ASSESSMENT OF THE EXPANSION OF ALFALFA CULTIVATED AREAS IN THE EMIRATES OF ABU DHABI USING GEOSPATIAL TECHNIQUES

Abdulaziz Abdulla Aljaberi[1] khalid Hussein[2]
[1]Graduate Student, Department of Geography and Urban Sustainability, United Arab Emirates University
Email: 201211689@uaeu.ac.ae

[2]Associate Professor, Department of Geography and Urban Sustainability, United Arab Emirates University
Email: Khalid.Hussein@uaeu.ac.ae

KEY WORDS: Alfalfa Plant, Vegetation Indices, Visible and Near Infrared, Unsupervised ISODATA Classification.

ABSTRACT: The agriculture sector poses a real threat to groundwater. Irrigated crop cultivation practices change groundwater levels as a result of cultivating crops or farming plants that consume large amounts of water. Alfalfa is an example of a high-water consuming crop, being a widely cultivated crop in the UAE. It needs 18 to 36 inches of water per season and according to Statistics Center Abu Dhabi (SCAD) in 2016, most of the farms are producing alfalfa. This research has been conducted with the objective of assessing the expansion of the alfalfa-cultivated areas in the Abu Dhabi Emirate over two decades. It is based on a total of five vegetation indices (VIs) were calculated and stacked with visible and near-infrared bands (VNIR), producing a composite image. The image was then classified applying unsupervised ISODATA algorithm, with the end goal of generating a map that shows the areas planted with alfalfa for three different years using images provided by the Landsat satellite. As a result, we detected an ongoing increase in the area occupied by alfalfa in around 20 years, which increased from 102.32 km2 to 430.59 km2 between 2002 and 2020. The output was cross validated with field samples, and the overall accuracy of the method was around 81.7%. The significant and rapid increase of the areas planted with alfalfa in Abu Dhabi farms prompts the government to replace it with other crops that are better suited to the region's arid climate.

1. INTRODUCTION

1.1 Overview

Agriculture is a general term referring to the practice of farming, including cultivation of the soil for the growing of crops and the rearing of animals to provide food, wool, and other products. Broadly defined, agriculture is the practice of cultivating plants and livestock. Agriculture has many aspects, it helps reduce poverty, raise incomes and improve food security. On the other hand, there are a number of challenges linked to agriculture that should be looked into, including for example the scarcity of water reserves primarily caused by agriculture. The increase in cultivable areas resulted in the depletion of groundwater and an increase in water salinity. Recently, the United Arab Emirates (USE) Cabinet issued a direction calling for a shift to a modern irrigation system such as drip irrigation instead of the traditional flood irrigation in order to achieve the objectives of the National Strategy for Sustainable Agriculture. In particular, there are some plants that consume large amount of water and are widely cultivated in the UAE, such as Rhodes, alfalfa and vegetables can be classified as high-water consumers.

The study focuses on alfalfa that widely cultivated in the UAE and needs 18 to 36 inches of water per season, and groundwater is the main water source for alfalfa, and it categorized as the highest water consuming crop. According to the agricultural annual report issued by Statistics Center Abu Dhabi (SCAD) in 2016, most of the farms are producing alfalfa. In Al Ain 27% of farms area cultivated by Alfalfa, the same percentage in Al Dhafra, while in Abu Dhabi only 8% of the total farm area cultivated by Alfalfa crop. However, these percentages might be increased between 2016 and 2020, due to the policy of increasing agricultural production. Obviously, the expansion of cropland led to an increase in demand for water. Therefore, it is important to study and assess the expansion of the high consumer plants. This study calculates the area cultivated by alfalfa on last two decades using geographic information system and remote sensing technology.

In the last decades, Geographic Information System (GIS) and Remote Sensing (RS) have proved to be a great combination; they complement each other in providing in-depth studies and monitoring of the Earth. GIS is a computer-based tool that integrates database operations with maps in order to analyze and model different phenomena on the earth's surface (Hussein et al., 2020). With RS techniques we can interpret the images by measuring the radiation collected by the satellite sensors to acquire information about any object without being in direct contact. The GIS and RS are part of geospatial technologies and are considered as advanced tools to deal with geographic data. Several studies have shown that RS and GIS techniques offer good ability to map, model, and simulate the expansion of the green area over long time. It is widely used to study various Land Use Land Cover (LULC) classes at different scales by providing reliable and up to date information on the subject. Multi-temporal information enables researchers to easily define the pattern of changes of any certain land cover.

1.2 Objective

Through this research, we aim to achieve one main goal that will have a significant impact on the future of our society. Our goal is to assess the expansion of the area cultivated by Alfalfa over a period of two decades. The objectives of this study are to assess the ability of remote sensing and GIS techniques in mapping specific plant by creating maps of the alfalfa crop cultivated in the Emirate of Abu Dhabi using vegetation indices (VIs), unsupervised classification, and satellite data and field measurements.

1.3 Study Area

The United Arab Emirates is a federation of seven Emirates, i.e., Abu Dhabi, Dubai, Sharjah, Ajman, Umm Al-Quwain, Ras Al Khaimah and Al Fujairah. It is located in the Middle East and the southwest of Asia. The UAE has a border with Saudi Arabia and Oman and is surrounded by the Arabian Gulf and the Gulf of Oman (Hussein et al., 2021). The UAE has a population of about 9.9 million according to a census conducted in mid-2020, with UAE citizens representing only 19%. And according to the CIA's World Factbook, the UAE has a total surface area of 83,600 square kilometers, which means that the population density in the United Arab Emirates is 118 per km2. The country has a diverse landscape that includes desert, coastal lowlands and marches, and mountains (Hussein et al., 2021).

This study was conducted in the Emirate of Abu Dhabi. It is the largest Emirate in the country, comprising more than three-quarters of the UAE's total land area (around 87%). Abu Dhabi is located in the west and southwest part of the UAE, between latitudes 22 and 25 degrees north and the longitudes 51 and 56 east (Figure 1). It has borders with Dubai and Sharjah. Abu Dhabi is divided into three regions: Central Abu Dhabi; Al Ain; and the Western region (Al Dhafra). The Arabian Gulf is the only water body in Abu Dhabi, with 450 km long (Hussein et al., 2021).

