4-2023

ASSESSING THE IMPACT OF ALFALFA (MEDICAGO SATIVA) CROP ON GROUNDWATER RESOURCES IN THE EMIRATE of ABU DHABI USING GEOSPATIAL TECHNIQUES

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Recommended Citation

Aljaberi, Abdulaziz Abdulla, "ASSESSING THE IMPACT OF ALFALFA (MEDICAGO SATIVA) CROP ON GROUNDWATER RESOURCES IN THE EMIRATE of ABU DHABI USING GEOSPATIAL TECHNIQUES" (2023). *Theses*. 1069.
https://scholarworks.uaeu.ac.ae/all_theses/1069

جامعة الإمارات العربية المتحدة
United Arab Emirates University

MASTER THESIS NO. 2023: 52

College of Humanities and Social Sciences

Department of Geography and Urban Sustainability

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Abdulaziz Abdulla Faisal Mubarak Aljaberi

This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science in Remote Sensing and Geographic Information Systems

April 2023

United Arab Emirates University Master Thesis
2023: 52

Cover: Withdrawal groundwater from aquifer base to be used for irrigation of plant in farms.

(Photo: By California Department of Water Resources)

Print: University Print Service, UAEU 2023

Declaration of Original Work

I, Abdulaziz Abdulla Faisal Mubarak Aljaberi, the undersigned, a graduate student at the United Arab Emirates University (UAEU), and the author of this thesis entitled "*Assessing the Impacts of Alfalfa (Medicago Sativa) Crop on Groundwater Resources in the Emirate of Abu Dhabi Using Geospatial Techniques*", hereby, solemnly declare that this is the original research work done by me under the supervision of Dr. Khalid Hussein, in the College of College of Humanities and Social Sciences at UAEU. This work has not previously formed the basis for the award of any academic degree, diploma or a similar title at this or any other university. Any materials borrowed from other sources (whether published or unpublished) and relied upon or included in my thesis have been properly cited and acknowledged in accordance with appropriate academic conventions. I further declare that there is no potential conflict of interest with respect to the research, data collection, authorship, presentation and/or publication of this thesis.

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Abstract

Groundwater is a major source of fresh water in the world, especially in arid and semi-arid countries like the United Arab Emirates (UAE), where rainfall is not evenly distributed through the four seasons of the year. Therefore, it is necessary to pay serious attention to the importance of preserving groundwater resources. 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. This research has been conducted with the objective of studying the impact of the alfalfa-cultivated areas on groundwater. It is based on calculating the groundwater level (GWL) in wells located near or inside a number of farms, with the end goal of generating a map that shows the areas planted with alfalfa in the same area for three different years using images provided by the Landsat satellite. The study assessed in a detailed manner, the expansion of alfalfa-cultivated areas in the Emirate of Abu Dhabi. 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. Furthermore, GWL was calculated using two parameters: the height above mean sea level and the depth of groundwater in the wells. The data were provided by the National Water and Energy Center (NWEC). The aim was to study the effect of the cultivation alfalfa crop on groundwater storage. As a result, we detected an ongoing increase in the area occupied by alfalfa in the last two decades, which increased from 102.32 km^2 to 430.59 km^2 between 2002 and 2020. The output was cross validated with field samples, and the overall accuracy of the method was around 81.7%. The well measurements, which were located near or inside the farms accessed and used in this study, showed that there was a significant decrease in the average groundwater amount in the Emirate of Abu Dhabi from 2005 to 2013 and that the mean groundwater level (MGWL) has decreased from 41.4 m to 5.11 m between the years 2005 and 2017, despite the fact that the amount of precipitation had not significantly changed during the mentioned period. In conclusion, the study indicates that the more the area is planted with Alfalfa, the lower the groundwater levels are.

Keywords: Groundwater Level, Alfalfa Plant, Mean Groundwater Level, Vegetation Indices, Visible and Near Infrared, Unsupervised ISODATA Classification.

