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ARTICLE

Detecting Changes in Land Degradation Trends in the Arab Gulf Countries for the Period 2000 to 2020

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ABSTRACT

This study aims to monitor land degradation changes in the Arab Gulf countries using time series NDVI (Normalized Difference Vegetation Index) images generated from the MODIS13 dataset from 2000 to 2020. The data, collected on bi-monthly basis, were downloaded from NASA Earth Observation data with an accuracy of 250 meters, covering the whole area of the AGC, for the purpose of analyzing the distribution and spread of NDVI vegetation. A simple linear trend approach was used to examine potential land degradation trends, utilizing the Mann-Kendall statistical confidence limits for 122 selected sites during the study period. Seven classes of land degradation status were identified, representing: degraded land, land with no significant change, and improved land. The results indicated that more than 95% of AGC lands are bare land vulnerable to degradation processes. In contrast, less than 5% of the land showed improvement in land quality reflected by vegetation cover. The findings emphasized an increase in land degradation status over time, as evidenced by a decline in vegetation cover. The main causes of land degradation were climate change, characterized by rainfall decline and more moisture loss resulting from the increase in temperature and evapotranspiration, in addition to poor human activities. Land improvement occurs in some areas of the AGC, mainly in Iraq and the coastal region due to agricultural activity and geographic location.

Keywords: Land Degradation; Desertification; Land Cover; NDVI; Arabian Gulf Countries

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1. Introduction

Desertification was defined as land degradation (LD) in arid, semi-arid, and dry sub-humid regions caused by climatic changes and human activities [1]. Land degradation (LD) was defined as a negative trend in land condition, caused by direct or indirect human-induced processes, including anthropogenic climate change, expressed as long-term reduction or loss of at least one of the following: biological productivity, ecological integrity or value to humans [2]. While UNCCD [3,4] stated that LD refers to the reduction of the biological or economic productivity resulting from human activities (land uses) and habitation patterns, such as (i) soil erosion; (ii) deterioration of the physical, chemical, biological, or economic properties of soil; and (iii) loss of natural vegetation. In semi-arid regions and drylands, particularly in the Arab States of the Gulf, land degradation leading to desertification is a significant ecological concern, addressed in the 1992 review by the United Nations Conference on Environment and Development (UNCED). Desertification affects nearly 1 billion people across 110 countries, especially in the Arab States of the Gulf [5].

Generally, Land faces serious threats from various degradation processes, which weaken its essential functions and services, thereby creating a major risk to soil security, ecosystem health, and agricultural sustainability. Human-induced land degradation, water scarcity, and climate change are heightening risks for agriculture and ecosystem services. Increased evapotranspiration and altered rainfall patterns are changing land and crop suitability and making water supplies more variable; some regions will see less water, others more [6]. Human activities, especially intensive farming, deforestation, and overgrazing, have greatly sped up these degradation processes [7–9]. Approximately 90 percent of the Arab world's total area is classified as dry land, characterized by harsh environments, fragile ecosystems, and limited water resources and arable land [10]. Each year, approximately 12 million hectares of land are lost to degradation, with a cost of more than 10% of the annual global Gross Domestic Product (GDP) in lost ecosystem services such as preventing harmful nutrient run-off into streams and reducing flood effects, in addition to affecting the well-being of at least 3.2 billion people [11]. Ziadat et al. [12] indicate that in the Arab region, two-thirds of the 70 million hectares affected by human-induced degradation, over 46 million hectares are agricultural land, with croplands particularly impacted. Agriculture is both affected by land degradation and contributes to it through unsustainable land and water management practices [13]. LD can impact people over a large part of the Earth's surface, leading to extreme poverty and hunger, as a result of declining quality of natural resources and environmental unsustainability. LD is a global environmental issue that significantly affects agricultural productivity and poses a threat to farmers' livelihoods worldwide. Food production has been affected by LD as a result of losing land productivity and its ability to provide services [14]. LD includes different issues: erosion, compaction, desertification, salinization, loss of nutrients, loss of biodiversity, etc., and could lead to temporary or permanent decline in the productive capacity [15].

The most visible impact of land degradation is reduced land productivity and the destruction of soil properties. Impacts also include increased vulnerability to droughts and water scarcity, extreme climatic events such as flash floods and heat waves, a greater rate of desertification, and reduced resilience [16].

The Gulf countries are located in the eastern part of the Arabian Peninsula, where crude oil is extracted from several fields. The states face numerous environmental problems, including drought, land degradation, and vegetation loss, largely due to their geographic location, global climate change, and oil extraction activities. The problems include high temperatures, induced earthquakes, and pollution in the soil and marine coast, as well as desertification processes, dune movement, and other environmental problems [17].

Land degradation in the AGC is a significant issue, driven by a combination of human activities and climate change. This degradation includes desertification, soil erosion, salinization, and deforestation, leading to reduced agricultural productivity and biodiversity loss [18]. The GCC-STAT Stat and UNCCD [16,19] reported that About 90% of the region is considered very arid, and the remaining 10% is covered by semi-arid and dry sub-humid areas. 73% of the already limited arable land is affected by land degradation. Climate change is significantly impacting land degradation in the Arabian Gulf countries, with rising temperatures, increased drought frequency, and sea-level rise leading to soil erosion, desertification, and reduced agricultural productivity[20]. Muhaimeed et al.[21] indicated that the Arab Gulf countries have faced various climate change threats in recent decades, evidenced by a significant rise in average annual temperature, a decline in rainfall, and increased potential evapotranspiration, which worsen water scarcity and environmental issues degradation. The annual temperature increases significantly at a 95% confidence level, ranging from 0.18 °C to 1.48 °C. Decade −1. Per decade, with an overall rising rate of 0.83 °C, making it one of the fastest-warming regions in the world.

