Review

The Environmental Impacts of Wetland Areas in Saudi Arabia: The Case Study of Al-Asfar Lake, Review and Perspectives

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The Environmental Impacts of Wetland Areas in Saudi Arabia: The Case Study of Al-Asfar Lake, Review and Perspectives

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Abstract: Saudi Arabia consists mainly of desert land. However, it has big and small natural wetlands and artificial wetlands. Most of these wetlands are seen along the Red Sea and the Arabian Gulf coastal regions. Al-Asfar Lake, located in the Eastern Region of Saudi Arabia, is one of the historical landmarks of Al-Ahsa province. The primary lake water source is agricultural drainage water, which some refer to as an artificial lake. This paper mainly aims to reflect shade on the wetlands in Saudi Arabia in general and to show in detail the environmental impacts of Al-Asfar Lake on the ecosystem and biodiversity of the study area. The analytical review of the previous studies conducted in Al-Asfar Lake was adopted in this article. Hence, the impact of the lake on the land-use system, water quality and biodiversity was illustrated as the main outputs of the review analysis. However, the sustainable management of Al-Asfar Lake requires the stakeholders to adopt the wetland ecosystem health concept, which might lead to improving the lake's environmental conditions.

Keywords: Wetlands; Biodiversity; Environmental Hazards; Water Quality; Al-Asfar Lake; Saudi Arabia

1. Introduction

Wetlands are a crucial factor affecting the hydrological cycle and greatly impacting ecology and human life [1–3]. Although wetlands cover less than 5% of the ice-free areas, they significantly influence worldwide hydrology, biodiversity, carbon cycle and biogeochemistry [4,5]. In addition, wetlands contribute to food security worldwide and are essential for agricultural production, fisheries, grazing and home for nest sites of migratory birds [6,7]. However, wetlands significantly benefit humans as they contain various habitats with different species and can also be used for recreation, cultivation, education and timber production [8]. Accordingly, wetlands provide consumptive and non-consumptive uses areas. For example, the consumptive uses might include hunting and fishing, while the non-consumptive uses include nature and bird watching and studying flora and fauna. Therefore, wetlands provide valuable resources for local communities in many parts of the world [9].

Wetlands functions are the physical, chemical and biological processes emerging and forming the ecosystem. Thus, the loss of ecosystem services in wetlands might have environmental and economic consequences. In addition, wetlands have economic value through supporting livelihood and providing many services and products to humanity [10,11]. The hydrological functions of the wetlands play an essential role in regulating water flow, controlling floods during the wet season and affecting the local microclimate through the high potential evapotranspiration rates of the dense wetland vegetation [12]. Also, water balance, as one of the hydrological functions, is considered critical for regulating water movement within the watershed and the global water cycle [13]. In addition, wetlands also act to control climate as another hydrologic function [14]. Moreover, wetlands

can act as a water supply for retaining and releasing surface and groundwater in the watershed. Furthermore, wetlands can help control floods in the downstream areas from potential flood damage. Also, wetland plants hold the soils in place with their roots and control erosion [15]. Wetlands play a critical role in regulating ecological and biophysical processes. The vegetation in wetlands can absorb strong winds and tides, making them excellent for shore protection. Hence, wetlands influence the recharge or discharge of groundwater. The carrier functions of the wetlands indicate that they can provide services to human beings like, agriculture, irrigation, grazing, wildlife, transport, energy production, tourism and human habitation and settlement. Consequently, wetlands give production functions to human beings, such as water, food, fuel, wood, and raw materials for buildings. Also, wetlands give information functions like research, education and monitoring uniqueness, rarity or naturalness and role in cultural heritage.

The term wetlands describe the formation of hydrology, soil, and vegetation combined to form wide ranges of landscape units [16,17]. Hence, these combinations are sufficient to support the natural life of diverse habitats within the wetland environment. However, Ramsar [18] provides a comprehensive definition of wetlands, which coated as "wetlands include a wide variety of habitats such as marshes, peatlands, floodplains, rivers and lakes, and coastal areas such as saltmarshes, mangroves, and seagrass beds, but also coral reefs and other marine areas no deeper than six metres at low tide, as well as human-made wetlands such as waste-water treatment ponds and reservoirs". Nevertheless, climatic zones define the expansion of wetland surface area worldwide [19–21]. Accordingly, the wetland's nomenclature and descriptions vary concerning place, region, language and heritage [22]. For instance, wetlands can be expressed as swamp, marsh, delta, mangrove, mire, fen and bog [17]. Although this diversity in wetlands terminology might confuse the international scientific community, it might help understand the wetlands ecosystems for the local communities [21].

