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Land Cover Dynamics of Al-Hammar Marsh: Restoration Plan Methodology Assessment

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ABSTRACT

The restoration plans for the Iraqi marshlands face significant challenges due to water scarcity and climate change. The Al-Hammar Marsh, which spans more than 3000 km^2, is the biggest marsh in Iraq's southern region. It is located between the cities of Nasiriyah to the west and Basrah to the southeast. The marsh's water supply mainly comes from branches on the right bank of the Euphrates River and as seasonal runoff from Al-Qurnah Marsh, with waterways leading to the Shatt Al-Arab receiving the marsh outflows. The current study aims to assess the effect of the restoration plan on the land cover dynamics in the Al-Hammar Marsh. OLI satellite images from 2013 to 2024, ArcGIS 10.8, and several spectral-based indices, such as Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Normalized Difference Moisture Index (NDMI), were applied for this purpose. Six land cover classifications have been identified: open water, wet soil, medium-density vegetation, sparse vegetation, dense vegetation, and dry area. The data from 2019 and 2020 revealed an increase in the water area, comprising 52.57% and 61.29% of the total Marsh area, respectively, with 2020 recording the highest percentage of open water. Conversely, the vegetation area did not significantly improve over the study period, with the highest rate at 33.64% in 2014 and the lowest at 7.75% in 2021. the analysis revealed that immersed areas exceeded 80% from 2013 to 2024 except in 2016, 2017, 2022, and 2024, which recorded lower values of 71.35%, 77.64%, 76.94%, and 69.86%, respectively time series analysis is a useful method for describing and monitoring changes in each wetland use category, and approach will help conserve marshes through improved water management.

1. INTRODUCTION

The marshlands of Iraq are the largest on the Asian continent, spanning thousands of square kilometers south of Iraq and western Iran at the confluence of the Tigris and Euphrates rivers. These swamps harbor unique biodiversity and are vital economic and social ecosystems for regional human life and nature [1]. However, over the past decade, these marshlands and their native ecosystems have suffered from desiccation, destroying the entire ecosystem. The IMoWR (Iraqi Ministry of Water Resources) launched a substantial initiative in 2003 to rehabilitate the Iraqi marshes and associated ecosystems. Despite intensive efforts by relevant organizations to implement these plans, challenges such as insufficient water resources, population change, and various industrial activities hinder the successful implementation of the restoration plan. Addressing these obstacles requires a comprehensive assessment of the feasibility of achieving the recovery plans [1, 2].

It is essential to employ effective methods and tools for a comprehensive physical assessment to understand wetlands. The initial step involves mapping wetlands and evaluating changes in vegetation and other ecological impacts. Satellite data and geographic information system (GIS) methods are invaluable for monitoring and analyzing changes in land cover and ecosystem characteristics [3]. Furthermore, remote sensing and GIS technology have been instrumental in monitoring, analyzing, and investigating various wetlands activities.

Numerous researchers have studied the various changes the southern Iraqi marshes have undergone by applying geographic information systems (GIS), and remote sensing to analyze them and study the various activities. An NDVI threshold for the Iraqi marshes was produced by IMOS (Iraqi Marshland Observation System) [4] for Landsat satellite images. Vegetation cover is associated with regions having an NDVI value larger than 0.125, and values of the NDVI between 0.125 and 0.25 represent sparse vegetation. In contrast, NDVI values ranged from 0.25 to 0.5, representing medium-density vegetation and dense vegetation associated with a value higher than 0.5. Changes in land use and land cover LULC in Iraqi marshes were studied by the study [5] utilizing GIS applications with remote sensing and Landsat images of TM, ETM, and MSS recorded at various intervals spanning from 1973 to 2004. Vegetation cover is also extracted using NDVI. The classification results indicate a considerable decline in water mass and an increase in wasteland area in 2000. However, the area expanded by more than 50% in 2004 following the restoration operations. The study [6] employed the Color Extracting Technique, an unsupervised classification approach, to categorize satellite images captured by four different sensors: TM1990, MSS1973, ETM+ in 2000 and 2002, and MODIS in 2009 and 2010. They detect changes in the Al-Hammar Marsh's main land cover categories (water, vegetation, and soils). The research results showed that there was an unexpected decrease in water quantities since 1990 and beyond due to the policy of the ruling regime at that time, in addition to the construction of dams in Turkey. The research also found a direct relationship between water areas and plant areas, on the contrary, there was an inverse relationship between water areas and soils. The study [7] used remote sensing techniques (GIS) and satellite images of Landsat TM, MSS, MODIS, and ETM to monitor the AL-Hammar Marsh Land cover from 1973 to 2010. Additionally, these images were categorized using Erdas Imagine software ver. 9.1. The ArcMap software ver. 9.3 was employed to generate the final maps. The study period was divided into three stages: the critical stage at the beginning of the drying process, the after-drying stage, and the recovery stage. The results showed a significant decrease in water areas between the years (1990-2000) due to the marsh being affected by the water crisis as a result of the policy of the ruling regime at that time, in addition to the construction of dams in Turkey. The results also showed that the recovery operations after 2003 did not restore the marsh with sufficient water quantities to revive it, which portends an environmental disaster with the emergence of desertification as a result of climate change and the disappearance of aquatic life, in addition to the migration of the region's population. Detection of the water content of the southern Iraqi marshes was the aim of the study that was adopted by the study [8], Satellite images were used with the help of the adaptive technology of supervised classification to evaluate the plants, water, and dry areas in the southern Iraqi marshes for 48 years (1972-2020), which represented two main stages depending on the deterioration that occurred during the 90s. The first stage was between (1972-2000) and the second stage represents the years (2000-2020). Satellites, MSS, TM, ETM, and OLI /TIRS were used to achieve the goal. The results showed that the increasing trend in the second stage was almost double the decreasing trend in the first stage and that the water quantities for the second stage recorded a continuous increase except for some decreases that occurred in the years 2015 and 2018. The study showed that the classification of visual differences is the most appropriate economic approach to detecting different environmental changes compared to common methods. The study [9] used remote sensing and geographic information systems (GIS) in a study to produce maps of the wetlands of Mesopotamia in southern Iraq to monitor the change caused by human activities. Using satellite images available from Landsat at the United States Geological Survey (USGS). Supervised classification and unsupervised classification techniques and a maximum likelihood algorithm were used to produce the maps to detect the changes that occurred over (15 years) between 1985 and 2000. The results showed a decrease in land cover by 85.37% and an increase of 46.32% for the desert and the deep water decreased to only 2.31% with a complete disappearance of shallow water. The study also revealed that intensive human activities such as dam construction and agriculture may have been the cause of the collapse of wetlands in southern Iraq.

A model builder in ArcGIS was created based on a series of spectral-based indices including (NDVI), (NDMI), and (NDWI), with OLI satellite images to monitor the land cover change for the western part of Al-Hammar Marsh in southern Iraq from 2013 to 2020 by the study [10]. The researcher divided the land cover classes of the marsh into six classes: water, dense vegetation, medium-density vegetation, sparse vegetation, wet arid lands, and dry arid lands. The results showed no improvement in the area of vegetation cover except for a slight improvement of 48% in 2017 and an increase in water areas in 2019 and 2020 to 47.33% and 42.85% of the total area of the marsh, respectively. The highest percentage was in 2019 and the lowest percentage was 14.05% in 2018. The study [11] used data from Landsat 8 and Sentinel-2 satellites to classify and monitor the Al-Hammar Marsh in southern Iraq for the years 1991, 2002, 2015, 2016, and 2017, and proposed a relationship between three indicators, NDVI, NDWI, and NDMI. The researcher divided the land cover categories of the marsh into six categories, including (dense vegetation, sparse vegetation, medium-density vegetation, open water, wet soil, and dry area). Temporal land cover maps represented the land cover of the marsh. The results showed that the correlation (R) for all classes between Landsat 8 and Sentinel-2 was (0.78) and explained that the approach of using multispectral satellite imagery will help to preserve marshes through improved water management.