Monitoring vegetation dynamics and land cover change in AGC is essential for the sustainable management of natural resources and biodiversity conservation. Satellite remote sensing data and GIS, are ideal techniques with which to obtain a broad overview of Land degradation[22–24]. The satellite-derived Normalized Difference Vegetation Index (NDVI), which is the normalized ratio of red and near-infrared (NIR) reflectance[25], can be regarded as an indicator of vegetation activities and the status of land degradation[26].

The objective of this study is to detect the dynamic spatial and temporal changes of land degradation status in the area of AGC using satellite data and GIS techniques for the period from 2000 to 2020.

2. Materials and Methodology

2.1. Geographic Location and Climatic Conditions of AGC

The Arab Gulf countries are a group of Arab states bordering the AGC. There are seven member states of the Arab countries in the region: Bahrain, Kuwait, Iraq, Oman, Qatar, Saudi Arabia, and the United Arab Emirates. Yemen is bound to the eight countries based on history and culture. AGC is located in the southwestern part of Asia and the northeastern part of the Arab world, lying between two latitude circles, 12°29′–37°25′ north and 34°29′–60° east longitude. Consistently, its extension from east to west is approximately equal in length from north to south, with a total area estimated to be 3,258,467 km^2 (**Figure 1**).

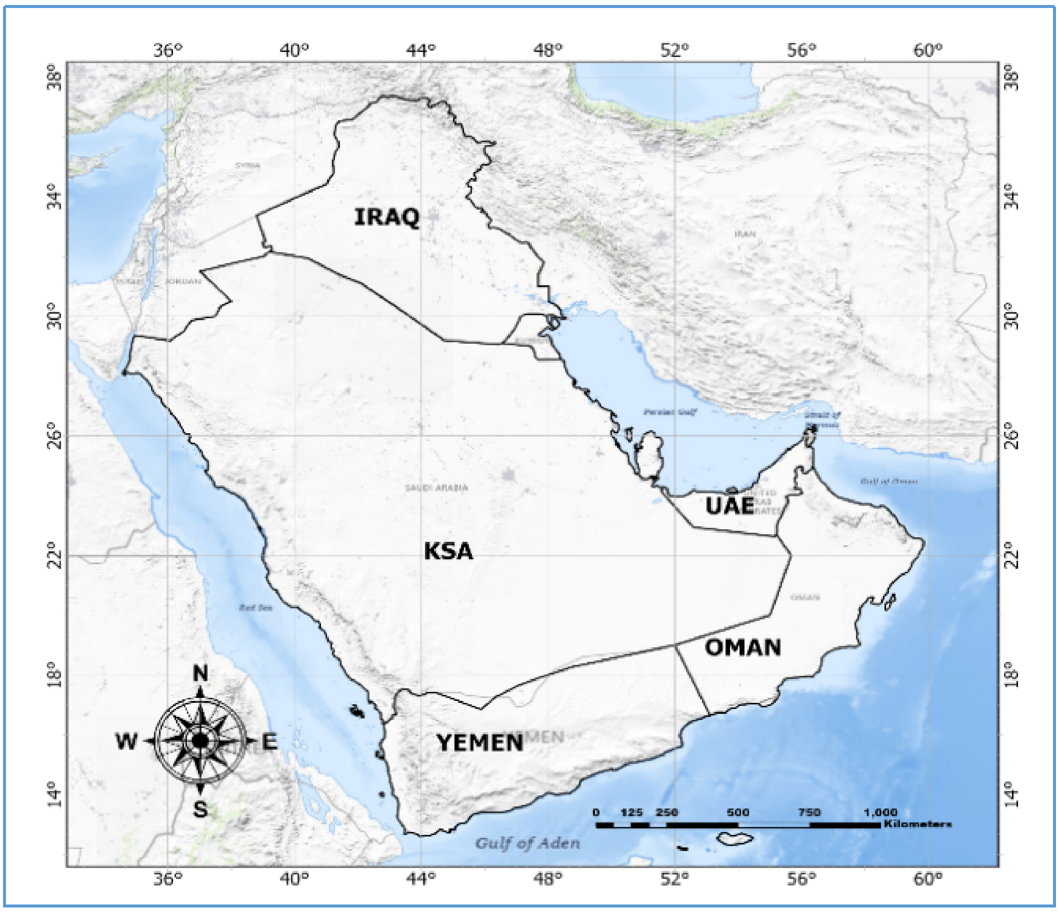
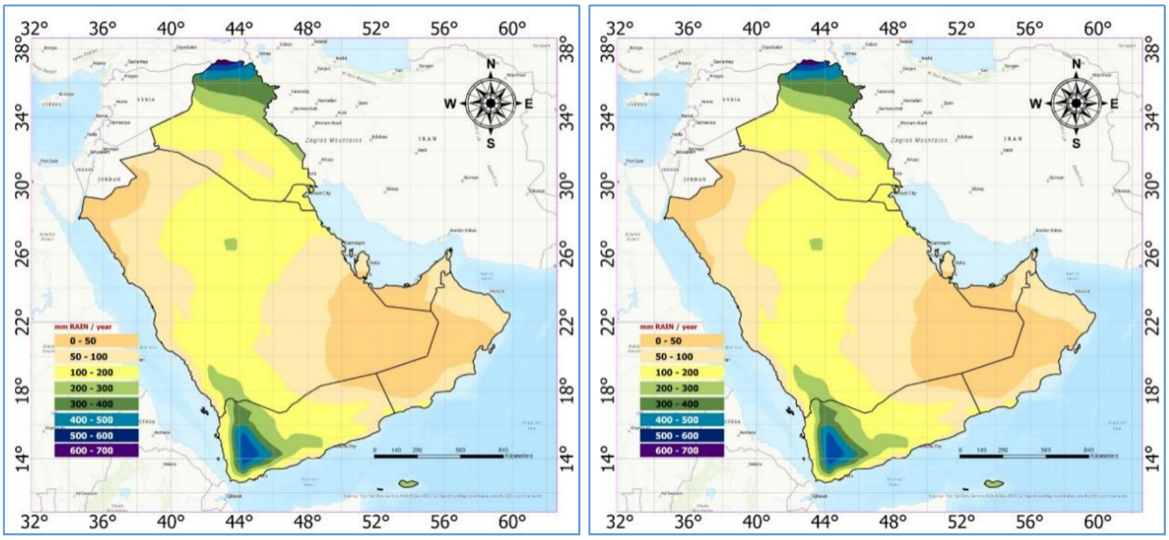


