An Integrated Field Data and Remote Sensing Approach for Impact Assessment of Human Activities on Macro-benthos Biodiversity Along Western Coast of Aqaba Gulf

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Abstract

The Egyptian coast of Aqaba Gulf, north of the Red Sea suffers from severe destruction and deterioration in habitat and biodiversity due to anthropogenic activities and flooding. The present work aims to evaluate the impacts of different human activities and flooding on the biodiversity of macro-benthos invertebrates along the Egyptian coast of the Aqaba Gulf. From January 2019 to December 2019, many field trips (12 trips) were conducted to survey macro-benthos-invertebrate communities and monitor water quality at nine sites within three sectors along the study area. Each site was divided into four ecological zones and one of five categories, according to the main activities at each site. Furthermore, satellite data were used to monitor the progress of land use, and turbidity in the study area. Therefore, the current study assessing the relationship between these factors and water quality and macro-benthos-invertebrates distributions, similarity, diversity, dominance and abundance. The results revealed that fifty-three macro-benthos-invertebrates species belonging to four phyla (Crustacea, Mollusca, Echinodermata and Annelida) were recorded. *Echinometra mathaei* was the major eudominant species. The northern part of the Gulf was higher abundance and diversity with low land use and lowest water turbidity, while the south part showed the contrary findings. All statics analysis confirmed that the dissolved oxygen concentration was considered the only limiting factor for the abundance and diversity of macro-benthos invertebrates. Also, the variation in activities at investigated sites affected the dominance state of species in each site. Moreover, GPS data confirmed that the tourism activity had the largest influence on marine ecosystems and biodiversity, followed by fishing and desalination practices. Otherwise, flooding has significant influence on marine habitats and creates a habitat in which other certain species can be survived. In the absence of awareness, intervention and disregard for the effective coastal zone management concept, especially for the unique marine ecosystems such as the Gulf of Aqaba, the degradation of biodiversity will continue until extinction, and human life is rendered unsustainable.

1. Introduction

The movement of populations to coastal areas for tourism, recreation, industrial development, and residential purposes presents a major hazard to biodiversity. There has been a steady increase in population growth in coastal zones, causing land areas to erode rapidly. This is expected to create a serious ecological imbalance in the already fragile ecosystem unless some effective coastal management measures are implemented (El-Naggar et al. 2017). As a consequence of the growth and development of coastal communities, the density of people and infrastructure have increased in highly ecologically sensitive areas rich with marine life located. A strategic conservation plan is essential to saving our beaches through natural, sustainable development (Birdir et al. 2013). The importance of biodiversity, although vital for our survival, is often not stressed enough. Even though few people realize it, biodiversity provides humans with food, water, oxygen, energy, detoxification of waste, stabilization of earth's climate, medicine, opportunities for recreation and tourism, and other benefits (CBD 2000; Farrag et al. 2019). There is a need to preserve biodiversity because of its important for the continuity of human life. Recently, many marine organisms, have been used as sources of medicines and primary products (Hasaballah A.I. and El-Naggar 2017; El-Damhougy et al. 2017; El-Naggar and Hasaballah 2018).

Coastal ecosystems are highly productive and contain high biological diversity, rich fishery resources, and significant seabed minerals. Coasts also support a diverse array of related industries (e.g., tourism, shipping, oil and gas industries), which provide an enormous economic contributions. However, the shared demands of densely populated coastal regions impose stresses on finite coastal systems and resources (Juhasz 1991). There is no clear way of determining the total impact that humans are making on biodiversity; however, it is obvious that many human activities are causing a decrease in biodiversity. To mitigate the overall impact that humans make on a given environment, management and production practices must account for the area which yields a particular resource, the environmental costs of production, and the waste produced by such activities (Wackernagel et al. 2002).

The Gulf of Aqaba has unique and special habitats such as coral reefs, mangroves, coastal wetlands, and volcanic and coralline islands. Each of these habitats accommodates the high biodiversity of plants and animals. However, the development of the region has adversely affected the Gulf and, as a result of its semi-enclosed nature, the Aqaba Gulf is

particularly susceptible to marine pollution and ecosystem degradation. Thermal industrial pollution, sewage discharges, frequent small to moderate oil spills, and phosphate deposition from ship loading operations have severely eroded coral life. Poorly regulated resort development, intensive tourism, and overfishing have also caused environmental devastation. There is cooperation between countries overlooking the Gulf that share a commitment to preserving and protecting the region's fragile environment. For this reason, Egypt has paid special attention to natural resource conservation issues over the last three decades with the support of political leadership, has enacted legislation to conserve natural heritage and to ensure integration of development sectors with environmental protection and conservation of natural resources for the existing and future generations (Mona et al. 2019). Along the Egyptian coasts of the Aqaba Gulf, there are many protected areas at South Sinai, including Ras Mohammed National Park, Nabq Managed Resource Protected Area, and Abu Galum Managed Resource Protected Area (Ibrahim et al. 2017).

Advanced technologies like satellite imaging and remote sensing have made it easier to assess anthropogenic activities and the threat of human impact on marine resources (El-Kafrawy et al. 2020). Satellite imagery has immensely helped mapping of coastal ecosystems and provided estimates of the extent and nature of land cover alteration in the coastal ecosystem (Zakaria et al. 2019).

Therefore, this study was conducted to detect the most important human activities on the Egyptian coast of the Gulf of Aqaba and to monitor the impacts of these activities on macro-benthos-invertebrate biodiversity using remote sensing and ground truth techniques. The current study will help decision-makers to assess the most destructive activities of the environment and biodiversity based on reality remote sensing and field data. Also, it presents a complete overview of the current status of this spot.

2. Materials And Methods

2.1. The Study Area

The present study was carried out along the Egyptian coast of the Aqaba Gulf, Northern Red Sea (Fig. 1). The Gulf of Aqaba is a narrow deep trench extending from 28°N and 34° 23'E to 29° 33'N and 35°E, respectively. It is about 180-km long and has a maximum width of 30 km with an average of 16 km, and a mean depth of about 800 m. Its diverse marine habitats are comprised of sandy shores, rocky beaches, sandy lagoons, mangrove swamps, mud flats, and coral reefs.

2.2. Site Description

In this study, nine sites located in three sectors (Dahab, Nuweiba, and Taba) along the Aqaba Gulf were chosen to investigate the effect of different human activities on the spatial distribution of macro-benthos-invertebrates in the region. In Dahab sector, three sites were chosen: Lagoon, Canyon, and Blue Hole. The Lagoon site is a one of the most famous fishing sites for the local South Sinai community; residents fish primarily with angle and gill nets. The Canyon site is an internationally-renowned dive site that receives huge numbers of tourists. Blue Hole is one of the most famous dive sites in the world. Three sites were also selected in Nuweiba sector: El-Sokhn, Hobeiq, and Helnan. El-Sokhn is considered a typical coral reef habitat within the protected area and located on the northern boundary of the Abu Galum protected area. Hobeiq is a popular angle and gill net fishing site for local Bedouin. Helnan site has a desalination plant at Nuweiba with an operating power of 5000 m^3/day and drainage directly to the sea. The three sites selected in the sector of Taba are El-Norus, Morgana, and Solar Lake. The Norus site is considered as an active flood area and is located at the mouth of the flood. The Morgana site is located in front of Taba's desalination plant with an operating power of 3500 m^3/day. The Solar lake site is located at the front of Solar Lake, which is fully protected. While the names of the selected sites depend on local inhabitants, the global position (longitude and latitude) were determined by Global Positioning System (GPS), as shown at Table 1 and Fig. 1. For purposes of this study, the nine mentioned sites were selected to cover the major different human activities in the Gulf as follow: fishing (two sites), tourism (two sites), desalination (two sites), flooding (one site), and two fully protected sites, as

shown in Table 1. At each site, the area from the shoreline to the reef slope was divided into four ecological zones: intertidal, reef flat, back reef, and 3-m deep reef slope.

Table 1
Location, coordinated position and impacts level at the study sites.

Sectors	Sites	Coordination		Human Activities	Impact Level	Impact Categories
		Longitude	Latitudes			
Taba	Solar Lake	29.42189	34.83057	Fishing	Low	Protected
	Morgana	29.33019	34.75920	Brine discharges	High	Desalination
				Swimming	Low	
	Norus	29.19340	34.73089	Flooded	High	Flooding
				Fishing	Low	
Nuweiba	Helnan	29.02501	34.67400	Brine discharges	High	Desalination
				Fishing	Low	
	Hobeiq	28.88119	34.64396	Fishing	High	Fishing
				Swimming	Low	
	El-Sokhn	28.75801	34.62325	Fishing	Low	Protected
Dahab	Blue Hole	28.6055	34.54982	Diving	High	Tourism
				Swimming	High	
	Canyon	28.55465	34.52077	Diving	High	Tourism
				Swimming	High	
	Lagoon	28.47727	34.51169	Fishing	High	Fishing
				Diving	Low	

2.3. Physico-chemical Parameters

Physico-chemical Parameters at each site were measured as follow: 1- Water temperature (˚C) by ordinary thermometer graduated to 110ºC. 2- Salinity (‰) by Salino-meter (HANNA model HI 931100), 3- Hydrogen ion concentration (pH) by pocket digital pH meter (HANNA HI 991301), 4- Dissolved oxygen concentration DO (mg/L) by pocket digital DO meter (Eutech Instruments meter).

2.4. Sample Collection and Species Identification

Macro-benthos-invertebrate species inhabiting different sites in the study area were sampled seasonally during the period from January 2019 to December 2019 through many field trips (12 trips). The macro-benthos sampling data were collected using two methods: qualitative and quantitative. Qualitative sampling was conducted by slowly walking survey within the most studied sites; quantitative sampling was conducted using the visual quadrate method. The later was carried out by randomly placing thirty 1 m2 quadrates on the substrate of each of the sites and biological zones. Collected specimens were then preserved in 10% neutral formalin solution for subsequent identification. After collections, the macro-benthos-invertebrate samples were identified according to identification keys proposed by (Fishelson 1971; Sharabati 1984; Vine 1986; Campbell 1987; Lieskem and Myers 2004; Rusmore-Villaume 2008). All data (date, time, shore type, human activities, and substrate type) were recorded at each of the surveyed sites. All field data (survey and water quality) were replicated three times during all field trips and average was calculated for statically analysis.