However, the above studies were either much shorter in duration or studied the area during the drying operation years or these studies were on different spatial or smaller extent, as well as some researchers followed a different classification method. The study area Al-Hammar Marsh was selected for this research because of its importance as an essential water resource for the region, similar to the rest of the Iraqi southern marshes, and its inclusion in the World Heritage List 2014. Al-Hammar Marsh was exposed to severe deterioration and drought that affected the Iraqi southern marshes in the 1990s. After 2003, the IMoWR began developing plans to bring back the floods because of the drought's impact on the marsh's land cover. This research aims to detect and monitor the changes in the land cover categories of Al-Hammar Marsh in its eastern and western parts for the period (2013-2024) by classifying the spectral indicators adopted in this study and implementing land cover maps with a statistical examination to clarify the impact of the metrological data on the land cover categories. Also, to know whether the restoration operations carried out by the Iraqi Ministry of Water Resources have been beneficial in restoring the marsh and re-flooding it. Remote sensing techniques benefit this study because they are easy to produce and use, have a low cost, and provide quick results [5]. With the help of geographic information systems GIS, land cover maps of the Al-Hammar Marsh can be produced to achieve the goal of this research by monitoring the land cover of the marsh for the study period.

2. MATERIALS AND METHODS

2.1 Description of the study area

The greatest body of water in southern Iraq is called the Al-Hammar Marsh, located between longitudes (46º24´-47º39'E) and latitudes (30º33´-30º58'N). It is located on the Euphrates River's right bank. It extends along the Shatt al-Arab River from the western suburbs of Basra City to the west near Al-Nasiriyah City Figure 1. It is bordered to the south by saltwater lakes and the sand belt of the southern desert [12]. In the past, this marsh area included a lake and marsh covering around

2800 km², which grew to about 4500 km² at seasonal and transient inundation with 1.8 to 3 meters of maximum water depth [13, 14]. The marsh measured about 120 km in length and 25 km in width.

The Al-Hammar dike divides Al-Hammar Marsh into two halves. The eastern portion of the Al-Hammar Marsh, fed by the tidal phenomenon through the Shatt Al-Arab River, is located within Al-Basra City. The western portion is fed by many rivers and is situated in Thi-Qar province and spans 1326 km², extending northwest of Al-Basra, adjacent to Al-Nasiriyah [15]. The Al-Hammar Marsh's primary water sources are the Euphrates River and the Main Outfall Drain (MOD). Water from the UmNakhal, Al-Hamedy, and Al-Kurmashia rivers nourishes the western part of the marsh. The central opening, BC4, BC4 opening, BC3, and BC3 opening are the sub-rivers that feed the marshes. These rivers carry water from the Euphrates River to the marsh body, acting as both feeders and exits for the marsh, relying on the marsh's water level. For the purpose of feeding the marsh, Al-Khamissiya carries water from the MOD. The Al-Musahab, Al-Shafi, and Al-Salal rivers feed the eastern portion of the marsh [16] (Figure 1).

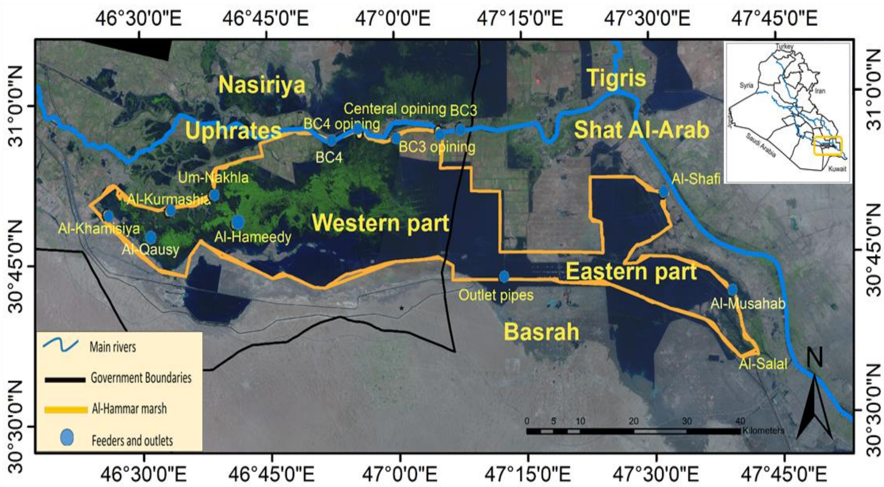


Figure 1. Location of Al-Hammar Marsh with its feeders

2.2 Plans for restoring marshes in Iraq

Since 2003, the Iraqi Ministry of Water Resources (IMoWR) has made many efforts with local and international research institutions to assess the status of the marshes and develop plans and programs to restore them. The plans have been developed based on extensive field surveys and research. The primary objective of the plans is to replenish 50% of the CRIMW (Centre for Restoration of Iraqi Marshes and Wetlands) delineated marshes, with an annual allocation of 5.825 billion cubic meters (BCM) of fresh water to the marshes. Adopting modernized agricultural practices and efficient land management will mitigate soil degradation and prevent arable land from transitioning into desert. This holistic approach not only aims to conserve the habitat and biodiversity in the marshes, rivers, and other vulnerable areas and to promote the sustainable utilization of freshwater resources. The restoration plans project a total freshwater surface consumption of marshlands in Iraq to amount to 5.825 BCM/year by 2035 and recommend an additional outflow of 2.611 BCM annually to Al-Hammar Marsh [10]. A diversion from the Euphrates into the marsh has been built as part of the Al-Hammar Marsh regeneration plan. The diversion is capable of withstanding a maximal discharge of 600 m³/s (SWLR, 2014). These initiatives are critical in the effort to guarantee the long-term sustainability of Iraq's marshlands [10].

2.3 Collected data

2.3.1 Hydro-climatic data

Monthly meteorological data, such as minimum and maximum air temperature, precipitation, and Earth skin temperature from the Iraqi Agrometeorological Center Al-Chibayish station (30° 56' 24" N and 47° 4' 12" E), were collected for the time between 2013/2014 and 2022/2023. Climate data were collected until December 2022 due to the lack of climate data for 2023 and 2024 within the Al-Chibayish station.

A software program called DrinC was employed to predict potential evapotranspiration [17]. The Hargreaves method has been used to compute potential evapotranspiration. According to the study [18], the Hargreaves method could be considered the main tool for estimating potential evapotranspiration for many climatic conditions, including arid and semi-arid climates, due to its suitability for climate change research and the backing of numerous studies in the field of water resources, such as the studies [18-20] also showed that the Hargreaves technique was linked to the best outcomes that closely matched the Food and Agriculture Organization's Penman-Monteith approach's whole equation. Mean monthly and annual inflow and immersion ratios were collected by the CRIMW (2023) [21].