Figure 1. Location of the Arab Gulf Countries.

The climate is semi-arid to arid, with high annual temperatures and low rainfall, making it one of the most climate-vulnerable. The mean annual rainfall generally revealed insignificant differences between AG countries. Oman and AUE show the lowest mean annual rainfall during the study period (49.8 mm to 69.3 mm), while Iraq and Yemen have the highest mean annual rainfall (160 mm to 208.5 mm), as shown in **Figure 2**[21]. The Gulf region exhibits a wide variety of landforms and habitats. It consists of mountains, steppes, marshes, coastal plains, dunes, alpines, and deserts, and is characterized by extreme climatic conditions in the form of long, hot, and dry summers with short, cool, and only lightly wet winters, with rainfall as little as 50 mm or less[18].



(**a**) Yearly Average Rainfall For the period 2001–2010. (**b**) Yearly Average Rainfall For the period 2011–2020.

Figure 2. Spatial distribution of the mean annual rainfall in the AGC for the period 2000–2020.

The mountainous regions support a cooler and more moderate climate compared to the surrounding lowlands, thus forming unique ecosystems that function as Refugia for plant and animal species, and have a high endemism of plant species. The desert ecosystems support a variety of life forms that are specially adapted to an extreme arid climate[27].

Most of the AGC is unsuitable for agriculture, except in the northern part, mainly Iraq, and the coastal area, making irrigation and land reclamation projects essential. The narrow coastal plain and isolated oases, which account for less than 1% of the land area, are used to grow grains, coffee, and tropical fruits. Climatic constraints and a lack of favorable soils for agriculture are responsible for the negligible agricultural wealth. On average, 1% of AGC land is cultivable, and less than 0.5% is cropped.

2.2. Satellite Data

To study the spatial distribution of land degradation on a wide area of the AGC, moderate resolution data for the MOD13Q1 Sensor were used in this study, on a bi-monthly basis. The data were downloaded from NASA Earth Observation data for the purposes of calculating the distribution and spread of NDVI vegetation with an accuracy of 250 m, covering the AGC domain, about 10 scenes for each type of MODIS data for 21 years, from 01/01/2000 to 31/12/2020 and the total number of scenes is (2 × 8 × 12 × 21), equivalent to 4032 scenes. In this study, 122 sites were selected to represent the entire variations within the area of the AGC to calculate the NDVI indices and assess land degradation trends for March during the period 2000 to 2020 (**Figure 3**).

The selected study sites show a wide variation in land cover types, climate conditions, and topographic location that have a high effect on land degradation status. NDVI stands as a common remote sensing index that researchers use to measure vegetation density in the study area precisely. NDVI represents the difference between satellite imagery obtained from near-infrared (NIR) and red bands, which generates numerical values from −1 to +1. The NDVI measurement produces better results in healthy vegetation areas but shows poor values in places where vegetation is absent, and degenerates, or the land becomes barren. The research examined seasonal and long-term plant changes via NDVI-based evaluation, which revealed vegetation health deterioration across areas suffering from serious desertification and land degradation. The NDVI is a normalized transformation of the ratio between near-infrared (NIR) and red reflectance, expressed as below [28].