Title and Abstract (in Arabic)

تأثير زراعة محصول البرسيم على موارد المياه الجوفية في إمارة أبوظبي بإستخدام نظم المعلومات الجغرافية والاستشعار عن بعد

الملخص

المياه الجوفية هي المصدر الرئيسي للمياه العذبة في العالم، وخاصةً في البلدان القاحلة وشبه القاحلة مثل دولة الإمارات العربية المتحدة حيث أن هطول الأمطار غير موزع بصورة متسقة خلال الفصول الأربعة. ولذلك فإن من الضروري الانتباه إلى أهمية الحفاظ على موارد المياه الجوفية. وقد شكّل قطاع الزراعة تهديدًا حقيقياً للمياه الجوفية، حيث أن الممارسات الزراعية مثل زراعة المحاصيل أو زراعة النباتات التي تستهلك كميات كبيرة من المياه تؤدي إلى تغيير ملحوظ في مستوى المياه الجوفية. ويعتبر البرسيم، والذي يزرع على نطاق واسع في دولة الإمارات العربية المتحدة، مثالاً على المحاصيل التي تستهلك كميات كبيرة من المياه. تم إجراء هذا البحث بهدف دراسة تأثير المساحات المزروعة بالبرسيم على مخزون المياه الجوفية، وذلك بحساب مستوى المياه الجوفية (GWL) في الآبار الواقعة بالقرب من المزارع أو داخلها، وكذلك إنشاء خريطة توضح المناطق المزروعة بمحصول البرسيم في نفس المناطق لمدة ثلاث سنوات مختلفة باستخدام الصور الجوية المقدمة من القمر الصناعي الأمريكي Landsat بهدف تقييم تمدد المساحات المزروعة بالبرسيم في المنطقة التي تستهدفها الدراسة. وقد تم حساب خمسة مؤشرات نباتية (VIs) وتكديسها مع أربعة طبقات اخرى وهي نطاق الأشعة تحت الحمراء والنطاقات المرئية الثلاثة (VNIR) ثم تم تطبيق منهجية Unsupervised ISODATA لتصنيف الصور. بالإضافة إلى ذلك، تم حساب مستوى المياه الجوفية باستخدام البيانات التي وفرها المركز الوطني للماء والطاقة (NWEC) بغرض دراسة تأثير نبات البرسيم على مخزون المياه الجوفية. الحساب تم باستخدام عاملين رئيسين، الأول هو الارتفاع فوق متوسط مستوى سطح البحر والثاني هو عمق المياه الجوفية في الآبار. نتيجة لذلك، لاحظنا زيادة مستمرة في المساحة التي يشغلها نبات البرسيم خلال العقدين الماضيين، حيث زادت المساحة من 102.32 كيلو متر مربع إلى 430.59 كيلومتر مربع بين عامي 2002 و 2020. وقد بلغت الدقة الإجمالية للطريقة المستخدمة لتحقيق أهداف الدراسة حوالي 81.7٪. كما أظهرت قياسات الآبار القريبة من المزارع أو داخلها، والتي تم استخدامها في هذه الورقة، أن هناك انخفاض في متوسط كمية المياه الجوفية في إمارة أبوظبي ما بين الأعوام 2005 و2013، كما انخفض أيضاً متوسط مستوى المياه الجوفية (MGWL) من 41.4 م إلى 5.11 م بين عامي 2005 و2017 آخذين في الاعتبار أن كمية هطول الأمطار لم تتغير بشكل جلي خلال نفس الحقبة. وفي الختام، تشير نتائج الدراسة إلى أنه كلما زادت المساحة المزروعة بالبرسيم، كلما قل مستوى المياه الجوفية.

مفاهيم البحث الرئيسية: مستوى المياه الجوفية، محصول البرسيم، متوسط المياه الجوفية، المؤشرات النباتية، نطاق الأشعة تحت الحمراء، النطاقات المرئية الثلاثة.

Author Profile

Abdulaziz Abdulla Aljaberi is a United Arab Emirates (UAE) national who lives in the Emirate of Abu Dhabi. He currently works at the Statistics Center Abu Dhabi (SCAD) as a Geographic Information System (GIS) specialist. His work focuses on GIS data integration within different databases as well as the processing of all relevant data in a way that achieves the objectives of the center.

Mr. Aljaberi graduated from the UAE University (UAEU) with a bachelor’s degree in Geographic Information Systems (GIS). After graduation, he started his career at the National Space Science and Technology Center (NSSTC) as a remote sensing researcher, focusing specifically on Land Cover and Land Use (LCLU) and 3D modeling projects.