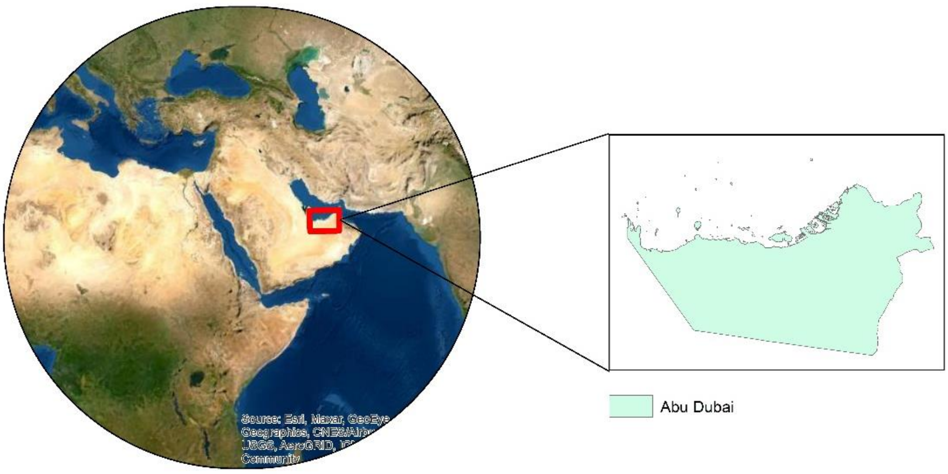

Figure 1. A Map Showing the Study Area (Emirate of Abu Dhabi).

Around 160,000 hectares in the UAE are covered by cultivable areas, with most of it being date palms. Recently, the agriculture sector in the UAE developed rapidly. Since 1970 the number of farms has increased from 4000 to more than 30000. The UAE produces 6% of the world's date production as date palms can thrive in the UAE climate. However, they are many other crops produced by the country's farmers. Among the various crops grown in the UAE is the alfalfa. This forage crop is widely used in the UAE for green manure, grazing, hay and silage, as well as for livestock fodder. Alfalfa is a suitable crop for cultivation in the UAE because it is native to warmer temperate climates.

1.4 Literature Review

Regular monitoring of agricultural production requires better understanding of the spatial and temporal dynamics of croplands. It is also necessary to have dependable spatial information to study, map, and analyze cropland dominated areas (Hao et al., 2018).

There are various approaches and many different types of data used for cropland mapping. For example, Mtibaa and Irie (2016) used the time series of the Normalized Difference Vegetation Index (NDVI) to identify vegetation phenological profiles in Tunisia. The NDVI provides significant information that can help researchers to efficiently and objectively evaluate phenological characteristics in any study area. The NDVI index is derived from greenness sensitive bands of satellite images. In their study, Mtibaa and Irie, concluded that the cropland dominated area mapping starts with determining the Start of Season (SOS) and Peak of Season (POS) dates. Both SOS and POS are considered as indicators of phenology change. The NDVI was calculated for the targeted dates; April 09, 2014 (POS) and November 19, 2014 (SOS) using Landsat-8 images according to Equation 1 (Irie et al., 2016). Subsequently, a new index termed NDVI Change was developed. It was calculated according to the following Equation:

$$\text{NDVI Change} = \frac{Standarized\ NDVI\ SOS\ date}{Standarized\ NDVI\ POS\ date} \qquad (1)$$

Other researchers used the same methodology with NDVI as the main tool to map cropland in different study areas (Ovidiu & Mariana , 2018; Hao et al., 2018). Additionally, Ovidiu and Mariana (2018) added a multitemporal image segmentation algorithm to the output regarding these areas. The most common approach to segment images, referred to as multi-resolution segmentation, was used to divide the Sentinel-2 images into homogeneous objects (Ovidiu & Mariana , 2018).This approach was used in a central Asia study aimed at assessing the contribution of each feature in cropland identification (Nino et al., 2009). Some researchers also used the Gini index and the importance of Radio Frequency (RF) and selected two features as optimal features for cropland identification in each study site (Hao et al., 2018) using the following equation:

$$\text{NDVI} = \frac{(NIR-RED)}{(NIR+RED)} \qquad (2)$$

2. METHODOLOGY AND RESULTS

2.1 Overview

Agriculture is a massive sector involving several crops and plants, with each of them having different textures, properties, and shape, leading to a variation in their interactions with radiation. This difference in the nature of plants and crops results in inaccurate image classification. Because of this fundamental issue in mapping vegetation, this research is specifically focusing on mapping one of the crops in the Emirate of Abu Dhabi using remotely sensed data and remote sensing techniques. Alfalfa was chosen to be an indicator of the vegetation expansion in the study area. The crop is widely used in the UAE despite the fact that it has a high-water requirement.

Alfalfa crop is used in the UAE for green manure, grazing, hay, and silage, as well as for livestock fodder. It is a suitable crop for cultivation in the UAE because it is native to warmer temperate climates (Environment Agency Abu Dhabi, 2020). Agriculture is one of the largest consumers of fresh water, but it is essential in achieving food security. Her Excellency Dr. Sheikha Salem Al Dhaheri, Secretary-General of Environmental Agency – Abu Dhabi (EAD) said: “About 65% of the water resources are used for irrigation in the agricultural sector, forests, gardens and parks”. The amount of groundwater storage in agriculture sector is 1.756 million cubic meters, which represents 84% of the total groundwater used. Alfalfa crop needs 18 to 36 inches of water per season, and groundwater is the main water source for Alfalfa.

2.2 Data

2.2.1 Landsat Images

Earth Observation (EO) data delivered from the space is considered as the most common geospatial data type. It captures larger area, allowing the user to track human activities and monitor changes happening on the Earth. There are more than 150 EO satellites currently active, such as Landsat, WorldView, CARTOSAT-2, KhalifaSat, Resurs-p, and Sentinel-2. They mostly orbit at altitudes ranging between 160 and 2000 km so that they can be as close as possible to the Earth.