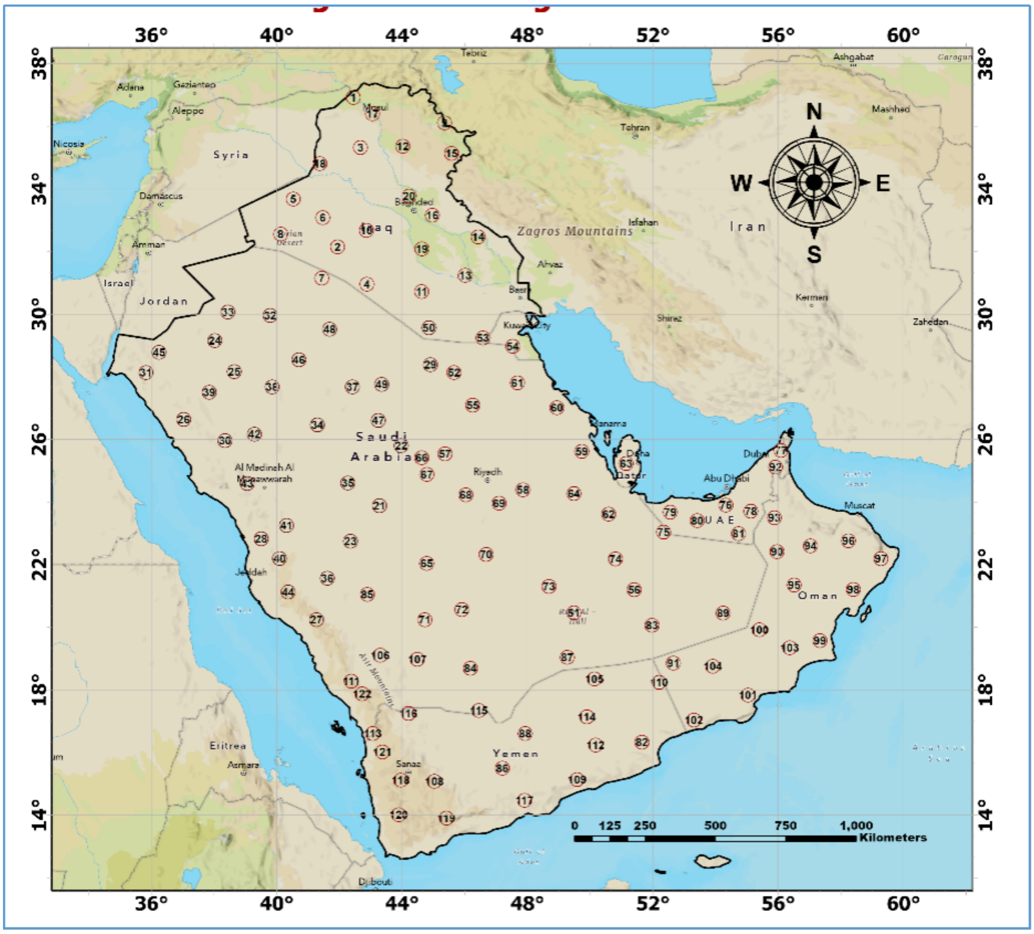


Figure 3. Location of the selected sites in the study area.

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{Red})/(\mathrm{NIR} + \mathrm{Red}) \quad (1)$$

A simple linear trend approach was used to analyze potential land degradation trends using the Mann-Kendall statistical confidence limits for 122 selected sites during the study period.

3. Results and Discussions

3.1. Temporal Distribution Trends of NDVI in the Age for the Period 2000 to 2020

To understand the temporal trend of land degradation worldwide, we selected 122 sites to represent the total area of the AGC NDVI trend as shown in **Figure 3**. The results indicated that the mean annual NDVI values are greatly fluctuating over time as vegetation cover was affected by many factors, such as climate change, human activities. Generally, the NDVI values ranged from 0.0 to 0.80, and most of the AGC area (92%) appears as bare land, with a small part covered by vegetation (less than 6%) due to climate change and the dominance of dry climatic conditions and severe water shortages in the region [29].

The results of the Mann-Kendall statistical analysis of the temporal NDVI values from 2000 to 2020 reveal a significant decline over time, except for some selected sites occupy less than 10% of the total area of AGC, have an upward trend over time (**Figures 4** and **5**), that means the improvement of vegetation cover due to the impact of climatic condition and development of agricultural activities. This is attributed to the effects of human activities and climate change, as evidenced by the decrease in mean annual rainfall and the rise in mean annual temperature and evapotranspiration in the AGC area [30]. Sites that show an increase in NDVI over time are mainly located in the northern part of Iraq (and the coastal regions (sites 9, 7, 11, 17, 20, 47, 63, 129, 121), which received a higher amount of rainfall. These results indicate that the land degradation process has become more serious in the past 20 years, causing a decline in the vegetation cover over time due to the effect of climate change during the last two decades which caused water scarcity and drought.

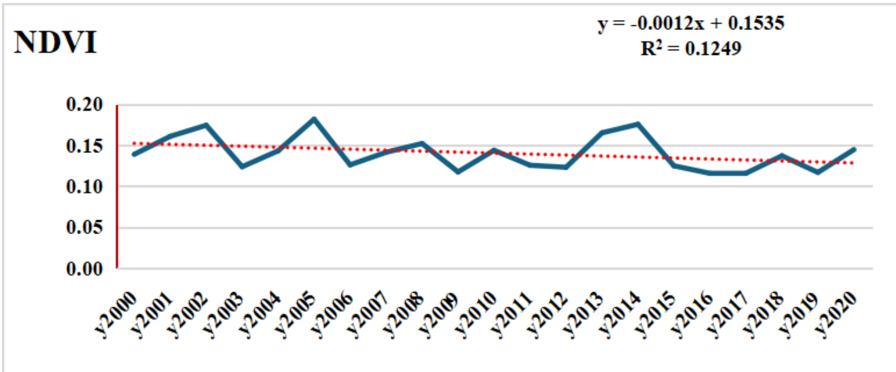


Figure 4. Temporal distribution of mean annual NDVI changes over time for some sites in AGC from 2000 to 2020.