The author has four years’ experience in the fields of remote sensing and GIS. His research interests focus primarily on freshwater issues. His academic contributions include, but are not limited to, a paper titled "The Impact of Urbanization on Groundwater Resources in Jebel Ali, Dubai". The paper was presented at the Earth Resources and Environmental Remote Sensing and GIS Applications Conference.

Acknowledgements

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.

Dedication

To my beloved parents and family

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List of Abbreviations

BSI	Bare Soil Index
GCVI	Green Chlorophyll Vegetation Index
GIS	Geographic Information System
GWL	Groundwater Level
LSWI	Land Surface Water Index
LULC	Land Use Land Cover
MGWL	Mean Groundwater Level
NDVI	Normalized Difference Vegetation Index
RS	Remote Sensing
SAVI	Soil Adjusted Vegetation Index
VI	Vegetation Index
VNIR	Visible and Near Infrared

Chapter 1: Introduction

1.1 Overview

Water is a natural resource necessary for life. It is, indeed, the key to human life. Therefore, it is necessary to stress the importance of preserving freshwater resources. However, there are numerous challenges in this regard, including serious threats of depletion of these vital resources. The need of the agriculture sector to achieve food security is one of these challenges. Broadly defined, agriculture is the practice of cultivating plants and livestock. Nowadays, fresh water is limited. 71% of planet earth is covered by water, but only 2.5% of it is fresh. As a matter of fact, only 0.5% of this amount of water is accessible because it is located in polar ice caps, glaciers, soil, and atmosphere. There is also a large amount of fresh water which is almost impossible to extract because it exists too deep below the earth's surface. Groundwater is, by definition, a major source of fresh water in the world as it represents 0.62% of the earth's water. It seeps into the ground through porous materials and travels deep into the ground to aquifer layers. Groundwater supplies are recharged by melted snow and rain that infiltrates down into these layers. This water resource is vital for agriculture irrigation, especially in semi-arid regions. It has been scientifically proven that irrigated crop-cultivation practices change groundwater levels as well as its quality. Groundwater can practically be located anywhere. However, withdrawal of groundwater from aquifers for crop irrigation can cause a higher rate of evapotranspiration, which disrupts this natural cycle (Foster, 2018). Obviously, evaporation prevents water from running off the land or returning to groundwater. Generally, in order to ensure the sustainability of groundwater, it is crucial to understand the impact of irrigated agriculture on the hydrological cycle, particularly ground water storage.

1.2 Statement of the Problem

It is vital to be fully aware of the effects of agriculture practices on groundwater resources whether by growing crops or farming plants which consume large amounts of water. Groundwater is extremely important, especially in arid and semi-arid areas that lack surface water sources like the UAE, where water sources have always been limited due the fact that rainfall distribution is not uniform in all seasons. Groundwater is the main source of water in the UAE, accounting for more than 60% of water use in the capital of the emirate. However, it is affected by human activities such as agricultural practices which are the most common human-induced activities that affect the groundwater system (Keune, 2018). There is a clear relationship between crop and plant areas and water quantity which is a determining factor in the socio-economic development of a country (Hussein et al., 2020).

Recently, the Emirate of Abu Dhabi government has been extensively investigating this issue. In September 2017, the Ministry of Energy and Infrastructure unveiled the United Arab Emirates (UAE) Water Security Strategy 2036. The strategy aims to ensure sustainable access to water and stresses the UAE's vision for prosperity and sustainability. The challenge facing the UAE is how to ensure that reduced rainfall and a higher rate of population growth and civilization development will not lead to excessive depletion of groundwater resources and rapid dependence on desalination. In other words, groundwater supplies are struggling to keep up with rising demand which is being driven by the increase of the green-dominated areas. Obviously, the expansion of cropland led to an increase of demand for water. Therefore, it is important to study the effect of cultivation of crops on groundwater resources. This study evaluating the effect of the expansion alfalfa cultivated areas on ground water storage using geographic information system and remote sensing technology.

1.3 Geographic Information System and Remote Sensing

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 groundwater recharge. It has also been reported to be useful for groundwater exploration. In addition, GIS and RS technologies are widely used to study

LULC 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, which allows us to predict the influence of agriculture on groundwater.