In many parts of the world, including Saudi Arabia, wetlands face severe threats and problems. Environmental threats and climate change impacts on wetlands might occur over time. Nevertheless, human impacts on wetlands are most pronounced. Thus, human activities like overgrazing, over-cultivation, over-abstraction of water for domestic use, agriculture and improper use of forest practices result in unsustainable use of wetlands resources. Also, establishing new human and livestock settlements in wetlands affects their sustainability. Cutting and burning aquatic and other vegetation for housing and commercial activities like charcoal and firewood severely influence wetlands resources. However, the need for an operational national wetlands policy, cross-cutting sectorial policies, and limited funds provided to the research and management institutions may restrict wetlands development. In addition, the lack of community participation and awareness in the management of the wetlands can limit the action plans set for wetlands sustainability.

Therefore, this review paper aims to provide an overview of wetlands in Saudi Arabia and to show in detail the environmental impacts of Al-Asfar Lake on the ecosystem and biodiversity of the study area.

2. Wetlands in Saudi Arabia

The Kingdom of Saudi Arabia extends in about 2145000 km2, with coastlines extended along the Red Sea and the Arabian Gulf [23].The topography in Saudi Arabia varies from extensive mountains to vast sand deserts, including coastal and inland plains, with an altitude range from sea level to 3000 m [24]. The climate in Saudi Arabia is arid to hyper-arid, although the southwestern mountain ranges receive an average rainfall of 300-500 mm [25,26]. The air temperature and humidity vary greatly. The daily summer temperatures are often in the range of 35°-45°C [27,28]. Humidity is highest in the summer, especially on the Gulf and southern Red Sea coastlands [29].

Although Saudi Arabia is highly arid, various wetlands provide a habitat for extensive biodiversity. They are vulnerable ecosystems currently facing challenges from human activities and invasive species. Studies classified the wetlands in Saudi Arabia into the following systems [30,31]:

- Coastal systems include coral islands, reefs, mudflats, mangroves, and freshwater marshes.
- Dunefield systems include relatively minor aquifer seeps.

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- Sabkha systems include continental lagoons and inland marshes.
- Karst systems include the aquifer-fed karst crater lakelets.
- Mountain systems, including various seeps and marshes in volcanic areas.
- Geothermal systems include springs confined to the southern Tihamah.
- Wadi systems include intermittent streams and perennially flowing rivers.
- Man-made systems, including dams and reservoirs, irrigation and drainage canals and outflows from sewage treatment plants or industrial areas.

The widespread wetland systems in Saudi Arabia support diverse aquatic and ornithological activities. However, some wetlands, particularly coastal areas, support a wide range of migratory shorebirds and breeding seabirds. Also, they support breeding turtles, dugongs, fish and coral inhabitance [32,33].

Figure 1 shows the locations of the most recognized wetland areas in Saudi Arabia. The detailed descriptions of these wetlands are shown in Table 1. Accordingly, the wetlands data provides information about the covered area, location region, the main land use and the most dominant fauna and flora.

Wetlands in Saudi Arabia are facing severe threats and problems. Most coastal zones are now suffering from expanding commercial and industrial fisheries. Nevertheless, the fish nurseries were lost due to coastal reclamation from industrial, residential and recreational facilities. The Gulf and the Red Sea lost about 40% and 8% of their inter-tidal area due to urbanization development, respectively [34]. Also, the increasing populations in the coastal cities resulted in considerable pollution from domestic sewage and industrial discharges. However, oil pollution events were also observed along the Gulf Coast. In addition, risks related to climate change and rising sea levels could threaten Saudi Arabia's wetlands [31].