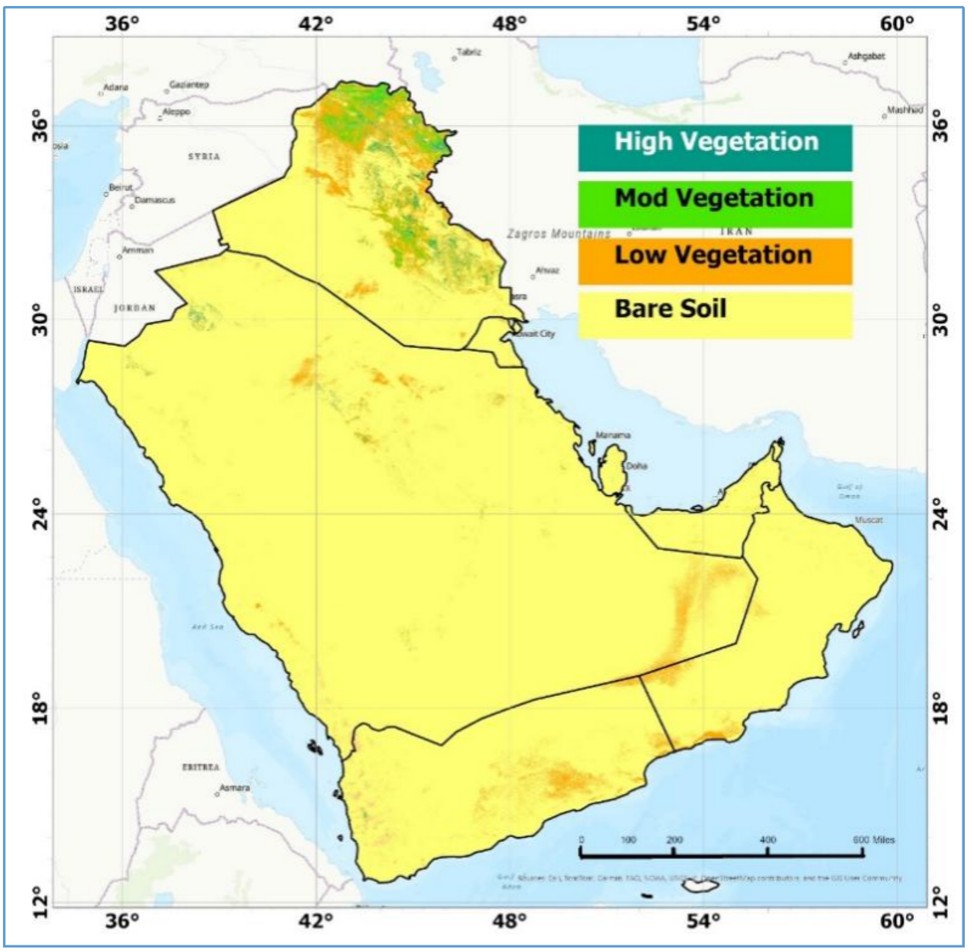


Figure 5. Spatial Distribution of Land Cover Classes in the AGC.

3.2. Classification of Land Degradation and Vegetation Status in the AGC Using NDVI

According to the results of NDVI classification (**Table 1** and **Figure 5**), four classes were identified: high vegetation, moderate vegetation, low vegetation, and bare land. The results indicate that bare land covers the majority of the total area of the AGC (92.76%), reflecting the dominance of dry climatic conditions and water scarcity in the AGC. This class consists of degraded land, including deserts, dunes, salt-affected soils, and highly eroded land. The bare lands exist in all of the AGC as a result of dry climatic conditions and severe drought, which have a great effect on plant growth and soil quality. On the other hand, less than 8% of the region, located in Iraq and the coastal area, as well as some oases, shows the presence of vegetation cover.

Table 1. NDVI Values and land cover classes in AGC.

NDVI Value	Land Cover Class	Area sq km	Area %
0.40–0.80	High vegetation	15,393.17	0.47
0.30–0.40	Mod vegetation	47,901.30	1.47
0.15–0.30	Low vegetation	172,751.76	5.30
0–0.15	bare soil	734,175.56	92.76
Total		3,258,467.26	100.00

3.3. Temporal Change in Land Degradation and Vegetation Status in the AGC for the Period 2000 to 2020

The results reveal the presence of three main land degradation classes in the AGC, including the negative change, no change, and positive change classes. The change classes were subdivided into six subclasses according to land degradation status, three classes for each of them, including high, moderate, and low change classes (**Figure 6** and **Table 2**). The no-change class, which represents the dominant class and occupies about 61.51 % of the total area of the AGC, consists mainly of the desert, mountains, and dune area. The negative classes occupy 33.34% of the total area of the study areas, 31.48% of it represents low negative change, which can be considered part of the bare land with a total area of 94.84%. While 4.53% shows a positive change in its vegetation, which represents land improvement of most AG counties, mainly in Iraq and the coastal zones, during the period from 2000 to 2020 (**Figure 6** and **Table 2**). The agricultural activities are represented by increasing the mangrove cover, mainly in Qatar and the United Arab Emirates (UAE), during the last two decades. This trend is attributed to government conservation initiatives aimed at expanding mangrove afforestation and restoration through direct seeding and seedling planting [31,32].

The dominance of bare land in the AGC can be attributed to the impact of the dominant dry climatic conditions and water crisis in the region. The GCCSTAT [19] reported that about 90% of the region is considered very arid, and the remaining 10% is covered by semi-arid and dry sub-humid areas. 73% of the already limited arable land is affected by land degradation. The economic cost of land degradation is $9 billion per year. 82% of the regions' land is affected by some form of land degradation, with deforestation, overgrazing, desertification, and soil erosion being major contributors. The impacts of land degradation are multifaceted, including reduced agricultural productivity and significant biodiversity loss. It damages ecosystems and habitats, contributing to climate change feedback loops, as degraded lands emit more greenhouse gases and sequester less carbon [30].

Table 2. Land degradation classes in the AGC.

