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Degradation of mangrove forests and coral reefs in the coastal area of the southwestern region of Saudi Arabia

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SUMMARY

This study aimed to monitor the degradation of ecosystem biodiversity in one of the most diverse areas in Saudi Arabia. The coastal area of southwestern Saudi Arabia has a rich diversity of flora and fauna, particularly in mangrove and coral reef ecosystems. The total area covered with mangroves was approximately 40 km^2 at the end of the 1900s but decreased to approximately 19 km^2 by 2019. Coral reef decline was not as extreme, with a total decrease of approximately 330 km^2 during the study period. Total reef area declined from approximately 2533.7 km^2 in 1990 to approximately 2202 km^2 in 2019. Population growth and urban sprawl, as well as overfishing, are among the main factors causing the degradation of both mangrove and coral reefs in this region.

INTRODUCTION

Biodiversity loss is one of the most important environmental issues and has attracted international interest since the mid-1980s. The Convention on Biological Diversity (CBD), adopted at the 1992 UN Conference on Environment and Development in Rio de Janeiro, Brazil, was intended to stimulate and encourage governments to counteract rapid declines in the extent and condition of natural ecosystems, abundance of wild species, and benefits to humanity provided by nature (Sachs et al., 2009). Although biodiversity is described as a global issue, it is at times vulnerable to exaggeration and neglect because of the different ways in which environmental importance and biodiversity are assessed by local populations (Sparks et al., 2011).

Biodiversity loss challenges the benefits of development in many ways, leading to fewer

wild foods, reduced nutritional security, poor pollination, and less productive and resilient agricultural systems. Further, it can cause higher exposure to agro-chemicals, reduced access to traditional medicines, and lost opportunities for drug development, which can translate into higher disease burdens. Lost ecosystem services can even affect gender specific labour burdens (Roe et al., 2019)

Coral reefs and mangrove forests represent very important components of biodiversity in marine and coastal ecosystems. These systems play a vital role in environmental productivity and balance, yet are suffering from numerous negative physical and human-driven impacts. Mangroves, which include a variety of species, can grow in both tropical and subtropical intertidal zones and can adapt to muddy coastal tidal areas (Bengen, 2001).

Along the Red Sea coast of Saudi Arabia, mangroves grow as scattered groups that range from the southern border with the Republic of Yemen to Dhaba in the north

Mangrove forests are highly productive ecosystems on which millions of people in coastal communities depend, yet are being lost at a rate of 1% per year, which is twice that of terrestrial forests (Thomas et al., 2017). Mangroves play a critical role in coastal protection, both as nurseries and carbon sinks. However, due to various human and environmental impacts, the overall coverage of mangroves is declining on a global scale (Almahasheer et al., 2016).

Mangrove swamps are tidal swamps that are formed in the tropics and subtropics by the deposition of recent origin alluvial sediments and characterized by dense and fringing growth shrubs and trees. They are also referred to as mangrove forests or tidal forests (Knox, 2001). Only two species of mangroves are known to occur in the area*: Avicennia marina* (Forssk.), the most dominant and the only species on the mainland, and *Rhizophora mucronata* (Lam.), found only on the Farasan Archipelago (Mandura et al., 1987) (Figs. 1, 2).

Figure 1. *Avicennia marina* (Forssk.).

Figure 2. *Rhizophora mucronata* (Lam.).

Mangroves occupy the entire intertidal zone along the tropical and subtropical coastlines. They also play an important role in reducing coastal erosion, as many species have extensive cable root systems that assist in binding sediment particles (Nguyen & Luong, 2019). Mangroves are highly productive ecosystems with rates of primary production equal to those of tropical humid evergreen forests (Alongi, 2014). Healthy mangroves are a precious, almost priceless resource, and yet over the past 50 years, the world has witnessed staggering levels of mangrove loss and degradation. Mangroves can quite literally save lives during storms, and loss of mangroves

leads to loss of livelihood, food security, valuable timber production, coastal defence, and one of the most efficient and important carbon stores on the planet (Global Assessments of Mangrove Losses and Degradation: IUCN & Nature Conservancy, 2019).

Aptly named the rainforest of the sea, reefs are rocky marine structures (made of a combination of coral and a hard form of algae) that support one of Earth's most biologically diverse ecosystems. Although a large and inter-dependent life force relies on reefs for survival, they occupy a mere 0.2% of the world's oceans. Not only are these underwater habitats crucial to supporting the ocean's biodiversity, they are home to 25% of all marine species (Munn, 1998; Alexander & Fairbridge, 1999; Fletcher et al., 2008).

Thirty-two of the 33 known animal phyla are found on coral reefs, compared to nine in tropical rain forests (Reaka-Kudla, 1997).

Due to their unique complexity and diversity, coral reefs can provide food and livelihood opportunities for millions of people. They are vital for small–scale and artisanal fisheries, producing 10% of the world's fishing harvest. Furthermore, they support a wide range of organisms that may hold the key to future medical advances. They also provide services such as shoreline protection and recreational opportunities, making their importance for the economies of coastal communities and entire nations immeasurable (UNEP & WWF, 2003).

Some of the major threats to coral reefs include landfilling and dredging for coastal expansion, destructive fishing methods, damage by the recreational SCUBA diving industry, shipping and maritime activities, sewage and other pollution discharge, lack of public awareness, and insufficient implementation of legal instruments that affect reef conservation (Pilcher & Alsuhaibany, 2000).

Over 194 species of corals have been recorded along the Saudi Arabian coast in the early 1980s, with the greatest diversity recorded in the central portion of the kingdom (Persga, 2003). In the Arabian Gulf, reefs mostly appear as small pinnacles or outcrops, as patch reefs between Ras Al-Mishab Saffaniyah and Abu Ali and between Abu Ali and Ras Tanura, and as fringing reefs around the offshore islands. In 1998, patchily distributed and variable bleaching resulted in mass coral mortality in the central-northern Saudi Arabian Red Sea. The most intense bleaching occurred near Rabigh, wheres 65% of total coral cover was bleached or recently dead. Significant levels of coral mortality were also observed along the southern Red Sea (Pilcher & Alsuhaibany, 2000).

A clear shortage of documented scientific data about the habitats and life history of many species has trigged a "Knowledge and data crisis" in many Arab countries.

The coral reefs in our study area face two main types of degradation: loss of habitat quality through events such as bleaching (qualitative degradation), and the loss of total reef area along the coast (quantitative degradation). However, this study will be limited to the latter.