To obtain the full benefits from these collections of functionalities, there are many types of specialized GIS software used to analyze and process geospatial and remotely sensed data. Environmental Systems Research Institute (ESRI) is the most popular organization in this regard. It provides GIS software to all users around the world. Its products are characterized by powerful mapping and statistics capabilities. ArcGIS is one of ESRI's products which has many features. It is a geographic information system software used in processing geographic data. There is also the Environmental for Visualizing Images software (ENVI) which is a well-known software. ENVI mainly focuses on raster data processing. It has a great capability to handle multispectral and hyperspectral remotely sensed data. Each software provides useful services to GIS professionals and scientists.

1.4 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 impact of changes occurring in agricultural areas on groundwater over a period of two decades. The objectives of this study are to: [1] assess the ability of remote sensing and GIS techniques in mapping agricultural areas. [2] create maps of the alfalfa crop cultivated in the Emirate of Abu Dhabi using vegetation indices (VIs), unsupervised classification, and satellite data and field measurements, [3] calculate the groundwater levels (GWL) in various wells located inside or near farms and to correlate this to the expansion of areas cultivated by alfalfa in the last two decades.

1.5 Research Questions

1. Have the areas cultivated by alfalfa plant increased in the last two decades?
2. Do human activities in the farms contribute to the decrease in the level of groundwater?

1.6 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).

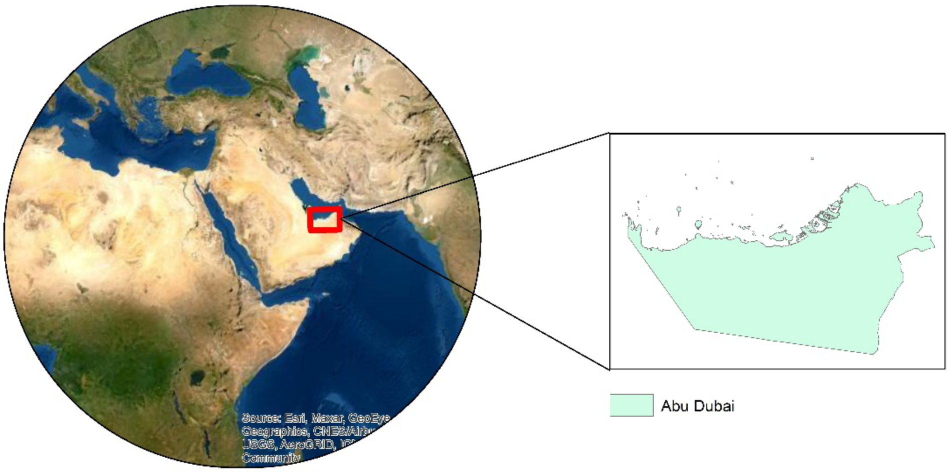

Figure 1: A Map Showing the Study Area (Emirate of Abu Dhabi).

1.6.1 Climate Condition

The Emirate of Abu Dhabi is located in an arid tropical zone. It is approximately seven meters above sea level. The Emirate is characterized by mild winters with maximum temperatures ranging from 24°C to 26°C, while in the summer the temperature could reach 50°C. In summer, the Emirate of Abu Dhabi normally experiences hot, dry, sunny and humid weather. In the spring season, the emirate is dusty due to strong winds which can cause sandstorms. This prevailing wind comes from the north-west direction. The windier time in Abu Dhabi is between December 27 and April 15, with an average wind speed of more than 8.8 miles per hour. The period from April 15th to December 27th is the calmest part of the year. It witnesses an average hourly wind speed of 7.5 miles per hour (Hussein et al., 2021), with the Emirate of Abu Dhabi receiving an annual precipitation of less than 100 millimeters occurring mostly in winter season. Usually, the largest amount of rainfall occurs in March and the least in May.