2.3.2 Satellite data acquisition and analysis

The study period from 2013 to 2024 was adopted in this research to monitor the changes in the Al-Hammar Marsh land cover after restoration operations. The Al-Hammar Marsh's time series of land cover maps were created using Landsat sensor images (OLI/TIRS) Two scenarios (path 166/row 039 and path 167/row 039) for each year in the same month, with a cloud cover of less than 10% for 12 years (2013–2024), were selected. Twenty-four Landsat images for the Al-Hammar Marsh were downloaded from the United States Geological Survey (USGS) (https://earthexplorer.usgs.gov/.) [22]. The details of the collected data are presented in Table 1.

Table 1. Landsat 8 (OLI/TRIS) imagery data was collected for the Al-Hammar Marsh during the period from 2013 to 2024

Year	Month	Days	Year	Month	Days
2013	Jun	10-17	2019	April	8-15
2014		13-20	2020		10-17
2015	April	13-20	2021	May	6-15
2016		15-22	2022		15-22
2017	May	11-20	2023	April	3-10
2018		23-30	2024		5-12

Subsequently, all images were then pre-processed and processed to analyze them for this study. The process of generating a mosaic for the images has been successfully executed after converting them to top-of-atmosphere spectral reflectance values to account for the radiometric contrast by using ENVI 5.3. Through the Extract option in the ArcGIS application options menu, the boundaries of the study area Al-Hammar Marsh were cut from the resulting mosaic image as it covers a larger area than the study area. All images were pre-processed and processed for analysis in this study.

2.4 Spectral indices

The normalized difference vegetation index (NDVI), the normalized difference water index (NDWI), and the normalized difference moisture index (NDMI) were used as spectrum-based indices to classify the spatial extent of the marshland over the study period, as listed in Table 2.

Table 2. The United Nations Environment Program (UNEP) classification based on the Landsat 8 (0LI*/TIRS**)

Equation	Values	Classification
$NDVI^1 = \frac{NIR^a - R^b}{NIR^a + R^b}$	NVDI < 0.125	Non-vegetation
	0.125 < NVDI < 0.25	Sparse vegetation
	0.25 < NVDI < 0.5	Medium vegetation
	NVDI > 0.5	Dense vegetation
$NDWI^2 = \frac{G^c - NIR^a}{G^c + NIR^a}$	NDWI ≥ 0	open water
$NDMI^3 = \frac{NIR^a - SWIR1^e}{NIR^a + SWIR1^e}$	NDMI ≥ 0	wetlands

1. Normalized Difference Vegetation;
2. Normalized Difference Water Index;
3. Normalized Difference Modified Index;
a Near-Infrared Red (0.85−0.88 μm);
b Red (0.64−0.67); c Green (0.53−0.59 μm);
e Shortwave Infrared (1.57−1.65 μm);
*Operational Land Imager;
** Thermal Infrared Sensor. Note: μm=micrometers (10-6 meters)

The NDVI is the most widely used index for vegetation monitoring. The index is based on a combination of near-infrared (NIR) and red (R) band wavelengths and can be computed using the well-known equation (Table 2). To differentiate between non-vegetative and vegetative extents, the NDVI is a reliable indicator of plants [23]. In general, the NDVI numerical figure range is -1 to 1. Features with vegetative cover have values between 0 and 1, whereas those without vegetation, like bare ground, inhabited regions, and water bodies, have values between -1 and 0. The land cover classes in the Iraqi marshes region include water, vegetation, wet soil, and dry soil [24].

The NDVI thresholds for the Iraqi marshlands were established to characterize the condition of the marsh vegetation. Vegetative cover was indicated by NDVI values greater than 0.125, according to a UNEP analysis [4]. It was also discovered that (medium-density vegetation) was associated with NDVI values between 0.25 and 0.5, while (sparse vegetation) was related to values between 0.125 and 0.25. Areas with NDVI values greater than 0.5 were found to have dense vegetation [25].

The normalized difference water index (NDWI) is a water body change monitoring indicator using green and near-infrared bands. It can be computed using the formula listed in Table 2. A body of water readily absorbs infrared and visible light, According to McFeeters [26]. In this study, the NDWI was used to estimate the dynamic of water bodies in the study area. NDWI was used to identify areas covered with open water. "Open water" was defined as areas with an NDWI higher than zero [24].

Additionally, the NDMI was used to identify dry areas and wetlands (open water, vegetation, and wet soils). The moisture content of vegetation could be determined by the NDMI by contrasting the leaf moisture absorption in the shortwave infrared band to the reflectance of the chlorophyll-a in the leaves in the near-infrared band [27] (see Table 2). It was found that wetlands matched with NDMI values greater than zero [24].

After calculating the indices, the correct threshold is important to distinguish between water and non-water areas. Due to the reflectance properties of water, the NDMI and NDWI values of water and moisture are usually greater than 0. To identify water areas from indices images, a threshold of 0 is usually used the studies [28, 29]. For example, the study [29] tested a range of threshold values (-0.4 - 0.4) for four water indices related to the differences between the corresponding classes of water and land and showed that a threshold value close to zero is the best for separating water from other classes for the NDWI index. Therefore, in this work, the (conventional zero threshold) was used for both NDWI and NDMI indices.

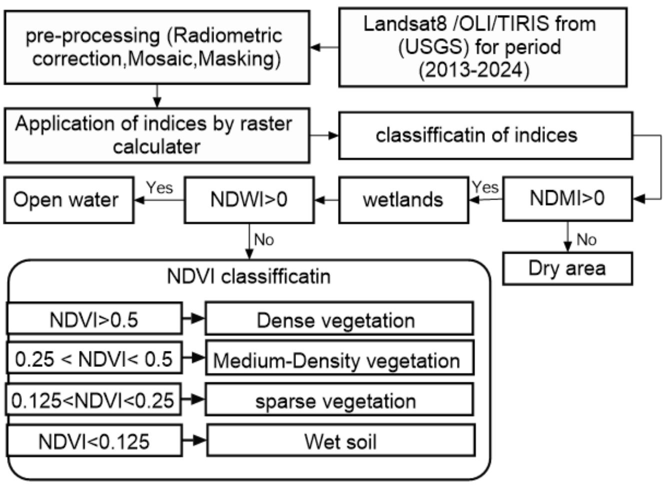


Figure 2. Methodology steps of the spectral indices classification

The spatial extent variations of the land cover categories within Al-Hammar Marsh over time based on the spectral indices were adopted as presented in the methodology shown in Figure 2. In the first step, wetlands regions were identified with NDMI values greater than zero, while the negative values represented dry regions. Then open water regions were identified when NDWI values were larger than zero. Non-water regions were then separated into vegetated areas or wet soils. If NDVI readings are less than 0.125 then these regions represent wet soils with no vegetation. Finally, UNEP [4] thresholds were used to classify the vegetation classes (see above).

ArcGIS is a collection of instruments for visualizing, analyzing, and interpreting geographic and spatial data. ArcGIS version 10.8 has become a widely used tool in numerous engineering projects. Users can analyze data using various menus and tools. Users can create models in ArcGIS, which allows them to create, modify, and manage workflows that connect geo-referenced processing tools in a specific order and pass one tool's output as input to another. This simplifies repetitive tasks for the user.