MATERIALS AND METHODS

Study Area

The study area encompasses the eastern coastline of the Red Sea for 1264 km as well as that of the Farasan Archipelago and Farasan Islands. The total study area is approximately 3995 km^2, The Farasan Islands cover an area of approximately 1050 km^2 with beaches reaching a length of approximately 300 km (Fig. 3).

Farasan Island is the largest of these islands with an area of approximately 369 km^2, which contains many aspects of biological richness. In most cases, the portion adjacent to the mangrove belt is low lying and forms a special kind of landform called Sabakha (Saifullah, 1996).

Figure 3. Inset map of the study area.

Data analysis

The current study uses satellite images from the Landsat series, where satellite imagery was used as follows:

- Five images from the Landsat 5 satellite, which carries a Thematic Mapper, were used from March and April 1990. The imaging consists of 7 spectral waves with a resolution of 30 m, with the exception of the sixth heat wave which has an accuracy 120 m. Table 1 shows the characteristics of this satellite.
- Five Landsat 7 (ETM +) images were used from the same months of the previous satellite in 2000. Table 2 shows the characteristics of this satellite.
- Five images were used from Landsat 8 satellite, which carries two scanners (OLI & TIR) from 2019, and the video consists of 11 spectral waves (Table 3).

Table 1. Landsat 5 Thematic Mapper (TM).

Bands	Wavelength (micrometers)	Resolution (meters)
Band 1 – Blue	0.45 - 0.52	30
Band 2 – Green	0.52 - 0.60	30
Band 3 – Red	0.63 - 0.69	30
Band 4 – NIR	0.76 - 0.90	30
Band 5 - Shortwave Infrared (SWIR) 1	1.55 - 1.75	30
Band 6 – Thermal	10.40 - 12.50	120
Band 7 - SWIR 2	2.08 - 2.35	30

Table 2. Landsat 7 Enhanced Thematic Mapper plus (ETM+).

Bands	Wavelength (micrometers)	Resolution (meters)
Band 1 – Blue	0.45 - 0.52	30
Band 2 – Green	0.52 - 0.60	30
Band 3 – Red	0.63 - 0.69	30
Band 4 – NIR	0.77 - 0.90	30
Band 5 - SWIR 1	1.55 - 1.75	30
Band 6 – Thermal	10.40 - 12.50	60
Band 7 - SWIR 2	2.09 - 2.35	30
Band 8 – Panchromatic	0.52 - 0.90	15

Table 3. Landsat 8 operational land imager (OMI) and thermal infrared sensor (TIRS).

Bands	Wavelength (micrometers)	Resolution (meters)
Band 1 - Ultra Blue (coastal/aerosol)	0.435 - 0.451	30
Band 2 – Blue	0.452 - 0.512	30
Band 3 – Green	0.533 - 0.590	30
Band 4 – Red	0.636 - 0.673	30
Band 5 – NIR	0.851 - 0.879	30
Band 6 - SWIR 1	1.566 - 1.651	30
Band 7 - SWIR 2	2.107 - 2.294	30
Band 8 – Panchromatic	0.503 - 0.676	15
Band 9 – Cirrus	1.363 - 1.384	30
Band 10 - Thermal 1	10.60 - 11.19	100
Band 11 - Thermal 2	11.50 - 12.51	100

The following flow chart shows the steps and procedures taken to analyze the satellite images and produce results with a high level of accuracy (Fig. 4).

RESULTS

Degradation indicators

Comparing the current state of mangrove forests in the Kingdom of Saudi Arabia to previous conditions indicates that mangroves are facing various sources of disturbance, which have negative effects on their growth, distribution, and quality. Some of these disturbances can be understood in the context of natural factors such as the movement of sand, but the vast majority are due to historic human exploitation (see El-Juhany, 2009).

Figures 5–8 show a general trend of decline. Total mangrove cover was reduced nearly from 39.1 km^2 in 1990 to 19.5 km^2 in 2019; the total loss of approximately area is about 20 km^2.

The total reef area also declined over the last three decades as shown in Figures 9–12 with the total area decreasing from 2533.7 km^2 in 1990 to 2454.1 km^2 in 2000 (82.2 km^2 loss). From 1990 to 2019, there has been a total loss of approximately 331 km^2 of reef area.

DISCUSSION

Degradation factors

Coastal communities worldwide are becoming increasingly vulnerable to a wide range of potential hazards including shoreline erosion, coastal inundation, and coastal resource degradation (Dadson et al., 2016). Recent estimates show that 1.2 billion people are living within 100 km of the shoreline at altitudes below 100 m, where population densities are approximately 3 times higher than the global average (Small & Nicholls, 2003).

Mangroves have been subjected to many threats resulting from the changing nature of the seashore due to excavation and backfilling. In the Farasan Islands, seaport construction required developments such as the establishment of a marina, a parking lot, and other construction projects. The necessary facilities associated with coastal recreation have had a negative impact on the mangrove environment (Nagi & Abubakr, 2013).