1.6.2 Groundwater in the Emirate of Abu Dhabi

Historically, the water resources in the UAE have always been limited because of the geographical location of the country. This creates a difficult situation for the country regarding the conservation of water resources. It faces tough challenges such as increasing industrial activities and expanding urban land, causing high evaporation rate. Rapid population growth is also another challenge. Groundwater is the main source of water, accounting for around 51% of the UAE's water supply, bearing in mind that more than 60% of water use in the Emirate of Abu Dhabi comes from groundwater (Almadfaei, 2017). Therefore, long-term availability of water is at risk.

To address the main issue regarding the decrease of groundwater level in the last years we need to look at the facts and numbers that explain the current situation. In 2016, the authorities in the Emirate of Abu Dhabi acted and worked on the Wells Inventory Project by issuing a law to organize groundwater abstraction in Abu Dhabi when the amount of groundwater extracted reached 2,013 million cubic meters in 2015, and the daily water consumption in the Emirate represented one of the highest rates in the world, with 590 liters per capita (Almadfaei, 2017). The other influential factor in this regard is the consumption of water in the agricultural sector. Recently, the number of operating farms in Abu Dhabi rose sharply to reach more than 24,000 farms, i.e., 38 times the number in 1971. This increase Abu Dhabi government to achieve its goal of reducing dependence on imported food and increasing local food production to reach 40% (Almadfaei, 2017). The increasing number of farms led Abu Dhabi government to dig approximately 100,000 wells across the emirate (Almadfaei, 2017).

1.6.3 Agriculture in the Emirate of Abu Dhabi

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. 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 (Figure 2.A). However, they are many other crops produced by the country's farmers.

Among the various crops grown in the UAE is the alfalfa (Figure 2.B). 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 (ICBA, 2020).

(A) (B)

Figure 2: Examples of Water-Absorbing Plants, (A) Date Palm Tree. (B) Alfalfa Plants.

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 area resulted in the depletion of groundwater and an increase in water salinity. Recently, the UAE 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 this regard, Rhodes, alfalfa and vegetables can be classified as high-water consumers. Rhodes grass is popular in the gulf countries like the UAE, Qatar, Oman and the Kingdom of Saudi Arabia. It has a high protein value and needs to consume an average of about 600 mm to 1200 mm of water for its production (Arshad et al., 2016). The study focuses on alfalfa that 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.

Chapter 2: Relevant Literature

There have been many previous studies on groundwater exploration using Geographic Information System (GIS) and Remote Sensing (RS) techniques. Further research was conducted over many years on the relationship between groundwater and Land Use/Land Cover (LULC). These studies applied several mathematical approaches. This study specifically focused on discussing the effect of the expansion of alfalfa cultivated areas on the decrease in the level of groundwater, bearing in mind the importance of food sustainability.

The literature review has covered six topics: [1] Geographic Information System (GIS) and Remote Sensing (RS) Software applied on groundwater research, [2] Spatial and non-spatial data integration for groundwater measurement, [3] Remote sensing data preprocessing, [4] Land use and land cover (LULC) Delineation, [5] Monitoring and analyzing agriculture areas, [6] Data and results validation.

2.1 Geographic Information System (GIS) and Remote Sensing (RS) Software Applied on Groundwater Research

In the last decades, many researchers have proven that RS and GIS techniques are great tools for mapping, modelling, simulating, and interpreting imagery data of different scales as they provide reliable and up to date information. They are also widely used to show the power of earth's observation by creating real world depictions. In order to apply these various techniques, many specialized GIS software have been developed to analyze and process GIS and remotely sensed data. ArcGIS, which is provided by ESRI organization, is the most well-known software in this field. There are also many other open-source software that are used for GIS applications. For example, QGIS software allows GIS users to edit, create, and publish geospatial information freely.

ArcGIS, which is software that uses different geographic data, has powerful mapping and statistics capabilities. It was used in several research studies to assess issues related to the preservation of water resources, such as the evaluation of water scarcity and crop water requirement. For example, a study was conducted to classify satellite images of Kenya, using different methods with the aim of mapping the amount of land occupied by crops (Changwony et al., 2017). The researchers found that in the year 1985 cropland was 21%, then it increased to 29% in 1995, and to 53% in the years 2005 and 2015 (Changwony et al., 2017). Nino et al. (2009) formulated a GIS-based model taking into consideration the interaction between irrigated crops and crop characteristics.