2.5. Extraction of Chlorophyll (Chl_a), turbidity and flooding downstream

To determine the Chlorophyll, flooding drainage network and downstream of the study area for turbidity spots detection, the Digital Elevation Model (DEM) of the Gulf of Aqaba had been exercised. DEM is the digital representation of the earth surface terrain essential for the hydrological models (Balasubramanian 2017). Furthermore, it was obtained from the Shuttle Radar Topography Mission (SRTM) data available at the United States Geological Survey website (USGS), with 30 m spatial resolution. Different processes were carried out for the extraction of drains including projection, clipping the boundary of the study area, creating a flow direction raster by using flow direction and flow accumulation, deriving of stream, and stream order using ArcGIS 10.1 Software. Moreover, a visual comparison of a satellite images with a resolution of 30 m in the period between 2007 and 2019 had been done for a certain detecting of a turbidity progress.

2.6. Land Use / Land Cover

Land use mapping along the study area was carried out using a set of images through the period between 2007 and 2019. The satellite images varied from the Landsat Thematic Mapper (TM), with a resolution of 30 m, and Sentinel-2, with a resolution of 10 m, one scene for each date was used. The approach was based on a combination of digital classification and visual interpretation of the images utilizing ArcGIS 10.1 software. A classification process was applied to represent all classes of land use/cover in the Gulf of Aqaba. Maximum likelihood supervised classification method was used to generate a land use/cover map of the Gulf using training data for the different land use/cover classes. To improve mapping accuracy, a GIS layer of urban and agricultural areas was created by using an on-screen interpretation and digitizing the images.

2.7. Data Analysis

Several mathematical relationships, statistics and diversity indices were used for data analyses. Multiple correlation analysis and multiple regression analysis were calculated to determine the relationship between the abundance and diversity of macro-benthos and the physio-chemical parameters with a significance level of $p \leq 0.05$. Many diversity indices, Species richness (Margalef 1968), evenness index (Pielou 1966), Shannon Weaver index (Hill 1973; Pielou 1977), and Simpson index (Simpson 1949) were calculated to express the species diversity. the comparison between the sites (Similarity index) was done by using two-ways hierarchical clustering based on species composition using Euclidean similarity matrix. All the previous analyses were done using several computer software including MINITAB Release 18, Primer Ver. 7.0.12.0., PAST PAleontological STatistics Ver. 3.25 and Excel 2016 program.

3. Results

3.1. Physico-Chemical Parameters

Physico-chemical parameters at surveyed sites within the same sector showed little variation, while they significantly varied between investigated sectors (Table 2). Spatially, the water temperature ranged from 23.95 ± 1.69°C at Helnan to 26.7 ± 2.68°C at El-Sokhn. The highest salinity (52.75 ± 8.42‰) was recorded at Helnan, while the lowest (44.65 ± 4.83‰) was recorded at Solar Lake. In this context, the highest dissolved oxygen was recorded at El-Sokhna (4.80 ± 0.52 mg/L) and the lowest (4.17 ± 0.76 mg/L) was recorded at Blue Hole. Hydrogen ion concentrations tended to the alkaline side, with the highest average (8.18 ± 0.88) recorded at El-Norus and the lowest (7.59 ± 0.8) recorded at Solar Lake.

Table 2
The average of the physico-chemical parameters in different investigated sites

Sectors	Sites	Physico-Chemical Parameters*			
		Temperature (°C)	Salinity (‰)	DO (mg/L)	pH
Dahab	Lagoon	25.89 ± 2.94	45.90 ± 4.77	4.21 ± 0.77	8.23 ± 0.53
	Canyon	25.20 ± 3.10	45.55 ± 4.78	4.25 ± 1.05	7.88 ± 0.83
	Blue Hole	25.37 ± 2.14	44.75 ± 5.67	4.17 ± 0.76	7.79 ± 1.10
Nuweiba	El-Sokhn	26.70 ± 2.68	45.02 ± 4.21	4.80 ± 0.52	7.69 ± 0.40
	Hobeiq	26.10 ± 3.98	45.60 ± 4.65	4.37 ± 0.58	7.78 ± 0.29
	Helnan	23.95 ± 1.69	52.75 ± 8.42	4.26 ± 0.62	8.14 ± 0.94
Taba	Norus	26.22 ± 2.91	46.27 ± 5.18	4.41 ± 0.31	8.18 ± 0.88
	Morgana	26.50 ± 5.49	48.22 ± 7.54	4.23 ± 0.75	7.65 ± 0.58
	Solar Lake	26.52 ± 3.40	44.65 ± 4.83	4.77 ± 0.62	7.59 ± 0.84

*The presented data are mean ± SD

3.2. Community Composition

A total of 53 species were recorded along the study area at the Gulf of Aqaba during the study period. Recorded species belonged to four phyla: Crustacea (Malacostraca); Mollusca (Gastropoda and Bivalvia); Echinodermata (Asteroidea, Ophiuroidea, Echinoidea, and Holothuroidea); and Annelida (Polychaeta), (Table 3). The data represented in Table 3 showed that Mollusca was the most common phylum that comprised of 34 species belonging to 22 families, representing 43.71% of the total macro-benthos abundance. Gastropoda has constituted the main bulk of Mollusca and represented by 25 species (76.25% of the total mollusks count) belonging to 15 families. Bivalvia was represented by nine species (23.75% of the total mollusks species) belonging to seven families. Echinodermata was the second abundant phylum and was represented by nine species (formed 33.9% of the total macro-benthos count) belonging to four classes and seven families. Crustacea was represented by nine species (20.4% of the total count) belonging to nine families. Annelida was represented by only one species (1.99% of the total macro-benthos count).

Table 3
The recorded macro-benthos species and their dominance among activities categories

Phylum	Species	Relative Abundance (%)	Categories of Impact Activities				
			Protected	Fishing	Tourism	Desalination	Flooding
Crustacea	*Alpheus lottini* (Guérin-Méneville, 1829)	0.80	M	-	-	-	-
	Petrolisthes rufescens (Heller, 1861)	0.12	-	R	-	R	-
	Grapsus granulosus (H. Milne Edwards, 1853)	0.66	R	R	-	R	-
	Actaea savignyi (H. Milne Edwards, 1834)	0.50	M	-	R	-	-
	Carpilius convexus (Forskal, 1775).	0.04	R	-	-	-	-
	Cymo andreossyi (Audouin, 1826	0.74	R	M	M	R	R
	Trapezia SP.	5.13	D	D	E	-	E
	Tetralia glaberrima (Herbst, 1790)	10.09	E	E	E	E	E
	Hapalocarcinus marsupialis (Stimpson, 1859)	2.32	M	S	D	M	M
Mollusca	*Conus arenatus* (Hwass in Bruguière, 1792)	0.95	S	R	R	R	-
	Conus taeniatus (Hwass in Bruguière, 1792)	0.08	-	R	-	-	-
	Conus textile Linnaeus, 1758	0.04	R	-	-	-	-
	Conus vexillum (Gmelin, 1791)	0.08	-	-	-	R	-
	Conus virgo (Linnaeus, 1758)	0.25	R	-	R	R	R
	Plauroploca filamentosa (Röding, 1798)	0.08	-	R	-	-	-
	Trochus maculatus (Linnaeus, 1758)	0.37	R	R	R	M	R
	Clanculus pharaonius (Linnaeus, 1758)	0.21	R	R	R	R	-
	Drupa ricinus hadari (Eme. &Cerno., 1973)	1.70	D	-	R	R	R
	Drupella cornus (Röding, 1798)	2.56	M	D	S	S	R
	Thais savignyi (Deshayes, 1844)	0.33	R	R	R	-	-
		6.29	S	-	E	E	-
		0.17	R	R	-	-	-
		0.04	-	-	-	-	R
		0.21	R	R	-	R	-
		0.25	R	R	-	R	-
		3.27	R	S	S	-	E
		1.78	D	R	M	R	-

* E = Eudominant ≥ 7%, D = Dominant 4–7 %, S = Subdominant 2–4 %, M = Minor 1–2%, R = Rare ≤ 1%

Phylum	Species	Relative Abundance (%)	Categories of Impact Activities				
			Protected	Fishing	Tourism	Desalination	Flooding
	Dendropoma maxima (Sowerby, 1825)	3.02	S	M	S	D	-
	Vermetus arenarius (Barnard, 1963)	1.82	R	R	R	D	-
		2.19	-	S	S	-	-
	Clypeomorus bifasciatus (Sowerby, 1855)	0.08	-	R	R	-	-
		7.44	M	E	M	S	E
	Quoyula madreporara (Sowerby, 1834)	0.04	R	-	-	-	-
	Morula granulate (Duclos, 1832)	0.08	R	-	-	-	R
		0.04	R	-	-	-	-
	Cellana eucosmia (Pilsbry, 1891)	0.08	R	-	-	-	-
	Patella vulgate (Linnaeus, 1758)	0.25	-	R	-	M	-
		2.98	S	M	S	S	E
	Nerita albicilla (Linnaeus, 1758)	0.08	-	-	-	R	R
	Nerita polita (Linnaeus, 1758)	0.17	R	-	-	R	-
		2.52	S	M	D	M	M
	Littorina littorea (Linnaeus, 1758)	3.76	S	D	S	D	M
		0.50	R	R	R	M	-
	Turbo radiates (Gmelin, 1791)						
	Coralliophilia violacea (Kiener, 1836)						
	Vasum turbinellus (Linnaeus, 1758)						
	Terebra crenulata (Linnaeus, 1758)						
	Modiolus auriculatus (Krauss,1848)						
	Barbatia foliate (ForsskålinNiebuhr, 1775)						
	Streptopinna saccata (Linnaeus, 1758)						
	Pedum spondyloideum (Gmelin, 1939)						
	Pinctada margaritifera (Linnaeus, 1758)						