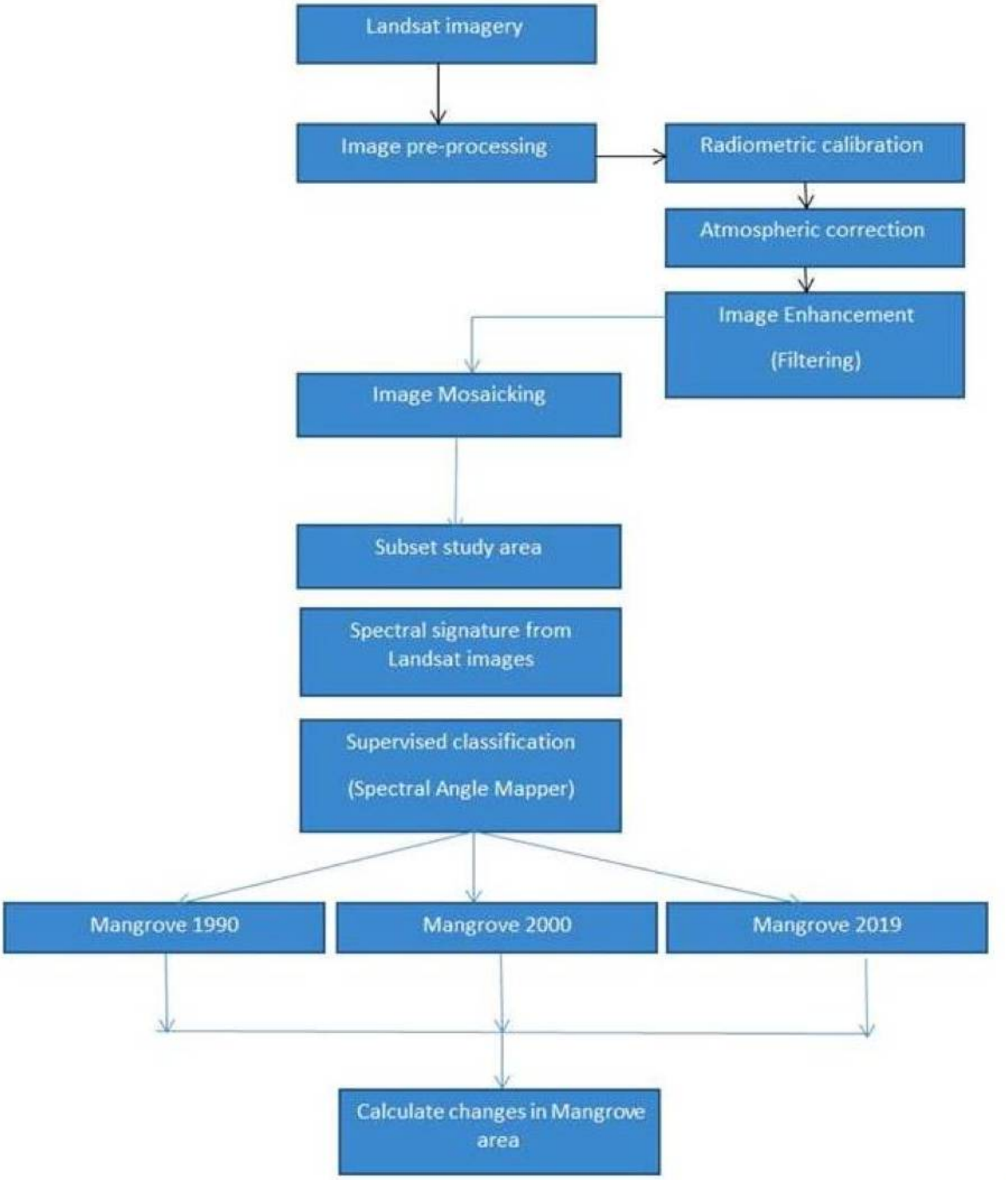

Figure 4. Steps and procedures taken to analyse the satellite images.

The causes of coral loss are even more difficult to decipher, due to the context-dependency of the many potential causal factors and the scarcity of data on nearly all putative drivers of coral mortality. This is especially true for local stressors such as sedimentation, nutrient inputs and concentration, fishing intensity, and chemical contamination (Bruno & Valdivia, 2016).

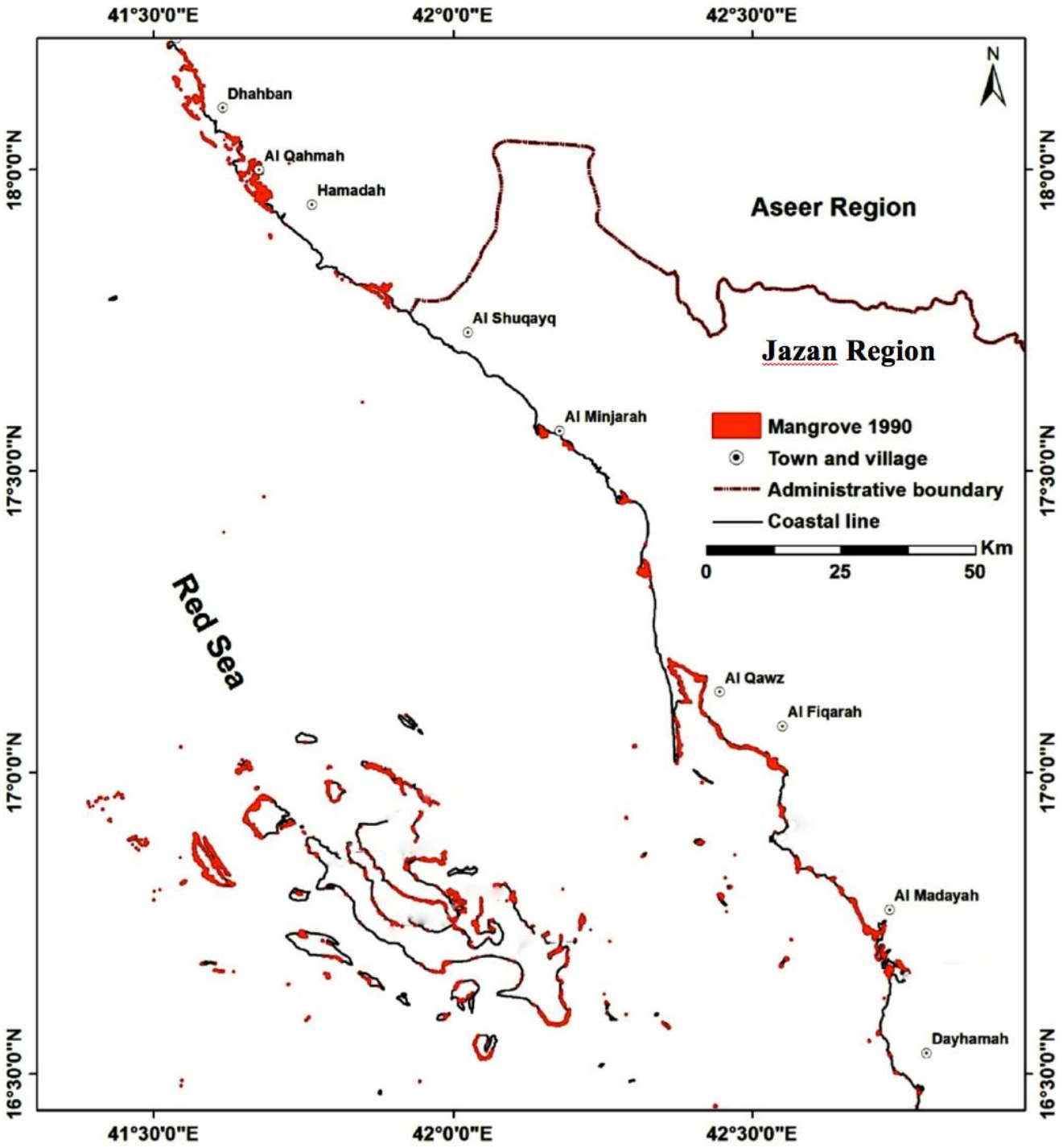

Figure 5. Area covered with mangroves in 1990.