Degradation Classes	Area (km²)	Area%	Land Degradation%
High negative changes	10,049.66	0.31	
Mod negative changes	50,935.72	1.56	
Low negative changes	1,025,801.48	31.48	Bare Land = 94.86
No change	2,004,306.11	61.51	
Low positive changes	122,762.71	3.77	
Mod positive changes	29,090.11	0.89	
High positive changes	15,521.46	0.48	Vegetated Area = 5.14
Total	3,258,467.26	100.00	100.00

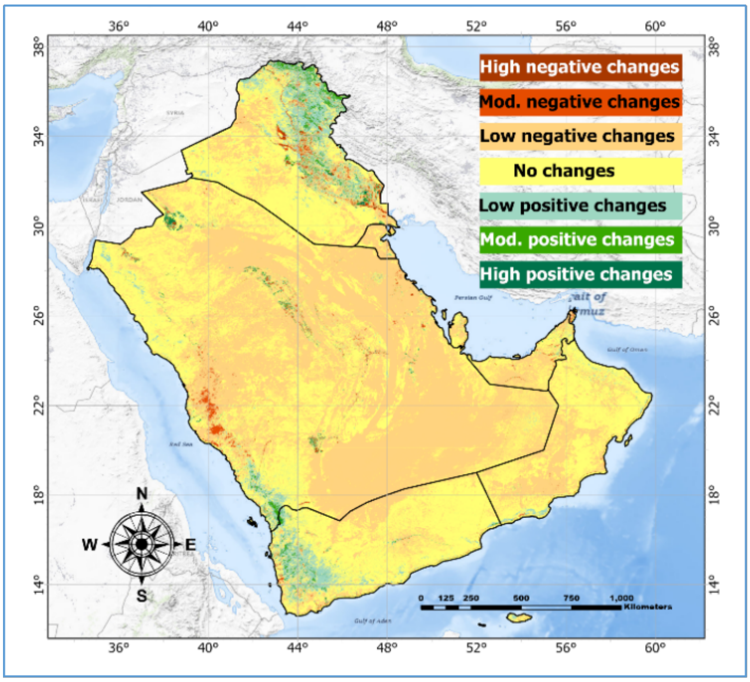


Figure 6. Spatial distribution of land degradation classes in the AGC.

The results in **Figures 7** and **8**, and **Table 3**, illustrate land degradation trends over a five-year interval in the AGC for the period 2000 to 2020. The findings revealed that all degradation classes exhibit a fluctuating trend of change over time. In general, the negative change classes have the highest rate of change compared to the no-change and positive classes, indicating an increase in land degradation over time in the AGC. The moderate degradation class exhibits the highest effect of land degradation, with mean annual values ranging from 0.71% for the interval 2009–2013 to 80.0% for the interval 2005–2009 (**Table 3**). Generally, the results revealed that the land degradation trend in the AGC extended over time, for the same reasons as mentioned before (**Figure 5**). Muhaimeed et al.[21] indicated that the Arab Gulf countries have faced various climate change threats in recent decades, evidenced by a significant rise in average annual temperature, a decline in rainfall, and increased potential evapotranspiration, which worsen water scarcity and environmental issues degradation.

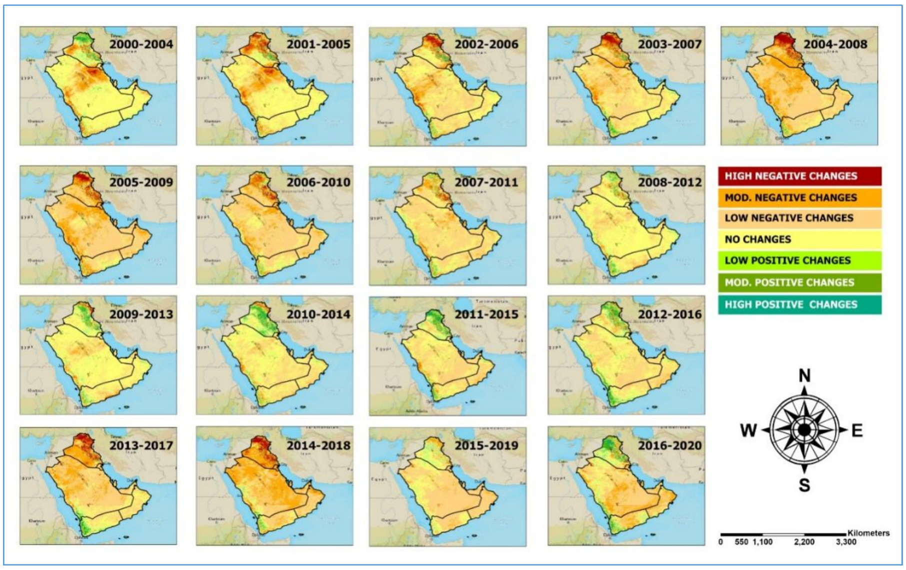


Figure 7. Change Detection of Land Degradation and Vegetation Classes in the AGC over a five-year interval for the period 2000 to 2020.

