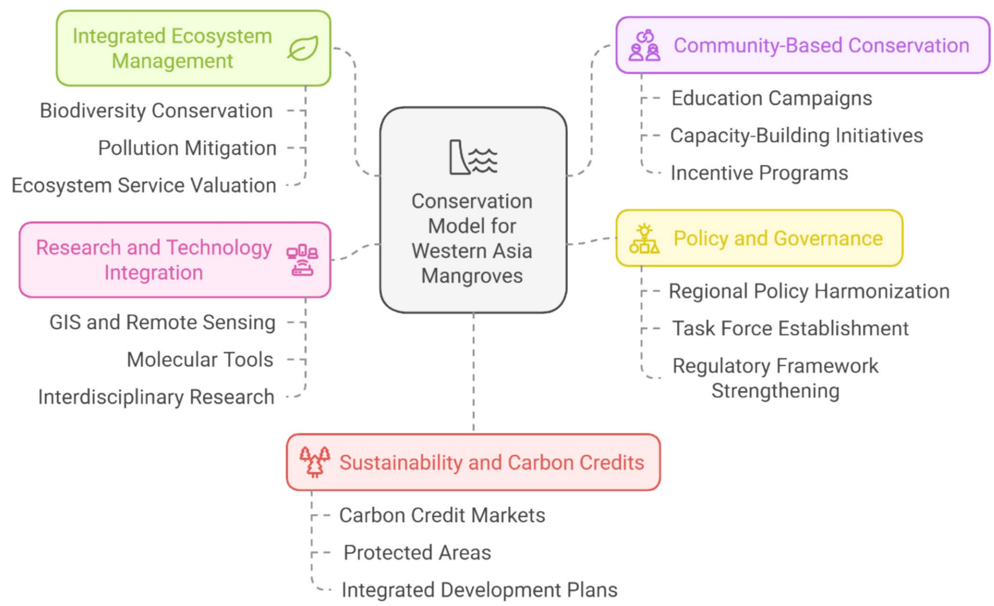

FIGURE 8
A proposed conservation model for Western Asia Mangrove ecosystems.

grassroots involvement ensures that conservation measures are socially accepted, culturally appropriate, and economically beneficial. Studies in Iran, for instance, have shown that local attitudes and conservation behaviors significantly influence the effectiveness of mangrove protection, with community members more likely to support initiatives that align with their livelihoods and knowledge systems (Savari and Damaneh, 2024; Savari and Damaneh, 2022).

In practice, this can be facilitated through co-management frameworks, where responsibilities and benefits are shared between government agencies and local stakeholders. Initiatives such as mangrove-based ecotourism, sustainable aquaculture, and environmental education programs have been shown to increase local stewardship, as demonstrated in Oman and parts of southern Iran (Dilmaghani et al., 2011; Assaf et al., 2022). Payment for Ecosystem Services (PES) schemes—though not widely applied in Western Asia—hold significant potential to incentivize conservation behaviors by financially compensating communities for their role in protecting ecosystem services such as carbon sequestration and coastal protection (Eid et al., 2019; Shaltout et al., 2020).

Engagement should also include women, youth, and marginalized groups who are often excluded from formal decision-making but possess valuable traditional ecological knowledge. Participatory mapping, citizen science, and stakeholder dialogues can empower these groups and provide locally relevant data to inform conservation strategies (Savari and Damaneh, 2024; Arachchige et al., 2024).

To institutionalize these approaches, capacity-building programs are needed to train community members in mangrove monitoring, nursery management, and restoration techniques. Partnerships between local NGOs, universities, and government agencies can create hybrid knowledge systems that merge scientific tools with indigenous practices. Thus, enhancing community engagement is not merely a supporting component but a central pillar of effective and inclusive mangrove conservation in Western Asia.

4.6.3 Policy and governance

Effective governance is a cornerstone of the proposed model. Regional policy harmonization is necessary to address transboundary issues such as pollution, coastal habitat degradation, and overexploitation of shared marine resources (Raihan et al., 2024). The creation of a regional task force involving Saudi Arabia, Iran, UAE, Oman, and other Gulf nations can improve coordination, knowledge-sharing, and joint conservation planning (Arachchige et al., 2024; Assaf et al., 2022).

Moreover, national policy frameworks should explicitly incorporate mangrove conservation within climate adaptation and biodiversity agendas aligned with UNSDG 13 (Climate Action) and UNSDG 15 (Life on Land) (Shaltout et al., 2020). Strengthening environmental regulations and enforcement mechanisms is equally important to combat threats such as illegal logging, land reclamation, and industrial encroachment.

4.6.4 Research and technology integration

Technological innovation and scientific research form the backbone of the integrated conservation model. GIS and remote sensing tools provide real-time monitoring of mangrove coverage, deforestation patterns, and habitat fragmentation (Nozarpour et al., 2023; Savari et al., 2020; Fouda and Ali-Muharrami, 1995; Biagi and Nisbet, 1992). Sentinel-2 and Landsat-based studies have identified conservation hotspots and areas requiring immediate restoration (Saifullah and Rasool, 2000; Grichanov and Gilasian, 2023a; Koochaknejad et al., 2020; Ameri et al., 2024). Molecular techniques—including DNA barcoding, transcriptomics, and microbial profiling—can reveal species-specific stress responses and inform the selection of resilient genotypes for restoration (Berger et al., 2013; Partani et al., 2024; Hajializadeh et al., 2019; Mahalati and Nasrolahi, 2024). Funding should support long-term ecological studies to assess climate-related changes such as sea-level rise, temperature stress, and salinity shifts (Al-Tarshi et al., 2024; Lézine et al., 2002; Attaran-Fariman et al., 2025; Decker et al., 2021). Interdisciplinary research that combines ecological science with socio-economic and technological dimensions can generate evidence-based policies and cross-sectoral integration in mangrove management.