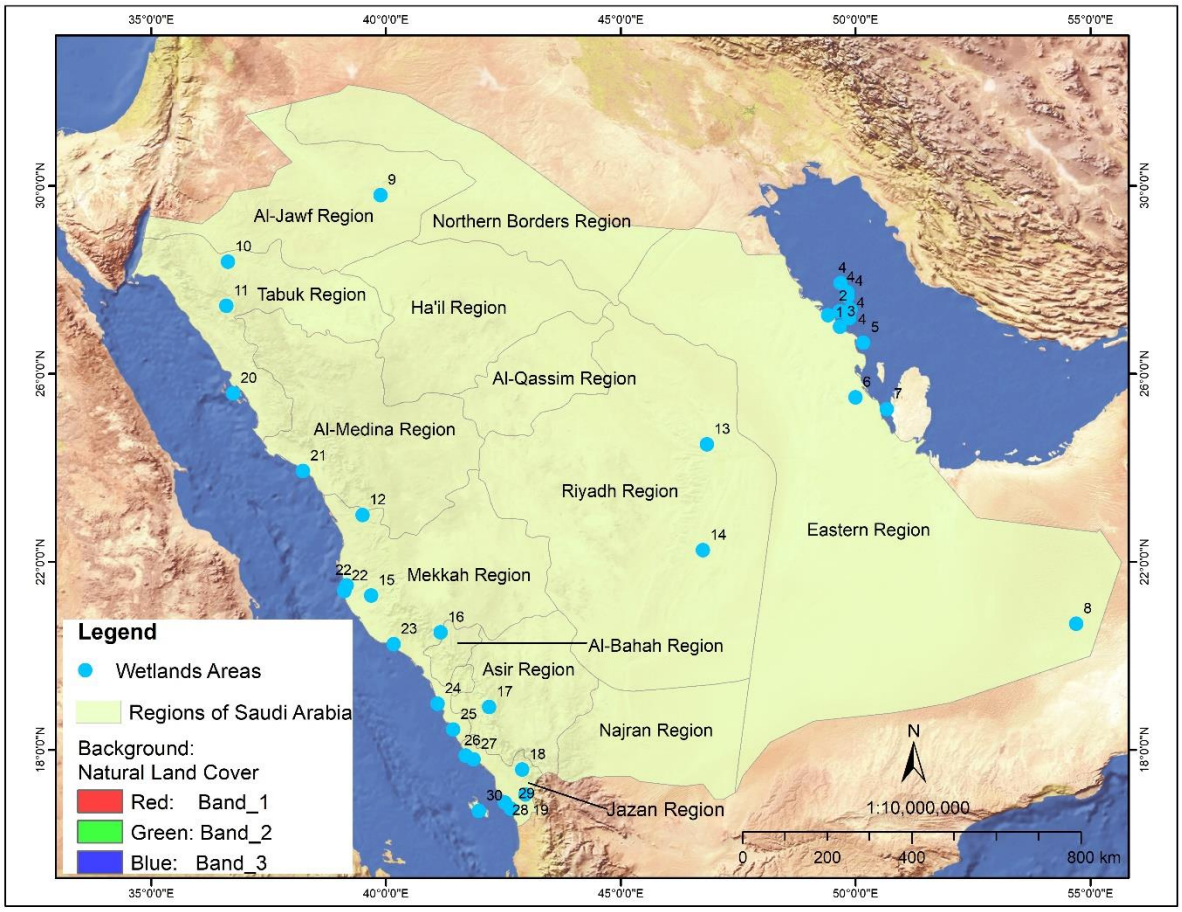

Figure 1. Locations of the wetlands areas in Saudi Arabia. Map adapted from Scott [35]. The numbers refer to the names of the wetland as indicated by "ID" in Table 1.

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Table 1. Description of wetland area in Saudi Arabia, Scott [35].

ID	Name	Area (ha)	Land Use	Fauna	Flora
1	Dawhat ad-Dafi and Dawhat al-Musallamiya	2000	Livestock, fisheries & cement factory.	Green Turtles, Hawksbill Turtles, Indo-Pacific Humpback Dolphin, Bottlenose Dolphin, Common Dolphin, Finless Porpoise, Western Reef Egrets, Great Cormorant, Socotra Cormorant, Houbara Bustards & Asiatic Jackals	Saltmarsh and Mangrove
2	Abu Ali	12500	Compound for oil industry.	Asiatic Jackals, White-cheeked Tern, Little Tern, Sandwich Terns, Great Cormorants & Crab Plovers	Seagrass beds
3	Sabkhat al-Fasl Lagoons	500	Industrial and commercial properties and a golf course.	Breeding of Avocet, Lesser Sand Plover, Kentish Plover, Curlew Sandpiper, Broad-billed Sandpiper, Ruff, Ruddy Turnstone, Little Stint, Dunlin, Sanderling, Marsh Sandpiper, The Peregrine, Greater Flamingos, Common Shelduck, Eurasian Wigeon, Gadwall A., Common Teal A., Mallard A., Pintail A., Shoveler A. & Reed Warbler	None known
4	Harqus	2	The four islands form together the "Gulf Coral Islands". They dominated with shelter for local fishermen & fringing reefs for recreation.	Hawksbill Turtles, Green Turtles, Lesser Crested Tern, Bridled Tern, White-cheeked Tern, Great Crested Tern, Saunders' Little Tern, Socotra Cormorant, Crested Lark, Lesser Short-toed Lark, Bimaculated Lark, Short-toed Lark, Corncrake, Red-necked Phalaropes, Wheatears, Marsh Warblers, Willow Warblers & Red-backed Shrikes	None known
4	Karan	128			
4	Kurain	8			
4	Jana	33			
4	Juraid	20			
5	Tarut Bay	41000	Industrial and urban areas, palm groves & small farms.	Sea snakes, Green Turtles, Pallas's Fish Eagle, White-tailed Eagle, Spotted Eagle, Western Reef Egret, Lesser Crested Tern, White-cheeked Tern, Bridled Tern, Great Cormorant, Grey Heron, Black-winged Stilt, Grey Heron, Black-winged Stilt, Kentish Plover, Greater Sand Plover, Eurasian Curlew, Redshank, Dunlin, Slender-billed Gull, Yellow-legged Gull, Gull-billed Tern, Caspian Tern, Grey Plover, Lesser Sand Plover, Bar-tailed Godwit, Whimbrel, Terek Sandpiper, Ruddy Turnstone, Broad-billed Sandpiper 6 Great Knot	Mangroves and Seagrasses
6	Al-Hasa Lagoons	7500	Intensification of cultivation is likely to occur.	oasis fishes, frog, pond turtle, Asiatic Jackals, Houbara Bustards, Black-winged Stilt, Great Bittern, Ferruginous Duck, Black Francolin, Little Bittern, Ruddy Shelduck, Cream-coloured Courser, Moustached Warbler, Savi's	None known.

