Monitoring temporal changes in coastal mangroves to understand the impacts of climate change: Red Sea, Egypt

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Abstract

This paper focuses on the current state of mangroves in Egypt, analyses how climate change is affecting mangrove forests and suggests a conservation strategy to safeguard this valuable maritime resource. Mangroves in Egypt are primarily found in regions around the Red Sea, making them popular for ecotourism across the globe. A crucial breeding and feeding ground for many commercial fishery species, mangroves are a maritime habitat that is both economically and environmentally significant and a variety of living things call them home. Mangroves are one of the most threatened tropical and subtropical ecoregions in the world. These threats come from both natural and human sources, including oil spills, human waste runoff, herbicide use, and coastal development, all of which have the potential to harm the environment. Mangrove habitats are immediately impacted by salinity changes and rising sea levels brought on by climate change. This is unfortunate as mangroves are one of the most important global carbon sinks, and their loss due to climate change may accelerate sea level rise and ocean acidification, which will cause the extinction of numerous commercial fish species. A conservation strategy should be implemented to safeguard the mangroves around the Egyptian Red Sea by using mitigation techniques, creating marine protected zones near the mangroves, and consulting the owners of the mangrove stalks. Analysis of multi-temporal satellite imagery is one of the most significant methods to assist decision-makers and environmental planners in obtaining high-precision information about environmental and climatic changes. Analysis of satellite imagery is a valuable way to detect, monitor, assess and map the environmental, human, and natural activities that are threatening the growth of the mangrove forest ecosystem. Change detection analyses using satellite imagery were conducted to evaluate the effects of rapid coastal sustainable development, including human urban and tourism activities; the decline and destruction of large areas of the mangrove forest for animal feeding along camel trade roads; and the threat of natural impacts such as flash flooding, coastal and soil erosion or human impacts such as established desalination plants and other human activities along the coastal zone of the Egyptian Red Sea.

Keywords Red Sea · Conservation · Climate change · Mangrove · Human threats · Satellite Imagery

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Introduction

Conservation involves the elimination of waste and the prudent use of resources. It is therefore essential to understand, monitor, evaluate, and manage the coastal zone for human and natural influence activities to preserve natural resources and promote sustainable development. The abundant natural resources that assist local communities come from the various types of coastal zone ecosystems that exist; therefore, conservation is a goal that can be justified (Arnous and Green 2011; Arnous and Mansour 2023). Coastal resources including seagrass beds, estuaries, coral reefs, beach systems, and mangrove habitats. are used in order to sustain both economic development and social advancement, welfare, and international concord. When these are taken into consideration for coastal regions, conservation and planning becomes extremely important since there is an opportunity to use the forces of nature at the land-sea interface, in nearshore seas, and to protect renewable natural resources. Additionally, it is possible to quantify the value and contribution of coastal resources economically. The continuing use of coastal resources, which would otherwise be exhausted by the harmful impacts of unmanaged coastal area growth and activities, has been made possible through a number of effective, straightforward, and financially viable solutions. The preservation of diversity is another result of conservation. Major natural and economic resources are concentrated in coastal areas, and indeed in many parts of the world, but these resources are not used to their utmost extent (Arnous et al. 2022). For any sustainable development processes, five primary coastal resource units - mangrove ecosystems, coral reefs, estuaries, beach systems, lagoons, and seagrass beds - must be monitored, assessed, managed, and understood. Mangrove forests in particular offer a variety of ecosystem functions and socioeconomic advantages on a worldwide scale. However, climatic, and human-related influences have had a negative impact on this unusual vegetation species. Human activity has significantly raised the threats to mangroves in recent years. These include, amongst other concerns, the overuse of resources, pollution, the growth of the tourism industry, reclamation of land for urban development, and aquaculture farming (Veitayaki et al. 2017; Carugati, 2018; Ramsewak et al. 2022).

Mangrove growth, while continuing to be significantly damaged in some parts of the world, has also benefited from environmental policies in some regions. Mangrove forest mapping and monitoring, for example, aid in determining loss rates and implementing protective measures. However, due to the logistical challenges involved in trying to enter mangrove swamps, it is impossible to achieve these mapping objectives using solely conventional field surveys. Mangrove mapping methods and remote sensing data have improved over time. When combined with Geographic Information Systems (GIS), remote sensing data has many advantages for mapping and monitoring mangroves (Son et al. 2015; Pham et al. 2019). This data can provide as a source of current and accurate information that can be utilized to map the extent and distribution of mangroves. Maps showing the distribution and range of mangrove species are also important for comprehending the system's overall ecology and can serve as a baseline for monitoring changes to lessen the effects of anthropogenic activities and climate change (Giri 2016; Ghosh et al. 2016). Such information, which is essential for the sustainable management of this vital resource, can be provided via geospatial mapping techniques.

In the Red Sea coastal zone area of Egypt, mangrove forests have recently experienced losses. To comprehend the effects of climate change in the Red Sea, Egypt, the current study used a literature analysis, fieldwork, remote sensing, and Geographic Information System(GIS) techniques to track the temporal changes in coastal mangroves. Additionally, the research identified important changes in mangrove coverage during the previous 37 years. The major objectives of this work were to use multi-temporal satellite data to produce an updated map of mangrove distribution and extent in the Egyptian Red Sea coastal zone. In addition, an evaluation of satellite data from 1984 to 2021 was undertaken to recognize and track changes in the distribution of mangroves and to understand the causes of destruction of mangroves. Comparing satellite data from 1984 to 2021 also allowed the identification of changes in the distribution of mangroves and potential threats to them. Consequently, a conservation strategy was outlined to safeguard the mangroves in the Egyptian Red Sea and to highlight the further need for conservation of mangroves.

