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# Economic valuation of changes in ecosystem services of 77 Ramsar wetlands in West Asia over 37 years (1984–2021)

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**Research Paper**

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## Summary

In the West Asia region, the vulnerability of Ramsar Convention wetlands due to unsustainable utilization driven by water scarcity continues to grow. Here, a global surface water product generated by the European Joint Research Centre was used to assess changes in surface water in 77 wetlands listed under the Ramsar Convention over a 37-year period (1984–2021). By combining this product with a quantitative valuation model, estimates were made of the economic value of the ecosystem services provided by these wetlands, enabling the determination of the economic losses resulting from any reduction in surface water. We show that 20% (7550 km$^2$) of permanent surface waters in Ramsar sites have disappeared or are no longer classified as permanent. Based on this, USD 106 billion of the economic value of wetlands ecosystem services have been lost. Additionally, 33% (12 100 km$^2$) of seasonal surface waters in these wetlands have experienced a decrease in area. Iran and Iraq account for 90% of water losses, primarily in 34 wetlands (30 in Iran and 4 in Iraq). These findings underscore the urgent need for water management policies and conservation strategies in the West Asia region.

## Introduction

Remote sensing is a cost-effective and versatile method for collecting and interpreting environmental data, overcoming the limitations of terrestrial methods and investigating spatial and temporal variability in natural processes (Chupin et al. 2022). Global remote sensing programmes have significantly developed in quantity and quality (Lin et al. 2019, Xu et al. 2019a, 2019b), and advancements in sensors have improved their spectral resolution (Guo et al. 2019).

One of the 2030 Sustainable Development Goals set by the United Nations is to measure, protect and restore water sources. Remote sensing techniques, empowered by advancements in cloud processing, offer the most efficient option for achieving this goal globally; widely available global remote sensing products serve as powerful tools for monitoring changes in critical land resources, especially surface water, including wetlands (Zhao et al. 2013, Cooley et al. 2017, Ferral et al. 2019).

Ecosystems are facing increasing human pressures. A clear example of this is the rapid changes in water resources and wetlands (Ashournejad et al. 2019). Despite the Ramsar Convention's efforts since 1971 to promote global wetland protection, wetland areas internationally decreased by 35% between 1970 and 2015, and this decline is expected to continue due to climate change and increased global demand for land and water resources (Junk 2013, Gardner et al. 2018, Aquino 2021, Bridgewater et al. 2021). Several studies have revealed severe deteriorations in Ramsar sites (Xu et al. 2019b). Both the Kilombero Ramsar site in Tanzania (Munishi et al. 2019) and the Meke Maar Ramsar site in Turkey (Yagmur & Musaoglu 2020) have experienced 90% declines in surface water due to escalating agricultural and anthropological pressures. Preventative measures suggested include safeguarding vital water resources for food security and efficient land-use management. Mao et al. (2021) identified that 18 of 57 Ramsar wetlands in China were experiencing declining surface water, mainly due to agriculture. Successful conservation programmes to protect China's Ramsar sites have involved advanced management of human-made wetlands, prevention of land-use changes and compensation mechanisms.

Wetlands play an irreplaceable role in global climate regulation, human and natural disturbances, the maintenance and regulation of the global hydrological cycle, erosion control, nutrient cycling, waste treatment, protection of biodiversity and safeguarding of human well-being. They are highly productive ecosystems that maintain a wide range of biodiversity and provide valuable goods and services to society. Wetland ecosystem services constitute 47% of the total value of global ecosystems, making them of direct economic value to humans (Costanza et al. 1997, Smardon 2009, Song et al. 2021). Understanding and conserving wetlands is crucial to preserving the economic value of the ecosystem services that they provide (Hu et al. 2017).

Incorporating ecosystem services into environmental management and spatial planning can lead to long-term social and environmental improvements (Arkema et al. 2015). Since the Millennium Ecosystem Assessment (2005) and The Economics of Ecosystems and Biodiversity (2010) reports, there has been increased attention given to developing indicators of ecosystem services to guide conservation and management (Hossain & Hashim 2019). While various methods to assess ecosystem services have emerged, the most comprehensive involve assigning them economic value. Valuing ecosystem services enhances understanding of environmental issues, informs decision-making, demonstrates their costs and benefits and promotes sustainable management tools (Aylward & Barbier 1992, Daily et al. 1997). Economic valuation helps integrate ecosystem services into public policy by highlighting their importance in decision-making (Costanza et al. 1997). This approach supports sustainable management and the achievement of sustainable development goals (Mouchet et al. 2014, Van Oudenhoven et al. 2018).