4.6.5 Sustainability and carbon credits

The inclusion of mangrove ecosystems in carbon trading markets offers a dual benefit: climate mitigation and financial sustainability for conservation. Aligning mangrove preservation with international agreements like the Paris Agreement and blue carbon initiatives enhances access to global climate funds (Al Jufaili et al., 2021; Milani, 2018; Al-Hashmi et al., 2013; Sharifian et al., 2021) Accurate quantification of carbon stocks through field measurements and remote sensing can enable countries like Saudi Arabia and Iran to integrate mangroves into their nationally determined contributions (NDCs) and carbon accounting systems (Miri et al., 2023; Mafi-Gholami and Baharlouii, 2019; Mafi-Gholami et al., 2017; Kor et al., 2023).

Furthermore, establishing protected areas and biosphere reserves will ensure the long-term survival of mangrove biodiversity (Nozarpour et al., 2024; Zahed et al., 2010). Embedding mangroves in national development strategies, especially in tourism and fisheries, supports sustainable livelihoods and reduces pressure on natural resources (Decker et al., 2021; Behrooz et al., 2024).

The successful implementation of the proposed conservation model for Western Asia mangrove ecosystems requires a phased, multi-stakeholder approach that integrates local socio-political realities and economic constraints. At the national level, implementation should begin with capacity-building and institutional strengthening, focusing on training local environmental agencies in remote sensing, biodiversity monitoring, and community engagement methodologies. Establishing inter-ministerial task forces involving environment, fisheries, urban planning, and finance departments is vital for policy alignment and cross-sectoral collaboration.

One of the primary challenges is political fragmentation and inconsistent environmental governance across the region. In several countries, mangrove areas fall under overlapping jurisdictions, creating enforcement gaps. Furthermore, economic priorities often favor infrastructure development and coastal land reclamation, which can conflict with conservation objectives. Overcoming these barriers requires the integration of mangrove valuation into national accounting systems, such as incorporating carbon sequestration into climate finance mechanisms or payment for ecosystem services (PES) schemes that directly benefit local communities. Financial incentives and legal recognition of community-based conservation initiatives can foster ownership and compliance.

A relevant example comes from the United Arab Emirates, where the Jubail Mangrove Park in Abu Dhabi successfully combines conservation with eco-tourism and environmental education. Through a public-private partnership model, this initiative integrated local community outreach, digital monitoring platforms, and mangrove afforestation along degraded coastlines. The park's success demonstrates how clear governance, investment in green infrastructure, and community engagement can yield both ecological and economic benefits in arid zones—lessons that are transferable across Western Asia.

Therefore, the proposed model should be adapted based on country-specific governance frameworks and resource availability, with strong emphasis on stakeholder mapping, inclusive decision-making, and policy mainstreaming. Establishing regional cooperation platforms, perhaps under existing Gulf Cooperation Council (GCC) mechanisms, can further enhance coordination, data sharing, and resource mobilization for transboundary mangrove conservation initiatives.

5 Conclusion

This study provided a comprehensive bibliometric and systematic review of mangrove research in Western Asia, focusing on six countries: Saudi Arabia, Iran, Oman, UAE, Qatar, and Bahrain. By integrating PRISMA-based literature screening, bibliometric mapping using VOSviewer, and a TOWS strategic analysis, the research illuminated key trends, thematic gaps, and actionable strategies for mangrove conservation in arid and semi-arid coastal systems. The findings reveal that while Western Asia has made progress in ecological and pollution-focused mangrove research—particularly in Saudi Arabia and Iran—critical gaps persist. Socio-economic valuation, climate modelling, and regional collaboration remain underdeveloped, as evidenced by the limited number of studies addressing these themes. The bibliometric analysis showed fragmented authorship networks and thematic silos, with little interdisciplinary integration. Furthermore, while pollution studies and species inventories are well represented, their practical translation into policy remains limited. The TOWS matrix added significant depth to the analysis by connecting internal strengths and weaknesses with external opportunities and threats. It identified viable strategies such as using carbon stock data to access climate finance (SO), applying remote sensing to address fragmented governance (WO), leveraging biodiversity data to guide MPA designation (ST), and building regional institutions to mitigate climate risks (WT). These insights offer a regionally relevant framework for translating research into policy and practice.

However, several limitations of the study must be acknowledged. First, the exclusive reliance on the Scopus database and English-language publications may have excluded important regional grey literature or non-English research, especially from Iran and the Gulf states. Second, while bibliometric tools like VOSviewer offer robust mapping capabilities, they may overlook deeper content nuances that qualitative thematic coding could capture. Third, the TOWS analysis—although grounded in evidence—is inherently interpretative and may benefit from stakeholder validation through expert interviews or Delphi methods in future work. Despite these limitations, this study offers a novel contribution by synthesizing three decades of mangrove research in a data-scarce yet ecologically vital region. It bridges empirical gaps through a quantitative-qualitative hybrid approach and proposes strategic pathways that align with national visions and international sustainability agendas such as the UNSDGs.

Future research should prioritize interdisciplinary studies that integrate ecological, economic, and governance dimensions of mangrove conservation. More importantly, there is a need to mainstream regional collaboration, establish shared monitoring platforms, and develop climate-resilient management frameworks tailored to Western Asia's unique biogeographic and political context. Through coordinated action grounded in both science and policy, mangrove ecosystems in the region can be preserved not only as biodiversity hotspots but also as critical assets for climate adaptation and coastal resilience.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: upon request. Requests to access these datasets should be directed to yapckong@hotmail.com.

Author contributions

CY: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. KA-M: Funding acquisition, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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