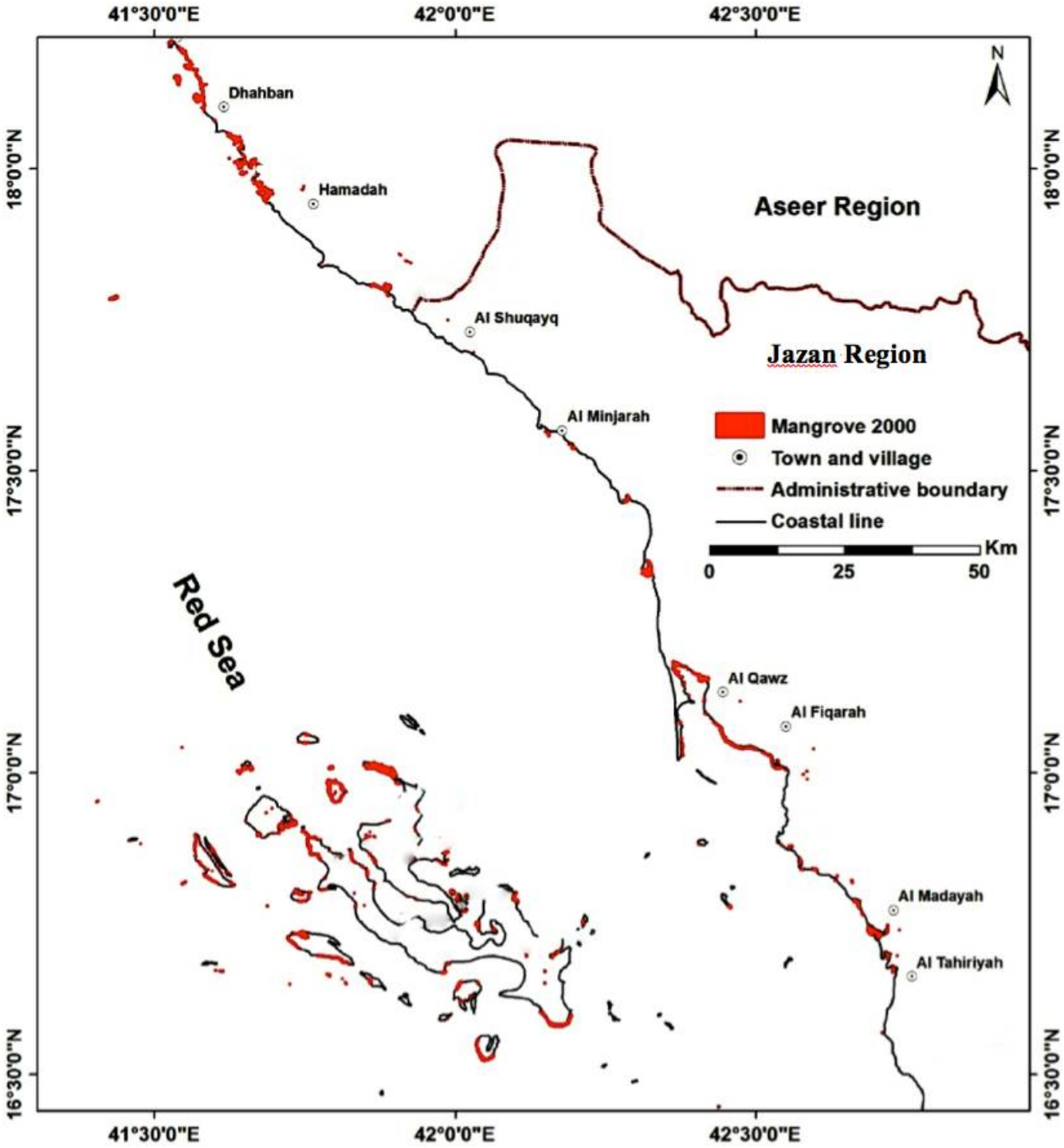

Figure 6. Area covered with mangroves in 2000.