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				Warbler, Grey Heron, Little Egret, Ruff & Black-tailed Godwit	
7	Gulf of Salwah	62500	Remarkably undeveloped.	Dugong, Socotra Cormorant, Lesser Crested Tern, White-cheeked Tern, Bridled Tern, Caspian Tern, Western Reef Egret, Great Crested Grebes, Black-necked Grebes, Grey Herons & Yellow-legged Gulls	Seagrass and algal beds occur in the shallow water, while Common reed salt-tolerant plants abound on land.
8	Uruq al-Mutaridah	40	Infrequent visits by Bedouin and their livestock may occur.	Water Rails, Moorhens & Water Pipits	None known
9	Dawmat al-Jandl	2500	Agriculture	Rüppell's Fox, Large flocks of Common Coot, Flocks of White-winged Black Tern, White-headed Duck, Pallas's Fish Eagle & Saker.	None known
10	Tabuk (King Faisal Airbase)	Not defined	Unlikely in the foreseeable future.	Little Bittern, Ferruginous Duck, Water Rail, Little Crake, Baillon's Crake, Little Ringed Plover, Clamorous Reed Warbler, Desert Finch, Common Coot & White-winged Black Tern	Phragmites and Tamarix
11	Jabal Qaraqir	160000	Grazing & Irrigated cultivation.	Bonelli's Eagles & Nubian Ibex	None known
12	Wadi Rabigh Springs	35	Grazing & small cultivation.	Baboons, Hyaena, Wolf, Caracal, The lizard, Little Bittern, Philby's Rock Partridge, Collared Pratincole, Little Tern, European Kingfisher, Black Stork & Common Buzzards	Acacia tortilis is one of the dominant trees in the area.
13	Al-Ha'ir	2500	Grazing by goats, sheep, camels and cattle & irrigated by central-pivot for crop growing.	Desert Monitor, several species of Agama and Uromastyx, Black-crowned Night Heron, Little Egret, Grey Heron, Ferruginous Duck, Black-winged Stilt, Little Bittern, Squacco Heron, Purple Heron, Reed Warbler, Black Stork, Spotted Eagle, Marsh Harrier,White Pelican, Marbled Teal, Imperial Eagle, Lesser Kestrel, Corncrake & Sociable Plover	Tamarix and Phragmites dominate the area, lush grasses and sedges also thrive & Acacia trees grow in places relatively close to the water's edge.
14	Uyun Layla	3000	Intensive cultivation, livestock & A tourist resort has been constructed.	African Dragonfly, Aphanius dispar, Tilapiine cichlids, Little Grebe, Moorhen, Common Coot, Little Bittern, Little Ringed Plover, Savi's Warbler & Garganey	Little of interest remains

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15	Makkah Wastewater Stream	300	Livestock	Black-winged Stilt, Glossy Ibis, Collared Pratincole, Common Crane, Demoiselle Crane, The Arabian Bustard, Lichtenstein's Sandgrouse & Chestnut-bellied Sandgrouse.	None known, Salvadora persica occurs.
16	Wadi Turabah	5000	Cultivation	Cyprinion mahalensis, Garra buettikeri, Barbus apoensis, Baboons, Hyaena, Wolf, Hyrax, Hamerkop,Black Storks, Grey-headed Kingfisher, Moorhen, Little Egret, Grey Heron, Common Sandpiper,Green Sandpiper, Yemen Warbler, Asir Magpie, Golden-winged Grosbeak, Verreaux's Eagle, Bonelli's Eagle, Mountain Nightjar, Bruce's Green Pigeon & Cinereous Buntings	No information is available, though a high diversity of plants certainly occurs.
17	Shallal ad-Dahna	200	Grazing surrounding hillsides & cultivation in the valley bottom.	Bufo arabicus, frog (Rana ridibunda and Hyla savignyi), snake (Eirenis coronella fennelli and the shrew Crocidura russula), Bald Ibis, Arabian Red-legged Partridge, Philby's Rock Partridge, Yemen Thrush, Asir Magpie, Arabian Serin, Yemen Linnet, Eagle Owl	Wetland plants have mostly been lost, Primula verticillata also grows.
18	Wadi Lajb	250	The canyon is scarcely utilised at present.	Hamerkop, Arabian Serin, Masked Shrike, Asir Magpies, Arabian Leopard	Berchemica discolor Celtis africana and Diospyros mespiliformis.
19	Malaki Dam	2500	Cultivation of sorghum & goat grazing.	Bufo tihamicus, B. Dhufarensis, B. arabicus and Euphlyctis ehrenbergii, Side-necked Turtle, Cattle Egret, White Stork, Common Cranes, Pallas's Fish Eagle, Black-crowned Night Heron, Little Egret, Spoonbill, Black Stork, Black-tailed Godwit, Ruff, White Pelican, Large roosts of harriers, Spotted Eagles, Arabian Helmeted Guineafowl, Little Button Quail, Grey-headed Kingfisher, White-browed Coucal, Abyssinian Roller & Little Grey Hornbill	Dobera glabra trees
20	Al-Wajh Bank	288000	Seasonal fishing camps.	Dugong, Osprey, Sooty Falcon, Brown Booby, Sooty Gull, White-eyed Gull, White-cheeked Tern & Bridled Tern.	Mangrove, salt-tolerant bushes (Salicornia)
21	Yanbu Royal Commission Zone	700	Nature conservation, though surrounded by the largest oil terminal in the Saudi Red Sea.	Dugong, Terek Sandpiper, Striated Heron, Western Reef Egret, Purple Heron, Osprey, African Reed Warbler, Clamorous Reed Warblers, Goliath Heron, White-cheeked Tern, Saunders' Little Tern & Crab Plovers	Mangrove