Importance of mangroves and threats to mangroves

Mangrove plants are halophytic plant species that include more than twelve families and eighty species worldwide. They are unique environmental habitats where trees grow in stationary coastal waters, estuaries, and riverbanks. These trees have exposed root systems, forming a mass, which raises them above the water's surface, often resembling silt in appearance and leading to them to be known as "walking trees". The trees can obtain the nutrients needed for persistence and adapt to very oxygen-poor soils (Kennedy, 2019). Mangroves occur worldwide within the tropics, subtropics, estuaries, and marine shorelines (in the forest form) between latitudes 25° N and 25° S (Fig. 1). The estimated number of mangrove forest areas around the globe in 2000
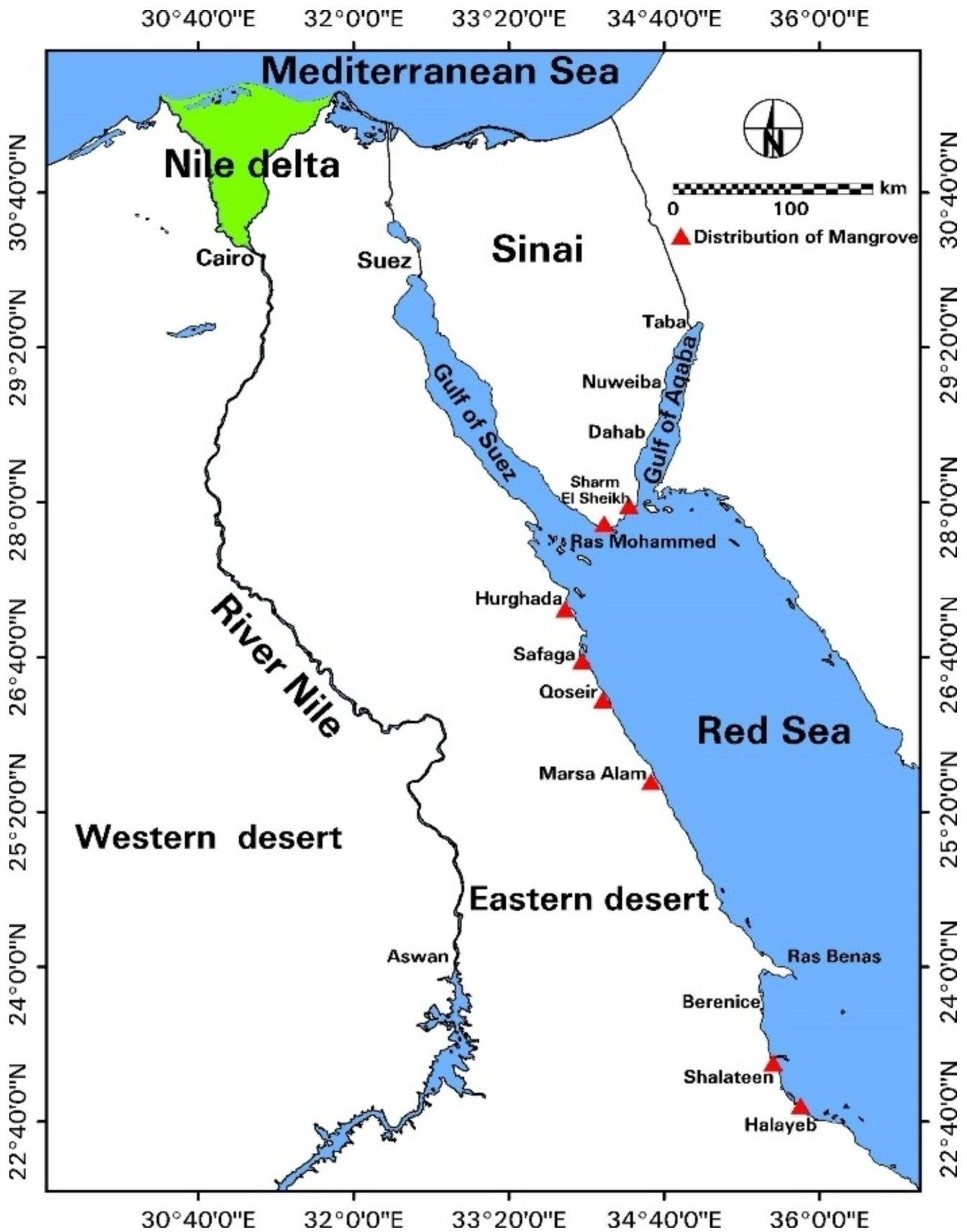
Fig. 1 Spatial distribution of the mangrove in Egyptian coastal land

was 137,800 square kilometers, spanning 118 countries and territories (Singh et al. 2010).

Mangrove plants are adapted to live in severe coastal conditions. They need a complex filtration system and a complicated root system to survive saltwater immersion and wave action. They are adapted to the low oxygen conditions of waterlogged mud (Flower & Colmer, 2015). Mangroves must draw fresh water from the surrounding seas because saltwater typically kills vegetation. Many mangrove species survive by filtering up to 90% of the salt in seawater before it reaches their roots. Some species release salt from glands in their leaves and are encrusted in dried salt crystals. Another adaptation employed by some mangrove species is the shedding of old leaves and bark which removes the salt that was previously stored in them. Mangroves also hold fresh water in their dense, wet leaves, much like desert plants do. Some mangrove species' leaves have a waxy coating that seals in water and lowers evaporation. These tiny apertures are located just beneath the leaf surface of some mangrove species, concealed from drying wind and sunlight. The mangrove biome is a unique salty shrubland habitat distinguished by depositional shore habitats, where fine sediments (sometimes with significant organic content) accumulate in regions thriving from strong wave activity. Numerous mangrove species can withstand a variety of salinities, including brackish water, pure saltwater (3 to 4%), and water that has been concentrated through evaporation to be more than twice as salty as ocean seawater (up to 9%). According to a NASA-led study based on satellite data, mangrove forests have a larger capacity to transport carbon dioxide "from the atmosphere into long-term storage" than any other forests, making them "among the planet's top carbon scrubbers" (Rasmussen and Carlowicz 2019, p.1). The number of species that can live in these tree ecosystems is significantly constrained by their intertidal adaptation. When the tide recedes, heat evaporation of the seawater in the soil causes salinity levels to rise since high tide often brings in salt water. These soils may be flushed out by the tide's return, returning their salinity to that of seawater. At low tide, organisms are also exposed to temperature spikes and decreases in moisture levels before the tide cools them down and floods them again. As a result, only a limited number of species, including those that can endure wide variations in salinity, temperature, and wetness, as well as a number of other crucial environmental factors such as oil pollution, urbanization, aquaculture practices, agriculture, mining operations, cutting for timber, fuel and charcoal in addition to prevention of freshwater flow and tidal flow, make up the mangrove tree community. Mangrove plants require a variety of physiological adaptations to deal with the challenges posed by low oxygen levels in the environment, excessive salinity, and frequent tidal

floods. Each species has its own responses to these issues, which may be the main factor in the distinct zonation of mangrove tree species along some coastlines. Small environmental variations within a mangrove biome (or mangal) can lead to significantly different coping mechanisms. As a result, the mix of species may be influenced by other factors, such as crabs preying on shrub seedlings and how well-adapted each species is to certain physical conditions, such as salinity and tidal floods. Mangrove roots have been recognized as providing an oyster habitat and slowing river flow, which enhances sediment deposition in regions where it already occurs (Dhond 2012). Colloidal particles in sediments also scavenge various heavy (trace) metals from the water and deposit them in the fine, anoxic sediments beneath mangroves. When mangroves are removed, the underlying sediments are disturbed, frequently resulting in trace metal poisoning of the local organisms and water.