Landsat is an EO satellite set up as a joint mission of NASA and USGS whose data is mostly provided free of charge. What distinguishes this program from others is that it provided a 50-year archive of Earth imagery. As of 2021, 9 satellites in the Landsat series mission have launched. The first satellite was launched on July 23, 1972. While all satellites carried data with 80 meters resolution, it improved to 30 meters starting from Landsat 4-5. Table 1 shows the characteristics of each Landsat satellites. Landsat 4, 5 ,7, and 8 orbiting at the same altitudes with the same spatial resolution, something which makes them comparable.

Unfortunately, this series was not perfect as it at times experienced some problems. All the Landsat 4-5 ground stations were not active in Central and South Asia from 2002 until Landsat-5 was officially decommissioned in 2013. Moreover, while Landsat-6 failed to reach its orbit, Landsat-7 had a different problem. Starting from 2003, Landsat-7 delivered images with lines gaps caused by the Scan Line Corrector (SLC) failure. That is why this study used Landsat-8 for 2015 and 2020 and Landsat-7 for 2002.

Table 1. Landsat Satellites Basic Information.

Satellite	Launch Year	Spatial Resolution (m)	Altitude (km)	Multi Spectral Bands
Landsat-1	1972	80	920	4
Landsat-2	1975	80	920	4
Landsat-3	1978	80	920	4
Landsat-4	1982	30	705	7
Landsat-5	1984	30	705	7
Landsat-7	1999	30	705	8
Landsat-8	2013	30	705	11
Landsat-9	2021	30	705	11

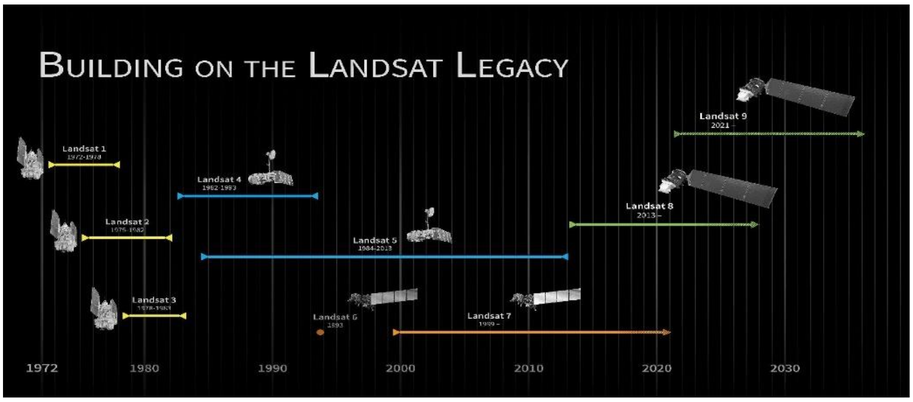

Figure 2. Landsat's Launch and Expiration Dates. Source: NASA.

2.2.2 Worldview Images

Worldview is a constellation of six remote sensing satellites providing high-resolution satellite imagery owned by DigitalGlobe and operated by Maxar. In this study, WorldView-2 will be used. The satellite was launched on 8 October 2009. It has 8 bands with 1.8-meters spatial resolution which provide panchromatic imagery of 0.46 meters (Table 2). This dataset is used in this research to assess the accuracy assessment of the alfalfa map. The images have been acquired from the National Space Science and Technology Center (NSSTC).

Table 2. WorldView-2 Bands.

Band	Wavelength (nm)
Coastal Blue	400 – 450
Blue	450 – 510
Green	510 – 580
Yellow	585 – 625
Red	630 – 690
Red edge	705 – 745
NIR1	770 – 895
NIR2	860 – 1040

2.2.3 Farm Data

Farm data consists of 27,911 records representing all the farms located in the Western Region, Al Ain, and Abu Dhabi in 2020 as shown in Figure 3 and Figure 4. While more than half of the farms in the Emirate of Abu Dhabi are located in Al Ain region (53%), there are around 6000 farms in Abu Dhabi and the Western Region. In addition, the municipalities in the Emirate of Abu Dhabi classified all farms into seven classes (ranch, poultry operation, palm garden, nursery farm, farm, dairy livestock facility, and agricultural land). The majority of the farms in the Emirate are considered as a farm and they are more than 20 thousand farms.

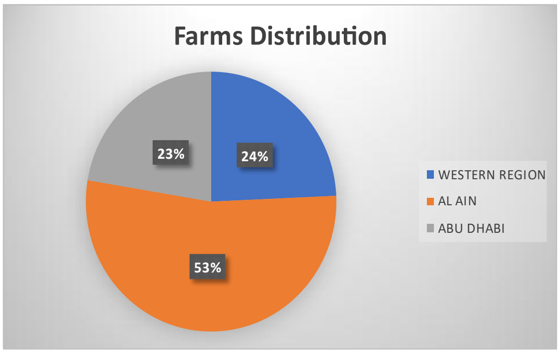

Figure 3. Percentage of Farms Distribution Over Emirate of Abu Dhabi.

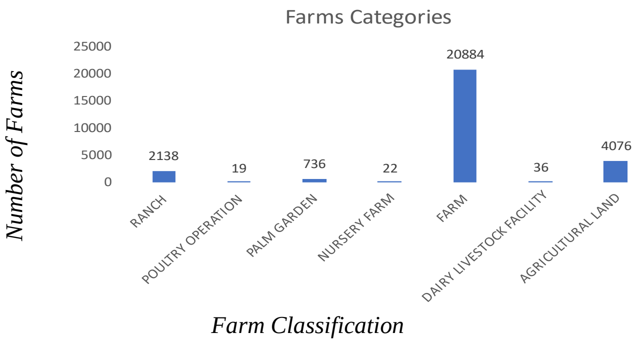

Figure 4. Farm Classification Based on Municipalities’ Categorization.