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22 22	Jeddah (central) north of Port Jeddah South Corniche	900	The two sites are from Jeddah. Urbanization, livestock grazing and a small fishing village are the most common activities.	Western Reef Egret, Slender-billed Gull, Gull-billed Tern, Caspian Tern, Greater Flamingos, Little Stint & Ruff	Small patch of mangrove.
23	Qishran Bay	40000	Artisanal fisheries; livestock grazing (camels); falcon trapping.	Dugong, Hawksbill Turtle, Green Turtle, Bridled Tern, Pink-backed Pelicans, Goliath Heron, White-collared Kingfisher & Crab Plover.	Large stands of mangrove.
24	Umm al-Qamari	14.7	There is no established human use on the islands, but they are visited occasionally by coastguards and fishermen.	African Collared Dove, Cattle Egret, Spoonbill, Sooty Gull, White-eyed Gull, Pink-backed Pelican, Striated Heron, Western Reef Egret, Osprey & Graceful Warblers.	Salvadora persica and Suaeda form the densest, tallest thickets, with Cyperus conglomeratus, Atriplex farinosa and Zygophyllum album predominating on more open ground.
25	Khawr ‘Amiq	150	Artisanal fishing; camel grazing.	Dugong, White-collared Kingfisher, Striated Heron, Pink-backed Pelican, Spoonbill, Clamorous Reed Warbler & African Reed Warbler.	Mangrove Avicennia marina is the dominant plant.
26	Kutambil Island	8	This is an uninhabited island, occasionally visited by fishermen.	Spoonbill, Western Reef Egret, Osprey, Sooty Falcon, Brown Boobies & Pink-backed Pelicans.	None known.
27	Shuqaiq Mangrove	200	There is a small fishing village, and the site is a very popular recreational area.	White-collared Kingfisher, Clamorous Reed Warblers, African Reed Warblers, Goliath Heron & Purple Heron.	Mangrove Avicennia marina is the dominant plant.
28	Jizan Bay	200	Urban: the bay is used as mooring area by artisanal fishermen, and there is a fish market nearby.	Crab Plover, Lesser Sand Plover, Grey Plover, Dunlin, Broad-billed Sandpiper, Gull-billed Tern, Bar-tailed Godwit & Terek Sandpiper.	None.
29	Khawr Wahlan	1000	Khawr Wahlan is used as an anchorage by local fisheries and a small harbour has been constructed, heavey grazing of camels and goats.	Pacific Golden Plover, Pintail, Crab Plover, Lesser Sand Plover, Curlew Sandpiper, Bar-tailed Godwit, Redshank, White Stork, Marsh, Hen, Pallid & Montagu’s.	The freshwater marsh flora has yet to be described in detail.

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30	Farasan Islands	70000	Urban and settlement, grazing of camels and goats, palm plantations and sorghum cultivation, small fishing camps	Green Turtle, Hawksbill Turtle, Dugong, Bottlenose dolphin, Indo-Pacific Humpback dolphin, Long-snouted Spinner dolphin, Bryde's Whales, White-cheeked Terns, Bridled Terns, Common Noddies, Crab Plover, Pink-backed Pelican, Western Reef Egret, Goliath Heron, Spoonbill, Sooty Gull, Caspian Tern, Lesser Crested Tern, Saunders' Little Tern, Sooty Falcons, Lesser Sand Plover, Ruddy Turnstone & Mountain Gazelle.	The Rhizophora mucronata stand is of interest in a national context; seven species of seagrass occur.