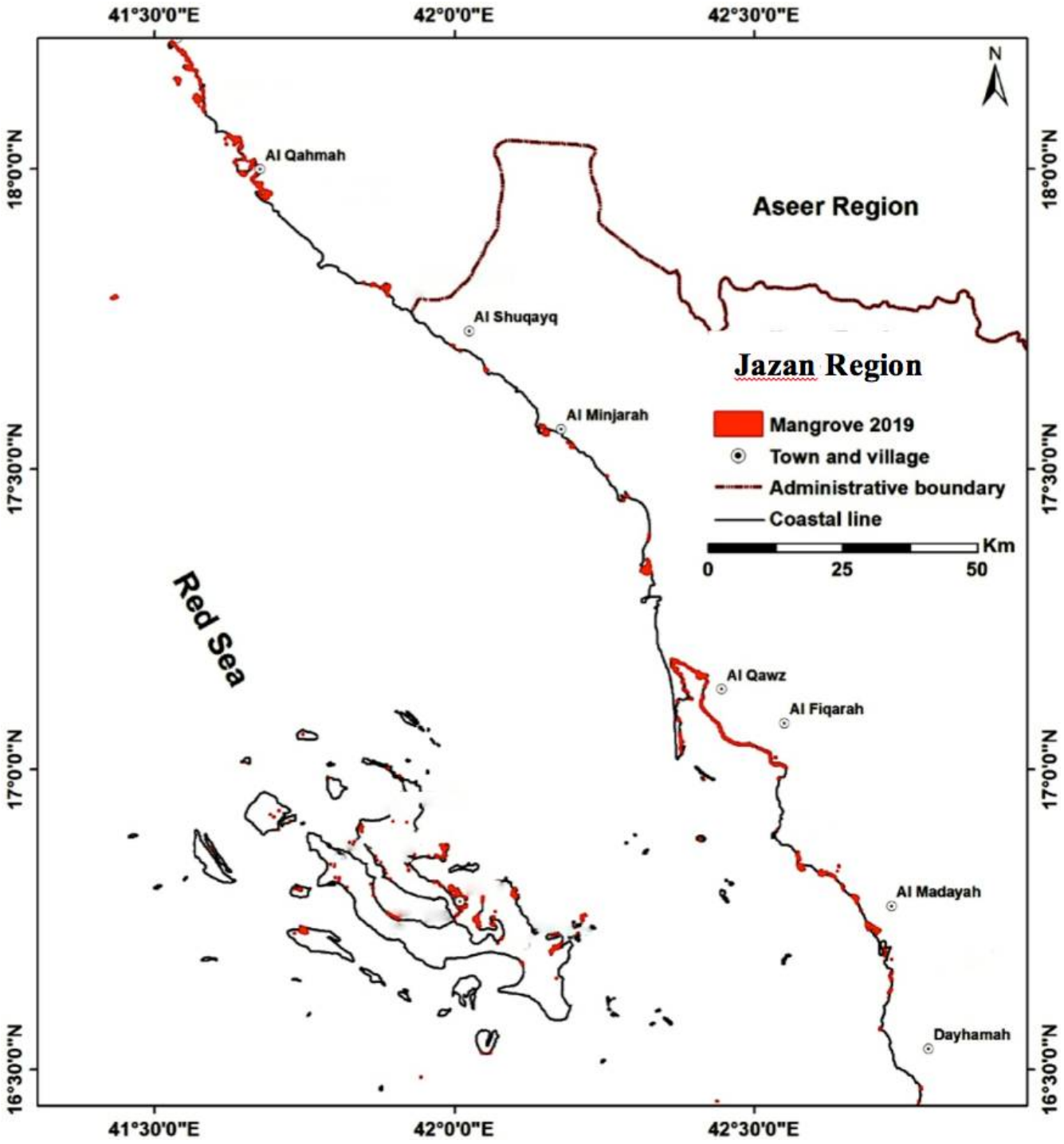

Figure 7. Area covered with mangroves in 2019.

It is worth mentioning that there are many factors involved in the degradation of mangrove and coral reef ecosystems (Saenger, 2003). It is therefore important to identify both natural and human-derived driving factors influencing degradation. In this study, we concentrate on the quantitative degradation of mangroves and coral reefs as we are primarily interested in identifying the influence of human activities on ecosystem degradation.

Mangrove forests are found in almost every warm coastal region of the world, but vast areas have been lost or degraded (IUCN & Nature Conservancy, 2019). Some have been cleared for short-term gains for agriculture or aquaculture, while others have been over-harvested for firewood, timber, or charcoal production, often by poor communities. In some places, mangroves have been lost to urban expansion and the development of coastal infrastructure, including roads and ports. The profits and benefits from loss and degradation are typically short term, and often only flow to a small number of people. These benefits are impeded by the losses, as coastal communities are deprived of one of the most productive ecosystems on earth (IUCN and Nature Conservancy, 2019).

Major threats to coral reefs include landfilling and dredging for coastal expansion, destructive fishing methods, damage by the recreational SCUBA diving industry, shipping and maritime activities, sewage and other pollution discharges, lack of public awareness, and insufficient implementation of legal instruments that affect reef conservation (Pilcher & Alsuhaibany, 2000).

Coral reefs need clear water free from pollution with low nutrients, and mangroves play an important role in this matter, as they prevent the arrival of excess nutrients that affect the status of coral reefs (Szmant, 2003). In this regard, mangrove decline has a negative, albeit indirect, effect on the state of coral reefs. We identified four driving factors causing the degradation of mangroves and coral reefs: developmental activities, urban sprawl, and marine pollution, Overfishing and fishing mismanagement.

A. Developmental activities

The study area experienced many developmental activities over the last three decades, which has permanently altered biological components of the marine ecosystem, a few are as follows:

- The northern and southern beach areas of Jazan city are expanding at the expense of the tidal range in which mangroves are grown. This has resulted in a clear decline in the total mangrove area at these sites, where areas of no less than 2 km^2 were removed to establish a recreational or service area (Fig. 13) or to hold motorcycle races (Fig. 14).
- The expansion and development of the port of Farasan resulted in the decline of mangrove extent as shown in Fig. 15.

Many mangrove plants are exposed to the process of drying and depriving the plant of water, thus paving the way for its death and preparing the ground for expansion, as shown in Fig. 16.

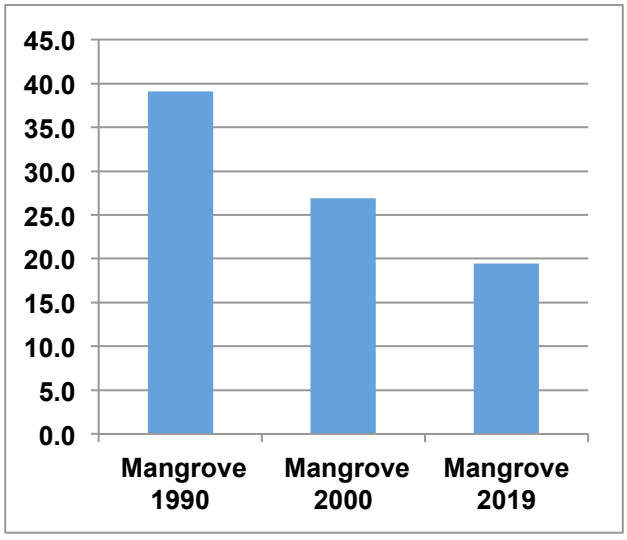

Figure 8. The percentage of coastal area covered with mangroves during the study period.