3. RESULTS AND DISCUSSION

3.1 Hydro-climatic data

Figure 3a shows the mean monthly variation of the maximum and minimum air temperature, earth surface temperature, and the computed potential evapotranspiration for the period spanning 2013 to 2022. However, Figures 3b and c display the study region's mean monthly and annual precipitation values. In arid and semi-arid regions, the water balance of marshes is significantly impacted by evapotranspiration, which plays a critical role in determining vegetation cover and water levels. It is important to note that high reference evapotranspiration is most pronounced from May to October due to the high temperatures during this period.

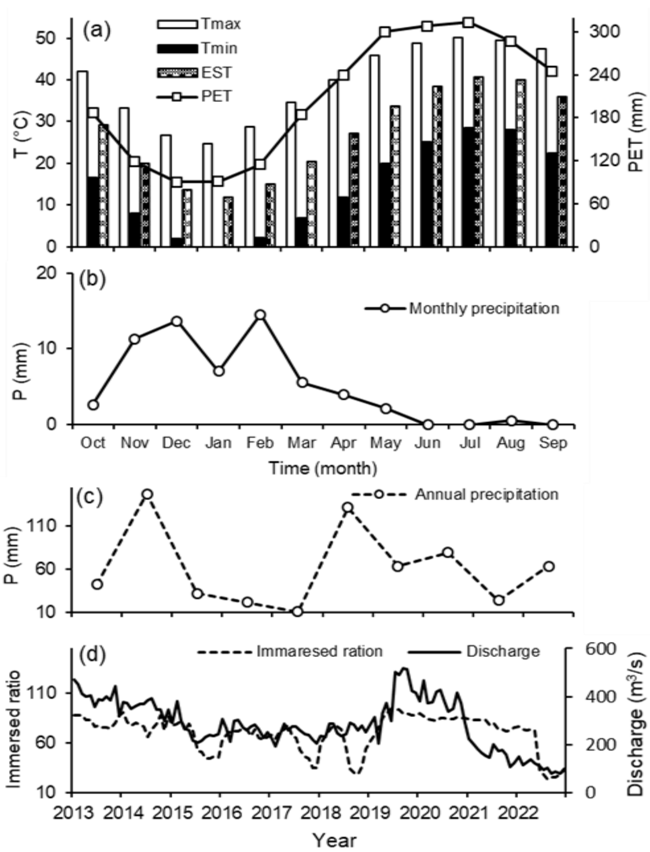


Figure 3. (a) Mean monthly (T max, T min, and EST) in (℃), with their related PET (mm), (b) and (c) Mean monthly and annual precipitation respectively, (d) Monthly Immersion ratio and Monthly discharge of the Al-Hammar Marsh for the period (2013-2022)

The relationship between inflow discharge and the respective submerged areas is shown in Figure 3d. Two curves record an identifiable increase in the years 2019 and 2020 and a decrease during the years 2015, 2018, and 2022, which indicates that there is a good correlation between these parameters.

3.2 Satellite image classification based on spectral indices

The data presented in Figure 4 shows that the majority of the vegetation is densely localized in the western region of the marsh, particularly in the northeastern areas. In contrast, the vegetation in the eastern part is noticeably less widespread than the plants in the western part of the marsh. Wet soils cover separate areas of the Al-Hammar Marsh, with noticeable areas almost continuously distributed throughout the marsh area. Water areas are mainly concentrated in the eastern region of the western Al-Hammar Marsh, near the dike that separates the eastern and western parts of the marsh. Additionally, water areas sporadically appear across the rest of the western and eastern parts of the marsh. The network line of the oil field dam project is observable near the dike that separates the eastern and western parts of the marsh, especially for the years 2016 and 2024, as the water level specifically decreased in this area during those years, as depicted in the maps in Figure 4.

A thorough analysis was conducted over 12 years, from 2013 to 2024, to observe changes in land cover types in the Al-Hammar Marsh, as seen in Figure 5.

The most notable changes occurred in the open water areas. In 2014, 2019, and 2020, significant increases were observed, accounting for 33.35%, 52.57%, and 61.29% of the total area, which equated to 604.63 km^2, 953.07 km^2, and 1111.30 km^2, respectively. The highest percentage of open water areas was recorded in 2019 and 2020 (Table 3). At that time, the eastern part of the marsh was entirely submerged in open water, covering most of the marsh's total area (Figure 4). Conversely, open water areas decreased in the remaining years, with the most substantial decline in 2018, reaching 13.04% and covering 236.59 km^2. By 2022, the majority of open water areas were found in the eastern sections of the western portion of the marsh, while intermittent water areas were found in the eastern portion of the Al-Hammar Marsh.

In 2014, the wet soil decreased by approximately 22.41% of the total area, covering 406.3 km^2, which was replaced by open water and plants (Figure 4). In the subsequent years, it fluctuated between gradual increases and decreases until a significant rise was observed in 2018, reaching 42.38% of the total area. In 2018, 2021, and 2023, the area of the wet soil land cover class fluctuated from 768.18 km^2, 737.69 km^2, and 863.59 km^2, respectively, and dominating most regions of the Al-Hammar Marsh in its eastern and western parts. Figure 5 also depicts a rapid decline in 2019, 2020, and 2024, accounting for 15.59%, 7.67%, and 22.68% of the total area, respectively, encompassing 282.65 km^2, 140.85 km^2, and 411.13 km^2. These were the lowest values recorded for wetlands between 2013 and 2024 when open-water areas were substituted (Table 3).

Dry-land values increased in 2016 and 2024 reaching their maximum values of 28.47% and 30.14% over 516.16 km^2 and 546.45 km^2, respectively. While, dry regions fell to 10.6%, 22.36%, 19.43%, 15.35%, and 7.977% of the total area in 2014, 2017, 2018, 2019, and 2020, respectively. In 2020, they reached their lowest point, accounting for 144.63 km^2, with 7.977% of the total (Table 3).

The total vegetation cover increased from its value in 2013 to 33.64% in 2014, or 609.87 km^2, the highest vegetation cover percentage ever recorded. Close percentages of vegetation areas (26.16%, 26.93%, 25.15%, 23.06%, and 26.33%) in 2013, 2017, 2018, 2020, and 2022, respectively were recorded with 474.04 km^2, 488.31 km^2, 456.05 km^2, 416.27 km^2, and 477.39 km^2. While there was a rapid decline in the value of vegetation cover by 7.75% and 9.59% in 2021 and 2023, with an area of 140.57 km^2 and 173.92 km^2, respectively, convergent low values of vegetation cover were recorded in the years 2015, 2016, and 2019, reaching 19.58%, 18.41, and 16.49, respectively, with areas reaching 354.94 km^2, 333.74 km^2, and 299.09 km^2, respectively. The lowest recorded values for vegetation cover through the period 2013 to 2024 were in 2021, 2023, and 2024, as shown in Table 3.