* E = Eudominant ≥ 7%, D = Dominant 4–7 %, S = Subdominant 2–4 %, M = Minor 1–2%, R = Rare ≤ 1%

Phylum	Species	Relative Abundance (%)	Categories of Impact Activities				
			Protected	Fishing	Tourism	Desalination	Flooding
	Pteria aegyptiaca (Röding, 1798)						
	Tridacna squamosa (Lamarck, 1819)						
	Lithophaga spp.						
	Chama limbula (Lamarck, 1819)						
Echinodermata	*Echinometra mathaei* (Blainville, 1825)	12.57	E	E	E	E	S
	Heterocentrodus mammillatus (Linnaeus, 1758)	1.16	M	R	M	M	-
	Diadema setosum (Leske, 1778)	8.31	E	E	R	E	-
	Chitodiadema savignii (Linnaeus, 1758)	0.91	M	M	R	-	R
	Holothoria atra (Jaeger, 1833)	1.08	R	R	-	S	M
	Synapta maculate (Chamisso&Eysenhardt, 1821)	0.74	S	-	-	-	-
	Ophiocoma erinaceus (Muller &Troschel, 1842	4.25	D	S	S	D	M
	Ophiocoma scolopendrina (Lamarck, 1816)	4.84	D	D	D	S	S
	Ophioneries porrecta (Lamarck, 1816)	0.04	R	-	-	-	-
Annelida	*Spirobranchus giganteus* (Pallas, 1766)	1.99	M	M	R	S	S
* E = Eudominant ≥ 7%, D = Dominant 4–7 %, S = Subdominant 2–4 %, M = Minor 1–2%, R = Rare ≤ 1%							

According to the data represented in Table 3, *Echinometra mathaei* was the main eudominant species along the study area and represented 12.57% of the total count of macro-benthos- invertebrates. *Tetraliagla berrima* was the second eudominant species (10.09% of the total count of macro-benthos-invertebrates). On the other hand, *Diadema setosum* (8.31%) was the main dominant species, followed by *Coralliophilia violacea* (7.44%). Moreover, there were four subdominant species namely; *Dendropoma maxima* (6.29%), Trapezia sp. (5.13%), *Ophiocoma scolopendrina* (4.84%), and *Ophiocoma erinaceus* (4.25%). Fourteen species were ranked as minor species and the other remaining recorded species were classified as rare species.

3.3. Spatial distribution and Zonation

Among sectors, the highest abundance of macro-benthos-invertebrates was observed at Taba sector (18.67 ind./m^2), followed by Nuweiba (18.54 ind./m^2); the lowest abundance was recorded at Dahab (15.75 ind./m^2) (Fig. 2a). On the other hand, out of 53 species identified during this study, 46 were recorded in Taba, 44 in Nuweiba, and 36 in Dahab.

From a site-specific perspective, the highest abundance of macro-benthos-invertebrates was observed at Solar Lake site (24.81 ind./m^2), followed by El-Sokhn site (20.69 ind./m^2); the lowest abundance was recorded in Blue Hole (10.38 ind./m^2), as shown at Fig. 2b. The highest number of species was recorded at Solar Lake (37 species), followed by El-Sokhn (35 species), and Hobieq (34 species); the lowest was recorded at Blue Hole (20 species), followed by the lagoon (22 species), and Norus (24 species), (Fig. 2b).

Concerning zones, Macro-benthos-invertebrate abundance varied among investigated zones (Fig. 2c). The highest abundance was recorded in the 3-m depth zone (22.31 ind./m^2) and the reef flat zone (22.31 ind./m^2), followed by the back reef zone (12.75 ind./m^2), while the lowest was recorded in the intertidal zone (9.87 Ind./m^2). In this context, the highest number of species was recorded in the back reef zone (39 species), followed by the reef flat zone (38 species) and the 3-m depth zone (28 species); the lowest number of species was recorded in the intertidal zone (13 species), as shown at Fig. 2c.

From an overview on Fig. 2e, the highest abundance of macro-benthos-invertebrates was recorded at Norus site (35.25 ind./m^2) in the reef flat zone, followed by Solar Lake site (33 ind./m^2) in the 3-m depth zone and El-Sokhn site (31 ind./m^2) in the 3-m depth zone; the lowest abundance peak was recorded at Blue Hole site (3.25 Ind./m^2) in the intertidal zone, as shown at Fig. 2d. In this context, the highest number of species (21 species) was recorded at the back reef zone of El-Sokhn site and Solar Lake site, and the reef flat zone of Hobieq site. The lowest (three species) was recorded at Morgana site of the intertidal zone, followed by four species in the intertidal zone of Blue Hole site and seven species in the back reef zone of El-Sokhn site.

3.4. Diversity Indices

The ecological diversity indices of the community of recorded macro-benthos-invertebrates varied within a narrow range between investigated sectors (Table 4). The values of species richness recorded its highest value at Taba (15.47) and the lowest value at Dahab (13.45). The Shannon index was high at Nuweiba (3.194) and low at Dahab (2.877). On the other hand, the highest evenness index value was recorded at Nuweiba (0.844) and the lowest value was recorded at Dahab (0.803). The highest Simpson index value was recorded at Dahab (0.995) and the lowest value was recorded at Nuweiba (0.9942) (Table 4).

While, the variation of diversity indices between different zones fluctuated within a wide range, as shown in Table 4; this means there are significant differences in species diversity and abundance between zones. As summarized in this table, the highest value of species richness was recorded in the back reef zone (14.92), while the lowest value was recorded in the intertidal zone (5.258). In this context, the Shannon index value was high at the reef flat zone (2.887) and low at the intertidal zone (2.196). On the other hand, the highest evenness index value was recorded at the intertidal zone (0.8562) and the lowest value was recorded in the back reef (0.7658). The highest Simpson index value was recorded at the intertidal zone (0.9716) and the lowest value was required at the 3-m depth zone (0.9616).

On the other hand, the diversity indices in Table 4 clearly show that no significant changes occurred between different sites. Where the highest value of species richness was recorded at Hobieq (11.4), while, the lowest value was recorded at Blue Hole (8.122). In this context, the value of Shannon index was high at El-Sokhn (2.97) and low at Solar Lake (2.091). On the other hand, the highest evenness index value was recorded at Solar Lake (0.856) and the lowest was recorded at the lagoon (0.7491). The highest Simpson index value was recorded at Hobieq (0.9882) and the lowest value was recorded at Norus (0.9121) (Table 4).

Table 4
The diversity indices of the community of macro-benthos-invertebrates species

Categories		Species richness	Shannon index	Evenness index	Simpson index
Sectors	Dahab	13.45	2.877	0.8028	0.995
	Nuweiba	14.73	3.196	0.8444	0.9942
	Taba	15.47	3.11	0.8123	0.9943
Sites	Lagoon	8.127	2.315	0.7491	0.9121
	Canyon	10.26	2.839	0.8347	0.98
	Blue Hole	8.122	2.43	0.8113	0.9574
	El-Sokhn	11.22	2.97	0.8353	0.9674
	Hobieq	11.4	2.965	0.8409	0.9882
	Helnan	10.26	2.889	0.8493	0.9842
	Norus	8.303	2.454	0.7723	0.9321
	Morgana	8.66	2.666	0.8388	0.9795
	Solar Lake	11.21	2.091	0.856	0.9799
Zones	Intertidal	5.258	2.196	0.8562	0.9716
	Back Reef	14.92	2.806	0.7658	0.9715
	Reef Flat	11.92	2.887	0.7937	0.965
	3m depth	9.017	2.756	0.8185	0.9616
Human activities Categories	Protected	14.08	3.143	0.8258	0.9814
	Fishing	13.09	2.948	0.8165	0.9916
	Tourism	12.25	2.854	0.8163	0.986
	Desalination	11.66	2.894	0.8278	0.9903
	Flooding	8.303	2.454	0.7723	0.9321

3.5. Multiple Correlation and Regression Analysis

The multiple correlation analysis between the abundance and diversity of macro-benthos-invertebrates and measured parameters revealed that the macro-benthos-invertebrates abundance and diversity were positively correlated only with dissolved oxygen ($r = 0.841$ and 0.727, respectively). While all other parameters haven't any effect on macro-benthos-invertebrates abundance and diversity (No significant correlation).

On the same side, the multiple regression analysis between macro-benthos-invertebrates abundance and diversity and deliberated parameters showed in the following prediction regression equations:

Abundance (Ind./m2) = -6.5–1.18 Temperature + 0.096 Salinity + 15.86 DO – 2.56 pH

Diversity (No. of species) = 84–3.27 Temperature + 0.034 Salinity + 21.13 DO – 8.28 pH

While, Stepwise regression equations explained that the previous equations of prediction regression have some errors that could be constricted by exclude the non-influential parameters, which were not significantly correlated with the macro-benthos-invertebrates abundance and diversity, as follows;

Abundance (Ind./m2) = – 45.71 + 14.29 DO

Diversity (No. of species) = – 50.61 + 18.07 DO

Concerning the effect of the measured parameters on dominant species, the water temperature was positively correlated with the abundance of *Tetralia glabberrima* (r = 0.727) and negatively correlated with *Nerita polita* abundance (r = -0.763). Otherwise, the salinity was the strongly positive affect on each *Nerita albicilla* (r = 0.693) and *Nerita polita* (r = 0.802). Likewise, the dissolved oxygen concentration in the water was act as a positive limiting factor for the abundance of each *Tetralia glabberrima* (r = 0.696), *Drupa ricinus hadari* (r = 0.917) and Patella vulgate (r = 0.871). In contrast, pH value was negatively limiting factor for the abundance of *Echinometra mathaei* (r = -0.689) and *Ophiocoma erinaceus* (r = -0.707), but it was positively effected on the abundance of *Coralliophilia violacea* (r = 0.802).