Earth Resource Mapper (ER) professional software is also used worldwide, especially in the oil, gas, and mineral exploration industries for raster data exploitation. It was found to be very helpful in extracting the lineament in the Northwest of Iran using visual interpretation in modeling groundwater indicators (Kamal & Hamid , 2011).

For raster data processing, there are three important types of software: PCI Geomatica, Earth Resources Data Analysis System (ERDAS), and Environment for Visualizing Images (ENVI) all of which are specialized in dealing with continuous data. Usman et al. (2021) removed the strips in Landsat ETM+ using gap filling tool in ENVI. Other researchers have relied on ERDAS IMAGINE. Due to the software's capability of carrying out raster analysis and map production, it used to generate supervised classification to assess the effects of different strategies for groundwater recharge and storage in Indira Sagar Canal Command Area, India (Tiwari et al., 2015). Furthermore, PCI Geomatica offers great image processing techniques. It was found useful for automatic lineament extraction to explore the groundwater in Nigeria (Oyedele & Akinola, 2019).

There are some types of software that are used for research in specific fields; MODFLOW and AquaChem are examples of such software. MODFLOW is a three-dimensional finite difference groundwater flow model that was first published by the United States Geological Survey (USGS) in 1984 (Ghazavi & Reza, 2016). It is a type of software used to assess the long-term effect of land use change on the groundwater levels and fluxes in Belgium (Changwony et al., 2017). Steady-state MODFLOW models for each year from 2000 until 2020 were developed by Dams et al. (2008). The results of the MODFLOW models showed a decrease in the average groundwater level for all different scenarios (Changwony et al., 2017). Researchers in Iran employed this software to estimate groundwater recharge from return flow using remotely sensed data (Ghazavi & Reza, 2016). Another example used AquaChem software for the plotting of Piper-Trilinear diagrams in Lower Shiwalik hills, Nepal, to assess the impact of land-use and land-cover change on groundwater quality (Singh et al., 2010). However, Ovidiu and

Mariana (2018) implemented the satellite images in the eCognition software with the purpose of segmenting the multi-temporal images as a step to obtain a better cropland map. The eCognition software has indeed pioneered object-based analysis techniques and feature extraction.

2.2 Spatial and Non-Spatial Data Integration for Groundwater Measurement

Sources of data in GIS and RS can be classified as follows: Field data, existing cartographic documents, and digital images such as aerial photographs and satellite images. Field data is most probably used for validation. Many researchers went to the field to enhance the accuracy of the LULC maps they created (Ghazavi & Reza, 2016; Changwony et al., 2017; Irie et al., 2016; Andualem & Demeke, 2019). Additionally, Singh et al. (2010) observed the surface water quality at the field to assess the Impact of LULC change on groundwater quality in the Lower Shiwalik hills. Generally, point measurements are manually captured and represented in vector format.

Continuous data is completely different from feature data. It is transited smoothly from one value to another without boundary. Elevations, temperature, and atmospheric pressure are some examples. Digital Elevation Model (DEM) is the most used model in groundwater research. It generates slope, curvature, roughness, drainage and other index maps in order to locate the groundwater potential area (Benjmel et al., 2020; Arulbalaji, 2019; Andualem & Demeke, 2019). DEM is a representation of the bare ground topographic surface of the earth excluding any other surface objects achieved by humans. It can be created by different RS techniques using remotely sensed data as well as in situ measurements.

Moreover, existing maps that have been created by other organizations such as municipalities played a major part in groundwater projects. Several earlier experiments used geological maps provided by government authorities for groundwater exploration studies (Oyedele & Akinola, 2019; Arulbalaji, 2019; Andualem & Demeke, 2019). There are many other pre-made maps used previously in groundwater studies, like vegetation, topography, soil, LULC (Karimian at al., 2019; Dams et al., 2008). Vegetation maps provided to researchers from the forests and rangelands organization. They are designed by experts using around 60 study points collected from the field (Karimian, et al., 2019). Rarely we find scientific research about RS in which digital images are not a part.