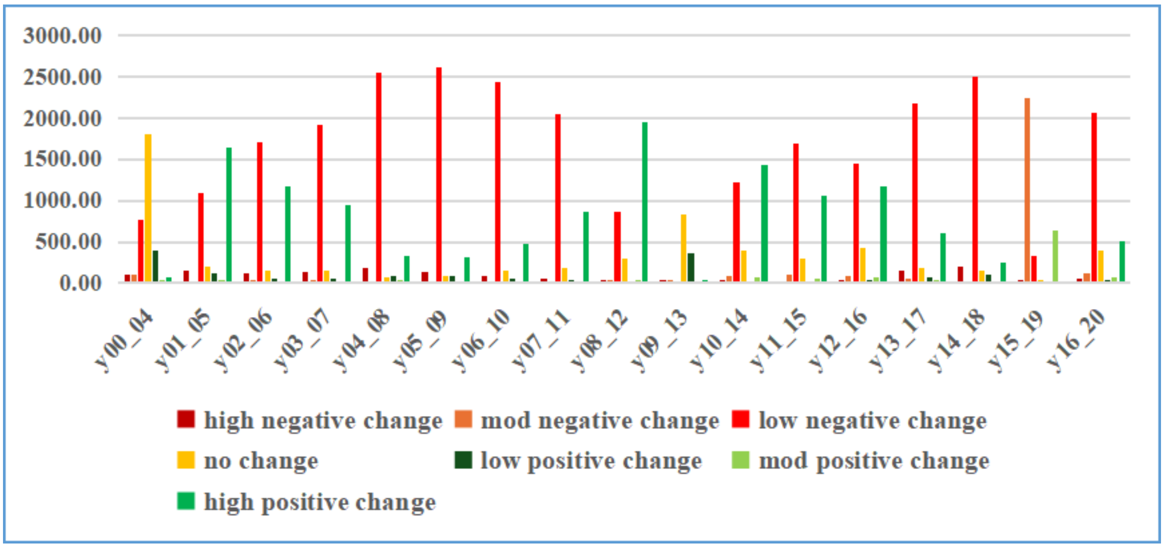


Figure 8. Monitoring of land degradation change over a five-year interval in the AGC for the period 2000 to 2020.

Table 3. Temporal Changes of Land Degradation and Vegetation Classes in the AGC over a five-year interval for the period 2000 to 2020.

Year	**High Negative Change**		**Mod. Negative Change**		**Low Negative Change**		**No Change**		**Low Positive Change**		**Mod. Positive Change**		**High Positive Change**	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
2000–2004	102.73	3.06	99.75	23.38	761.80	55.18	1797.92	12.13	395.10	1.12	36.61	1.98	64.56	3.14
2001–2005	159.91	0.93	30.19	33.51	1091.90	6.12	199.36	3.63	118.39	0.51	16.50	50.41	1642.20	4.89
2002–2006	116.61	1.09	35.43	52.33	1704.77	4.81	156.56	1.74	56.60	0.66	21.51	35.82	1166.99	3.56
2003–2007	131.64	1.21	39.56	58.80	1915.83	4.62	150.52	1.68	54.57	0.82	26.58	28.84	939.76	4.03
2004–2008	184.56	0.69	22.39	78.05	2542.89	2.44	79.39	2.72	88.50	0.42	13.71	10.04	327.03	5.65
2005–2009	144.51	0.59	19.30	**80.02**	2607.05	2.51	81.68	2.63	85.58	0.40	13.19	9.43	307.16	4.42
2006–2010	94.56	**0.79**	25.75	74.82	2437.71	4.51	147.02	1.85	60.36	0.60	19.49	14.54	473.59	2.89
2007–2011	61.35	0.88	28.82	62.98	2051.98	5.81	189.43	1.23	39.92	0.80	26.02	26.43	860.96	1.87
2008–2012	32.04	1.29	41.96	26.74	871.29	9.34	304.24	0.63	20.55	1.22	39.74	59.81	1948.65	0.97
2009–2013	34.90	1.34	43.73	**0.71**	23.11	25.60	834.18	11.24	366.11	0.76	24.76	1.34	43.50	59.01
2010–2014	32.87	2.86	93.14	37.44	1219.82	12.00	391.06	0.74	24.01	2.13	69.24	43.84	1428.32	0.99
2011–2015	27.93	3.29	107.25	51.68	1683.70	9.27	302.08	0.59	19.28	1.94	63.28	32.38	1054.96	0.84
2012–2016	31.65	2.93	95.55	44.44	1447.93	13.14	428.14	0.41	13.47	2.17	70.59	35.95	1171.13	0.96
2013–2017	146.40	1.52	49.38	66.84	2177.65	5.58	181.87	2.03	66.08	1.04	33.74	18.52	603.34	4.48
2014–2018	194.50	0.77	25.17	76.63	2496.49	4.66	151.95	3.40	110.69	0.76	24.70	7.83	254.98	5.96
2015–2019	14.97	**68.64**	2236.14	10.21	332.72	0.98	31.83	0.09	3.05	19.64	639.75	0.00	0.00	0.45
2016–2020	54.55	3.68	119.75	63.33	2063.33	12.18	396.89	1.29	42.09	2.29	74.63	15.57	507.23	1.66

Comparison of the temporal changes of land degradation status, two periods were selected to show the changing trend. The results in **Figure 9** and **Table 4** illustrate the temporal changes in the degradation classes between the period (2000–2005) and (2015–2025). The results confirmed the presence of a significant difference in the degradation trends within and between the two periods. **Figure 9** and **Table 4** reveal the dominance of bare land, accounting for approximately 50% of the total area during the first period, which includes desert, dunes, saline, and eroded lands. Comparison to the negative and positive classes occupied 42% and 7.5%, respectively, during the period 2000–2005. While the dominance was for the negative change class, which occupies 66.3% of the total area, compared to the positive and no change classes, which occupy 18.15% and 15.57%, respectively, during the second period. The increase in the total area of the negative change class can be attributed to the effect of climate change, reflected by the increase in the mean annual temperature and evapotranspiration with a decline in rainfall [21].

Table 4. Temporal Changes in the Area of Degradation classes in AGC for the period 2000 to 2025.