According to the present findings, there are some species that were a limiting agent for others. This was evident in the gathering which occurred between the molluscs *Littorina littorea* and *Lithophaga* sp., as well the echinoderms *Ophiocoma scolopendrina* and *Ophiocoma erinaceus*. Where, there are positive correlation between each other as that between *Littorina littorea* and *Lithophaga* sp. (r = 0.709); *Littorina littorea* and *Ophiocoma scolopendrina* (r = 0.901); *Littorina littorea* and *Ophiocoma erinaceus* (r = 0.714); *Lithophaga* sp. and *Ophiocoma scolopendrina* (r = 0.759); *Lithophaga* sp. and *Ophiocoma erinaceus* (r = 0.847) as well as *Ophiocoma scolopendrina* and *Ophiocoma erinaceus* (r = 0.759). Also, the gathering which occurred between the molluscs *Drupa ricinus hadari*, *Tetralia glabberrima*, *Patella vulgate* in the correlations of (r = 0.697), (r = 0.952) and (r = 0.699) between *Drupa ricinus hadari* with *Tetralia glabberrima*, *Drupa ricinus hadari* with *Patella vulgate* and *Tetralia glabberrima* with *Patella vulgate*, respectively. In addition, the echinoderm *Diadema setosum* was positively rely on each Ophiocoma *erinaceus* (r = 0.816) and *Lithophaga* sp. (r = -0.719). Otherwise, the echinoderm *Echinometra mathaei* had a positive relationship with *Tridacna squamosa* (r = 0.724) and a negative relationship with *Coralliophilia violacea* (r = -0.851). Finally, there is a positive relationship between the Neritedae of *Nerita albicilla* and *Nerita polita* (r = 0.847).

3.6. The principal component analysis

The relation between the abundance and diversity of macro-benthos and physicochemical parameters is shown in figure (3). The principal component analysis in this figure confirms that the dissolved oxygen concentration was considered the only limiting factor for the abundance and diversity of macro-benthos. Where, there is positive closed relation between dissolved oxygen concentration with abundance and diversity and related to component 1. While, other parameters (temperature, pH, and Salinity) haven't any effect on the abundance and diversity of macro-benthos (No significant correlation) and all were related to component 2. In this context, the most abundant and diverse sites were Solar Lake and El-Sokhn which also the most saturated sites with dissolved oxygen concentration. Also, Helnan was the most site influenced by high salinity and low temperature followed by Morgana which effect on their content from abundant and diversify to a low level. On the same side, Blue Hole was the most site influenced by low dissolved oxygen and salinity Which led to a sharp decline in the abundance and diversify, this may stem from the strong influence of tourism in it.

3.7. Similarity and Cluster analyses

A similarity study was conducted based on abundance and species distribution (Fig., 4). According to the current data, Cluster analyses showed that there was no significant difference between sectors, where the highest similarity value was recorded between Nuweiba and Taba (82.53%), followed by that recorded between Taba and Dahab (76.3%) and that found between Dahab and Nuweiba (74.91%). Otherwise, the Cluster analysis between zones showed that the intertidal zone differs substantially from other zones, whereas the similarities between it and the back reef, reef flat, and 3-m depth zones were 22.95%, 18.53%, and 15.41%, respectively. In contrast, there is no significant difference between the back reef, reef flat, and 3-

m depth zones. The most similar values were recorded between the 3-m depth and reef flat zones (78.39%), followed by the back reef and reef flat zones (69.09%), and that recorded between the back reef and 3-m depth zones (62.17%)

On the other hand, two-way Cluster analyses between investigated sites in figure (4) revealed that there are four subclusters. The first and highest subcluster was found between Morgana and Helnan (75.32% similarity), the second subcluster was recorded between Hobieq and Canyon (72.11%), the third was recorded between El-Sokhn and Solar Lake (71.9 %), and the fourth subcluster was found between Norus and the lagoon (63.7%). The previous findings explained that the investigation sites were grouped according to the major human activity occupying each of them.

In the same context, the cluster analysis between recorded species showed that the species abundance and distribution relied on the clustering of investigated sites which mainly depending on the major activity in each one. Where the distribution of recorded species showed many clusters which gathering under sites have the same major activity. for instance, some species (*Alpheus lottini*, *Carpilius convexus*, *Conus textile*, *Vasum turbinellus*, *Modiolus auriculatus*, *Barbatia foliate*, *Synapta maculate* and Ophioneries *porrecta*) were restricted only to protected sites (Solar Lake and El-Sokhn). Also, *Conus taeniatus* and *Plauroploca filamentosa* were restricted for sites that have Fishing activity.

3.8. Overall effect of different human activities on macro-benthic invertebrate.

3.8.1. Distribution

The highest abundance of macro-benthos-invertebrates was recorded at the protected stations (22.75 ind./m^2), followed by the flooding station (15.96 ind./m^2), fishing stations (15.66 ind./m^2), and desalination stations (15.56 ind./m^2); the lowest abundance (13.63 ind./m^2) was recorded at the tourism stations. Moreover, the highest number of species was recorded at protected stations (45 species), followed by fishing stations (37 species) and tourism and desalination stations (33 species each); the lowest number of species was recorded at the flooding station (24 species) (Fig. 2d).

3.8.2. The Dominance status according to different activity.

Table (3) shows the dominance status of recorded species according to different activities. It was clear from the table that the variation of activities in investigated sites affected the dominant status of species. For example, *Hapalocarcinus marsupialis* was minor in most activities categories and became dominant in tourism activity, *Drupella cornus* was rare and minor in most activities categories and became dominant in fishing activity, *Coralliophilia violacea* was also rare and minor with most activities and became eudominant in each fishing and flooding categories, *Pedum spondyloideum* was eudominant in flooding even though it was a minor in all categories and *Tridacna squamosa* was minor in all categories and became dominant with the presence of tourism activity. In addition to that, there are some species that were disappeared as a result of a specific activity such as *Diadema setosum* which was eudominant in all categories but completely disappeared in the presence of flooding in some sites. Also, *Conus arenatus*, *Patella vulgate*, *Nerita albicilla*, and *Nerita polita*, which appeared in all stations with multiple dominance statuses and also completely disappeared with the flooding. As well as, *Celana eucosmia* and Trapezia SP. disappeared from desalination sites. Also, *Dendropoma maxima* was disappeared from fishing and flooding activities. On the other side, many species were restricted to a certain category of activity.

3.8.3. Diversity indices among different activities

The highest species richness and Shannon index values were recorded at protected stations (14.08 and 3.143, respectively), while the lowest species richness and Shannon index values were recorded at the flooding station (8.303 and 3.143, respectively), as shown in Table 4. On the other hand, the highest Evenness index value was recorded at the desalination stations (0.8278), and the lowest value was recorded at the flooding station (0.7723). The highest Simpson index value was recorded at fishing stations (0.9916) and the lowest value at the flooding station (0.9321) (Table, 4).

3.8.4. The relationship between different activities and species distribution

The relationship between different activities categories based on species density and distribution was conducted by principal component analysis (PCA) (Fig. 5). With regard to the protected category, there was a close relation between desalination and tourism categories which obviously more correlated with the first axis, and other relation between flooding and fishing categories which more correlated with the second axis. Figure 10 illustrates this relation and showing the most categories impacting species density and distribution was tourism, followed by flooding, fishing then desalination. Where, there are some species that disappears from flooding and fishing categories that help the emergence of others. Whereas the protected category is a control for all, all species included in quarter 1 were denser in desalination and tourism categories than flooding and fishing categories and vice versa for quarter 2. Furthermore, the species included in quarter 3 were recorded in only desalination and tourism group, while the species included in quarter 4 only in flooding and fishing categories.

3.9. Some Remote Sensing Approach for Impact Assessment of Human Activities

3.9.1. Estimation of turbidity (KD), Based on satellite data

According to the flooding drainage network and satellite images comparison along the Gulf of Aqaba (Fig. 6), the turbidity was gradually increased at each site. The Blue Hole, Canyon, lagoon, and Hobeiq sites, as well as the Norus site were strongly affected by sediment-carrying floods; otherwise the Morgana and Helnan sites were affected by brine discharges from the desalination plant. On the other hand, at protected sites like El-Sokhn and Solar Lake that are far from human activities or are only exposed to slight human impacts, the rate of increased turbidity between 2007 and 2019 is very tiny.

3.9.2. Estimation of Chlorophyll (Chl_a) Based on satellite data

Figure (7) shows the comparison of satellite images of Chlorophyll between 2007 and 2019 along Aqaba Gulf. It is clear from the figure, the whole gulf affected by the increase in productivity rate between these two years, which indicates an increase in eutrophication which portends a threat to coral reefs.

3.9.3. Land Use/Land Cover

Land use/land cover between 2007 and 2019 at selected sites were compared and shown in figure (8). The satellite images clearly showed that the sites of Morgana; Norus; Helnan; Blue Hole; Canyon and Lagoon were exposed to a high increment rate of human impacts, whether from fishing or tourism activities. The result derived from the rapid development of urban between the two chronicles. This indicates that the increase in areas used by humans may affect biodiversity and that the available area for marine and terrestrial species may be shrinking. On the other hand, the rates of land use in highly-protected sites like El-Sokhna and Solar Lake, as well as Hobeiq, are very low and almost non-existent; this means the organisms in these sites can move freely without hindrance and the human impacts on the organisms are very low.