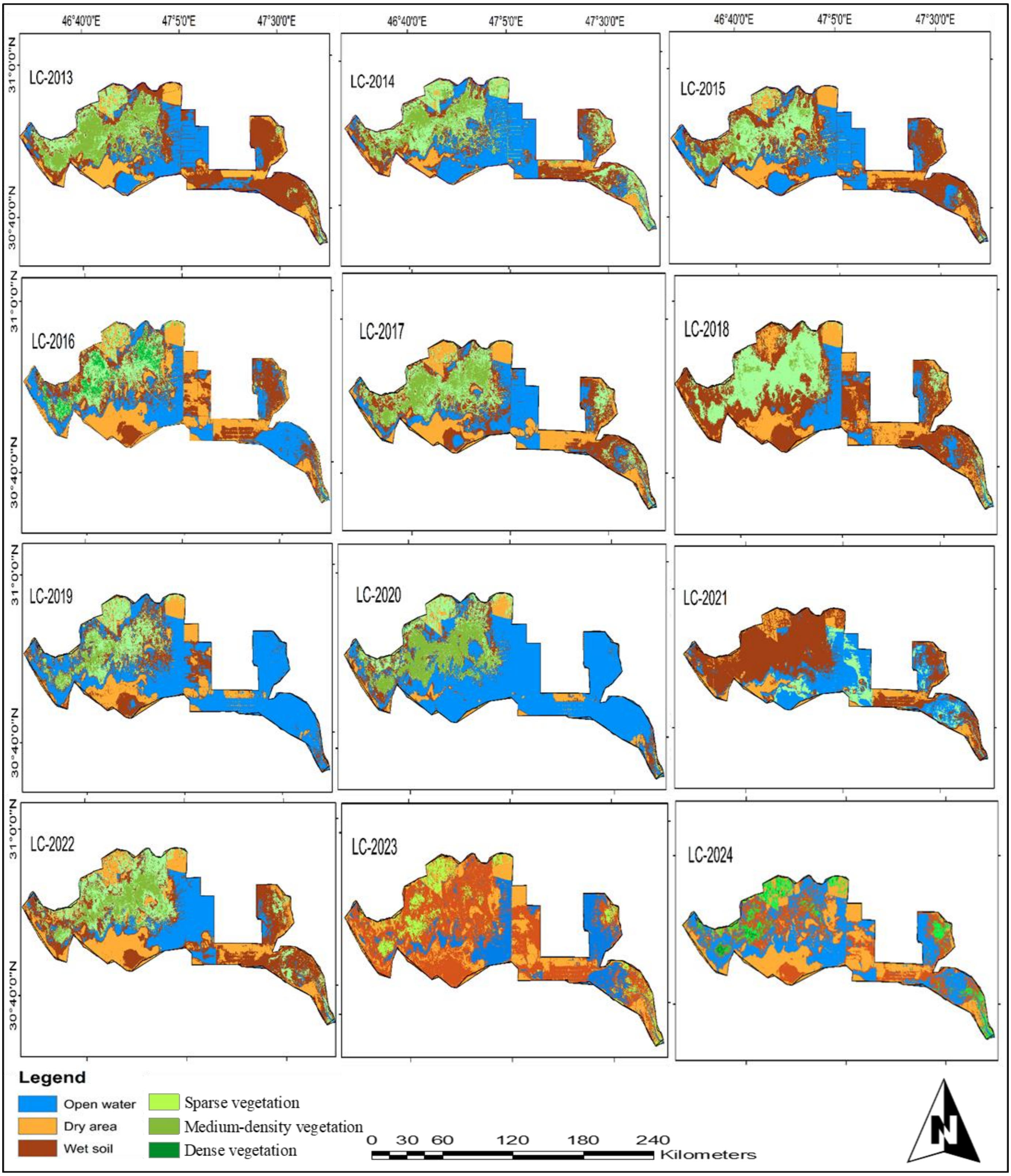


Figure 4. The spatial distribution of the land cover categories of Al-Hammar Marsh based on the classification for the spectral indices during the period (2013-2024)

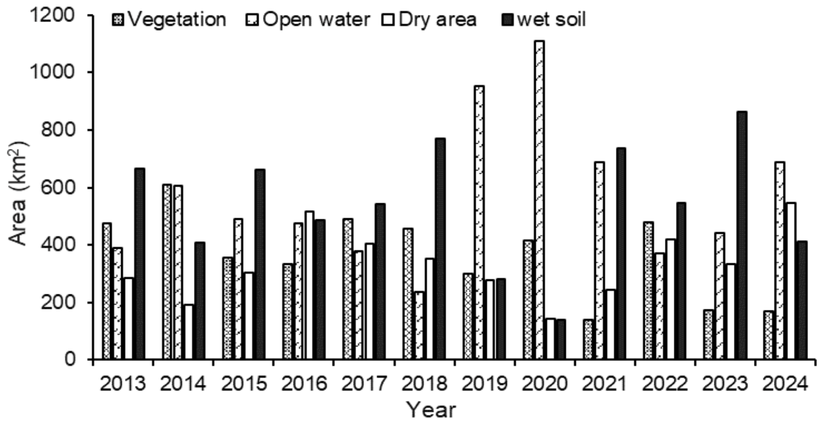


Figure 5. The land cover variation of AL-Hammar Marsh based on the classification for the spectral indices during the study period (2013-2024)

Table 3. Total area and percentage of land cover categories of Al-Hammar Marsh for the period from 2013 to 2024

1	2		3		4		5		6	
	Land cover categories									
Year	**Open water**		**Wet soil**		**Vegetation**		**Dry**		**Total Immersion (2+3+4)**	
	Area		**Area**		**Area**		**Area**		**Area**	
	km^2	**%**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**
2013	388.41	21.42	665.94	36.72	474.04	26.16	284.65	15.7	1528.39	84.3
2014	604.63	33.35	406.3	22.41	609.87	33.64	192.25	10.6	1620.8	89.4
2015	491.49	27.11	662.96	36.56	354.94	19.58	303.66	16.75	1509.39	83.25
2016	476.83	26.3	486.32	26.82	333.74	18.41	516.16	28.47	1296.89	71.53
2017	377.66	20.83	541.7	29.88	488.31	26.93	405.37	22.36	1407.67	77.64
2018	236.59	13.04	768.18	42.38	456.05	25.15	352.23	19.43	1460.82	80.57
2019	953.07	52.57	282.65	15.59	299.09	16.49	278.23	15.35	1534.81	84.65
2020	1111.30	61.29	140.85	7.673	416.27	23.06	144.63	7.977	1668.42	92.02
2021	689.66	38.04	737.69	40.69	140.57	7.75	245.12	13.52	1567.92	86.48
2022	371.29	20.48	546.32	30.13	477.39	26.33	418.05	23.06	1395.00	76.94
2023	441.53	24.35	863.59	47.64	173.92	9.59	334.00	18.42	1479.04	81.58
2024	687.46	37.92	411.13	22.68	168.01	9.27	546.45	30.14	1266.60	69.86

Note: Total marsh area = 1813.05 km^2

Table 4. Classification of the Normalized Difference Vegetation Index (NDVI) in the Al-Hammar Marsh for 2013 and 2024