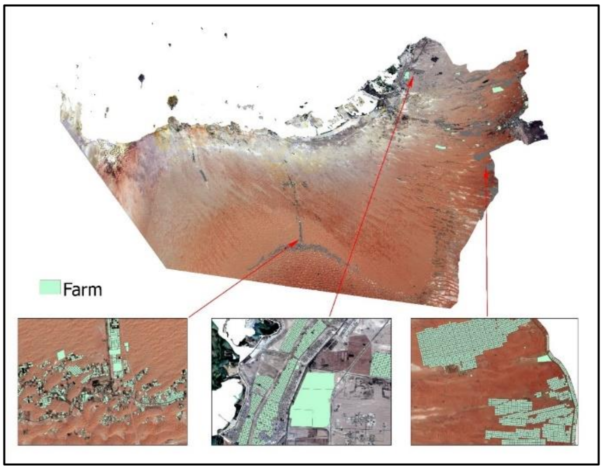

Figure 5. Farms’ Locations in the Emirate of Abu Dhabi.

2.2.4 Alfalfa Area Samples

Field data generated by GIS and RS mostly refer to the LULC samples that are taken to enhance and validate the output maps. In this research, this step was conducted using Trimble R10-2 Global Navigation Satellite System (GNSS) device to collect samples for Alfalfa crop in different privately-owned farms in the Emirate of Abu Dhabi.

R10-2 GNSS is a device commonly used for surveying. It works by collecting GNSS signals via a receiver and an antenna to determine the position of different objects on the surface. It is used by GIS users to generate a higher accuracy map. This device has a potential to work precisely against sources of interference and spoofed signals. It also delivers GNSS data that has already been processed in real time.

Figure 6. R10-2 Trimble Device.

Table 3. WorldView-2 Bands.

Data Name	Data Provider	Data Type	Year
Landsat 7 & 8	The United States Geological Survey (USGS)	Raster	2002, 2015, & 2020
WorldView-2	The National Space Science and Technology Center (NSSTC)	Raster	2018
Farm Data	Government organization	Vector	2020
Alfalfa Samples	Researcher	Vector	2022

2.3 Methodology

2.3.1 Calculating vegetation Indices

Vegetation Index (VI) is an equation involving two or more wavelengths used for better understanding of vegetation properties. Many researchers applied this approach to map crops and plants in different areas. They calculated several VIs and subsequently stacked all these layers with some spectral bands in order to obtain a single image containing various and useful information about green areas. This procedure enables the classification algorithm to deeply and objectively read the collected samples and produce accurate maps.

This research used 5 VIs, Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Land Surface Water Index (LSWI), Green Chlorophyll Vegetation Index (GCVI), and Bare Soil Index (BSI) (Table 4), which all show the difference between visible and near-infrared reflectance of any vegetated area. However, SAVI is more advanced. It minimizes the influences of soil reflectance by using a soil-brightness correction factor. It should be noted that LSWI and GCVI are more sensitive in terms of vegetation content. LSWI is widely used to study the amount of water in the vegetation, whereas GCVI captures chlorophyll content in the vegetation. The last one, i.e., the BSI, is a numerical indicator that describes soil variations. All these indices were calculated using Raster Calculator tool in ArcMap to produce additional information on vegetation cover.

Table 4. Vegetation Indices Used in the Study.

Vegetation Indices	Formula
Normalized Difference Vegetation Index (NDVI)	$\frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}$
Soil Adjusted Vegetation Index (SAVI)	$\frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}} * (1 + L)$
Land Surface Water Index (LSWI)	$\frac{\text{NIR} - \text{SWIR}}{\text{NIR} + \text{SWIR}}$
Green Chlorophyll Vegetation Index (GCVI)	$\frac{\text{NIR}}{Green} - 1$
Bare Soil Index (BSI)	$\frac{(Red + SWIR) - (NIR + Blue)}{(Red + SWIR) + (NIR + Blue)}$

2.3.2 Image Classification

Image classification is a necessary step to achieve the research objectives. In this study, unsupervised classification approach was used. It is defined as a procedure that automatically categorizes all pixels in an image into LULC classes. It is a very basic technique which allows the computer to segment all pixels according to their spectral relationships (Singh et al., 2010). Applying ISO DATA algorithm, the images are classified into 40 classes to make sure that no two types of land cover are categorized in the same class. The algorithm calculates class means and then iteratively clusters the remaining pixels using minimum distance techniques (Adam et al., 2006).

The Reclassified Tool in Arcmap is then used to keep only the classes that represent alfalfa plants and remove all the remaining classes. To determine the places where these plants are located, the study relied on prior knowledge and some field work. Four private farms were visited to take samples of alfalfa dominated area using a Trimble device. Moreover, in order to increase the number of samples, WorldView-2 high resolution satellite images were used to collect some additional samples.

Some tools need the data to be in a vector format to process it. Therefore, the reclassified output has been converted into vector. Vector data has better representation capabilities in obtaining accurate topographic features than the raster data model, especially when looking for more efficient operations that require location information. Therefore, the classified image is converted to vector. Intersect tool in Arcmap was used by applying both layers, the converted Alfalfa layer and the farm data to extract only alfalfa plants in the farms as part of the output feature class. This tool is helpful in extracting only the features that overlap in all input layers. Through these steps, the areas used in the farms to grow alfalfa plants can be calculated, which allows the researcher to observe the change that occurred during different years.

2.3.3 Accuracy Assessment

There is no perfection in GIS and RS as long as there are attempts to study the Earth through space. Therefore, accuracy assessment is a necessary stage in any RS project. It is a process of identifying errors on input and output data. In this research, this process was applied to the recent Alfalfa classification image. To make this possible, four farms owned by one farmer in the Ramah district were visited. The locations of these farms are shown in Figure 7.