4. Discussion

Marine ecosystems and their substantial biodiversity are threatened all over the world (NRC 1995). The world's coastal zones and shallow seas are impacted directly and indirectly by increasing pressure to supply natural resources and space to meet human needs and the negative impacts of the resulting poor land-use practices. Multiple and cumulative threats have already caused the loss of both species and genetically unique stocks of organisms and have undermined the functioning of many marine systems. Conservationists, and the non-governmental organizations they represent, are concerned that unless

we change our attitudes towards the use of the seas, the marine biodiversity crisis will worsen. The ocean is home to millions of species and the health of the oceans is strongly dependent upon marine biodiversity. Climate change due to human activity has a direct impact on marine species by altering their abundance, diversity, and distribution. Their feeding, development, and breeding, as well as the relationships between species, are also affected. At present, the major perceived threats to marine biodiversity include the effects of climate change, ocean acidification, invasive species, overfishing, and other extractive activities, pollution and marine debris, habitat degradation, fragmentation and loss, human population expansion, tourism, and the impact of a wide range of human activities in the coastal zone (Harley et al. 2006; Occhipinti-Ambrogi and Charles 2007; Molnar et al. 2008; Zakaria et al. 2016; Zakaria et al. 2018a). In general, ecosystem components mainly affect the chemical and biochemical composition, distribution, and diversity of water organism communities (El-Naggar et al. 2017).

The Red Sea has a unique geographic location which makes its ecosystem is highly sensitive to temperature and salinity, which is reflected in the distribution, biodiversity and overall nutritional aspects of aquatic communities (Mona et al., 2019). Many studies cited that the aquatic communities, composition, distribution, and biodiversity, are strongly affected by variations in environmental and nutritional conditions (Farag et al., 2019; Mansour et al., 2020). In the current study, the data of physicochemical parameters showed little variations in water temperature, overall nine stations. Desalination stations (Helnan and Morgana) were recorded the highest salinity values, due to the brine discharges, which were negatively reflected on the average of abundance (15.56 ind./m^2) of macro-benthos-invertebrate in the Gulf of Aqaba. In the same line, tourism stations (Canyon and Blue Hole, which showed the lowest DO) were recorded the lowest average of abundance (13.63 ind./m^2). On the other hand, the protected stations (Solar Lake and El-Sokhna, which showed the highest DO) were presented the highest average of abundance (22.75 ind./m^2). These obtained data illustrated that the anthropogenic activities (tourism and desalination) are strongly affect ecosystem components (DO and salinity), as well as the abundance and biodiversity of macro-benthos-invertebrates in the Gulf of Aqaba.

The results of this study reveal there have been severe reductions in the macro-benthos-invertebrate diversity in the Gulf of Aqaba, where a total of 53 species were recorded during the study period. The increase in anthropogenic activities along the Gulf of Aqaba has played a significant role in the decline, absence, and even extinction of some species. Mona et al. (2019) confirmed that human activities are the major reason for these changes in biodiversity and that these activities can cause habitat destruction if they continue and not resolved or reduced. Human activities on the Aqaba Gulf have also led to the degradation of various natural habitats. These practices create changes in the environment that species must then adapt to; some species can adapt, while others cannot.

According to the results obtained in this study, the abundance and diversity of macro-benthos invertebrates increase toward the north of the Gulf and the lowest values were recorded in Dahab. This may be due to land use increases more in the south than in the north of the Gulf and because Dahab city is considered the most affected by tourism, fishing activities and flooding. On the other hand, due to the absence of human activities, the results revealed that the protected sites, like Solar Lake and El-Sokhn, have a higher abundance and diversity more than the others. On the contrary, Blue Hole has the lowest abundance and diversity because it is considered one of the world's most attractive sites for diving and snorkeling, as well as other tourism services. El-Naggar et al. (2017) decided that intense tourism in Blue Hole can lead to biodiversity degradation and ecosystem damage.

As for the distribution of micro-benthos among surveyed zones, the intertidal zone is the lowest in both abundance and diversity criteria; this is because the zone is the most directly affected by tourism, fishing activities and flooding, in addition to it being the first recipient of coastal impacts. For this reason, the species tend to escape to the other safer zones. On the other hand, the increase of abundance and diversity in the back reef zone may be due to the fact that its contains many microhabitats that can increase diversity; however, the abundance is low because it is also impacted by tourism, fishing, and other activities. In this context, the reef flat zone is safer than the back reef zone, and it is also usually used as a resting place for many species that escape the reef crest and back reef zone. Farrag et al. (2019) cited that any disturbance

occurring in the natural habitats of species strongly affects their presence and stability, thus affecting biodiversity. Accordingly, Costanza et al. (1971) stated that when the ecological impacts caused by habitat disturbance are coupled with general environmental degradation, such as eutrophication, toxic pollution, or global climate change, the capacity of marine ecosystems to support sustainable biodiversity is reduced. Even more importantly, when essential habitat is lost, as in the use of shores for coastal development, the critical threshold levels inevitably decrease (Dayton 2000). Ultimately, the paradox is that marine ecosystems are increasingly less able to support demand, even as demand continues to increase.

The results showed that there was a higher percentage of similarity between sites that are subject to similar human impacts, where the highest similarity percentage was between the Morgana and Helnan sites, which are affected by the presence of water desalination plants for both Taba and Nuweiba cites, respectively. There is also a high percentage of similarity between the Solar Lake and El-Sohkn sites, which are considered to be the most protected sites and have little or no impacts. The similarity was also high between the Canyon and Blue Hole sites, which are both affected by heavy activities of tourism, and between the lagoon and Hobieq sites, which are heavily affected by fishing activities. Astoundingly, the different types of influence create variation in the community structure. Therefore, the direct or indirect actions by humans have resulted in a decrease in biodiversity. The Convention of Biological Diversity states that there are both indirect and direct human drivers to biodiversity loss. Some of the indirect human drivers are demographic, economic, sociopolitical, scientific and technological, and cultural and religious factors. Some of the direct human drivers are changes in local land use and land cover, species introductions or removals, external inputs, harvesting, air and water pollution, and climate change (Vihervaara et al. 2010).

Based on the results of this study, tourism is the human activity that has the greatest influence on marine ecosystems. PCA analysis confirmed this finding. This can be attributed to the fact that the tourism beneficiaries are unable to deal with the environment and marine life. Tourism has become one of the largest economic activities in the world and the rapid growth of the industry has produced more infrastructure, increased pollution, and created adverse impacts on biodiversity. In the same context, the sites exposed to floods are significantly lower in biodiversity, even though there are species that can adapt to this natural phenomenon and that are increasing in abundances, such as the high abundance of the snails *Coralliophila violacea* and *Cellana eucosmia*. Accordingly, Nicholls (2002) confirmed that coastal flooding can result in a wide variety of socio-economic and environmental impacts on different spatial and temporal scales. Flooding can destroy coastal habitats and can erode dune systems.

It is clear from the present results that fishing activities have severe effects on biodiversity and habitat stability in the study area. Uncontrolled fishing practices dramatically affect biological communities by causing cascading effects down food webs that decrease diversity or productivity. Overfishing or unregulated fishing, which removes certain species or ages, have led to these effects because many of these species may be naturally rare or unevenly distributed. Due to its high nutritional value and easy access—as well as its popularity as a food source for fishermen and the local community of Bedouin—*Tridacna* spp. was decreased to its lowest abundance at sites that are directly affected by human activities, especially fishing. Courchamp et al. (2006) stated that overexploitation through fishing activities can lead to resource depletion and put a number of threatened and endangered species at risk for extinction. The exponential growth of the human population experienced in the last several decades has led to the overexploitation of marine living resources to meet the growing demand for food. For example, overfishing is by far the biggest threat for species listed as endangered or vulnerable to extinction, with species extinction being caused primarily by habitat loss, degradation, and fragmentation (Noss et al. 1995). In addition, over-collection of commercial mollusks reduces the number of certain species or may even result in the complete disappearance of other species from the area (Gössling et al. 2004). Anthropogenic activities (especially the salts as results of desalination processes) strongly affects the concentration of nutrient, nitrification, in the marine ecosystem (especially N and P), which considered an important key for plankton nutritional value and communities (El-Naggar et al. 2019; Zakaria & El-Naggar 2019), which is reflected on aquatic food webs (El-Damhougy et al. 2019; Zakaria et al. 2018b). Finally, the integration of remote sensing technique with macro-benthic-invertebrate distribution data revealed that anthropogenic activities affect the presence and absence of species, and influence the dominance status of species in the stations.

5. Conclusions

Anthropogenic activities strongly affect marine ecosystem components, as well as the abundance, communities, and diversity of macro-benthos-invertebrates, along the Western Coast of the Gulf of Aqaba. The present study presented that the northern part of the Aqaba Gulf was the highest abundance and diversity, comparing to the southern part of the Gulf. In contrast, the southern part of the Gulf presented the highest land use/cover and turbidity, comparing to the northern part of the Gulf. Many individuals do not care about the damage they are causing to biodiversity. However, it is important to realize the impact of anthropogenic activities on biodiversity because without it, there would be no human existence.

The integrated remote sensing and ground truth approach are strongly illustrated that the anthropogenic activities have a negative impact on macro-benthos-invertebrates biodiversity, causing damage in marine habitats, due to land use/cover, different lifestyles, and industries.

Humans affect biodiversity and cause damage to habitats due to their population numbers, land uses, and their lifestyles. If changes are not made to the ways humans use resources on earth, degradation of biodiversity will continue until human life can no longer be sustained. It is important to realize how anthropogenic activities affecting biodiversity and realize the importance of maintaining biodiversity left on the earth. Simply put, the human cannot continue without biodiversity. Through proper awareness, and by demanding that governments make decisions to preserve biodiversity, humans will be able to sustain life on earth longer.

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DATA AVAILABILITY

The datasets generated during and/or analysed through the current study are available from all authors.