A calm maritime environment for newborn organisms is compromised by the distinctive ecology found in the intricate network of mangrove roots (Bos et al. 2010). The species that live in areas where the roots are always submerged include barnacles, algae, bryozoans, oysters, and sponges. These organisms all require a firm surface to adhere to whilst they filter feed. The mud-covered bases serve as a home for shrimp and mud lobsters (Heidi 2005). Mangrove crabs eat the mangrove leaves, enriching the mangal 'muck' with nutrients for other bottom-feeders (Skov and Hartnoll 2002). Coastal food webs depend on the export of carbon fixed in mangroves. Termites, as well as bacterial and fungal activities, can cause mangrove trees to decompose into peat deposits. In favourable geochemical, sedimentary, and tectonic circumstances, can transform peat. These deposits are a crucial component of the carbon cycling and storage in tropical shoreline ecosystems, and their environment is dependent on the environment and the types of mangroves. It is possible to attempt to recreate the environment and use sediment cores to study changes to the coastal ecosystem over thousands of years (Versteegh et al. 2004). However, a further issue is the imported marine organic matter that is also deposited in the sediment because of mangrove forests flowering during the tidal period (Vane et al. 2013).

Mangroves offer coastal areas and people around the world affected by tropical storms calculable economic protections (Hochard et al. 2019). Only roughly fifty-four of the known eighty mangrove species—representing twenty taxa and sixteen families—can be considered "true mangroves," or species that inhabit mangrove areas exclusively (Hogarth 1999). For the continued existence and conservation of coastal fisheries, shoreline protection, and sediment stability, mangrove forests are extremely important from an ecological and environmental standpoint. Mangroves play a crucial role in the preservation of forest genetic resources on

a worldwide scale. A wide range of marine fish and shellfish find food and shelter in mangroves, which is linked to the maintenance of biota (flora and fauna), andsustain a range of terrestrial fauna as well. Overgrazing, solid waste dumping, overfishing, urbanization, and changes in hydrological patterns are some factors that have an impact on mangroves and endanger their survival. Additionally, mangroves are used for a very wide range of uses. For native communities that live in coastal areas, the mangrove forests are very important economically (Afefe 2014).

Our main goal in this paper is to emphasize and examine the significance of mangroves, examine how climate change may be affecting them, and develop a conservation strategy for Egypt's coastal mangrove forests (Fig. 1).

Distribution (ecology)

In general, the term "mangrove" refers to both the entire ecosystem and the plant species that make up that ecosystem. According to UNEP (2014), mangroves are a rare forest type that may be found in 123 different nations and make up less than 1% of all tropical forests with a projected area of 152,000 square kilometers (Spalding et al. 2010). Because of its unique structural and functional adaptations for coping with saline, oxygen-deficient soils and frequent tidal inundation, the mangrove ecosystem is well-known (Alongi 2002). There are eighteen families of mangrove plant species, although only one of them (Pellicieraceae) is known to be exclusively mangrove (UNEP 2014).

A mangrove assemblage's structural form is influenced by the local environmental factors as a community type. Mangroves are developing a slender fringe of stunted trees and plants in desert environments, which are known for their high temperatures and high salinity conditions, such as those found surrounding the Red Sea (around 3 m or less). On the other hand, mangrove forests are rivaling the splendor of their terrestrial counterparts in favorable situations, such as within tropical estuaries of Indonesia, Nigeria, and Brazil, which are characterized by dense forests and canopies of 30 m or more (UNEP 2014).

Mangrove forests are regarded as tough plants all around the world because of their capacity to endure in highly salinized waterways and low-oxygen soils. Mangroves are also resilient. However, they can only be found in tropical and subtropical regions and cannot withstand cold temperatures (Giri et al. 2010). Mangrove forests are found in over 123 nations around the world, with Asia having the highest percentage (42%) and Africa having the second-highest percentage (21%) after North and Central America (15%), Oceania (12%), and South America (11%) (Giri et al. 2010).

Mangrove forest mapping and monitoring aid in determining loss rates and implementing protective measures. Due to the logistical challenges involved in trying to enter mangrove swamps, it is impossible to achieve these mapping objectives using solely conventional field surveys. Mangrove mapping methods and remote sensing data have developed over time. When combined with GIS, satellite data has many advantages for monitoring and mapping mangroves. This data can provide as a source of current, accurate information that can be utilized to map the extent and distribution of mangroves. Maps showing the distribution and range of mangrove species are also important for comprehending the system's overall ecology and can serve as a baseline for monitoring changes to decrease the effects of anthropogenic activities and climate change.

Mangroves are typically located in difficult-to-reach locations, are patchy, do not occur as a continuous forest, and are typically restricted to low-energy lower environments. The traditional method of mapping and eradicating the mangroves distribution in both the northern and southern Egyptian Red Sea coast is fielding surveying. In comparison to fieldwork surveys, remote sensing and GIS techniques can give multi-temporal satellite data that can be used to identify, evaluate, track, and map mangrove forests (Fig. 2).