Wetland ecosystem services risk being undervalued by policymakers, resulting in economic losses (Turpie et al. 2010, Sharma et al. 2021). For example, swampy wetland ecosystem services saw a yearly decline of USD 9.9 trillion from 1997 to 2011, equivalent to 1.4 times China's GDP in 2011 (Costanza et al. 2014, Sutton et al. 2016). Nepal's Koshi Tappu Wildlife Reserve was demonstrated to provide an economic benefit of USD 982 per local household, highlighting the critical role of wetlands in local well-being and indicating the desirability of policies and incentives involving local communities in wetland management (Sharma et al. 2015). The total annual value of wetland ecosystem services in 35 Chinese nature reserves has been estimated at USD 33.168 billion (Li et al. 2020), suggesting the importance of prioritizing higher-value wetlands for restoration and employing a network approach for effective community engagement in wetland management.

Yet the economic value of wetlands in West Asia remains largely unknown. The West Asia region is experiencing water crisis (Madani 2014, Li et al. 2020), and over 70% of the world's surface water loss has occurred in this region under the influence of climate change and human activities (Pekel et al. 2016). As a main source of surface water supply, wetlands rank third in the world in terms of the value of their annual ecosystem services, estimated at USD 140.174 per hectare (Costanza et al. 2014). Despite the economic losses from wetland destruction, there has been no economic valuation of the ecosystem services provided by Ramsar Convention wetlands in the hot and dry climate of West Asia. Furthermore, given the lack of water resource management in the region, the economic valuation of these services can serve as a powerful means to raise awareness among policymakers and promote effective wetland management strategies (Madani 2014).

The present study aimed to assess surface water fluctuations in Ramsar Convention wetlands in West Asia using remote sensing data, to conduct an economic valuation of the ecosystem services provided by these wetlands and to estimate the economic losses from the damage done to these services.

## Methods

### *Study area*

Since West Asia, situated at the crossroads of Eurasia, Africa and the Indian Ocean, lacks a standardized definition (Phelps et al. 2019), for this study it comprises 13 countries, including Bahrain, Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Syria, Turkey, the United Arab Emirates, Yemen, Armenia and the Republic of Azerbaijan. Iran has 30 wetlands, Turkey 14, the United Arab Emirates 10, Iraq 4, Lebanon 4, Armenia 3, Bahrain 2, the Republic of Azerbaijan 2, Oman 3 and Jordan 2, and Kuwait, Syria and Yemen each have 1 wetland registered under the Ramsar Convention. These wetlands may include permanent or seasonal waters or both. The locations of West Asian countries and Ramsar Convention wetlands in this region are displayed in Fig. 1 & Fig. S1, and their characteristics are summarized in Table S1.

### *Surface water*

The conceptual model of the study method is given in Fig. S2. To estimate the economic value of ecosystem services, it was first necessary to assess wetland area and the spatial distribution of surface water. A comprehensive assessment of changes in surface waters within Ramsar Convention wetlands in West Asia was conducted using the Global Surface Water (GSW) product from the European Joint Research Centre. This product encompasses Landsat satellite images with a 30–m resolution spanning the 37 years from 1984 to 2021. Datasets of the GSW product by Pekel et al. (2016) include monthly maps, water change information and various multi-temporal maps; 12% of studies on surface waters have used this product as an auxiliary dataset or for validation (Sogno et al. 2022). The GSW product was used given its high spatial resolution, the lengthy period under investigation and the comprehensiveness of the surface water layers. In it, the entire Landsat archive, including Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper plus (ETM+) and Landsat 8 Operational Land Imager (OLI) data, was employed after orthorectification and top-of-atmosphere reflectance corrections. Cloud, snow and ice cover were systematically removed, and each pixel in the dataset was classified into water, land or invalid observations using a decision tree algorithm. A spectral library documented the spectral behaviour of the three target classes. Performance evaluations, based on over 40 000 reference points, demonstrated that the classifier generated fewer than 1% false classifications of water and missed fewer than 5% of water areas. Validation results indicated 99% accuracy for identifying permanent water bodies and 98% accuracy for identifying seasonal water bodies. Due to the dynamic nature of water as a target, visual analysis was incorporated alongside the decision tree algorithm. In cases where there were no overlaps between clusters, visual perception and analysis were applied.