Year	**Max^a**	**Min^b**	**Mean**	**SD^c**	**NDVI-Based vegetation density classes**					
					Class A[1]		**Class B[2]**		**Class C[3]**	
					Area		**Area**		**Area**	
					km^2	**%**	**km^2**	**%**	**km^2**	**%**
2013	0.5	-0.14	0.18	0.45	239.64	13.22	234.4	12.94	0	0
2014	0.50	-0.22	0.14	0.51	439.96	24.27	169.90	9.37	0.01	0
2015	0.44	-0.24	0.10	0.48	294.25	16.23	60.69	3.348	0	0
2016	0.46	-0.26	0.10	0.52	251.71	13.89	82.03	4.52	0	0
2017	0.46	-0.29	0.08	0.54	297.55	16.41	190.76	10.52	0	0
2018	0.34	-0.16	0.09	0.35	429.78	23.70	26.27	1.45	0	0
2019	0.46	-0.27	0.09	0.52	235.20	12.97	63.89	3.52	0	0
2020	0.56	-0.44	0.06	0.71	187.07	10.32	229.19	12.64	0.01	0.1
2021	0.49	-0.54	-0.03	0.73	140.49	7.75	0.078	0	0	0
2022	0.43	-0.22	0.10	0.45	332.27	18.33	145.12	8	0	0
2023	0.43	-0.34	0.04	0.55	168.32	9.28	5.60	0.31	0	0
2024	0.48	-0.35	0.06	0.59	151.42	8.35	16.59	0.91	0	0

a. Maximum; b. Minimum; c. Standard deviation; 1. 0.125 < NDVI values < 0.25 (sparse vegetation); 2. 0.25 < NDVI values < 0.5 (medium-density vegetation); 3. NDVI values > 0.5 (dense vegetation); Total marsh area = 1813.05 km^2; Note: The NDVI classes is based on the UNEP (2006) classification.

Table 4 shows the UNEP (2006) classification scheme for the Al-Hammar Marsh from 2013 to 2024. It can be noticed that dense vegetation cover is completely absent, except for 0.01 km^2 for the years 2014 and 2020, which is equivalent to just 10,000 m^2 of the marsh's total area. Medium-density vegetation covers a smaller portion of the marsh than sparse vegetation, with the highest percentage being 13% of the total area. The highest values were recorded in 2013, 2014, 2017, and 2020, at 12.94%, 9.37%, 10.52%, and 12.64% of the total area, respectively. This corresponds to areas of 234.64 km^2, 169.90 km^2, 190.76 km^2, and 229.19 km^2, respectively.

The lowest value was recorded in 2021, close to zero, covering an area of 0.078 km^2 (equivalent to 78,000 m^2). There was a significant decline in this type of vegetation cover in 2015, 2018, 2021, and 2023, where the percentages were 3.348%, 1.45%, 0%, and 0.31% of the total area, respectively.

The sparse vegetation cover is the largest category of the total vegetation cover in the Al-Hammar Marsh. This category has been consistently the most abundant throughout the years of the study, with higher values than the other two categories. The highest values were recorded in 2014, 2018, and 2022, reaching 24.27%, 23.70%, and 18.33% of the total area, respectively, with corresponding areas of 439.96 km^2, 429.78 km^2, and 332.27 km^2. In the remaining years, the percentages varied, with sharp declines in 2015, 2019, 2021, and 2023, at 16.23%, 12.97%, 7.75%, and 9.28% of the total area, respectively. In 2021, an area of 140.49 km^2 had the lowest reported value of 7.75% throughout the research period.

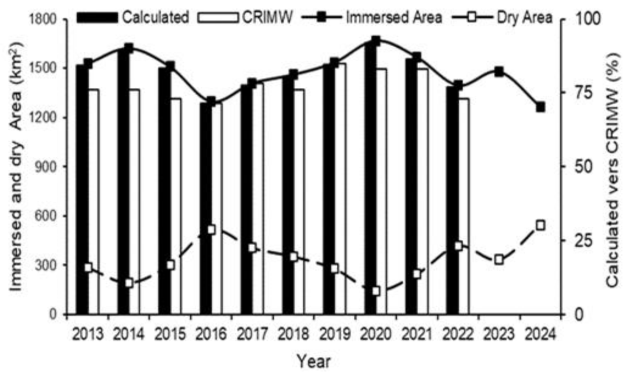
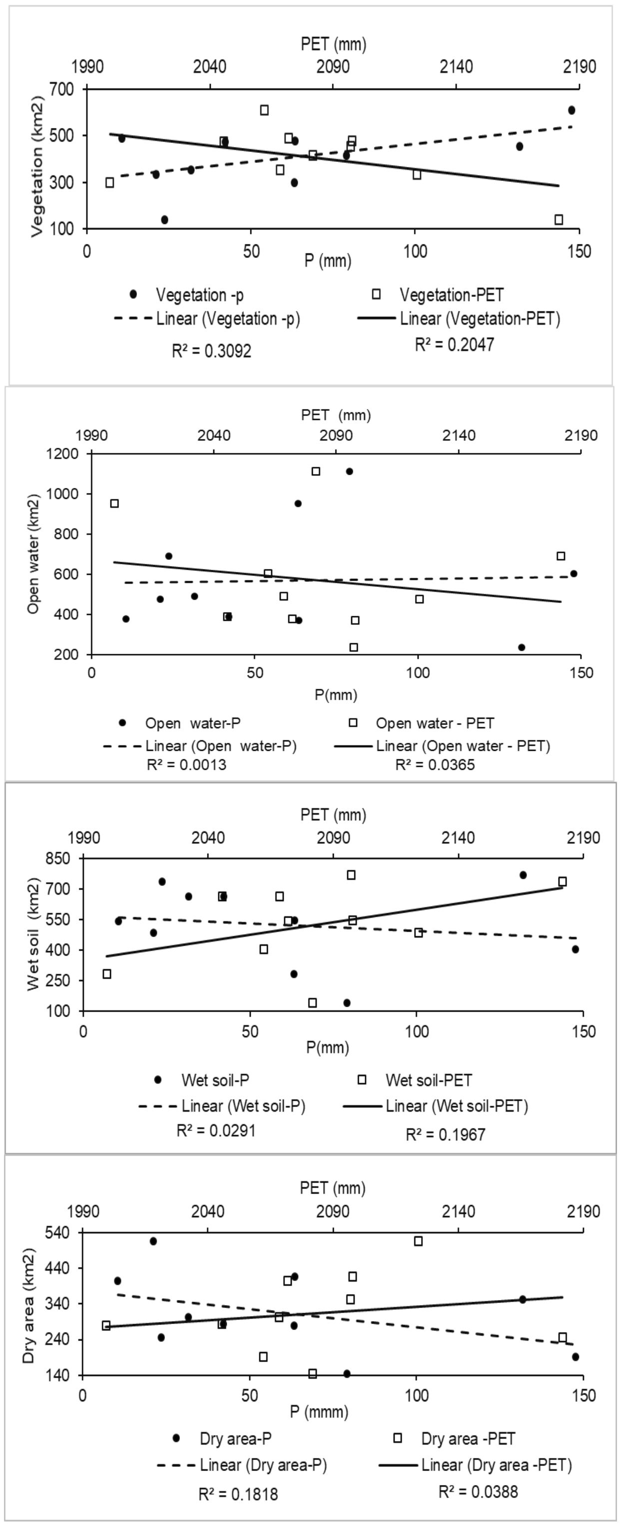


Figure 6. Calculated, and collected immersion areas, and dry areas of Al-Hammar Marsh during the period (2013-2024)

The Al-Hammar Marsh was analyzed using approved spectral indicators to classify immersed areas, including vegetation, water, and wet soils in the eastern and western parts of the marsh. Table 3 provides the computation of total immersion areas in Al-Hammar Marsh. The analysis revealed that immersed areas exceeded 80% from 2013 to 2024 except in 2016, 2017, 2022, and 2024, which recorded lower values of 71.35%, 77.64%, 76.94%, and 69.86%, respectively. The total marsh areas for these years were approximately 1296.89 km^2, 1407.67 km^2, 1395 km^2, and 1266.60 km^2. The highest marsh immersed value of 92.02% was documented in 2020, covering an area of 1668.42 km^2, while the lowest immersed rate of 69.86% was recorded in 2024, corresponding to an area of 1266.60 km^2. Figure 6 shows an inverse correlation between immersion and dry areas and compares the immersion ratio per the Centre for Restoration of Iraqi Marshes and Wetlands (CRIMW, 2023) with the immersion ratio derived from satellite imagery for each corresponding year. This figure shows that the immersion rates measured by CRIMW (2023) and those calculated by satellite images were at the same pace of rise and fall each year, even if the values differed. The difference in values may be due to the difference between the calculation methods used.