AUTHORS' CONTRIBUTIONS:

H.A.E.-N: Conceptualization, data curation, formal analysis, investigation, methodology, validation, Project administration, writing - original draft, writing - review & editing. E.-S.S.E.S.: Investigation, methodology, validation, writing - original draft. S.B.E.-K.: Data curation, formal analysis, Software, validation, writing - original draft. M.A.B.: Investigation, methodology, validation, Writing - original draft. M.A.: Data curtain, investigation, methodology, formal analysis, writing - review & editing. W.M.S.: Investigation, methodology, validation, Writing - original draft. M.F.M.: Investigation, methodology, writing. M.E.A.-M.: Mthodology, Data curation, formal analysis, Software, validation, writing - original draft.

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Figures

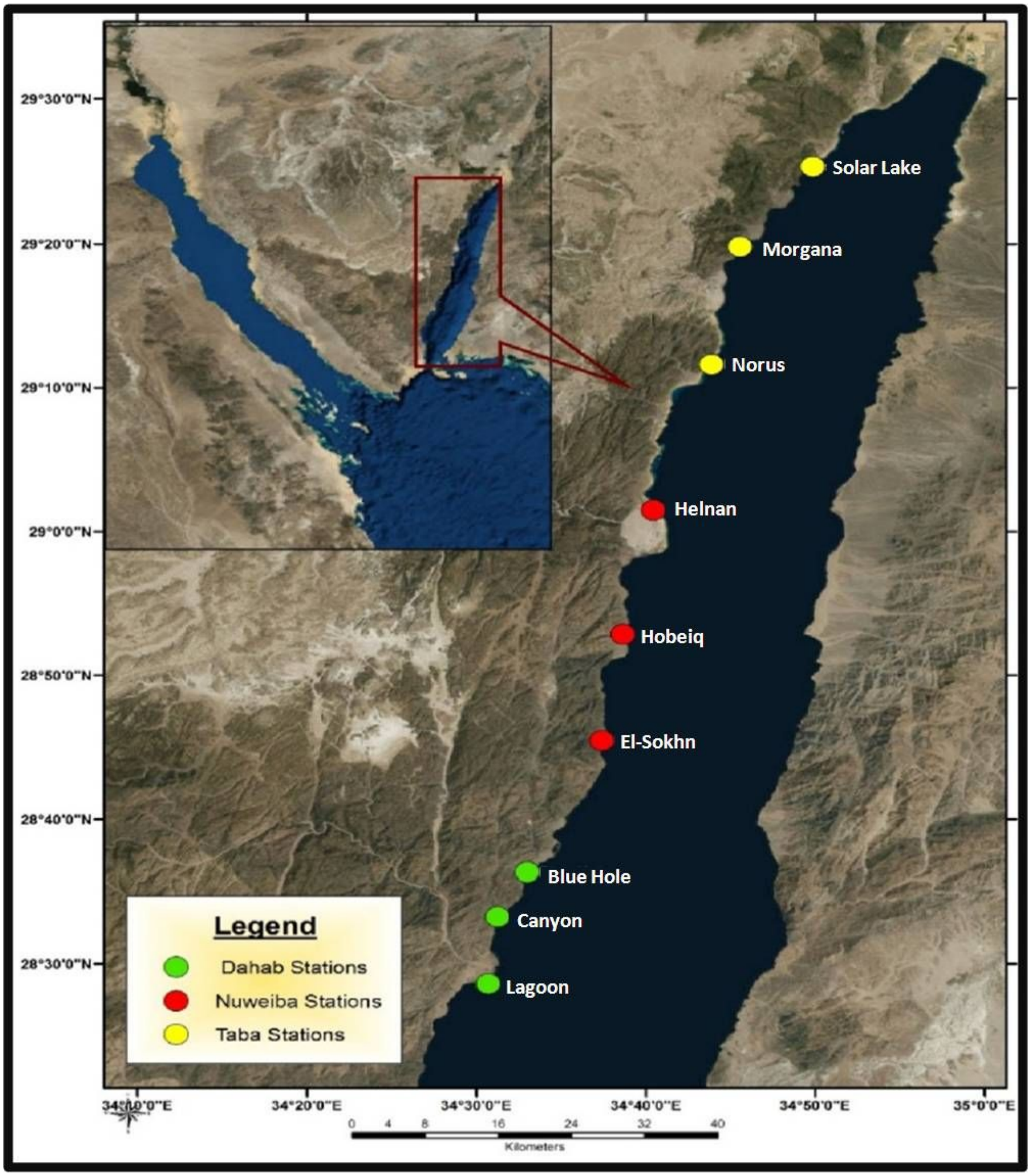

Figure 1

Study area and surveyed sites. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

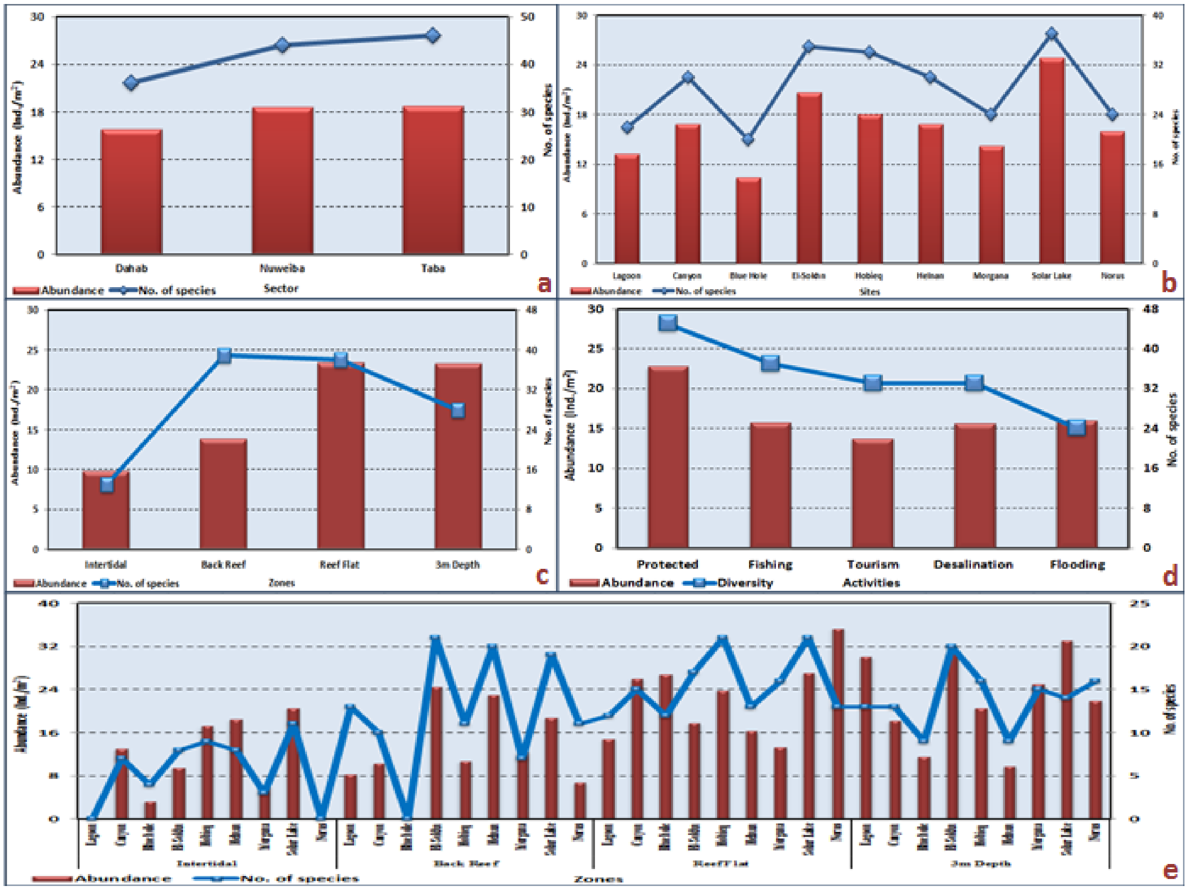

Figure 2

Abundance and No. of Species at each of sectors (a), sites (b), zone (c), Human activities (d) and the whole study area (e).