Degradation Classes	**2000–2005 Area (km²)**	**2000–2005 Area (%)**	**2015–2020 Area (km²)**	**2015–2020 Area (%)**
Negative Change	1,366,648.6	42.05	2,154,353.3	66.29
No Change	1,637,935.5	50.40	505,914.8	15.57
Positive Change	245,415.9	7.55	589,731.4	18.15
Total	3,250,000.0	100.00	3,249,999.5	100.00

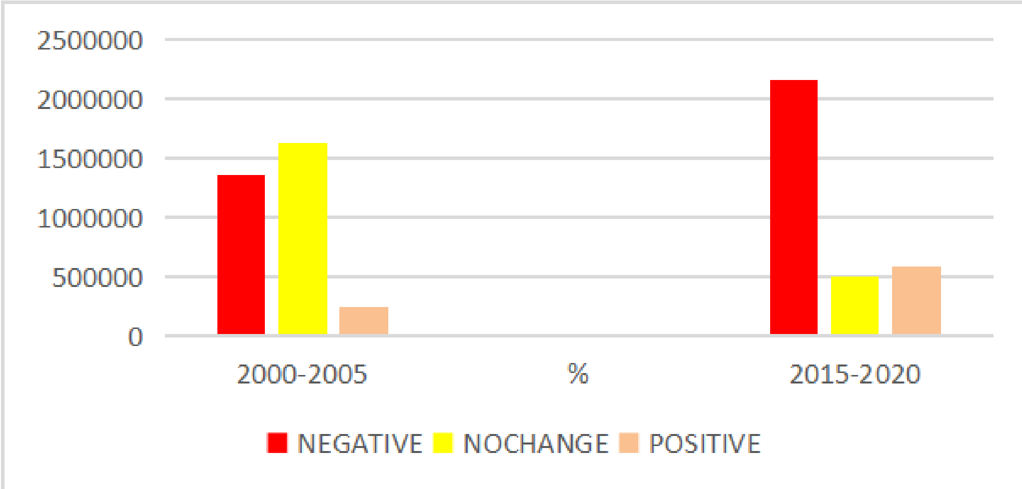


Figure 9. Temporal changes in land degradation classes in AGC for the period 2000 to 2025.

This study indicates that land degradation and desertification have worsened over the past two decades, and the future for vegetation appears bleak. Additionally, the NDVI fluctuates greatly because vegetation cover is influenced by the factors of climate change and human activities, except in the northern parts, mainly in Iraq, and in the coastal areas, where the NDVI showed a general upward trend, indicating that the vegetation cover has partially improved either by human activities throughout agricultural practice or the impact of climatic conditions. The northern part of Iraq is located within semi-arid to sub-humid zones with moderately high rainfall, which are more suitable for rain-fed cultivation, while the southern part is suitable for irrigated cultivation, so the vegetation cover is healthier than in other locations within the AGC. Also, the coastal region of the AGC shows an improvement in vegetation cover, mainly in the area which shows the cultivation of Mangrove during the last two decades. The improvement of vegetation cover in coastal AGC during the last two decades is caused by the impact of climate change, which had a significant effect on land cover dynamics and on mangroves and seagrass growth. While anthropogenic factors such as urban expansion and agricultural growth negatively impacted dense vegetation. Generally, the Arab Gulf countries have faced various climate change threats in recent decades, highlighting a significant increase in average annual temperature, a decreasing trend in rainfall, and a rise in potential evapotranspiration, exacerbating water scarcity and environmental degradation, causing vegetation cover to be weak, sparse, and covering a very limited area of the AGC [21].

Vegetation cover in the AGC is generally sparse due to the arid climate, but mangroves and coastal vegetation play a vital role in specific areas. Mangroves, primarily Avicennia marina, are important for coastal protection and biodiversity, while inland vegetation is adapted to arid conditions with species like Rhanterium epapposum dominating dune areas. However, urban expansion and agricultural practices are impacting vegetation cover, particularly in oases and the coastal regions. It was observed during the last decade that many activities have been operated to develop coastal areas in the Arab Gulf states, which have led to the development of the coastal region and unprecedented population growth and massive construction activities, mainly during the last two decades [33,34].

4. Conclusions

The study emphasized the dynamics of land degradation and vegetation in AGC over the past two decades. The findings revealed significant changes in land cover over time, reflected by a negative change in land degradation status, which occupied more than 95% of the AGC, representing bare land. It is vulnerable to the impact of degradation and desertification processes. In recent decades, the AGC has faced severe climate change threats reflected by drought conditions resulting from the increase in mean annual temperature and evapotranspiration, and a decline in the mean annual rainfall. In comparison, less than 5% of the region had shown a positive land cover improvement, mainly in the northern part of Iraq and the coastal region, due to the impact of climate change and anthropogenic factors. Climate change, as reflected by an increase in temperature and evapotranspiration, and a decrease in rainfall, was seen to negatively impact vegetation, while urbanization and agricultural expansion exerted significant pressure on these land covers. This study recommended establishing more detailed works using field work and high-resolution satellite data to illustrate the reality of the type and severity of land degradation processes in the AGC.

Author Contributions

All authors contributed equally to all stages of the study, from conceptualization and study design to data collection, analysis, writing of the manuscript, and final approval of the published version.

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Institutional Review Board Statement

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Informed Consent Statement

Not applicable.

Data Availability Statement

Data will be available on request from the author.

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Conflicts of Interest

There is no conflict of interest.

Abbreviation

AG	Arab Gulf
AGC	Arab Gulf Countries
GCCS	Gulf Center for the Cooperation Council for Statistics
LD	land Degradation
MGI	Middle East Green Initiative
UNCCD	United Nations Convention to Combat Desertification

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