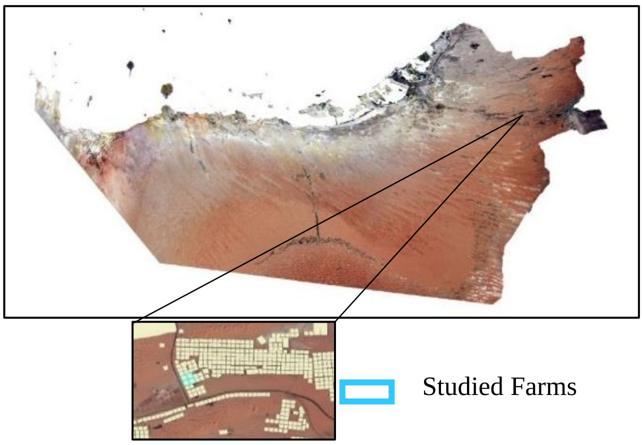

Figure 7. Farms from Which Data are Collected for Accuracy Assessment.

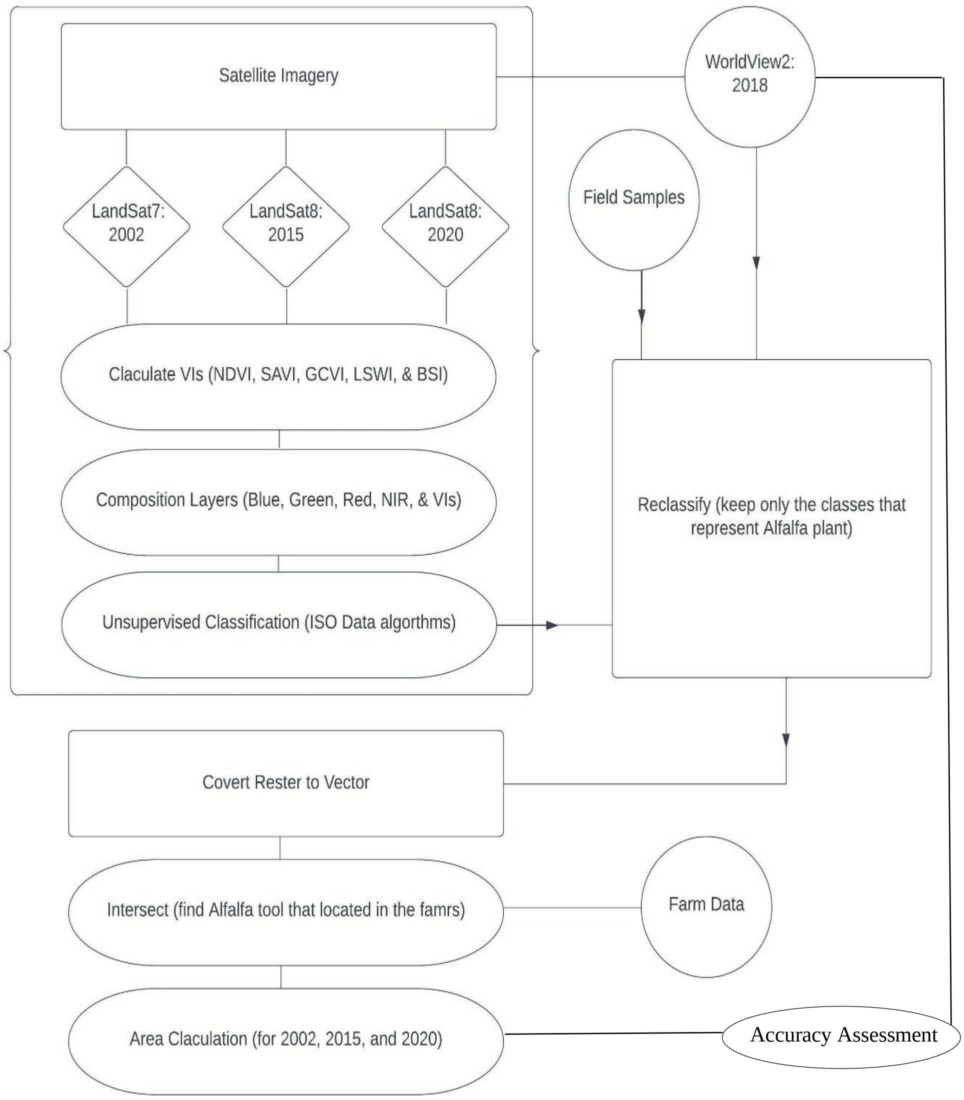

Figure 8. Functional Flow for Methodology Used for Mapping and Calculating the Areas Occupied by the Alfalfa Crop.

2.4 Results

2.4.1 Overview

The main objective of this study is to examine the changes that occurred in the areas cultivated by alfalfa crop in private and government farms in the last two decades in the Emirate of Abu Dhabi. The particular focus on alfalfa is justified by the fact that the properties of the crop greatly affect the groundwater reserves, being a crop that demands a high-water requirement.

To achieve this objective, five VIs (NDVI, SAVI, LSEI, GCVI, and BI) were calculated using Landsat satellite data. These various indices were combined with four spectral bands (Visible and Near Infrared (VNIR)) from Landsat imagery to better understand the nature of the study area and precisely classify the image, which allowed us to calculate the areas covered by alfalfa in the Emirate of Abu Dhabi. These four bands are always targeted in vegetation studies. Near Infrared and Green can detect Chlorophyll which is an essential component of plants. Because vegetation absorbs red and blue radiations for photosynthesis it is used to generate vegetation indices. Nine different bands in the composite image, with some of which indices and others Landsat VNIR wavelengths, were key to mapping alfalfa plant in the Emirate of Abu Dhabi.

2.4.2 Vegetation Indices

The VIs were useful for research purposes and provided significant information. It is worth noting that there are some indices such as LSWI and GCVI that need another index to generate accurate results of agricultural areas detection. Both VIs are sensitive regarding vegetation content, particularly when focusing on a different aspect of the plant components. While GCVI captures chlorophyll content in the vegetation, the amount of water in the vegetation can be detected by LSWI. Calculating one equation without the other can confuse measurements as GCVI is sensitive to soil in areas that have a very low vegetation cover (Figure 9). Pink color is supposed to indicate healthy vegetation because it represents a mixture of positive values of both indices. In the same composition, red was used to show water areas, and blue, which is sensitive to soil, was used to show desert areas. Looking at these images, one can see that the result of each index may be deceptive if it is not combined with other indices.