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3. Location and Importance of Al-Asfar Lake

Al-Asfar Lake is located in the Eastern Region of Saudi Arabia, about 370 km from the capital Riyadh and 70 km from the Arabian Gulf (Figure 2). Al-Asfar Lake is also located northeast of Al-Ahsa district, which covers large agricultural lands known as Al-Ahsa Oasis, designated by UNESCO as a World Heritage Site. The population in the area is about 1.3 million people, and the date palm plantation is the dominant land use system in the oasis. The main source of water for Al-Asfar Lake is the collection of drainage water from the irrigation system installed in the oasis in 1971 to serve around 22000 farms [36]. The delivery of the drainage water to Al-Asfar Lake is made through the drainage canal D2, which discharges about 328 million m^3/year to the lake (Figure 2c). Also, the lake received additional treated sewage water estimated as 12780 m^3/year supplied from the Al-Hofuf treated wastewater plant [37]. The total area covered by water in Al-Asfar Lake is estimated at 20.8 km^2 [38]. However, the lake land also includes Sabkhas, vast areas of vegetation, and is surrounded by dunes (Figure 2d).

Al-Asfar Lake has different zones, including wet, moist and dry zones. The diversity of the Lake Ecosystem makes it unique to the variety of wild vegetation and animals inhabitant in the wetland. Hence, different plant varieties and species were observed in the lake. However, various animals such as frogs, fish, turtles and native and migratory birds also survive in Al-Asfar Lake. The lake is also home to several algal and waterweed species.

Al-Asfar Lake has been considered a protected area since February 2019 by the Ministry of Environment, Water and Agriculture of Saudi Arabia [37]. Therefore, the lake has become a destination for tourism and recreation for visitors from inside and outside Al-Ahsa.

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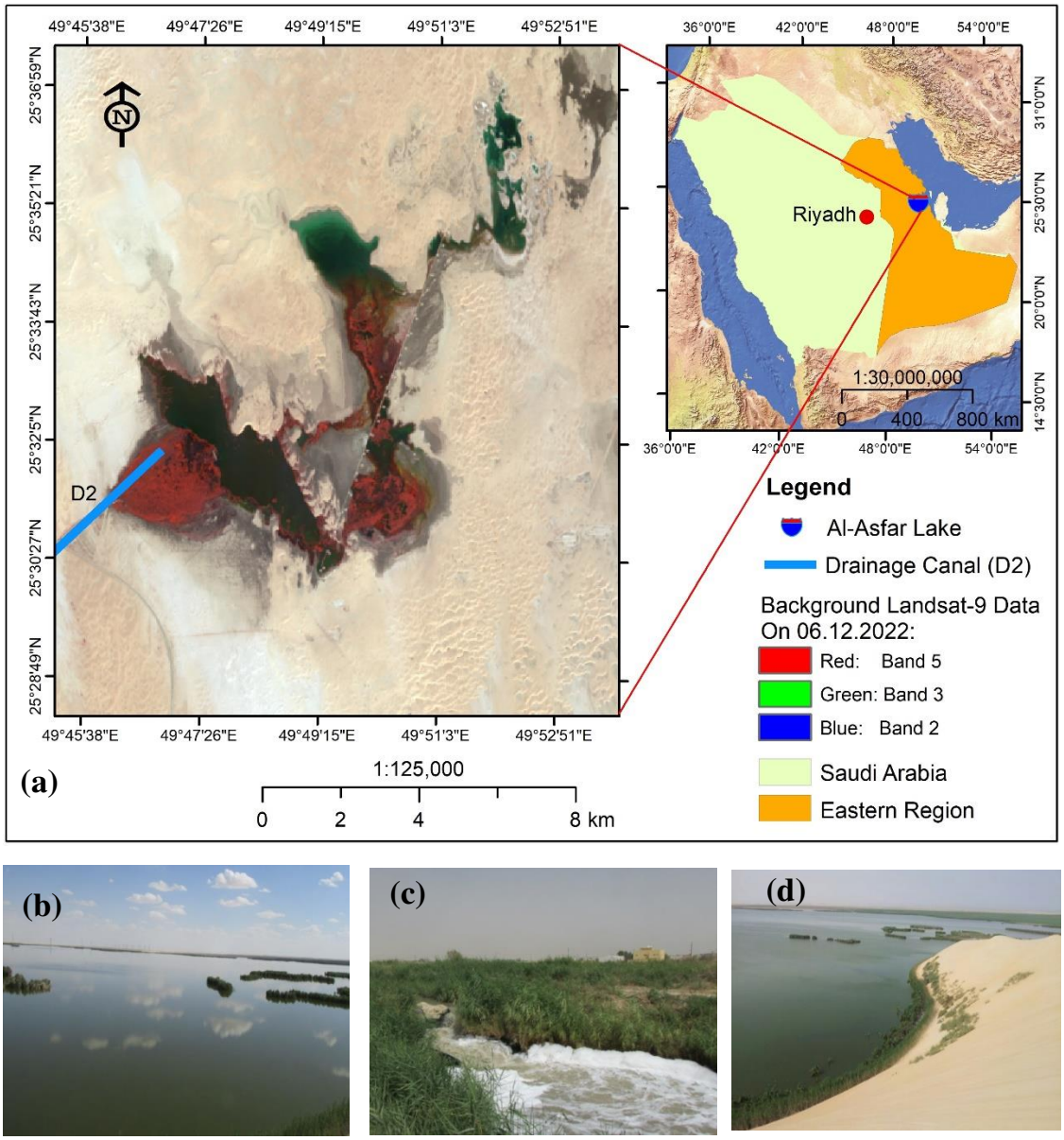

Figure 2. Location of Al-Asfar Lake. (a) The geographical location of Al-Asfar Lake; (b) An overview from Al-Asfar Lake; (c) The discharge outflow of D2 to Al-Asfar Lake; (d) Dunes surround Al-Asfar Lake. Source: Figures by authors.