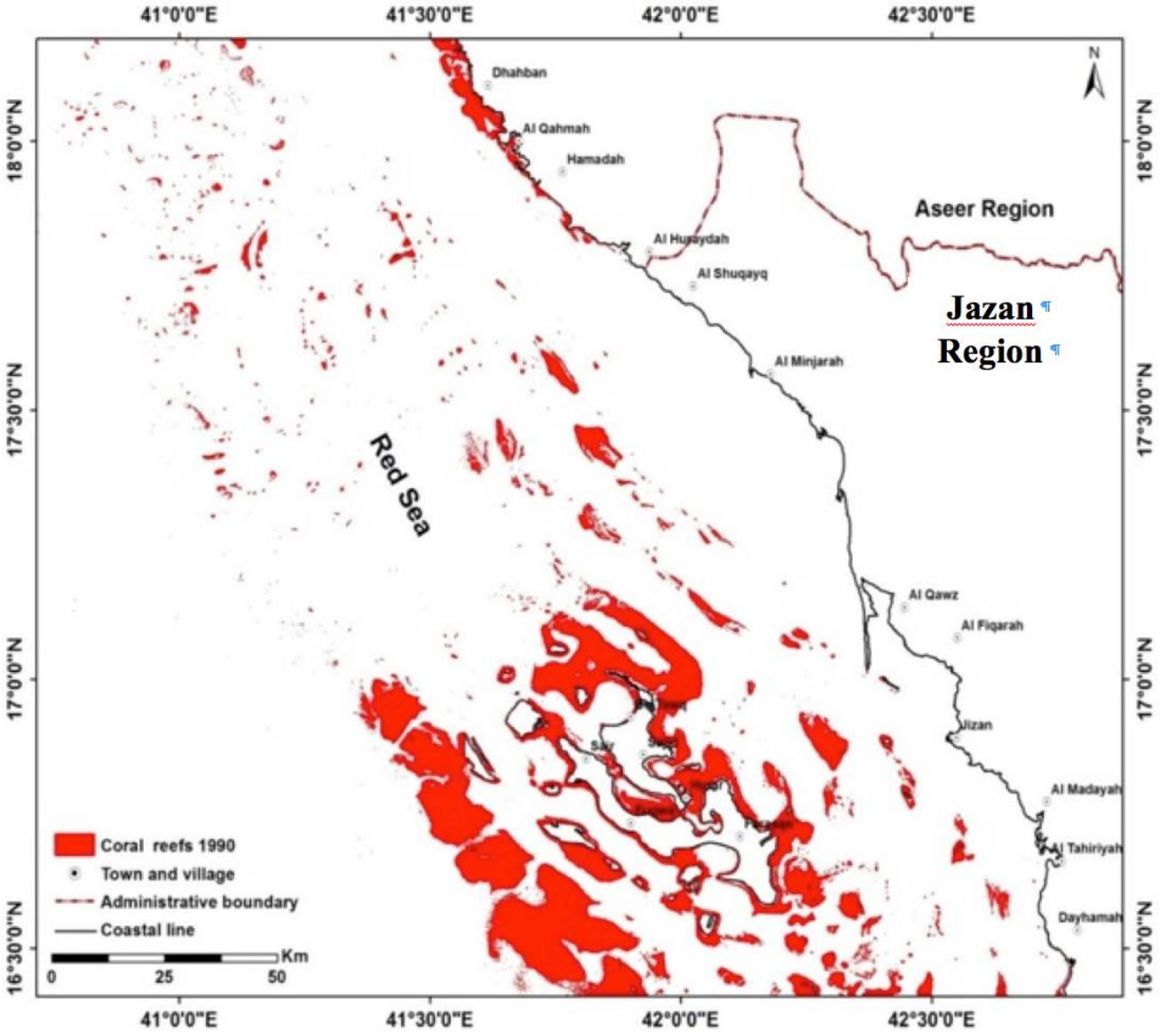

Figure 9. Area of coral reef in 1990.

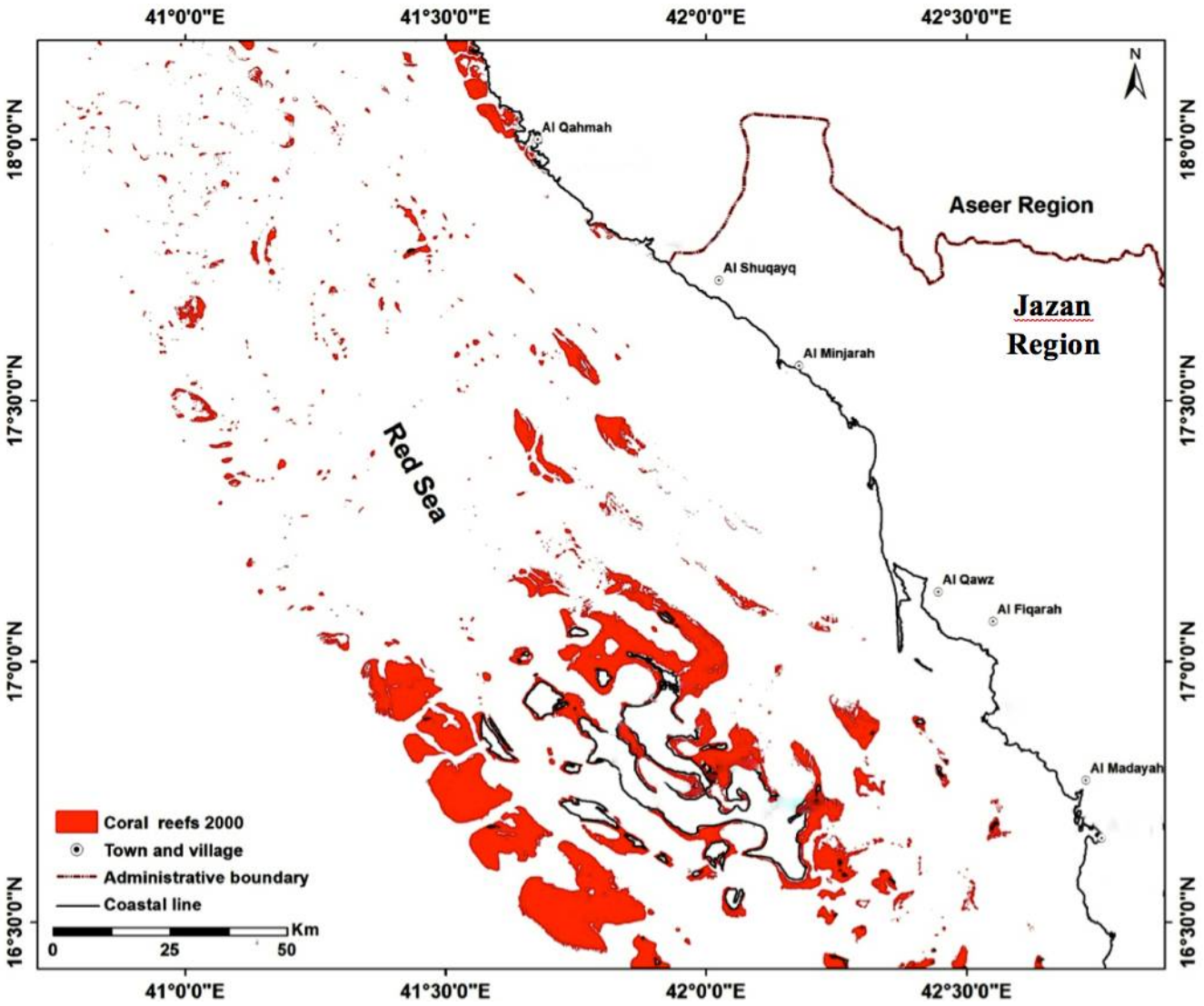

Figure 10. Area of coral reef in 2000.