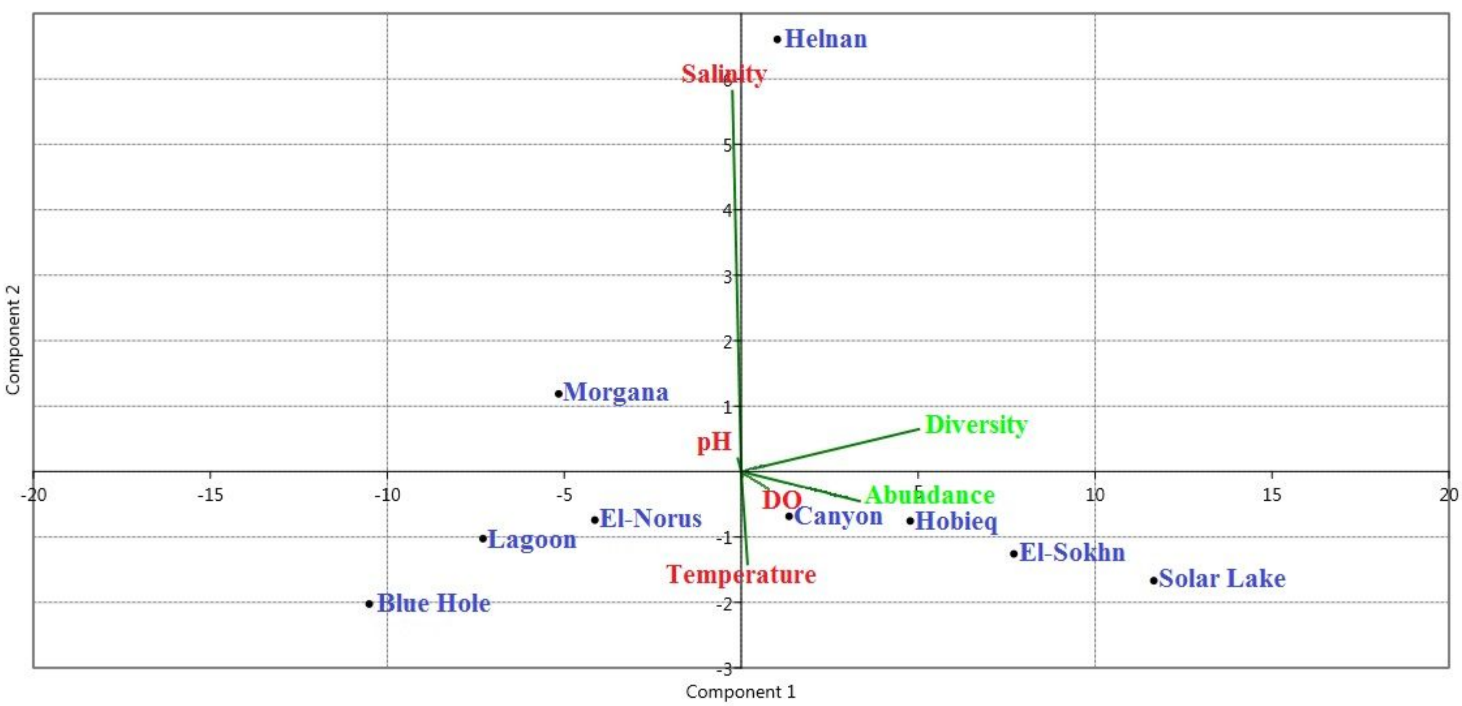

Figure 3

Principal Component Analysis (PCA) shows the relation between abundance and diversity of macro-benthos and physico-chemical parameters.

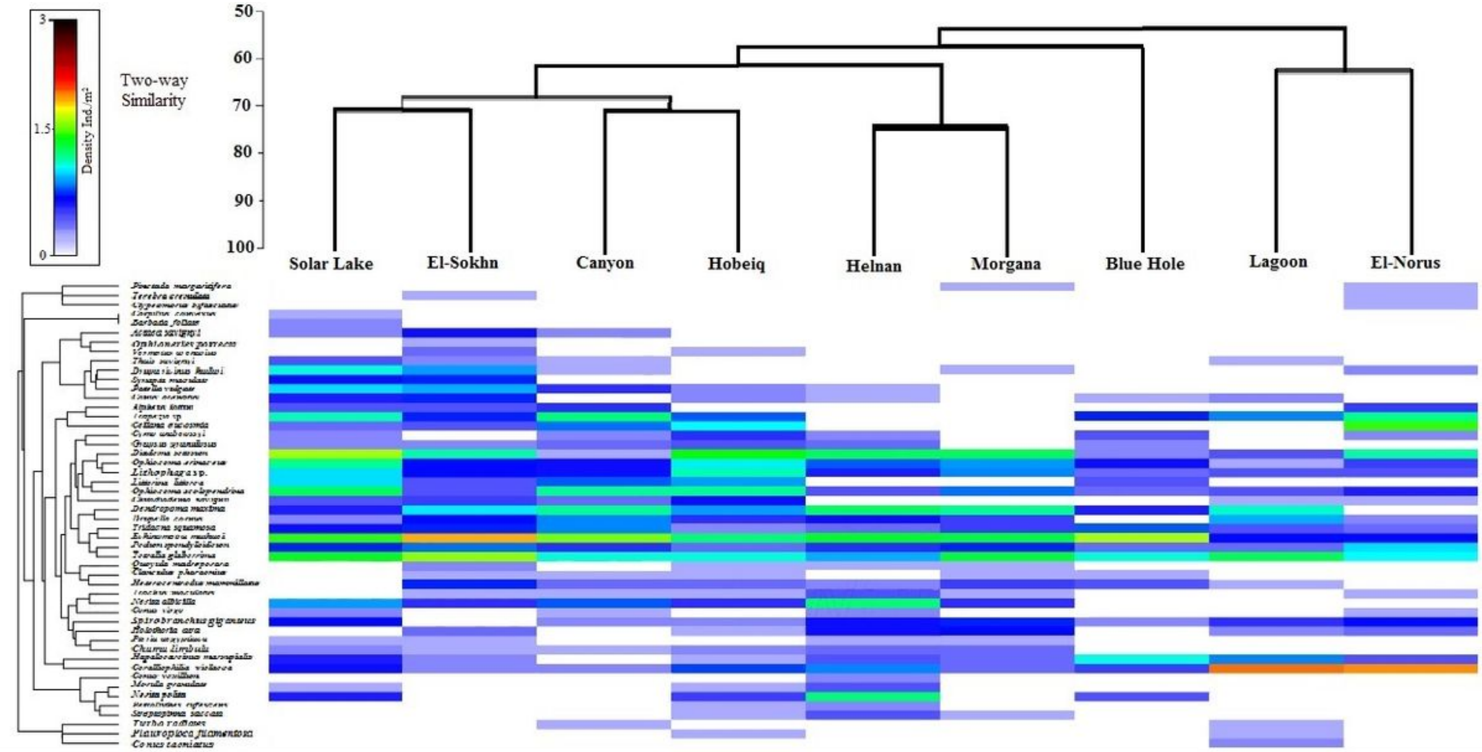

Figure 4

Dendrogram showing two-way cluster analysis based on species distribution and density.

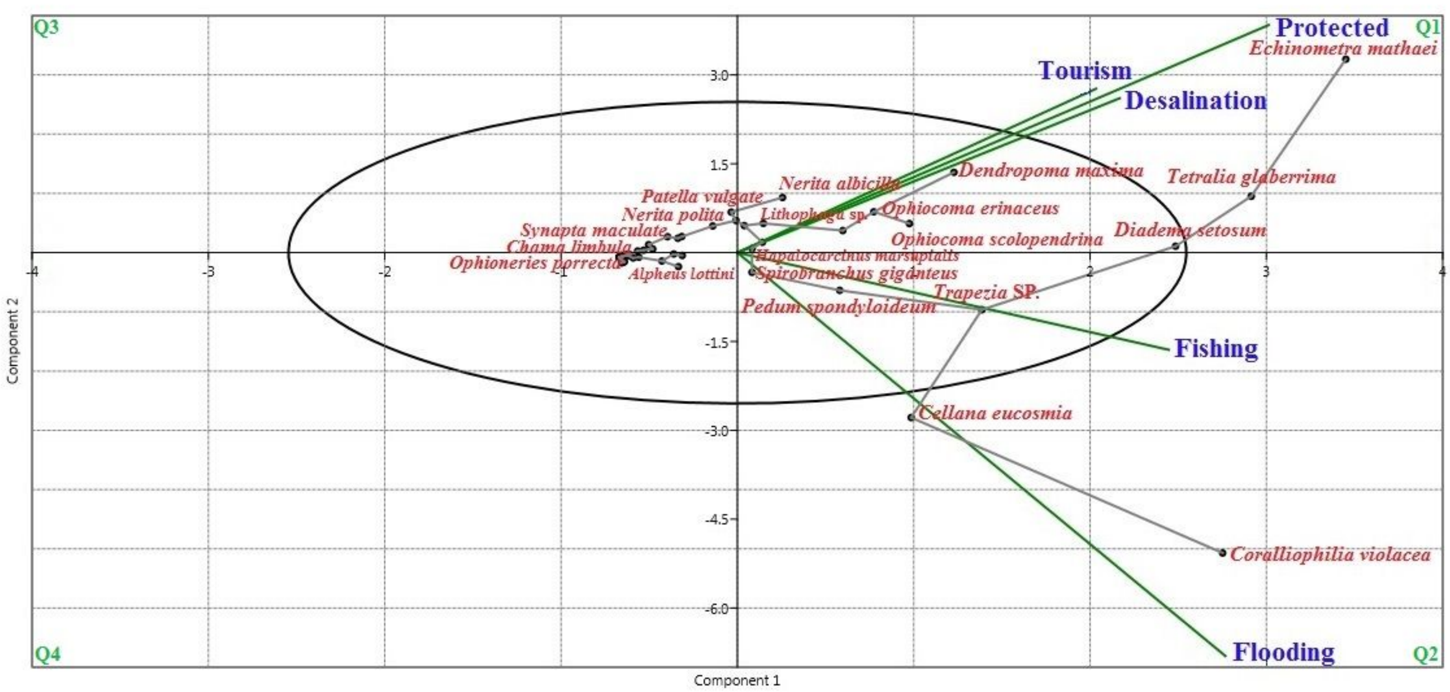

Figure 5

Principal Component Analysis (PCA) shows the relationship between activities categories based on species density and distribution.