The GSW product includes a Transitions layer that categorizes surface water changes into 10 classes: Permanent, New Permanent, Lost Permanent, Seasonal, New Seasonal, Lost Seasonal, Seasonal to Permanent, Permanent to Seasonal, Ephemeral Seasonal and Ephemeral Permanent. The area of each of these 10 classes was individually calculated for all 77 Ramsar sites in West Asia. Permanent surface waters are those that remain consistently covered by water throughout the year, while seasonal surface waters experience water coverage for fewer than 12 months annually. The Transitions dataset captures changes in water surface area from the series' beginning to its end (1984–2021), but it does not detail events in intervening years. Instances with no water at the record's start or end but with water being present in certain intervening years were classified as Ephemeral Permanent or Seasonal water. New Permanent and Seasonal waters were areas of land in 1984 that transformed into water by 2021. Conversely,

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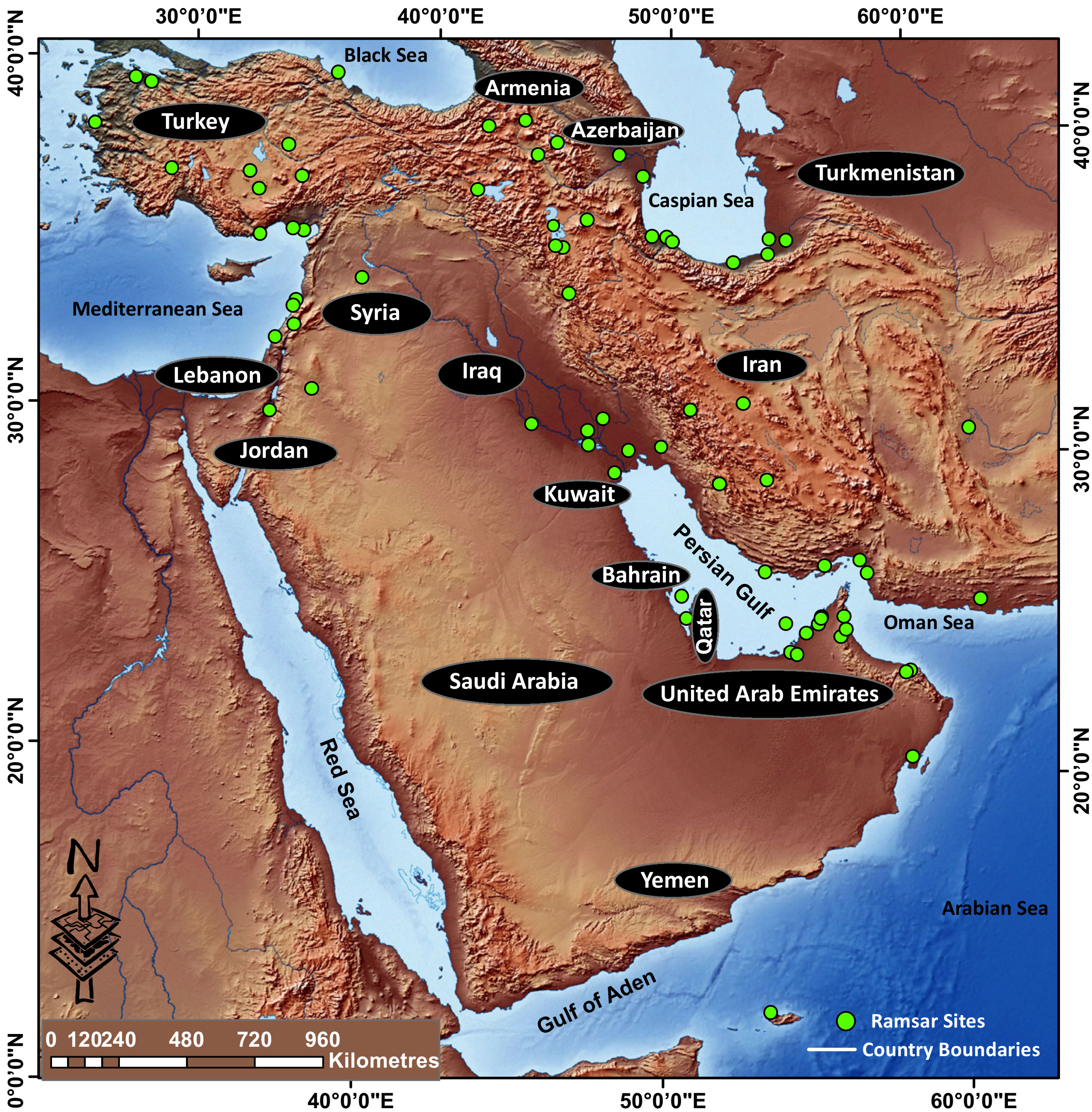