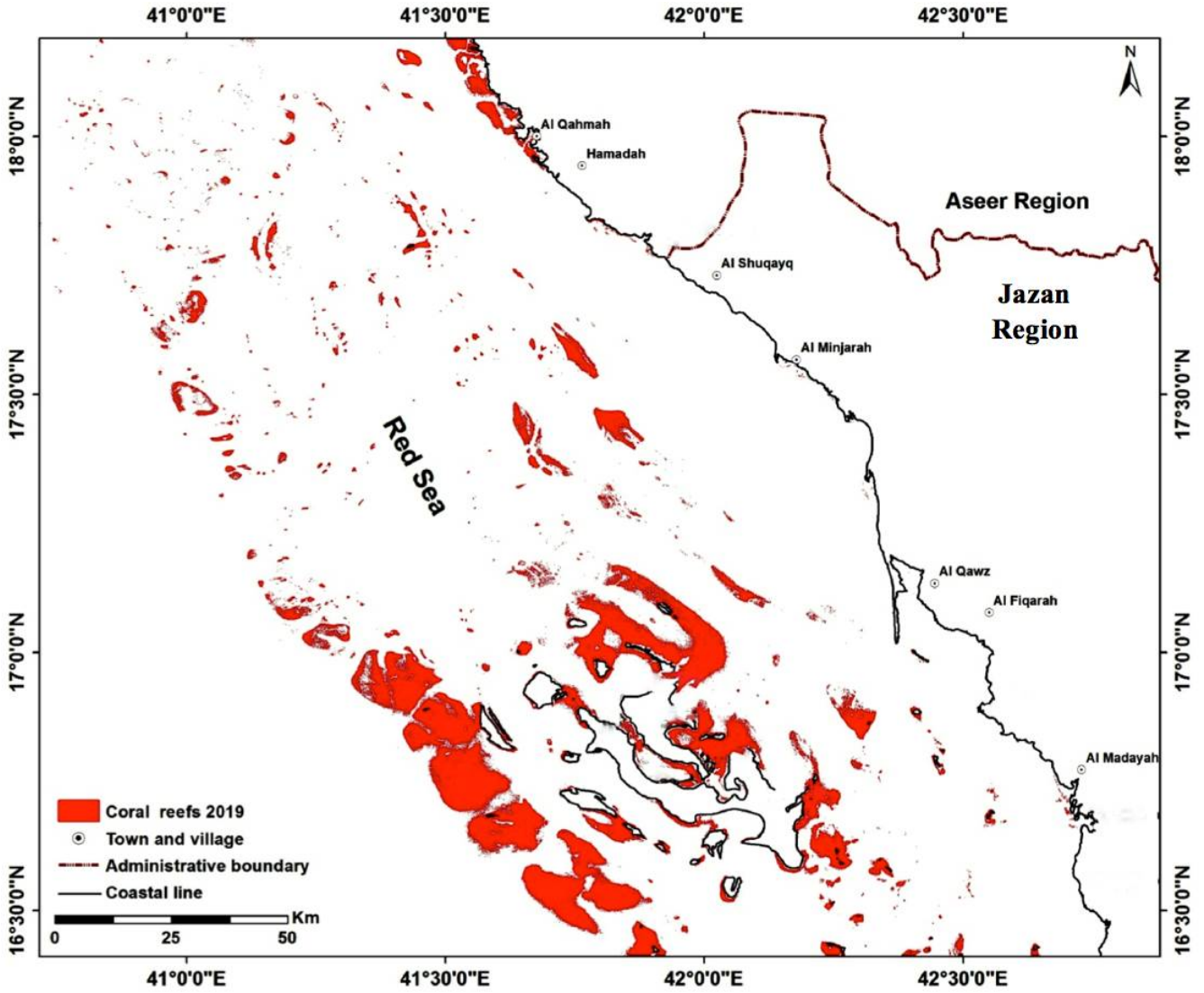

Figure 11. Area of coral reef in 2019.

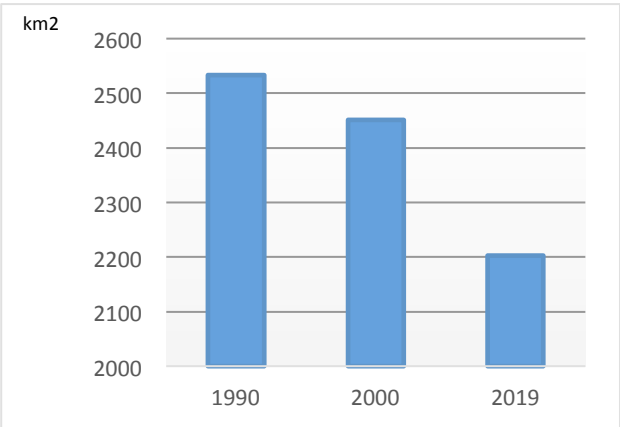

Figure 12. Extent of the area covered with coral reef during the study period.

Figure 13. The expansion of recreational services in Jazan north beach.

B. Urban sprawl

Urbanization is defined as "a multidimensional process that manifests itself through rapidly changing human populations and changing land cover" (Seto, 2013). Based on the analysis of satellite images, developed areas within the study region grew from 30.7 km^2 in 1990 to about 316.5 km^2 in 2016, indicating that the urban area increased over ten times (Fig. 17). According to evidence from terrestrial forests, deforestation translates to ecological effects by increasing the number of fragments and the length of edges (Blanco-Libreros & Estrada-Urrea, 2015).

C. Wastewater pollution.

Wastewater contains many constituents and impurities arising from diffuse sources (ICON, 2001). Water pollution can occur from two sources: point and non-point sources. Point sources of pollution include wastewater effluent (both municipal and industrial) and storm sewer discharge and affect mostly the areas in closest proximity. In contrast, non-point sources of pollution are those that arrive from different origins and in a number of ways, including the way in which contaminants enter groundwater or surface water and arrive in the environment from non-identifiable sources. (Valentukevičienė & Brannvall, 2008).

Coral reefs need clean water to thrive. From litter to waste oil, pollution is damaging reefs worldwide. Pollution from human activity inland can damage coral reefs when transported by rivers into coastal waters; hotels and resorts often discharge untreated sewage and wastewater into the ocean (Bryant et al., 1998).

The study area is exposed to the point source of wastewater pollution. Coastal plants, including mangroves, are generally degraded, qualitatively and quantitatively, at sites around the sewage plant in Jazan. Wastewater is discharged into the sea through a large pipe (Fig. 18), which creates high levels of pollution to water, wildlife and natural vegetation, especially mangroves.

Figure 14. Motorcycle race track on eroded mangrove field in Jazan.

Figure 15. The expansion and development of the port of Farasan resulted in the degradation of mangrove.

Figure 16. Drying mangrove preparing the ground for developmental projects, Farasan Island.