Digital image refers to the representation of part of the earth's surface as seen from orbit. Sentinel and Landsat are the most common open-source satellite imaging used widely in the GIS and RS studies. Sentinel has a series of satellites with different purposes are and they are operated by European Space Agency (ESA). Sentinel, which is an Earth observation platform, acquires optical imagery at moderate spatial resolution. Its resolution ranges between 10 to 60 meters with 12 bands. The mission supports many applications such as agriculture monitoring, LULC classification, water quality assessment, etc. Ovidiu and Mariana (2018) used this type of satellite imaging to map out cropland in Romania. Although Landsat has less spatial resolution, with only 30 meters compared to Sentinel satellites, it is the most used tool being the longest-running enterprise for acquisition of satellite imagery of Earth. It started in 1972 when Landsat-1 was launched until Landsat-9 took off on 27 September 2021 by the National Aeronautics and Space Administration (NASA). Landsat images have been used extensively to explore groundwater and find out which areas have the higher potential of groundwater recharge than the others (Kamal & Hamid, 2011; Oyedele & Akinola, Andualem & Demeke, 2019, 2019; Benjmel et al., 2020). It is also useful for other fields related to water such as water scarcity assessment (Changwony et al., 2017). In addition, there are satellite images which are specifically used in developing cropland maps and determining agriculture-dominated areas (Irie et al., 2016; Hao et al., 2018). On the other hand, the Indian Remote Sensing Satellite (IRS) LISS-III geo-coded false color composite satellite data was used by Arulbalaji and Sreelash (2019) to create LULC and geomorphology maps of India. The IRS was launched by the Indian Space Research Organization (ISRO) in October 2003 with 24 meters spatial resolution and 6 meters of panchromatic band.

In general, all the data types explained above belong to the spatial data that are defined by location through a coordinate system. The other part of geographic data can be referred to as "attribute data", which, in turn, refers to non-spatial characteristics that stored in a table.

Basically, wells are the main element in studying groundwater. A well is a hole drilled into the ground to reach water in an aquifer. Various case studies on groundwater wells and their depth were conducted and used to investigate groundwater storage and how these wells can be affected by LULC changes over the years (Ghazavi & Reza, 2016;

Karimian et al., 2019; Dams et al., 2008; Tiwari, 2015). Other researchers have provided a bulk of information on groundwater quality in terms of chemical and physical factors (Singh et al., 2010). It should be noted that both spatial and non-spatial data have different ways and processes of acquisition.

2.3 Remote Sensing Data Preprocessing

Data preprocessing is a data mining technique used for transforming raw data into a usable and efficient format. There are many ways for RS rectification and correction involving both radiometric and geometric approaches. Radiometric correction approaches are applied to solve the errors caused by illumination, atmospheric conditions, and sensor noise, whereas geometric correction is the process of transforming the X and Y dimensions of a digital image by image-to-image registration or image-to-map rectification. It is worth noting that Karimian et al. (2019) took geometric and radiometric corrections into account when they studied the impact of LULC on groundwater resources in Khan-Mirza Plain in Iran. Researchers have conducted a series of radiometric and geometric operations using raw data, after having identified and detected possible errors in the satellite data (Karimian et al., 2019). In another example, Landsat images have been corrected for radiometric and geometric distortion errors to assess water scarcity models in Kenya (Changwon et al., 2017).

On the other hand, preprocessing may be desirable to restore the data with the aim of data transformation and reduction. Principal components analysis (PCA) is one of the most common data reduction techniques. It is applied to transform an original correlated dataset into a much smaller set of uncorrelated variables that represents the majority of the information (Leandro, 2012). This method was part of the groundwater exploration research in Nigeria (Oyedele & Akinola, 2019). Additionally, to better understand the RS image, it is important to convert the digital numbers to measurements in units that represent the real reflectance or emittance of the surface. Mtibaa and Mitsuteru (2016) converted raw digital numbers (DN) to top of atmosphere (TOA) reflectance with correction for sun angle, with a view to mapping cropland dominated area in Tunisia (Irie et al., 2016). This has been carried out by applying the below Equation 1.

$$\rho_{\lambda} = \frac{M_P Q_{cal} + A_P}{\sin \theta_{SE}} \qquad (1)$$

Where: qk = TOA reflectance for band k. Mp = Band specific multiplicative rescaling factor. Qcal = Quantized and calibrated standard product pixel values (DN). Ap = Band specific additive rescaling factor. hSE = Local sun elevation angle in radians. Mp, Ap and hSE are given in the metadata file provided in the Level 1T data (Irie et al., 2016).