**Figure 1.** Locations of the 77 wetlands in the West Asia region.

Lost Permanent and Seasonal waters were areas covered by water in 1984 that had turned into land by 2021. Waters that were seasonal in 1984 and had become permanent by 2021 are considered transitions from Seasonal to Permanent. This also applies to permanent waters that had transitioned to seasonal. To present the results in a clear and understandable manner, Ephemeral Permanent waters were considered as Lost Permanent waters, and Ephemeral Seasonal waters were considered as Lost Seasonal waters. Additionally, permanent waters that transitioned into seasonal waters were classified as New Seasonal waters, and seasonal waters that transitioned into permanent waters were considered as New Permanent waters. By integrating the GSW product, with a pixel area of 900 $m^2$ (30 m × 30 m), and overlaying Ramsar Convention wetland boundaries, the area for each class of the Transitions dataset was individually determined for each corresponding wetland (Equation 1):

$$\mathrm{WPA}_{ij} = \mathrm{NP}_{ij} \times A \tag{1}$$

where $\mathrm{WPA}_{ij}$ is the area of water parameter of type $j$ for wetland $i$, $\mathrm{NP}_{ij}$ is the number of pixels of type $j$ water parameter for wetland $i$ and $A$ is the pixel size of the used product. Table S2 shows the main characteristics and features of the GSW dataset.

### *Valuing ecosystem services*

The results obtained from the wetlands area were applied to the ecosystem service value (ESV) estimation model of Costanza et al.

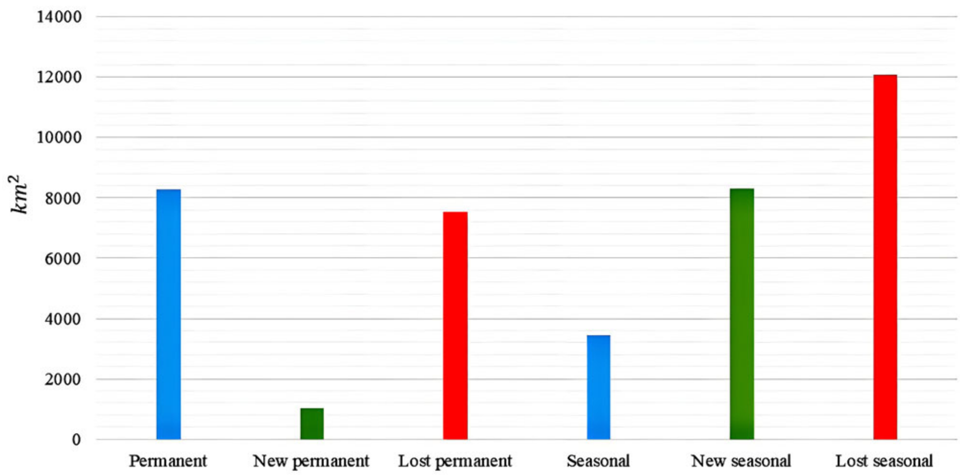


**Figure 2.** The total area of Ramsar sites in West Asia based on unchanged, new and lost permanent and seasonal surface water from 1984 to 2021 (measured in km$^2$).