Environmental and economic importance of mangrove habitat

According to a 2014 UNEP report, mangrove ecosystems provide a variety of benefits to humankind in the economic, social, and environmental spheres. The classification of these ecosystem services has been undertaken using a variety of classification schemes. Mangrove ecosystem services can be classified into three primary areas, including: (a) provisioning services (the items that humans obtain from ecosystems, such as fuel wood, food, and timber); (b) regulating and supporting services (including regulation of ecosystem processes, our climate, and the maintenance of healthy coastal ecosystems); and (c) cultural services (including nonmaterial supports people get from visiting or using the mangroves including for spiritual or religious practices, with cultural inheritance and entertaining services). Mangroves are frequently seen as muddy ecosystems that encourage the spread of illnesses. When mangroves are threatened or have deteriorated, it has an adverse effect on the people who live alongside Egypt's marine ecology. Mangrove fish and shellfish are typically thought of as the primary sources of protein, boosting the economy and quality of life for coastal communities. Mangrove forests serve as a coastal defense and offer housing through the materials that may be taken from the forests and utilized for construction, support,
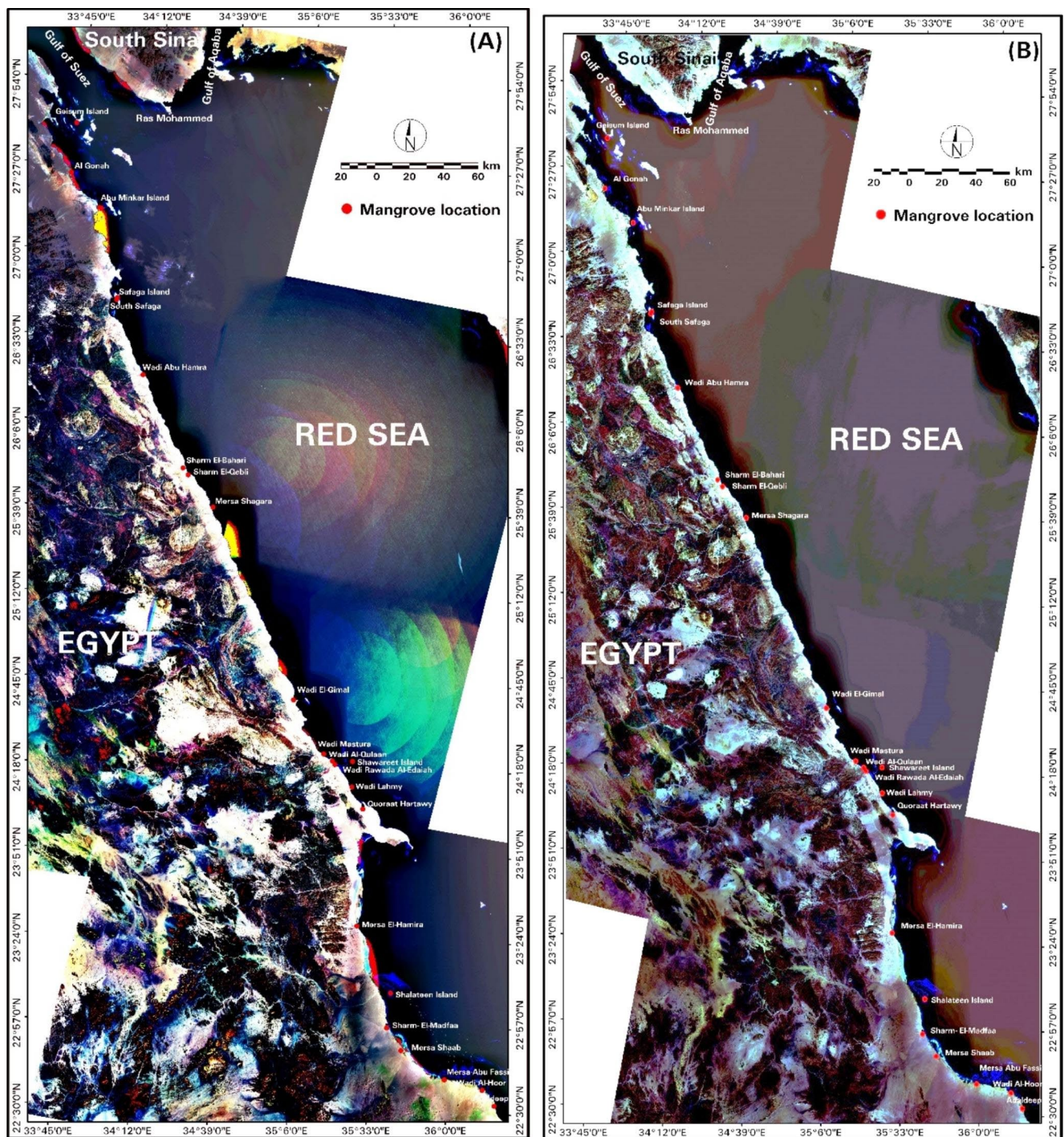
Fig. 2 Multi-temporal Landsat satellite data of TM (**A**) and (**B**) OLI, dated 1984 and 2021 respectively, showing the mangrove distribution along the Egyptian coastal land

and tiling. They are crucial for the safety of communities. Changes in services that are regulated, such as those that control our climate and safeguard coasts from erosion and storm damage, have a significant impact on security.

Mangrove habitats that are in good health are dynamic ecosystems that benefit both marine and human life. As a

barrier between the mainland and the water, mangroves serve one of their most important and beneficial ecological roles. These woodlands typically face the front of severe ocean weather and storms because of their unusual location. Mangrove environments' dense root systems work to halt erosion by slowing down inbound waves and deceiving

material as it is transported from the land and into the ocean. This not only prevents the ground from deteriorating, but it also prevents coral reefs from being covered by an overabundance of twisted debris. Additionally, a variety of fish, mollusc, and crab species can find habitat in mangroves. Mangroves are a desirable ecoregion for migratory and breeding birds, tigers, monkeys, and crocodiles because of the abundance of life they support and the refuge their roots provide. A variety of plant species also mature here, such as orchids, which draw a large number of honeybees (Spalding et al. 2010). Mangroves play a crucial role in protecting people and property from storm flows in lowland coastal areas, which are likely to increase because of climate change. Additionally, they establish secure shorelines and restore water value. Mangrove habitats are crucial because they provide a variety of fish, shellfish, and other animals with breeding, feeding, and rearing grounds. Mangrove environments support about 75% of game fish and 90% of commercial species. Mangroves are home to a variety of fish and fauna, including wading and sea birds like the brown pelican and great white heron that build their nests there (The National Wildlife Federation 2022).

Mangrove environments are essential to humans as a supply of timber, fishing, and tourism, as was previously determined. Mangrove wood is highly regarded in the timber industry because it resists rotting and insects. Local communities also rely on mangroves as a supply of building materials, cooking, and heating oil, animal food, and pharmaceutical plants (Spalding et al. 2010); for instance, applications of mangrove in traditional medicine where mangroves have a long historical connection with human culture and civilization. Mangrove extracts and species that depend on them have demonstrated antimicrobial effectiveness against human, animal, and plant infections (Premanathan et al. 1992, 2008). Mangroves have a rich history

Fig. 3 General view for one of the biggest habitats of Mangrove Forest at Sharm Elsheik

of knowledge about plant-based medicines that may be used for both therapeutic and preventive medicine. There are several nations that are well suited for the creation of medications made from medicinal plants. These plants are extensively grown in the wild and are specifically used in local drug stores. Some of these plants produce priceless pharmaceuticals with a significant export market. Since the beginnings of human civilization, plants and compounds from plants have been used as medicines. Traditional therapies have long used mangrove plants, and extracts from several of these species have been shown to have efficacy against infections that affect people, animals, and plants. Several mangrove species produce bioactive substances that might inhibit microbial development. Mangrove extracts have the potential to be sources of antiviral, antifungal, anti-cancer, and anti-diabetic compounds, as well as mosquito larvicides. Mangrove habitats are estimated to have an annual economic worth of $80,000 to $360,000 per acre (The National Wildlife Federation 2022). Mangrove loss will have a significant financial impact on both fisheries and residents along the beach. Mangroves have demonstrated to be a precarious source for preserving human lives in many developing nations by lowering wave heights and wind velocity during coastal storms (The National Wildlife Federation 2022).