Statistical analysis was conducted to clarify the relationships between the different elements of the water budget and the influential climatic factors within the arid and semi-arid regions (inflow, precipitation, and potential evapotranspiration) with the land cover categories of Al-Hammar Marsh that resulted from the classification of spectral indicators. The statistical regression analysis was adopted by using the Excel program, Figure 7 the trend lines showed a positive impact of the inflow and precipitation on both of the open water and vegetation categories as well as the immersion areas of the marsh, offset by their negative impact on the dry areas category. At the same time, there is a negative effect of the potential evapotranspiration on the categories of open water, vegetation, and total immersion areas of the marsh with its positive impact on the dry areas category. The impact of the inflow and precipitation on the wet soil was negative as noted in the trend lines, offset by a positive impact of the potential evapotranspiration on this category, due to that the increase in the open water category led to a decrease in the wet soil category and vice versa, as shown in Table 3.

The increase of water areas significantly with the inflow entering the marsh, and vice versa as shown in Figure 7 findings underscore the dynamic nature of open-water areas within the Al-Hammar Marsh, with fluctuations linked to inflow variations.



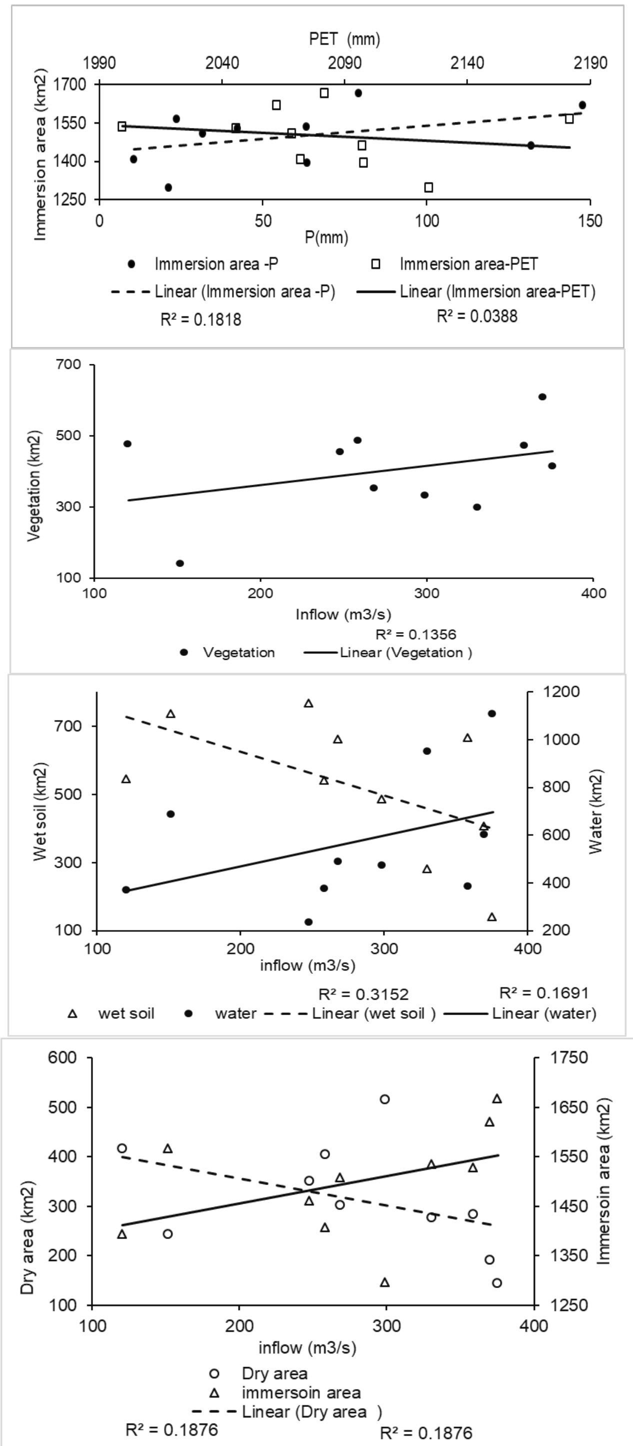


Figure 7. Statistical analysis shows the relationship between land cover classes and metrological data

4. DISCUSSION

It is evident from the observed trends that the vegetation area has not improved during the period (2013-2024), with the exception of a slight improvement in 2017 and 2022. This is consistent with the study [10] which explained that there was no noticeable improvement in the vegetation cover of the western part of Al-Hammar Marsh during the years 2013 to 2018, with the exception of a slight improvement in the year 2017. A rise in surface water for 2019 and 2020, and a progressive decline from 2015 to 2018, as well as in 2022. These findings align with the study [10] that found an increase in the open water areas of the western part of Al-Hammar Marsh occurred in the years 2014, 2019, and 2020, while 2018 recorded the lowest percentage of open water during the period (2013-2018). Also, the study [8] showed that water categories in Iraqi marshes began to rise gradually after the restoration operations towards the end of the year (2020), except for the years 2015 and 2018, when water quantities suddenly decreased.

It can be said that the results of this study are somewhat consistent with the data collected from the Center for Restoration of Iraqi Marshes and Wetlands (CRIMW, 2023) [21] which were previously shown in Figure 3d.

The deterioration of the marsh ecosystem cannot be solely attributed to the drying processes of the 1990s, as various factors have contributed to its decline over the years. These factors include inadequate water management post-inundation and the impact of global climate change on Iraq and its marshes, as evidenced by changes in annual maximum temperature, evapotranspiration, and precipitation.

5. CONCLUSIONS

The restoration of the remaining marshes necessitates a comprehensive, interdisciplinary approach. It is crucial to discuss with riparian nations that govern the Euphrates and Tigris Rivers and their tributaries, like Iran, Syria, and Turkey. In Iraq, the flow of these rivers has significantly decreased due to the presence of hydraulic structures like dams and dikes. Experts have discussed the effects of the Syrian dams and the Turkish GAP project in detail. Iran has built dams on every river that empties into the Al-Huwiza marsh. It is vital to designate the marshes as protected national areas, akin to Al-Huwiza, which has been selected as a Ramsar site [30]. In addition, it is critical to start public awareness campaigns about the conservation of water resources and to offer fundamental services to the marsh inhabitants. Preventing drainage water from entering the marshes is crucial for maintaining water quality, as is the proper maintenance of water distribution systems to minimize losses. Modernizing irrigation practices and employing appropriate techniques are also vital. Currently, 85% of Iraq's water resources have been used for agricultural purposes, and incorporating suitable irrigation techniques can result in significant water conservation. Non-traditional irrigation techniques and water harvesting techniques can also aid in augmenting available water supplies.