(2014) to assess the economic values of the wetlands' ecosystem services. Table S3 shows the services that wetlands provide and their corresponding values. In light of the focus on estimating the value of ecosystem services provided by wetlands, the model was modified as follows:

$$\mathrm{WESV}_r = \sum\nolimits_{f=1}^{n} A_r \times VC_f \quad (2)$$

$$\mathrm{WESV}_c = \sum\nolimits_{r=1}^{m} \mathrm{WESV}_r \quad (3)$$

$$\mathrm{WESV}_t = \sum_{c=1}^{j} \mathrm{WESV}_c \quad (4)$$

In Equation 2, $\mathrm{WESV}_r$ represents the economic value of ecosystem services provided by Ramsar Convention wetlands, $n$ denotes the number of different types of ecosystem services considered, $A_r$ denotes the area of the wetlands and $VC_f$ is the coefficient of the economic value of a given wetland for type $f$ ecosystem services. In Equation 3, $\mathrm{WESV}_c$ represents the aggregate area of Ramsar Convention wetlands within each nation and $m$ denotes the number of Ramsar Convention wetlands within each nation, while in Equation 4, $\mathrm{WESV}_t$ denotes the total area of all Ramsar Convention wetlands situated within the West Asia region and $j$ denotes the number of nations within the West Asia region.

## Results

### *Wetland surface area changes*

Only 8260 km$^2$ (22.28%) of wetlands had permanent surface waters that remained unchanged, while 3440 km$^2$ (9.29%) had seasonal surface water areas that also remained unchanged (Fig. 2). A total of 1030 km$^2$ (2.78%) were added to the permanent surface water area, and 7550 km$^2$ (20%) were lost from the permanent surface water area. The total area of seasonal surface water added to wetlands was 8300 km$^2$ (22.38%), while seasonal water loss in wetlands was 12 100 km$^2$ (32.58%).

In West Asia, Lake Urmia in Iran had the largest permanent surface water area (3420 km$^2$, 39.74% of the wetland area), followed by the Lake Sevan wetlands in Armenia (1910 km$^2$, 98% of the wetland area) and Miankaleh Peninsula in Iran (515 km$^2$, 58% of the wetland area). Shadegan Marsh in Iran dominated in terms of unchanged seasonal water (1140 km$^2$, 88.33% of the wetland area), followed by Hawizeh Marsh in Iraq (528 km$^2$, 16.86% of the wetland area) and Hammar Marsh in Iraq (385 km$^2$, 12% of the wetland area). Hammar Marsh in Iraq exhibited the most significant increase in permanent water from 1984 to 2021, covering 322 km$^2$ (9.96% of the wetland area), followed by Hawizeh and Central Marshes in Iraq, with 178 km$^2$ (5.67% of the wetland area) and 148 km$^2$ (4.22% of the wetland area), respectively. Over the 37 years, Lake Urmia experienced a loss of 3790 km$^2$ (44% of the wetland area) of its permanent surface water, representing the highest percentage of permanent water loss among any wetland in this region. The Hamun Wetland in Iran, with a loss of 1300 km$^2$ (34.76% of the wetland area), and Lake Bakhtegan in Iran, with a loss of 442 km$^2$ (23.09% of the wetland area), had the next greatest losses. The wetland with the highest increase in seasonal water surface area in 2021 compared to 1984 was Lake Urmia in Iran, covering 2890 km$^2$ (33.54% of the wetland area), followed by the Central Marsh in Iraq with 1040 km$^2$ (29.79% of the wetland area) and Hammar Marsh in Iraq with 865 km$^2$ (26.79% of the wetland area). In contrast, Hamun Wetland in Iran showed the greatest loss in seasonal water surface area among the West Asian Ramsar sites, losing 2360 km$^2$ (63% of the wetland area), followed by the Central Marsh of Iraq with 1820 km$^2$ (52% of the wetland area) and Hawizeh Marsh in Iraq with 1450 km$^2$ (46.45% of the wetland area).

Table S4 shows the area of each Ramsar site in West Asia. Despite registration with the Ramsar Convention and ongoing preservation efforts, the surface water areas of Ramsar sites in West Asia are declining. Of the 77 sites, 56% showed a net loss in permanent water, although the remaining 44% experienced a net increase in permanent water area. On average, the wetland area in West Asia has been decreasing by 34% annually. The rate of wetland area decline varied among the countries examined. For instance, Iran's wetlands have lost 67% of their permanent and seasonal water area during this period, and Iraq's wetlands have decreased by 49%. Certain countries, including Iran, Iraq, the United Arab Emirates and Turkey, have witnessed significant decreases in wetland areas, whereas others, such as Jordan and Lebanon, have experienced less pronounced reductions. Of the 25 wetlands located south of 30° latitude, 14 have experienced decreases in area, whereas 11 have seen increases. In contrast, of the 52 wetlands located north of 30° latitude, 28 have experienced decreases in area, whereas 24 have experienced increases in area.