Study area and methodology for analyses

Mangrove forests are made up primarily of *Avicennia marina* and *Rhizophora mucronata* and growin around twenty-eight stands covering about 525 hectares along the Egyptian Red Sea coast on both the Gulfs of Suez and Aqaba (Gab-Allah et al., 2010). While a few mixed stands of *Rhizophora mucronata* and *Avicennia marina* dot the southern Egyptian Red Sea coast, Afefe (2014) reports that mangrove forests in Egypt encompass almost seven hundred hectares and have a floristic structure dominated by monospecific stands of *Avicennia marina*. On the other hand, there are more records for the mangrove forests in Egypt that are considerably different from those recorded by Afefe (2014) and Gaba-Alla et al. (2010), which state that the Egyptian mangroves cover approximately 550 hectares (PERSGA, 2004) However, PERSGA (2004)'s detailed discussion of the mangrove distribution in Egypt considers them to be discrete belts of vegetation that serve as a forest structure (Fig. 3). Mangroves are scattered along the Red Sea's shoreline in protected bays and lagoons shielded by coral reefs, protecting the surrounding land as well. Geographically speaking, the mangroves of Egypt can be divided into the Sinai mangroves and the mangroves that grow along the Egyptian-African Red Sea coast. The mangrove forest in Sinai is centred around five

main areas, the first of which is near Ras Mohammed and is dominated by the *Avicennia marina*. The four other places, which are all along the alluvial fan of Wadi Kid that continues to the north of Nabq Oasis, are thicker, and include: Mersa Abu Zabad, Shura Al-Gharqana, Shura Al-Manquata, and Shura Al-Rowaisseya.

The Sinai mangroves have experienced cutting and contamination due to an overabundance of residential solid waste. A buildup of oil pollution from previous accidents was reported to be stressing the mangroves near Ras Mohammed (Baldwin et al. 1988). Recent field investigations found many small tarmac mats in the area, buried beneath the soft topsoil. Between latitudes 27° 40'N and 22° 33'N, twenty-three sites, small patches or combinations of stunted *Avicennia marina*, have been recorded based on Galal (2003) and cited by PERSGA (2004) (Table 1).

In order to detect, monitor, and assess how the distribution of mangroves is changing, as well as the key environmental and human impact elements required for mangrove development and conservation, it is vital to use remote sensing and GIS methods (Vo et al. 2013; Elsebaie et al. 2013; Jia et al. 2015; Thomas et al. 2018; Xia et al. 2018).

Table 1 The latitude and species names of Twenty-three localities of mangrove along African Red Sea costs by Galal (2003) and cited by PERSGA (2004)

Name of location	Latitudes	Species type/ Forest
1-Geisum Island	(27° 40'N, 33° 42'E)	*Avicennia marina*
2-Al Gonah	(27° 24'N, 33° 41'E)	*Avicennia marina*
3-Abu Minkar Island	(27° 13'N, 33° 52'E)	*Avicennia marina*
4-Safaga Island	(26° 45'N, 33° 59'E)	*Avicennia marina*
5-South Safaga	(26° 38'N, 33° 59'E)	*Avicennia marina*
6-Wadi Abu Hamra	(26° 21'N, 34° 09'E)	*Avicennia marina*
7-Sharm El-Bahari	(25° 52'N, 34° 24'E)	*Avicennia marina*
8-Sharm El-Qebli	(25° 50'N, 34° 26'E)	*Avicennia marina*
9-Mersa Shagara	(25° 40'N, 34° 35'E)	*Avicennia marina*
10-Wadi El-Gimal	(24° 40'N, 35° 05'E),	*Avicennia marina*
11-Wadi Mastura	(24° 23'N, 35° 16'E),	*Avicennia marina*
12-Wadi Al-Qulaan	(24° 21'N, 35° 19'E),	*Avicennia marina*
13-Wadi Rawada Al-Edaiah	(24° 20'N, 35° 20'E)	*Avicennia marina*
14-Shawareet Island	(24° 21'N, 35° 26'E)	*Avicennia marina*
15-Wadi Lahmy	(24° 13'N, 35° 26'E)	*Avicennia marina*
16-Quoraat Hartawy	(24° 06'N, 35° 30'E)	*Avicennia marina*
17-Mersa El-Hamira	(23° 29'N, 35° 29'E)	*Avicennia marina*
18-Shalateen Island	(23° 08'N, 35° 41'E)	*Avicennia marina*
19-Sharm- El-Madfaa	(22° 57'N, 35° 40'E)	*Avicennia marina*
20-Mersa Shaab	(22° 50'N, 35° 45'E)	*Avicennia marina* and *Rhizophora mucronata*
21-Mersa Abu Fassi	(22° 41'N, 36° 00'E)	*Avicennia marina*
22-Wadi Al-Hoor	(22° 38'N, 36° 13'E)	*Avicennia marina* and *Rhizophora mucronata*
23-Adaldeep	(22° 33'N, 36° 17'E)	*Avicennia marina*

Mangroves scattered spatially over the Red Sea coast of Egypt, have decreased drastically over the past 40 years, and can be attributed to development and human activities along the coast (Fig. 4). Climate change, environmental degradation, rapid urban, industrial, and tourism growth, as well as Bedouin grazing that completely devastated and decreased the size and quantity of mangrove sites, have all put these at risk (Fig. 5). Therefore, it is essential to assess, monitor and implement conservation management of the remaining mangroves sites and plant mangroves along the Egyptian Red Sea coastal area.

The main qualitative information supporting this research was gathered by the authors during field trips to the mangrove stands along Egypt's Red Sea coast from Shalateen and Halaib in the south to Ras Mohammed in the north. The information sources for the research were divided into primary and secondary sources, with the former relying on field trips and semi-structured interviews and the latter on papers, reports, books, etc. In addition to this multi-temporal satellite data used is represented by seven full scenes of each TM + 5, and OLI + 8 and TIRS + 8 images, scene numbers (path/row = 174–41, 174–42, 173–42, 173–43, 172–43, 172 − 44 and 172–45), dated 1984 and 2021 respectively captured in the summer season in June.

The mosaic of Landsat images was enhanced using ERDAS imagine 2015 software, and ArcGIS 10.8 software with spatial resolution of thirty meters. The atmospheric correction was completed to reduce the effect of noise. The multi-temporal remote sensing data was radiometrically and geometrically corrected to reduce the uneven sensor reaction over the image, and to correct the geometric distortion of the satellite image (Arnous and Green 2015; Moubarak et al. 2021). Image enhancement, including contrast stretching, selection of the optimal band combination, Principal Component Analysis (PCA), and change detection were used to produce high spectral resolution images required to detect and monitor the mangrove distribution along the Egyptian coastal land. These were used to prepare the initial mangrove maps to show the locations of the study sites and the mangrove management plan. In addition, the altitude was recorded for each site to use as an ecological gradient. Furthermore, for screening the threat of rapid coastal sustainable development and human activities to the mangrove localities along the coastal zone of Egyptian Red Sea from 1984 to 2021.