The other VI used in this research was NDVI. It is the most common vegetation index that characterizes the density of agricultural areas. Mainly, the result of NDVI did not show a different result from GCVI as shown in Figure 10. Both of them have a disadvantage when giving soil and plants same values.

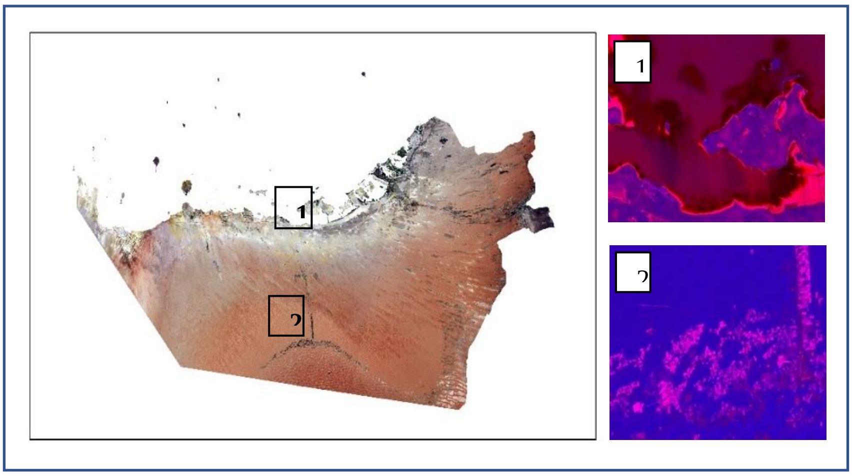

Figure 9. False Color Image of the Study Area Where Red = Land Surface Water Index (LSWI) and Blue = Green Chlorophyll Vegetation Index (GCVI).

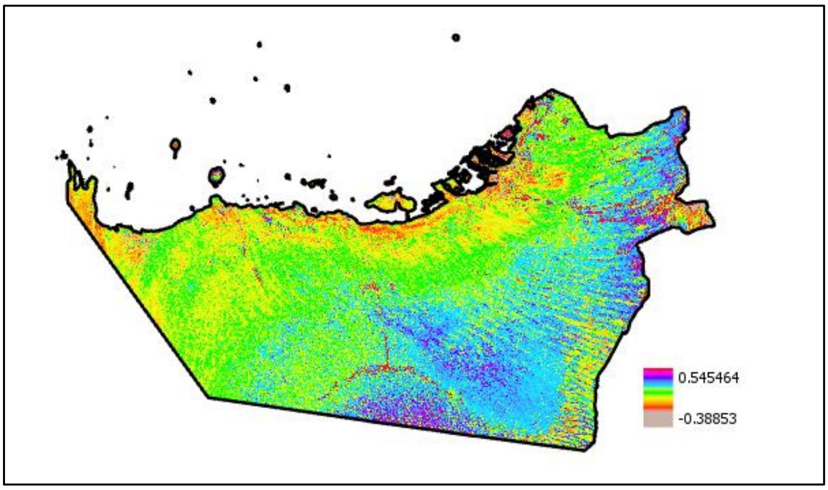

Figure 10. Normalized Difference Vegetation Index (NDVI) Map of the Study Area.

NDVI and GCVI are vegetation indicators that establish the relationship between different spectral ranges of remote sensing data containing vegetation in a particular pixel of the image. The only difference is that GCVI measures the green spectrum in the range from 0.54µm to 0.57µm instead of red spectrum as NDVI does. While GCVI is more sensitive to chlorophyll concentration compared to the NDVI, the effectiveness of NDVI is the sense of red band in plant canopies.

BSI was also used to map alfalfa accurately. It is a combination of various Landsat wavelengths - red, blue, near-infrared (NIR) and shortwave infrared (SWIR). It was used to capture soil variations. BSI is mostly used for sediment transport, soil erosion, and landslides. BSI, which is also applicable in vegetation mapping, was used to differentiate between dense plants and non-dense plants. Plant density refers to the number of individual plants present per unit of ground area. Alfalfa is an example of the high-density plant where the individual alfalfa plants are close to one another. That is what BSI result shows in Figure 11. Vegetation has various values depending on its density. Moreover, it can be seen that agricultural areas have low values compared to a desert area, and that can improve NDVI and GCVI results as well.

The Soil-Adjusted Vegetation Index (SAVI) was an additional index used in this research. It is a vegetation index that attempts to minimize soil brightness influences using a soil-brightness correction factor. SAVI is useful for monitoring different plants growth stages. The results showed that whenever the plants were in a high growth stage, their value became higher (Figure 12). Agricultural areas are shown in dark blue color.

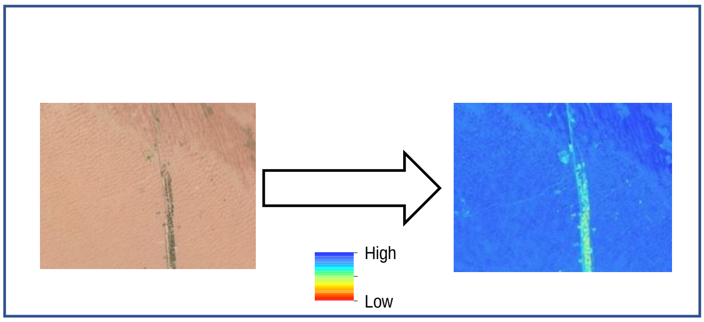

Figure 11. Bare Soil Index (BSI) Map of the Agricultural Areas in the Southern Part of the Emirate of Abu Dhabi.

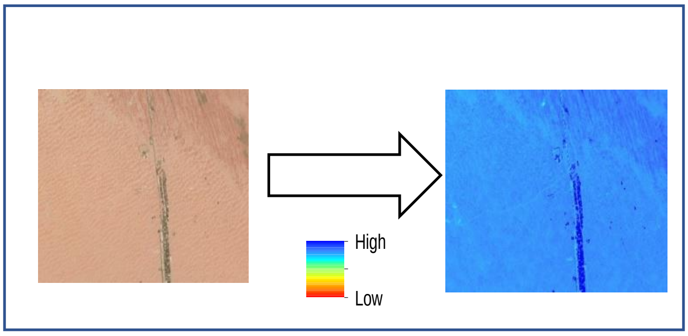

Figure 12. Soil Adjusted Vegetation Index (SAVI) Map of the Agricultural Areas in the Southern Part of the Emirate of Abu Dhabi.