4. The Impacts of Al-Asfar Lake on Ecosystem and Biodiversity

4.1. Water Quality in Al-Asfar Lake

The water quality in Al-Asfar Lake is crucial for its aquatic organisms. Also, the quality of Al-Asfar Lake water will be necessary for the potential use of this water for agricultural and urban purposes. Table 2 summarises some water quality indicators for Al-Asfar Lake. The water pH ranged from 7.0 to 9.0, indicating that Al-Asfar Lake water tends to be neutral to alkaline. The general tendency of the pH to be alkaline might be due to the increase in planktonic algae activity [39].

Nevertheless, the fluctuations of pH values in Al-Asfar Lake can be attributed to the large amount of agricultural water drained from Al-Ahsa Oasis and the decomposition of organic matter [40]. However, field observations showed that the pH values were high at the outlet of the D2 in Lake Asfar, which indicated that the primary source of the water pH to the lake is the agricultural lands [41]. Moreover, pH is an essential component that organizes the chemical and biological systems of

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the aquatic environment [42]. Also, pH levels can affect the bacteria activity in the water, which requires slightly acidic pH to degrade toxic substances to less harmful forms [43].

The studies reported that the electrical conductivity (EC) of Al Asfar Lake ranged from 8.1 to 102.3 dS/m (Table 2). Thus, the low EC values were associated with the main water body of the lake. However, the high extreme values of the EC were nearest the inland Sabkha, indicating a significant increase in water salinity in this part of the lake [44]. Hence, the variation of the salinity levels across the lake is relatively influenced by the evaporation rate, lithological characteristics and transportation of soil, solubility of salts and the rate of discharge from D2 to the lake.

The nitrate (NO3-) levels in Al Asfar Lake were between 0.8 – 2.3 ppm. Fahmy and Fathi (2011) indicated that high values of NO3- were found in winter and low in summer. However, the high $NO3^-$ values show the impacts of the drainage water collected from the agricultural fields on the lake water [45,46]. In addition, ammonia oxidation in the water lake might increase the $NO3^-$ [41].

Also, high concentrations of nitrogen (N), phosphorus (P), Biological-Oxygen-Demand (BOD) and Chemical-Oxygen-Demand (COD) were observed to be discharged in Al Asfar Lake from the D2 drain. Nevertheless, most BOD, COD and N were expected to originate from wastewater and leachate from irrigation to the lake [47,48].

Table 2. Water Quality Indicators of Al-Asfar Lake.

Year	pH	EC (dS/m)	$(NO3)^-$ (ppm)	Reference
2009	7.0 – 8.3	9.5 – 102.3	0.9 – 41.0	Al-Dakheel et al. [44]
2011	7.0 – 9.0	8.1 – 12.1	1.0 – 2.3	Fahmy and Fathi [39]
2016	7.3 – 8.7	8.3 – 11.3	0.8 – 2.3	Hussein et al. [41]

4.2. Environmental Hazards of Al-Asfar Lake

Pollution poses a significant danger to aquatic life in Al-Asfar Lake, and pollution also extends to animals and plants within the lake ecosystem. Heavy metals are dangerous pollutants as they can accumulate in water and the tissues of living organisms. The toxic effects of heavy metals occur when excretory, metabolic, storage, and detoxification mechanisms can no longer match uptake rates [49].

Hussein et al. [41] reported that the average concentrations of heavy metals in the surface water of Al Asfar Lake ranged from 0.027 to 0.159 ppm, 0.007 to 0.142 ppm, 0.005 to 0.017 ppm, 0.005 to 0.066 ppm, 0.001 to 0.033 ppm, 0 ppm, and 0 ppm for iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), cadmium (Cd), chromium (Cr), and lead (Pb), respectively. They also found that the heavy metals concentrations in water followed the order Fe > Mn > Cu > Zn > Cd > Cr = Pb, and only the Fe, Mn, and Zn concentrations were within the international permissible limits. However, the drainage water flow to Al Asfar Lake carried considerable amounts of chemical fertilizers in addition to domestic and industrial wastewater, resulting in high levels of heavy metals like Cu, Cd, Cr and Pb. Moreover, the concentrations of heavy metals were tested for two fish species in Al-Asfar Lake, namely the Tilapia Zilli and Aphanius dispar. The highest concentrations of heavy metals for Tilapia Zilli were found in the kidney, except for Cd and Cu, which were found highest in the liver. Regarding the heavy metals accumulation for Aphanius dispar, the highest was accumulated in the kidney, while muscles accumulated the lowest [39]. Fish, as one of the aquatic food chains, can concentrate large quantities of heavy metals in water [50]. Therefore, fish can be used to indicate heavy metal contamination within the aquatic ecosystem since they occupy high trophic levels [51].