Results and discussion

Many academics - from various countries - are particularly interested in mangrove topics, and a significant quantity of literature has been produced on mangroves in general and

Fig. 4 Showing the threat of rapid coastal sustainable development and human activities to the mangrove localities along the coastal zone of Egyptian Red Sea from 1984 to 2021 as; urban and tourism activities in South Sinai such as Sharm El-Sheikh and Al Gonah (**A & B**); decrease and destruction of wide areas of the mangrove forest for animal feeding along camel trade roads of Shalateen area and tourism activities (**C & D**); and the threatened of natural impact such as flash flooding, coastal and soil erosion or human impacts as established desalination plant and other human activities along the Red sea coastal zone (**E & F**)
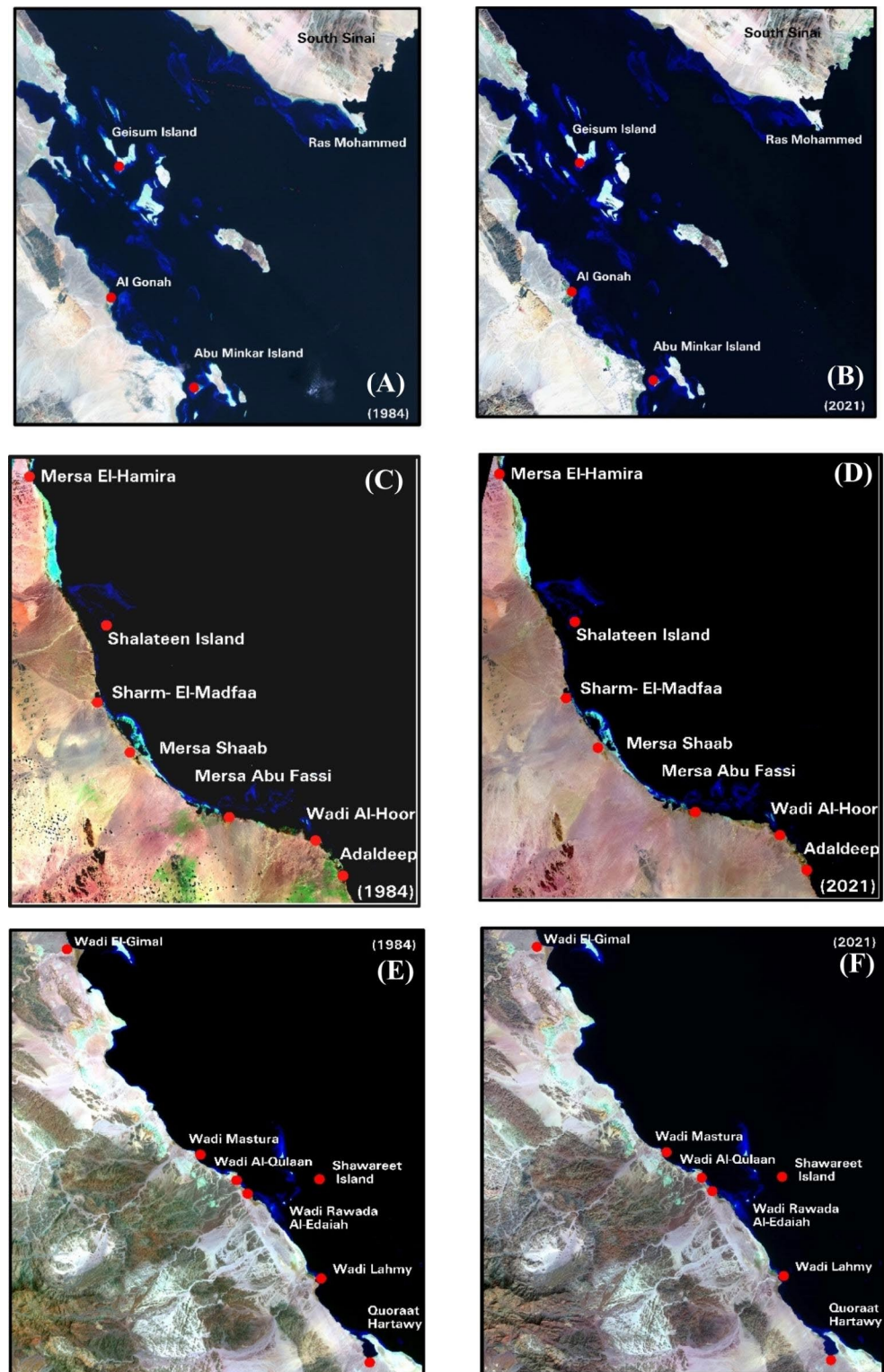
mangrove ecosystems (14,741) (Sharma, 2017). About half of these papers were in the fields of ecology, environmental sciences, and marine freshwater biology. Additionally, close to 50% of mangrove studies are extensive and involve a variety of specialized fields like physiology, climate change, production, water quality, pollution, and carbon dynamics (Sharma, 2017).

The impact of climate change on Egypt's mangrove forest is a concern of the current review. Even though approximately 1053 papers have examined the effect of climate on

Fig. 5 Mangrove subjected to human disturbance and fragmentation the natural habitats

mangroves worldwide (Sharma, 2017), this issue is still crucial given the importance of mangroves to the global economy. In truth, the world's mangrove supply has decreased due to a variety of factors, including the demands of population growth, food production, industrial and urban development, and wood chipping.

Mangroves are one of the world's most threatened tropical and subtropical ecoregions and 35% of mangrove habitats have already suffered damage (Fig. 5). In marine ecosystems, mangroves are being lost more quickly than rain forests, and forest areas are regularly being destroyed to provide space for large-scale urban development projects as well as good agricultural land. Over harvesting also results from the mangrove wood's widespread use in the wood industry. When trees are removed too soon, they cannot regenerate, which results in a decline in the area covered by mangroves. Mangroves are harmed by energy infrastructure along rivers and other waterways. Dams and other similar constructions restrict water from reaching the shoreline, causing the estuary's salinity to rise above acceptable limits. Further inland, deforestation causes more erosion and leads to more settlement of silt, which eventually reaches mangrove forests, thereby burying the root systems (Spalding et al. 2010).

Mangroves are under numerous pressures, including: (a) over harvesting when mangrove trees are exploited for fuel, building timber, wood chip and pulp manufacturing, charcoal production, and animal feeds; (b) natural hazards such as storms, root obstruction from larger water turbidity, and destruction from boring organisms and parasites; (c) clearance of regions where mangrove forests were previously thought to be infertile and offensive being removed to make way for industrial sectors, human settlements, and infrastructure (such as harbours), and more recently, where land has been cleared for salt farms, crab aquaculture, and coastal development; (d)oil pollution can suffocate mangrove trees and restrict mangrove roots, while fertilizers, pesticides, and other harmful man-made substances transported by river systems from sources upstream can kill species living in mangrove forests; (e) the global overfishing catastrophe affecting the oceans has impacts that extend far beyond the overfished population; such as provision of the initial line of defense against powerful waves and currents provided by coral reefs; stronger than usual waves and currents along the shore eroding the fine sediment that mangroves grow on when they are destroyed, hindering the germination of sprouts and washing away of the nutrients crucial to the health of mangrove ecosystems; and (g) the amount of water that reaches mangroves is often reduced by dams and irrigation along rivers, which changes the salinity of the water in the forest. The mangroves cannot survive if the salinity rises too high and mangroves may dry up because of changes to the freshwater environment. Additionally, the amount of sediment in rivers may significantly rise because of greater destruction brought on by land deforestation. This might surpass the mangrove forest's ability for sieving, which would overwhelm the vegetation.