2.4.3 Unsupervised classification

All the vegetation indices (VIs) with 4 spectral bands (Blue, Green, Red, and Near Infrared) were stacked together into a single image. Figure 15 shows different composition of the output image. This step was essential to classify agricultural areas accurately. ISO DATA unsupervised algorithms were used to classify the study area into 40 classes (Figure 14). In this classified image, the agricultural areas are presented in blue color.

2.4.4 Alfalfa Area Crop Calculation

The classified images were analyzed and the classes representing alfalfa crop were extracted into a separate layer using field visits and prior knowledge of some areas cultivated by alfalfa. The analysis showed a continuous increase in the area occupied by alfalfa (Figure 15).

It should be noted that there are many local farmers in the Emirate of Abu Dhabi who depend on alfalfa in grazing their cattle. During the years 2002, 2015 and 2020, the area covered by this plant was 102.32km^2, 239.01km^2, and 430.59 km^2, respectively. The increase is estimated at 133.6% between 2002 and 2015, while the increase was equal to 191.5% between 2015 and 2020. From 2002 to 2020 the increase is more than 325%.

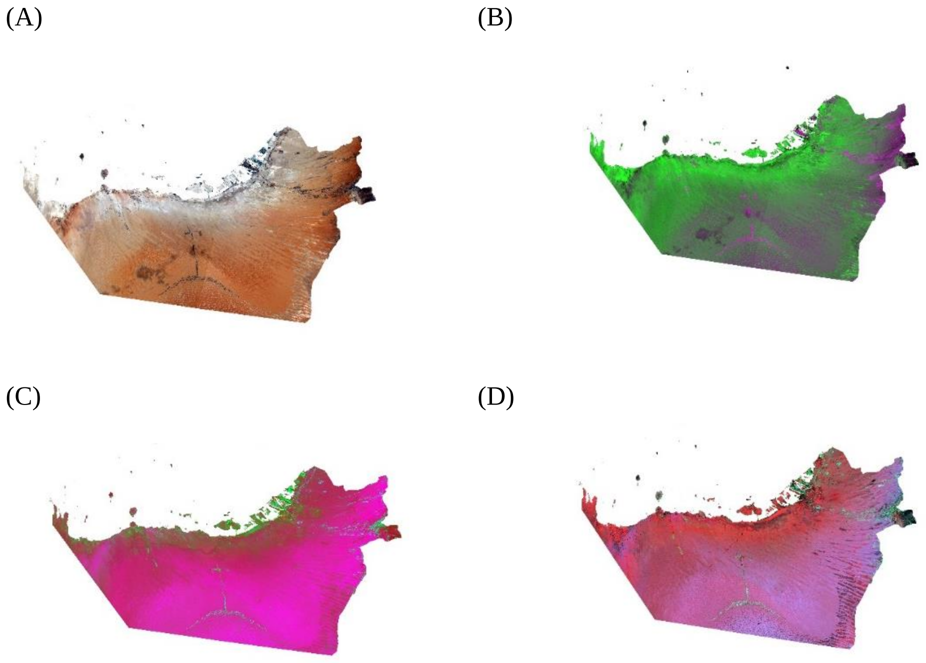

Figure 13. Different False Color Combination of Landsat Imagery (A) Natural Color; (B) Composite Image (B: Soil Adjusted Vegetation Index (SAVI), G: Green, R: Normalized Difference Vegetation Index (NDVI)); (C) Composite Image of (B: Bare Soil Index (BSI), G: Land Surface Water Index (LSWI), R: Green Chlorophyll Vegetation Index (GCVI)); (D) Composite Image (B: Near Infrared, G: Soil Adjusted Vegetation Index (SAVI), R: Green Chlorophyll Vegetation Index (GCVI)).

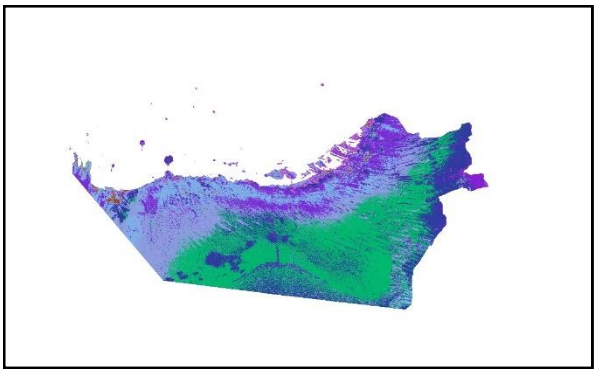

Figure 14. Land Use Land Cover Classes (40) Derived from the Composite Image Using Unsupervised Classification.

The area covered by alfalfa crop that was delineated in classified images had been evaluated for accuracy by comparing it with the areas measured during the field visits which aimed to examine the perfection of the approach used in the study. As a result, varying percentages of map accuracy were found on four different farms. These percentages ranged between 71% and 93%. There is always controversy about the percentage that must be reached to achieve an accurate classification map. According to Goodin et al. (2015) and Jiang et al. (2012), the values of classification ranging between 61% and 80% can be in good agreement with the actual LULC. In this study, the overall accuracies of the 2020 classified map in the four farms were 71.4%, 93.7%, 76% and 85.7%. On average, the Alfalfa map has an accuracy of 81.7% (Table 5).