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REFERENCES

[1] Al-Ansari, N. (2020). Can we restore the Marches in Iraq (Garden of Eden)? Engineering, 12(7): 466-486.

https://doi.org/10.4236/eng.2020.127033

[2] Allami, A. (2009).UNEP-Iraq-marshlands-project-final completion full report-English. https://www.academia.edu/24004523/UNEP_Iraq_marshlands_project_Final_Complition_Full_Report_English.

[3] Lane, C.R., Liu, H., Autrey, B.C., Anenkhonov, O.A., Chepinoga, V.V., Wu, Q. (2014). Improved wetland classification using eight-band high resolution satellite imagery and a hybrid approach. Remote Sensing, 6(12): 12187-12216. https://doi.org/10.3390/rs61212187

[4] IMOS: Iraqi Marshland Observation System, UNEP 2006 Annual Report. https://www.unep.org/resources/annual-report/unep-2006-annual-report.

[5] Jabbar, M.A., Al-Ma'amar, A.F., Shehab, A.T. (2010). Change detections in marsh areas, south Iraq, using remote sensing and GIS applications. Iraqi Bulletin of Geology and Mining, 6(2): 17-39.

[6] Muhsin, I.J., Mashe, F.K., Tawfeeq, R.J. (2011). Monitoring the vegetation and water content of Al-Hammar marsh using remote sensing techniques. Baghdad Science Journal, 8(2): 646-651. https://doi.org/10.21123/bsj.2011.8.2.646-651

[7] Hassan, Z.D. (2012). Using remote sensing techniques and geographic information systems (GIS) in sequences study to AL-Hammar marsh / south of Iraq for the period (1973-2010). IRAQI Journal of Desert Studies, 4(1): 72-77.

[8] Hason, M.M., Abood, I.S., Aldeen Odaa, S. (2020). Land cover reflectance of Iraqi marshlands based on visible spectral multi and of satellite imagery. Results in Engineering, 8: 100167 https://doi.org/10.1016/j.rineng.2020.100167

[9] Bukar, M.A., Bukar, W.M. (2018). Mapping wetland degradation in the Iraqi marshlands for the period 1985-2000 from Landsat satellite imagery. IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT), 12(6): 31-38. https://doi.org/10.9790/2402-1206023138

[10] Dhaidan, B.A., Alwan, I.A., Al-Khafaji, M.S. (2021). Utilization of satellite images-based indices for assessment of Al-Hammar Marsh restoration plan. Engineering and Technology Journal, 39(8): 1328-1337. http://doi.org/10.30684/etj.v39i8.2149

[11] Al-Maliki, S., Ibrahim, T.I., Jakab, G., Masoudi, M., Makki, J.S., Vekerdy, Z. (2022). An approach for monitoring and classifying marshlands using multispectral remote sensing imagery in arid and semi-arid regions. Water, 14(10): 1523. https://doi.org/10.3390/w14101523

[12] Al-Ansari, N., Knutsson, S. (2011). Possibilities of restoring the Iraqi marshes known as the Garden of Eden. In Water and Climate Change in the MENA-Region: Adaptation, Mitigation and Best Practices 28/04/2011-29/04/2011.

[13] Abdulraheem, Z.A. Mahmoud Saleh Al-Khafaji, M.S. (2015). Allocating the best representative water quality monitoring station. Thesis for: M.Sc.Advisor: Asst. Prof. Dr. Mahmoud Saleh Al-Khafaji. http://doi.org/10.13140/RG.2.2.31946.26564

[14] Al-Musawi, N.O., Al-Obaidi, S.K., Al-Rubaie, F.M. (2018). Evaluating water quality index of al Hammar Marsh, south of Iraq with the application of GIS technique. Journal of Engineering Science and Technology, 13(12): 4118-4130.

[15] Ministries, I. (2006). New Eden master plan for the integrated water resources management in the Marshland area, main report, Iraqi ministries of environment. Water Resources Municipalities and Public Works with Cooperation of the Italian Ministry for the Environment and Territory and Free Iraq Foundation, 20: 153.

[16] Hamza, Z.N., Mohammed, O.I. (2019). Possibility of storage restoration of Al-Hammar marsh based on forecasted water resources. Ph.D.dissertation. University of Babylon Civil Engineering /Water Resources.

[17] Tigkas, D., Vangelis, H., Tsakiris, G. (2015). DrinC: A software for drought analysis based on drought indices. Earth Science Informatics, 8: 697-709. http://doi.org/10.1007/s12145-014-0178-y

[18] Mohammed, R., Scholz, M. (2016). Impact of climate variability and streamflow alteration on groundwater contribution to the base flow of the Lower Zab River (Iran and Iraq). Environmental Earth Sciences, 75: 1-11. https://doi.org/10.1007/s12665-016-6205-1

[19] Vangelis, H., Tigkas, D., Tsakiris, G. (2013). The effect of PET method on Reconnaissance Drought Index (RDI) calculation. Journal of Arid Environments, 88: 130-140. https://doi.org/10.1016/j.jaridenv.2012.07.020

[20] Tigkas, D., Vangelis, H., Tsakiris, G. (2012). Drought and climatic change impact on streamflow in small watersheds. Science of the Total Environment, 440: 33-41. https://doi.org/10.1016/j.scitotenv.2012.08.035

[21] Center for Restoration of Iraqi Marshes and Wetlands (CRIMW, 2023). https://mowr.gov.iq/?page=20.

[22] United States Geological Survey (USGS). https://earthexplorer.usgs.gov/, accessed on September 2023.

[23] Younus, M.H., Mohammed, R. (2024). Spectral drought indices: A methodology for detecting basin-wide drought. Ecohydrology & Hydrobiology, 24(1): 178-187. https://doi.org/10.1016/j.ecohyd.2023.07.006

[24] Alawadi, W.A., Raheem, Z.A.A., Yaseen D.A. (2023). Use of remote sensing techniques to assess water storage variations and flood-related inflows for the Hawizeh wetland. Environmental Monitoring and Assessment, 195(10): 1246. https://doi.org/10.1007/s10661-023-11838-x

[25] Partow, H., Jaquet, J. (2006). Iraqi Marshlands Observation System—UNEP Technical Report. UNEP: Nairobi, Kenya, 74.

[26] McFeeters, S.K. (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. International Journal of Remote Sensing, 17(7): 1425-1432. https://doi.org/10.1080/01431169608948714

[27] Jin, S., Sader, S.A. (2005). Comparison of time series tasseled cap wetness and the normalized difference moisture index in detecting forest disturbances. Remote Sensing of Environment, 94(3): 364-372. https://doi.org/10.1016/j.rse.2004.10.012

[28] Xu, H. (2006). Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. International Journal of Remote Sensing, 27(14): 3025-3033. https://doi.org/10.1080/01431160600589179

[29] Huang, C., Chen, Y., Zhang, S., Wu, J. (2018). Detecting, extracting, and monitoring surface water from space using optical sensors: A review. Reviews of Geophysics,

56(2): 333-360.
[30] Ramsar Convention. (2005). Hope for the Mesopotamian Marshlands, Ramsar Bulletin 22713. https://www.ramsar.org/sites/default/files/documents/library/290901_press_release_the_garden_f_eden_now_internationally_protected_as_wetlands_of_international_importance.pdf, accessed on Jul. 1, 2024.