The health of mangrove environments is also seriously threatened by contaminants and climate change. The fertilizers and pesticides used on agricultural lands and the pollution from urban areas frequently flow into waterways and accumulate in mangroves. Both the trees and the other flora and wildlife in these ecosystems suffer because of this. Global sea levels are rising because of climate change, which also affects the health of mangrove habitats. For these eco-regions to survive, water levels must be steady (Spalding et al. 2010). The most significant risks to these ecosystems are the changing salinity and rising sea levels. Mangrove damage from stronger wave action is anticipated to rise where coral reefs that once sheltered mangroves have been lost by climate change. Along the beaches of the world, climate change is having two main effects. Sea levels are increasing, and the ocean's chemistry is changing (IPCC 2007, NRC 2011). It is conceivable that the rates at which these effects are occurring will outpace the capacity of mangrove forests and the organisms that inhabit them to adapt (Gilman et al. 2008). Mangroves cannot move inland in regions where highland coastal development is present. Mangroves all throughout the world have evolved to tidal regimes. If they are submerged for an increasing amount of time, they eventually will not be able to get rid of the ocean salt quickly enough and will wither and die. Additionally, they will not get the nutrients and sediment from freshwater flowing toward the sea that they need to survive. Increasingly, crabs, oysters, sea stars, and snails, which have shells and other hard structures, will have a harder time absorbing calcium carbonate from marine water as the ocean gets more acidic, resulting in developmental abnormalities and thin, less protective shells in adulthood (Doney et al. 2012). Corals are already being harmed by rising acidity and stressed by rising temperatures and bleaching (Hoegh-Guldberg et al. 2007). Many species, including many of those used in commercial fishing, rely on both mangrove environments and reef habitats at various stages in their life cycles. These environments, which are important for supplying food to billions of people worldwide, are directly threatened by climate change. 30–80% of commercial fisheries throughout the world depend on mangroves for their vital nursery and mature habitats (Rönnbäck 1999). Finally, mangroves are one of the most important carbon sinks on the planet (Donato et al. 2011). According to Donato et al. (2011), the loss of mangrove forests will result in higher carbon emissions, creating a positive feedback loop that will accelerate sea level rise and increase ocean acidity.

Nevertheless, according to Feller (2017), mangrove forests are one of the most endangered ecosystems in the tropics as a result of anthropogenic effects on mangroves, such as conversion to aquaculture and agriculture, urbanization, and pollution (UNEP 2014). In addition, they claimed that the susceptibility of mangroves is caused by stressors related to climate change, such as sea level rise (Lovelock et al. 2015), where changing environmental conditions push mangroves above their species' tolerance limits. Regarding the present global extent of mangrove areas, there is still a great deal of uncertainty. The current size of mangrove regions is estimated by Spalding et al. (1997, 2010) to be between 181,077 and 198,818 km^2 but concede the difficulties in making these estimates.

Conservation plan for protecting mangroves in the Egyptian red sea

For the aforementioned 'hot spot' mangrove areas, multi-temporal remote sensing mosaics were created. Each image of a particular site - between the years 1984 and 2021 - includes details about the environmental effects of the hot-spots located near the Egyptian Red Sea's coast. The data from these hot-spot regions (Table 1; Figs. 3 and 4) help to clarify the following points.

The following question might be posed: Why did the mangrove forest areas along the South Sinai coast grow while those along the Red Sea coast shrank? The answer to this question cannot be determined statistically, but according to Prof. Zahran, a former executive manager of the ITTO project, who observed the situation firsthand, unchecked human interference and impacts are the main causes of the decline of the mangrove forest along the Red Sea coast. The opposite is true.

Since there are few locals in the mangrove swamps of the South Sinai and they are aware of the value of these woods, they do not let their cattle graze on the leaves of A. marina constantly. Additionally, they just lightly chop the wood of the mangrove trees. In addition, the South Sinai mangrove forest sites are governed by rangers from the South Sinai Protectorate because they are among the popular coastline locations for the thousands of tourists who visit the Sharm El-Sheikh resort (EEAA). Ranger duties include protecting the mangrove habitat from any intrusion by tourism-related activity. On the other side, the situation is different along the Egyptian Red Sea coast, where camel commerce is concentrated on the southern part of the coast, particularly in the Shalateen area near the border with Sudan, in addition to the unrestricted logging. The Red Sea shoreline is the usual route taken by camel herds as they go from Eritrea and Sudan to Egypt. The only other food available to feed these creatures is mangrove leaves. Additionally, the construction of new tourist facilities along the Red Sea coast is causing extensive mangrove forest damage. Oil pollution has a devastating effect on the mangrove environment, killing numerous fish and other biota as well as mangrove trees.

We recommend the following to address this issue: (1) more in-depth research should be conducted with the goal of conserving, restoring, managing, and re-establishing Egypt's mangrove forests; (2) Public awareness campaigns for the local populace should be taken into consideration; (3) Supplying an alternative form of food for animals that are both local and temporary (camels); (4) Forbidding the construction of new resort hotels near mangrove forests; (5) Cleaning up the mangrove wetlands on a regular basis to remove any pollution, such as oil or trash; (6) To help the rangers of the Red Sea and South Sinai protectorates safeguard these priceless woods and strengthen their observation system; and (7) Assuming a scientific plan for the long-term improvement of Egypt's mangrove ecology. Such a programme could be implemented with the assistance of local, national, or international authorities.