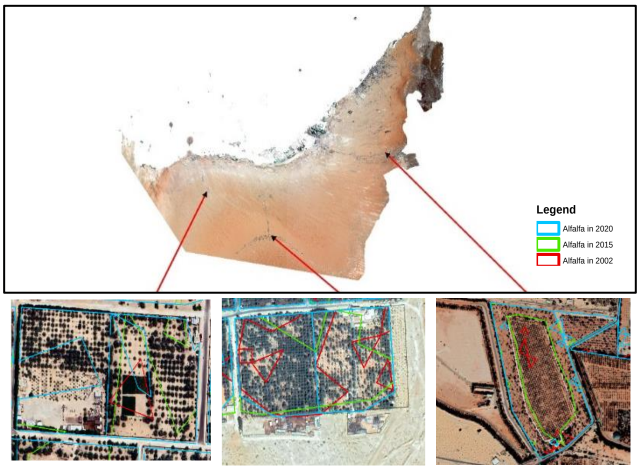

Figure 15. Alfalfa Crop Cultivated Areas in 2002, 2015, and 2020 in Different Farms in the Emirate of Abu Dhabi.

Table 5. Accuracy Assessment of Alfalfa Crop Land in the Four Farms.

Farm No.	**Area of the classified image (KM^2)**	**Area of the farms (KM^2)**	**Accuracy**
1	0.010	0.014	71.4%
2	0.016	0.015	93.7%
3	0.035	0.046	76%
4	0.012	0.014	85.7%
Overall Accuracy			**81.7%**

3. CONCLUSION

This study investigated the expansion of the area planting by alfalfa crop in the last two decades in the Emirate of Abu Dhabi using multiple GIS tools and remotely sensed data. This was done by making use of the tremendous value of the Landsat Program - the longest-running enterprise for the acquisition of satellite imagery of Earth. The program allowed the estimation of alfalfa cultivated area over an extended period of time. It should be noted that, choosing the study period was a major challenge, being dependent on the availability of data and satellite conditions over time. The challenge faced regarding Landsat Satellites' data, forced us to generate alfalfa maps only in the years 2002, 2015, and 2020 because the Landsat images in Asia were not available between 2003 and 2013. During this period, the stations of Landsat 4 and 5 stopped working in the region and Landsat-7 images showed line distortion.

The combining of multiple vegetation indices (VIs) and spectral bands into a single image, which was used in previous studies to map the area cultivated by potato crop (Danilo et al., 2021), had a great efficacy in mapping specific crops as concluded in this research in which an accuracy of 81.7% has been obtained. Each index made a different contribution, providing a valuable contribution in the process of mapping alfalfa. SAVI provides unique information in differentiating between different plant growth stages. It had been used in a number of studies for different purposes, e.g., Frag et al. (2012) who used SAVI to map different stages of wheat crop in the South Nile Delta of Egypt. The output of Bare Soil Index (BSI) was also useful because it helped in separating agricultural areas according to their density. It also did not confuse these areas with other sandy areas, as is the case with other indices.

Different researchers have applied various classification algorithms. In this research, ISODATA unsupervised classification was found to be the most suitable method for classifying the images, taking into account the difficulty of sampling different crops. The method was used by Amol (2013) when he worked on modeling of agricultural land use in India. The information provided by VIs is helpful for the computer algorithm to differentiate between several plant species in the study area and divide each species in a separate class based on natural groupings present in the values given by the composite image to extract alfalfa crop.

The significant and rapid increase of the areas planted with alfalfa in Abu Dhabi farms was expected as alfalfa is one of the most needed crops in the UAE. The crop is used as food for livestock, as well as green manure, grazing, hay, and silage. The cultivation of alfalfa is undoubtedly important for food security because of its high yield, wide adaptation, disease resistance, and excellent feeding quality (CAFA, 2001). However, despite the fact that alfalfa makes a tremendous contribution to the world food production, it consumes huge amounts of fresh water, making it a real threat to groundwater reserves.

This study has some limitations that can be addressed by improving the classification and validation methods. There is a wide variety of land classification methods, which allows us to always enhance our results. Comparisons between different classification algorithms can give a better idea of the best technique to map a specific crop. It is also important to have an existing high-resolution map produced by the government or other parties to be used in the validation process.

Alfalfa is a popular forage crop that is commonly used as animal feed in the United Arab Emirates (UAE). However, the arid and semi-arid climate of the region makes it challenging to grow alfalfa due to limited water availability. One of the solutions for the UAE's alfalfa shortage is to import it from water-rich countries. Alfalfa is a water-intensive crop that requires a lot of irrigation to grow. Countries with abundant water resources, such as the United States, Canada, and Australia, have been exporting alfalfa to the UAE for many years. While importing alfalfa may not be an ideal solution, it is a necessary one for the UAE's livestock industry. However, the UAE government can explore other alternatives to reduce its reliance on imported alfalfa.

Another solution for the UAE's alfalfa shortage is to replace it with other crops that are better suited to the region's arid climate. There are several crops that can be grown in the UAE with less water than alfalfa. For example, millet, sorghum, and corn are all drought-tolerant crops that can be used as animal feed. The UAE government can encourage farmers to switch to these crops by providing subsidies, technical assistance, and market access.

ACKNOWLEDGMENT

Over the past years, I have received support and encouragement from a number of people. First and foremost, I would like to thank my supervisor, Dr. Khalid Hussein, for his guidance, support, and assistance throughout the period I had been working on this research project. After many years of collaboration, I would honestly say that Dr. Hussein has significantly contributed to helping me become a good researcher, scientist, geographer, and critical thinker. He has largely contributed to paving my way towards success in my academic and professional career. I would also like to thank Mr. Hatim Elhag for editing the manuscript of this paper. I would also like to deeply appreciate the support I received from Dr. Nazmi Saleous, the coordinator of the MSc in Remote Sensing and GIS at the UAEU. My special thanks are also extended to Dr. Abd Elazim Ibrahim, who introduced me to the exciting field of groundwater and provided me with most of the data I needed to complete this important study. And as a matter of course, my sincere thanks and appreciation should go to the National Space Science and Technology Center (NSSTC), which provided me with satellite imagery and allowed me to use their valuable resources. Finally, and most importantly, I would like to say that I could not have undertaken this scientific journey without the sincere and heartfelt support from my mother, my father, and my siblings, whose selfless encouragement to me along the way helped me to do this research. Words cannot express my deepest gratitude and appreciation to them all.

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