The analysis of Al-Asfar Lake's phytoplankton indicated that the lake water is considered eutrophic and dominated by Chlorophyceae [39]. However, the concentration of microplastics in the lake water ranged from 0.7 to 7.8 items L^{-1} [37].

Al-Asfar Lake water was contaminated by pesticides, pharmaceuticals, and personal care products (PPCPs). The detected pesticides in Al-Asfar Lake include Acetamiprid, Bifenthrin, Carbendazim, Carbofuran-3-hydroxy, Chlorfenvinphos, Chlorpyrifos, Cyhalothrin, Diazinon, Fluvalinate, Imazalil, Imidacloprid, Isoproturon, Tebuconazole, Terbuthylazine-2-hydroxy, Thiabendazole and Thiametoxan. The average pesticide concentrations ranged from 0.1 ng L^{-1} for fluvalinate to 146 ng L^{-1} for diazinon. The highest concentration was for diazinon 1016 ng L^{-1}. The

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most frequently occurring pesticide was carbendazim, diazinon, and Imidacloprid [37]. These three pesticides were relevant in water and were transportable by runoff due to their water solubility. Also, about 24 different types of PPCPs were detected in Al-Asfar Lake, indicating the strong impact of anthropogenic pollution [37].

The daily actual evapotranspiration (ETa) for the surface water and vegetation of Al-Asfar Lake was between 5.6 and 8.7 mm day^{-1} in summer and about 2.3–5.6 mm day^{-1} in winter. However, evaporation loss from the lake's open water was around 2000 mm $year^{-1}$ [52]. Moreover, the vegetation of Al-Asfar Lake showed a significant increase from 4.2 km^2 in 1990 to 14.9 km^2 in 2020, and most of the vegetation area occupied by reed beds of Phragmites australis, Typha, and Juncus acutus species [53]. The eutrophication of the lake water due to the inflow of effluents, fertilizers, and agricultural nutrients resulted in an increasing number of reed beds. Accordingly, the range of geomorphological hazards that affect Al-Asfar Lake, such as the yearly change in shorelines, the yearly sand creep, salinity increase, change in physical and chemical properties and the vulnerability of the lake to salt weathering can significantly change the environmental system within the lake [38].

4.3. Challenges and Opportunities for Al-Asfar Lake

Al-Asfar Lake is characterised by a large environmental and biological diversity that includes water bodies, soil, vegetation, and different species of animals and birds. Although there are some indicators of pollution in the lake and the deterioration of its water quality, some measures and criteria can be set to conserve the lake ecosystem and sustain its future use. Therefore, several challenges and opportunities for Al-Asfar Lake can be summarised as follows:

- The related authorities and stakeholders should work to activate the regulations and policies related to preserving the ecosystems of wetlands to limit their excessive exploitation and the deterioration of their environment.
- A conceptual design of a suitable natural treatment process to clean the drainage water before entering the Al-Asfar Lake can be developed to improve the water quality in the lake. Such a process can protect the aquatic organisms and the lake's ecosystem.
- Economically, Al-Asfar Lake has the potential for investment in the field of fish farming and breeding and the investment in water quality for agricultural purposes.
- Systematic assessments of Al-Asfar Lake that aim to explore the status of the wetland ecosystem, categorize the health conditions and identify the blocks where the health condition is decreasing for a specific period are essential for wetland conservation.
- Raising awareness about the importance of the wetland for human well-being is a key indicator for Al-Asfar Lake protection and conservation.
- As a cultural and tourism site, Al-Asfar Lake might be a unique place for establishing recreational tourism, sports resorts, research, and educational units.
- Sustainability is a crucial measure for Al-Asfar Lake; therefore, future research should focus on the lake's floral, animal, algal and microbial biodiversity and their interaction with climate change.

5. Conclusions

This review shows a need for a comprehensive study in Al-Asfar Lake to assess different aspects quantitatively. The study can include the evaluation of the lake hydrology, water balance, sediment load, water quality and the conditions of the flora and fauna surrounding the lake. The study outputs might ensure that the lake might be sustained for many years and that its natural ecosystem can clean itself. Also, the pollution load entering the lake can be significantly reduced. Therefore, to assess the possibility of restoring the environmental conditions in Al-Asfar Lake, a wide concept of wetland ecosystem health can be implemented as an action plan. However, the sustainable management of the Al-Asfar Lake ecosystem necessitates the adoption by the stakeholders that leads to conserving biodiversity, preserving water resources, reducing the impact of climate change and allowing community engagement to adopt the best practices for increasing their economic benefits

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