All mangroves in Egypt are currently protected, and three important nurseries have been created to propagate mangroves: one in Safaga, one in Wadi El Gemal, and one in Nabq (South Sinai governorate). National and international non-governmental organisations have made contributions to Egypt through a variety of projects and programmes aimed at protecting biodiversity and managing mangroves sustainably while assisting local communities in mangrove zones. For instance, the Project of Valuation and Management of Mangrove Forests for Sustainable Use and Development in Egypt (2003–2005) secured the population of Egyptian Red Sea Mangroves and ensured their conservation and sustainable management. Studying the current situation of the biological environment and the social environment of the Red Sea shoreline in Egypt, with a focus on the full status of human impacts on mangrove habitat, is part of the research project "a study of human subsistence ecosystems in Arab (2009–2013)". Mangroves are a valuable yet limited resource in Egypt. The Egyptian government is aware of the relationship between coral reefs and the corresponding ecosystems, as well as the variety of products and services they provide, including the growth of ecotourism, which benefits the local and overall economies. Egyptians are creative and are trying their hardest to preserve and restore mangrove forests (FAO, 2022). The principal organizations are the Ministry of Agriculture and Land Reclamation (MALR) and the Egyptian Environmental Affairs Agency (EEAA) of the Ministry of State for the Environment (MSE). On the other hand, a number of other institutions, agencies, and groups are also interested in the nation's mangrove resources (FAO, 2022). Global nonprofits, governmental agencies, and organisations have joined forces to work toward maintaining and reestablishing these distinctive ecosystems in response to mangrove regions' significance. Twenty nations throughout the world have started restoration programmes by planting mangrove trees (mangrove world atlas). A number of international agreements and treaties have also addressed the preservation and reforestation of mangrove areas. The Ramseur Convention is one instance of this, which has 110 signatories and a mechanism to provide an additional level of protection to wetland ecosystems (including mangroves). In accordance with this arrangement, some 250 mangroves have been selected as accredited Ramseur sites. Marine Protected Areas are one example of other conservation decisions. Mangrove habitats are found in about 685 Marine Protected Areas around the world, enough to cover seventy-three nations and territories. These areas are protected by local, national, and international organizations that enforce fishing restrictions and development and exploitation bans that are known to safeguard the nearby ecosystem (mangrove world atlas). The lack of government funding frequently makes it difficult for residents to manage mangroves. Data about mangroves and their significance to the environment are similarly lacking in many parts of the world. Many cultures have implemented public education initiatives along with renovation initiatives to combat this (mangrove world atlas). The combined coastal zone management (ICZM) action plan for the Egyptian Red Sea was presented in a project financed by the Global Environment Facility (GEF). Numerous actions have been included in the ICZM outline for coastal areas, although mangroves are only covered through surveying and mapping mangrove zones. The MSE-EEAA and the Ministry of Agriculture and Reclamation (MALR), two mangrove-related entities, had no clear field engagement in the preservation and management of mangrove ecosystems. Therefore, to set up a local mangrove improvement programme focused on the management and sustainably organised mangrove ecosystem, the Government of Egypt enlisted the practical support of FAO. This work focuses on the goal of "directing studies and pilot projects on mangrove preservation, reintegration, and sustainable usage to collect experience crucial for the improvement and implementation of a national mangrove maintenance and development programme." Despite the study's many anticipated outcomes, its primary goal was to identify viable mangrove-based income-generating enterprises to boost the incomes of local communities while protecting the mangroves. Ecotourism and the proceeds from non-wood forest harvests are two examples of income-generating enterprises that must coexist with management initiatives. This could be done by: 1 Looking into existing and potential natural tourist attractions along Egypt's Red Sea coast; 2Investigating the viability of promoting ecotourism in mangrove regions and identifying potential sources of revenue for indigenous societies that are harmonious with the maintenance and sustainable use of mangroves; 3 creating a consultancy report that includes findings and references to assist the Egyptian government in implementing a local

development programme for the preservation, upkeep, and use that represents sustainable use of Egypt's mangroves; and 4 the survival of mangrove species, humans, and two other environments, such as coral reefs and sea grass beds, depends on the preservation of mangroves;

Summary and conclusions

The most significant elements directly affecting the distribution of mangroves, according to the current climate change scenarios, are an increase in temperature and a rise in sea level, which strongly suggests that these forests will spread. The growing body of evidence leads us to believe that mangroves will not only survive but thrive in some areas under the altered climatic conditions brought on by climate change. It is crucial for the current decision-making process - impacting the health of marine and coastal systems and their ability to sustain future generations - to understand how human activities and a changing climate are likely to interact and affect how these ecosystems supply their functions.

The studies analyzed in this review regarding the response of mangroves to global climate change revealed that, although there are areas where mangroves will suffer due to environmental changes, primarily in oceanic islands and deltas of several large tropical rivers, as well as those coastal sites enclosed by steep slopes that are at risk of being drowned by the advancing sea, in most regions mangrove area will increase responding to increasing sea level, decreasing rainfall, and salinity. Mangroves move further inland in response to shifting salinity and wave conditions in such environments, frequently at the price of other plant species and their capacity to expand their range to higher latitudes to benefit from warmer winter temperatures. Mangroves become more vulnerable because of human activities such as resource exploitation, river basin processes, and shoreline protection engineering projects, which are primarily intended to help people adapt to climate change. This reduces the options for mitigating the negative effects of climate change.

Mangroves' human-induced degradation is what needs to be addressed, according to adaptation choices to increase their resistance and resilience to climate change. As a result, reducing the risk of mangrove loss due to climate change will require regional monitoring to better understand how mangroves respond, as well as training and capacity-building programmes aimed at the public and decision makers to increase awareness of the value of goods and services provided by the mangrove ecosystem. As a result, the extent of human interference and how it interacts with climate change will be key factors in determining the future of mangroves.

In general, mangroves provide a variety of ecosystem products and services to people, which are together referred to as social, economic, and environmental welfare. In addition to goods like firewood, timber, and forest yields that continue to support the livelihoods of large numbers of people, it provides a crucial source of seafood. It also has a significant role in promoting human well-being, especially for those living close to the coast by facilitating access to necessities for health, safety, and positive social interactions. The most crucial aspect is that by absorbing pollutants, cycling nutrients, and sequestering and permanently storing carbon, mangroves help to protect water quality and control our climate. Due to human activity, big projects, climate change, and a decline in both population and covering area, the mangrove forest in Egypt is barely protected.

Finally, the study offers some recommendations based on the key findings, the primary causes of environmental climate change, and the effects of human activity. Due to this, it is therefore essential that decision-makers assume a sequence of informed activities about the following offered recommendations to allow the highest probability of resolution when the current environmental emergency eventually passes as:

1. Including information on mangrove area, health, and ecosystem service facility when building the geodatabase to enhance country-level data utilizing geospatial technology the need to assist and provide information for management and planning of land use is urgent.
2. Conducting change detection of the geographical distribution of mangroves to track, understand, develop, minimize, and adapt to any future environmental impact caused by climatic change and/or human activity.
3. To monitor and analyse the efficacy of management activities, including protection and restoration initiatives, mangrove health and geospatial distribution must be monitored and assessed.
4. It is necessary to conduct a number of interdisciplinary research to examine and quantify the ecosystem services offered by mangroves, including their function in carbon sequestration, and reducing coastal risk.
5. To ensure that mangroves are protected, it is crucial to evaluate the management efficacy of various legal restrictions and regulations. To prevent major future issues in these crucial mangroves hot spot locations, it is imperative that environmental planners and decision-makers seriously consider taking appropriate action immediately about the suggested mitigating measures.
6. Digital environmental atlas of Egyptian mangroves must be created and continuously updated to assist, guide, and enhance management choices that will help to preserve mangroves and raise public awareness.

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