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The wetlands with the highest amounts of permanent, seasonal, new permanent, new seasonal, lost permanent, lost seasonal, transitioning from permanent to seasonal, transitioning from seasonal to permanent and ephemeral permanent and seasonal water are depicted in Figs S3–S7. In addition, details of these changes over the past 37 years are illustrated in Figs S8–S12.

### Economic valuation of Ramsar sites

Ecosystem services of Ramsar sites in the West Asia region have an economic value of USD 130 billion, of which USD 116 billion is related to permanent waters that existed in 1984 and still exist in 2021, USD 9.04 billion derives from new permanent surface waters added (conversion of land into permanent water) and USD 5.39 billion relates to the transformation of seasonal water to permanent water over the course of the 37 years. Based on the amount of permanent water loss from the Ramsar sites, the economic value of their ecosystem services has declined by USD 106 billion. Of this, USD 31.6 billion is related to permanent surface waters that existed in 1984 and had disappeared by 2021, USD 24.1 billion is related to ephemeral permanent surface water that formed and disappeared between 1984 and 2021 and USD 50.2 billion of the loss is attributed to the transformation of permanent waters into seasonal waters over the 37–year period. The economic losses from lost permanent water are seven times greater than the economic gains from establishing new permanent surface waters.

In the West Asia region, Ramsar sites with the highest economic value, considering permanent water, new permanent water and change from seasonal to permanent water, include Lake Urmia in Iran (USD 47 billion), Lake Sevan in Armenia (USD 27 billion), Hammar Marsh in Iraq (USD 8.04 billion), Hawizeh Marsh in Iraq (USD 7.03 billion) and Miankale Peninsula in Iran (USD 7.03 billion). Over the 1984–2021 period, Hammar, Central and Hawizeh Marshes in Iraq, Sabkhat al Jabbul Nature Reserve in Syria and Shadegan Marsh in Iran have seen the most substantial increases in permanent surface water area, adding USD 2.99 million, USD 1.40 million, USD 1.37 million, USD 770 million and USD 647 million, respectively, to the economic value of their ecosystem services. In terms of converting seasonal water to permanent water, Hammar and Hawizeh Marshes in Iraq, Shadegan Marsh in Iran, Central Marsh in Iraq and Sabkhat al-Jabbul Nature Reserve in Syria have undergone significant changes, adding USD 1.52 billion, USD 1.12 billion, USD 1.01 billion, USD 665 million and USD 231 million, respectively, to the economic value of their ecosystem services. Conversely, the greatest decreases in ESV occurred in Lake Urmia and Hamun Wetland in Iran, Hawizeh Marsh in Iraq, Ghizil Agaj Wetland in Azerbaijan and Lake Burdur in Turkey, losing USD 16 billion, USD 5.19 billion, USD 1.69 billion, USD 1 billion and USD 428 million, respectively, due to net loss of permanent water over the period of 1984–2021. The transition from permanent to seasonal water significantly impacted the economic value of ecosystem services in five wetlands: Lake Urmia in Iran (USD 36.5 billion loss), Hawizeh (USD 2.25 billion) and Hammar (USD 1.94 billion) Marshes in Iraq, Ghizil Agaj Wetland (USD 1.26 billion) in Azerbaijan and Gomishan Lagoon (USD 1.21 billion) in Iran. Wetlands with the highest ephemeral water levels also suffered losses, including Hamun Wetland (USD 18.2 billion) and Lake Bakhtegan (USD 6.19 billion) in Iran, Ghizil Agaj Wetland (USD 4.62 billion) in Azerbaijan and Miankaleh Peninsula (USD 3.73 billion) and Gomishan Lagoon (USD 2.96 billion) in Iran. The greatest economic losses in ecosystem services due to permanent water loss have been in Lake Urmia (USD 53.7 billion), Hamun Wetland (USD 18.2 billion) and Lake Bakhtegan (USD 6.19 billion) in Iran, Ghizil Agaj Wetland (USD 4.62 billion) in Azerbaijan and Hawizeh Marsh (USD 4.57 billion) in Iraq (ESVs of each Ramsar site in West Asia for each year are given in Table S5).