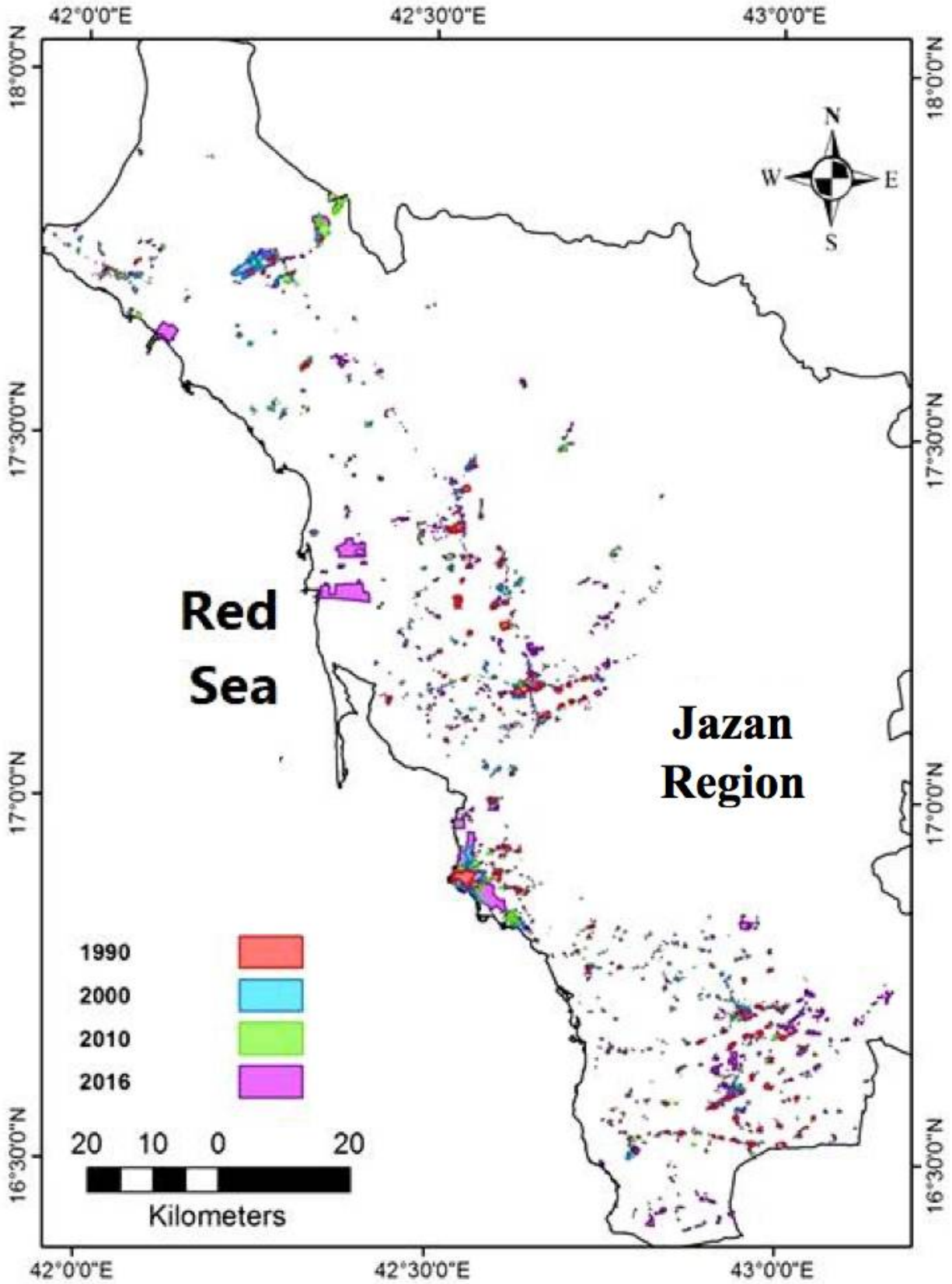

Figure 17. Development of the built-up area in the study area from 1990 to 2016.

Figure 18. Sewage flows between the mangroves of the coast of the Jazan region.

Some research suggests that sewage loading into mangrove swamps, which are known to be nutrient limited systems, can enhance the amount of available organic matter and nutrients leading to an overgrowth of both aerobic and anaerobic bacteria as well as of macroalgae, benthic diatoms, and larger trees (Meziane & Tsuchiya, 2002; Mohamed et al., 2008; Bartolini et al., 2011). However, what the author has observed through field work in this study area, wastewater pollution significantly reduced plant content (results not shown). Further, there is now a slippery black flat extending along the coastal area that receives wastewater, indicating that mangroves are no longer able to grow here.

D. Overfishing and fishing mismanagement

Increasing demand for fish has resulted in the overfishing of many reef species (Roberts, 1995). In addition, overfishing of certain species on or adjacent to coral reefs can affect the reef's ecological balance and biodiversity. For example, over-fishing of herbivorous fish can lead to high levels of algal growth (McClanahan, et al 2002).

Overfishing refers to the depletion of fish from our oceans by removing individuals beyond the point at which the population can continue to reproduce. If a species is continually overfished it runs the risk of not only extinction, but also unbalancing the oceanic ecosystem and putting other species at risk (Lanman, 2019).

According to our results, coral reefs in this study area are mainly destroyed by human encroachment through fishing and physical destruction. Fishing methods and tools in the area are used that destroy both the ecological environment as well as the physical reef structure during the fishing process itself. Further, reefs are degraded through the systematic truncation of these coral structures and their use for construction purposes.

CONCLUSIONS

According to this study, the coastal region in southwestern Saudi Arabia suffers from a clear decline in both mangrove and coral reef cover. As this research focused on the quantitative deficiency of both mangrove forests and coral reefs, a set of human-derived factors were identified as the putative direct causes of this decline. Among these, the most important factors are urban expansion, development and service activities, and associated landfill operations, as well as overfishing and pollution caused by wastewater.

Recommendations

Through the discussion and results of the current paper, we can speculate on the following recommendations that can contribute to improving the state of the marine environment in the study area, especially with regard to the protection of mangroves and coral reefs:

A - Conducting a comprehensive scientific study to determine the current status of living components (both plant and animal) to better predict their future status in light of the pressures and human encroachments on the region.

B - Working on urban expansion in the field of housing and services in mountainous areas and valleys - away from the risk of flash floods- as well as away from the coastal region

due to the consequences of these expansions of destroying environmental habitats and the vulnerability of the marine ecosystem in the region.

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