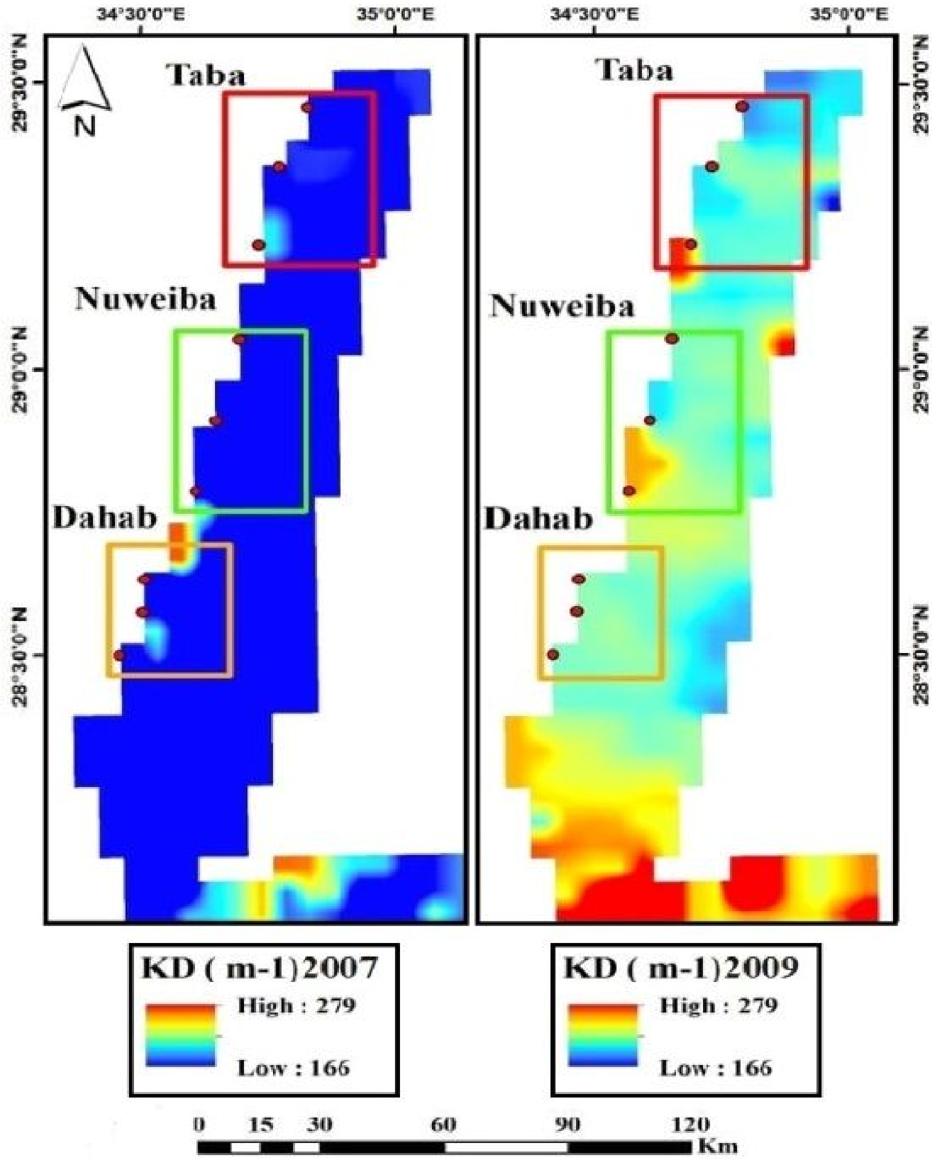

Figure 6

The turbidity (KD) among investigated sites during period 2007 and 2019.

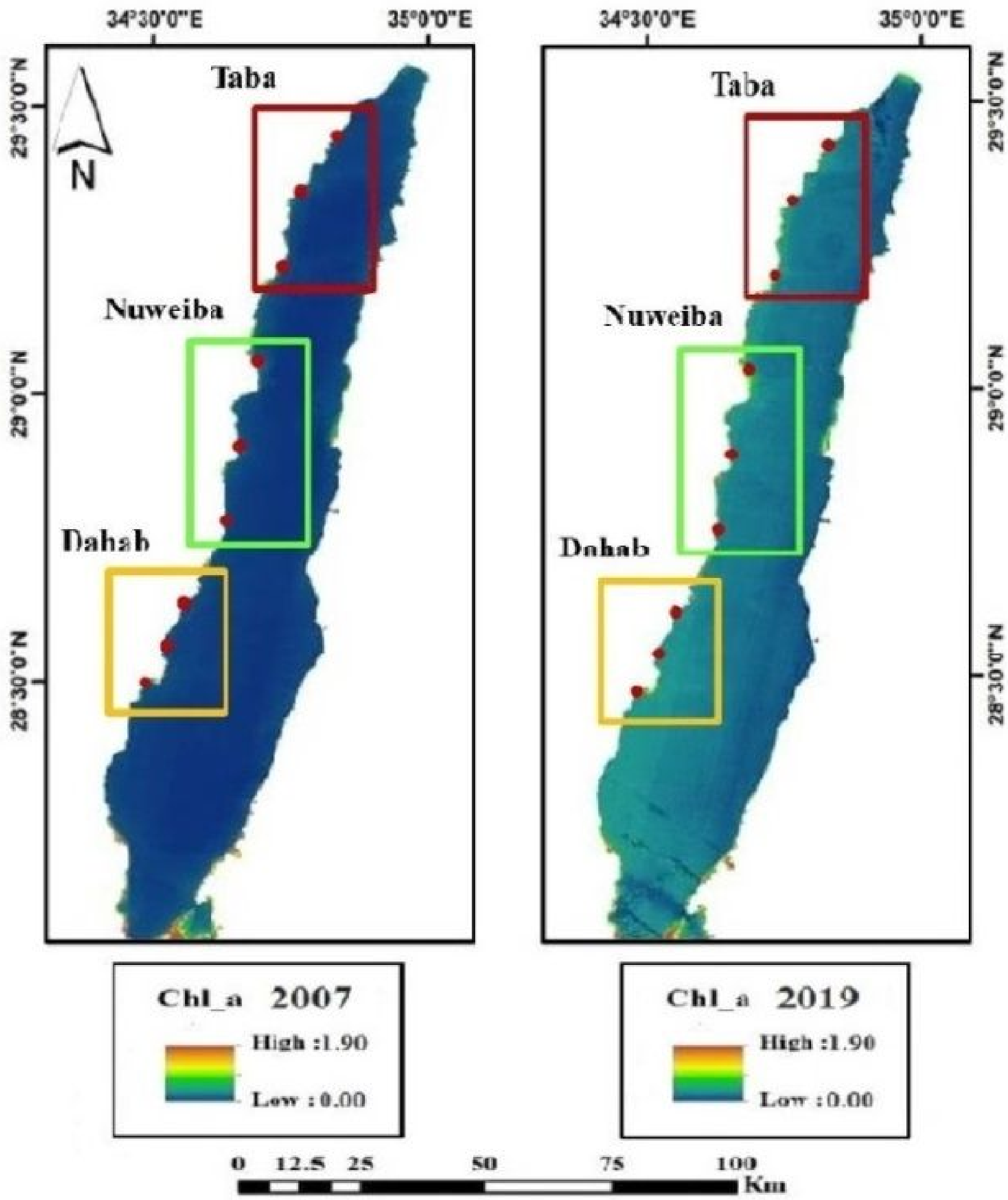

Figure 7

Chlorophyll (Chl_a) among investigated sites during period 2007 and 2019.

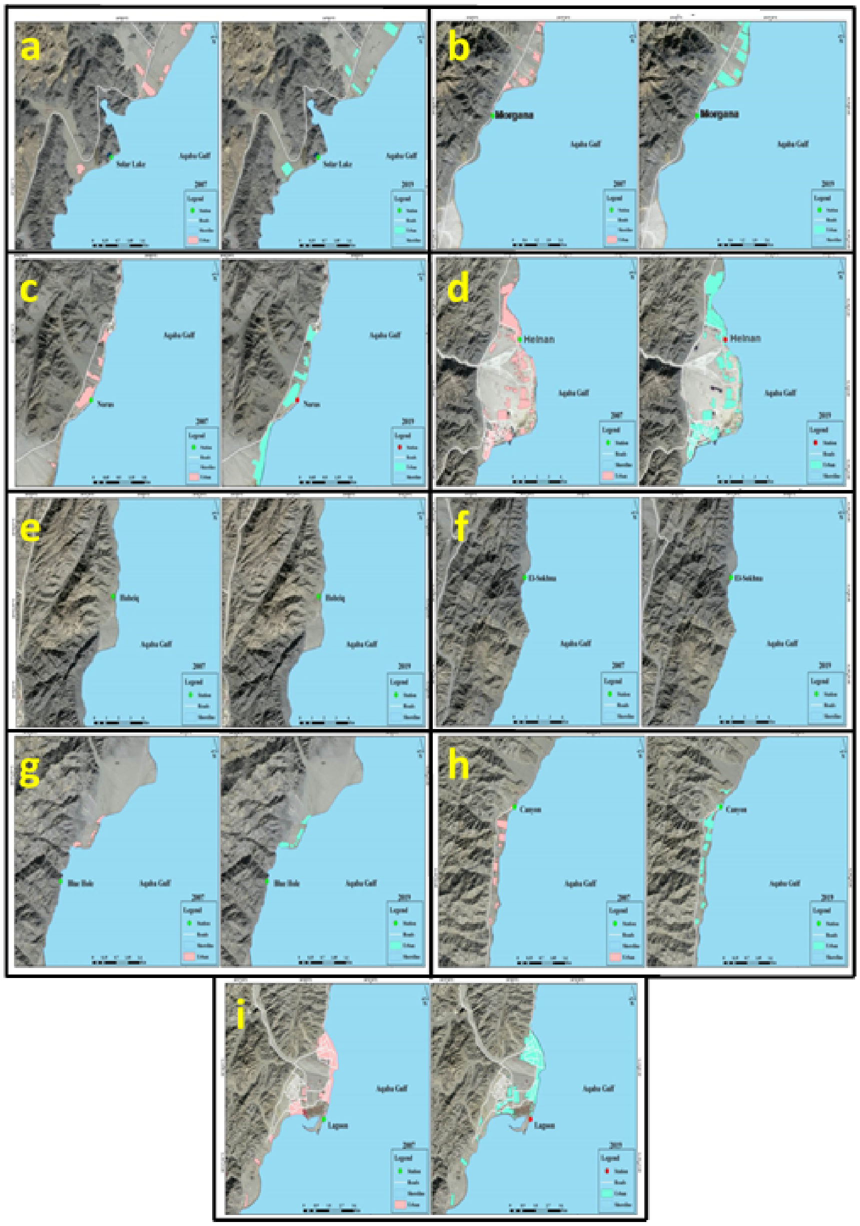

Figure 8

Land use/land cover (2007:2019) before and after field trip for a) Solar Lake, b) Morgana, c) Norus, d) Helnan, e) Hobieq, f) El-Sokhn, g) Blue Hole, h) Canyon and i) Lagoon. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.