## Discussion

Compared to other studies conducted on Ramsar sites in West Asia (Kharazmi et al. 2018, Yagmur & Musaoglu 2020, Dervisoglu 2021, Ehsani et al. 2021, Mozafari et al. 2022, Topal et al. 2023), this research evaluated the areas of both permanent waters and seasonal waters in wetlands.

The results indicate a significant reduction in both permanent and seasonal surface water areas across numerous Ramsar sites in West Asia from 1984 to 2021. Out of 77 sites, 42 experienced reductions in area. Notably, 20% of permanent waters have either disappeared or become non-permanent, as seen in the complete drying up of wetlands such as Meke Maar Wetland in Turkey, Lake Parishan in Iran and Lake Sawa in Iraq. Furthermore, 33% of the seasonal surface water areas have been lost, indicating the poor condition of seasonal wetlands.

The conversion of permanent water to land occurred at a rate six times greater than the creation of new permanent water bodies, and the loss of seasonal waters was 2.5 times greater than the formation of new seasonal waters. These findings corroborate the water crisis in the region (Madani 2014). The greatest fluctuations in surface water occurred in Iran and Iraq, accounting for 90% of the wetland area reduction, while Armenia experienced the least reduction. These disparities are attributed to climatic factors, human activity and governmental policies (Rahimi et al. 2023). Dam construction, land drainage, agriculture and urban and industrial development have critically contributed to wetland destruction (Al-Nasrawi 2021, Ballut-Dajud et al. 2022).

The study revealed significant economic consequences of the reduction in wetland water areas. The sixfold increase in the loss of permanent surface waters, compared to the creation of new such waters, has significantly exacerbated the decline in the economic value of wetland ecosystem services. Excessive exploitation of Ramsar sites to meet rising demand has resulted in a fall in the supply of ecosystem services, putting immense pressure on these ecosystems (Duku et al. 2022).

The current study's findings could help to shape decision-making processes for the conservation and management of Ramsar Convention wetlands in West Asia. It provides a comprehensive understanding of current states and trends, which could help policymakers to develop targeted strategies that address specific needs and vulnerabilities of these ecosystems. The study highlights the economic valuation of ecosystem services such as water purification, flood control, carbon sequestration and biodiversity support.

We suggest increased investment in wetland conservation and restoration, improved water resource management practices, stricter regulations to control activities leading to wetland degradation, engaging local communities and fostering international collaboration. Without immediate and concerted efforts to restore and protect these vital ecosystems, the economic and ecological benefits that they provide will continue to diminish, exacerbating the region's water stress and environmental challenges.

The lack of comprehensive and accurate information on water policies, agricultural practices, urban development and other factors affecting wetland decline (Al-Nasrawi 2021, Ballut-Dajud

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et al. 2022, Rahimi et al. 2023) means that the many factors likely to be directly and indirectly driving changes in wetland water levels could not be analysed. We recommend obtaining such information as the next step in the research underpinning future water management actions.

## Conclusion

The alarming decline of surface water in Ramsar Convention wetlands in West Asia reflects their high vulnerability, the insufficient awareness of the value of ecosystem services and inadequate planning for the preservation of wetlands. A significant net loss of permanent and seasonal water bodies has occurred (20% and 33% during 1984–2021, respectively). The reduction in permanent surface water in wetlands has resulted in a USD 106 billion decline in the economic value of the ecosystem services provided by these wetlands over this 37–year period. Recognition of these economic losses can serve as a powerful incentive for the implementation of stricter regulations and sustainable water management practices. Collaborative efforts guided by the Ramsar Convention are essential for mitigating wetland destruction, maintaining these ecosystems and preventing larger negative impacts, such as increased dust emissions affecting neighbouring countries. Protection plans could be informed by our economic valuation of wetland degradation. Moreover, future research should endeavour to elucidate the underlying causes – both human and natural – of surface water reduction. Regular monitoring through remote sensing is now essential for the preservation of Ramsar sites and for the mitigation of destructive pressures.

**Supplementary material.** To view supplementary material for this article, please visit https://doi.org/10.1017/S0376892924000183.

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