In addition to all the stages explained previously, mosaicking can be done. It refers to the combining of multiple images into a single image, bearing in mind that all the images should have the same cell size. This process is primarily processed after acquiring the images needed to make the image ready for interpretation as most of the satellite images are provided with the bands individually. It is also a way to reduce the size of the data as the researchers did to map annual cropland in central Asia. They chose 6 bands out of the eleven of the landsat-8 bands, combining them in one multiband raster dataset (Hao et al., 2018).

2.4 Land Use and Land Cover (LULC) Delineation

The use of geospatial information to define collected data is spreading and growing rapidly, with most of it being used to provide LULC information. Land cover refers to nature - the physical land type like water, desert, forest, etc. Land use, on the other hand, indicates how people use the land (NOAA, 2021). It has become essential to classify the LULC using satellite images and remote sensing techniques for any particular area in the world to better understand the current landscape and how humans use land for different purposes. The main objective of image classification procedures is to automatically categorize all pixels in any image into LULC classes. Spectral classification involves the categorization of image pixels on the basis of their differing values in each band of the digital image. Supervised image classification and unsupervised image classification are the two most common methods in this regard. In unsupervised approaches, the computer groups all pixels according to their spectral relationships and looks for natural clustering. It assumes that data in different cover classes will not belong to the same group.

Overall, unsupervised classification is a very basic and easy technique to be used in segmenting and understanding satellite images as no samples or prior knowledge are needed in order to use it. And that is why researchers from the School of Environmental Sciences in Canada used unsupervised classification to assess the groundwater quality in the Lower Shiwalik hills, Nepal. Their approach was based on an ISODATA algorithm, which means that the pixels were grouped into clusters. 120 spectral classes and 95% of convergence values were selected to perform this kind of classification (Singh et al., 2010). Another technique of unsupervised classification is he K-Means method. It generates initial class means that are uniform dispersed in the data space then using a minimum distance algorithm to iteratively clusters the pixels into the nearest class.

As for the supervised classification, users have to select samples for each LULC class and feed them to a computer which uses these samples as a “training sites” and applies them to the entire image. Identifying training sites could be done through a combination of fieldwork, map analysis, and personal experience. Many previous studies applied supervised classification technique to their data using Maximum Likelihood algorithm and Support Vector Machine (SVM) algorithm so that they could assess the impacts of LULC change on groundwater resources and water scarcity (Singh et al., 2010; Changwony et al., 2017). Maximum likelihood classification means that the algorithm assumes that the statistics for each class in each band are normally distributed. Hence it calculates the probability that a given pixel belongs to a specific class.

Another experiment used a completely different approach to classify the LULC of Khan-Mirza Plain in Iran. Artificial neural networks were first designed by Rosenblatt in 1985 (Karimian et al., 2019). In the years 2006 and 2016 LULC activity maps were prepared and compared by entering the educational samples into the network through the input layer. Then the errors of different methods were moderated by applying algorithms such as Back Propagation which modulates network weights to reduce network errors using the cost function gradient (Karimian et al., 2019).

2.5 Monitoring and Mapping Agricultural Areas

Agriculture is the main source of national income for most developing countries. However, agricultural practices are likely to have negative impacts on water availability and water quality. Currently, agriculture is a key factor in the process of managing sustainable natural resources (Ovidiu & Mariana, 2018). 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 to 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 2 (Irie et al., 2016). Subsequently, a new index termed NDVI Change was developed. It was calculated according to the following Equation:

$$\text{NDVI Change} = \frac{Standarized\ NDVI\ SOS\ date}{Standarized\ NDVI\ POS\ date} \qquad (2)$$

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:

$$\text{NDVI} = \frac{(NIR-RED)}{(NIR+RED)} \qquad (3)$$

2.6 Data and Results Validation

GIS data is not always perfect, and hence it is vitally important to validate its approaches when applied to any project meant to meet at least a minimum threshold of accuracy. It is an established fact that validation of analysis by GIS and RS is a process of detecting existing features, attributes, and relationships in a database that do not fulfill produced quality requirements using formal methods. In other words, it is a process, or a tool meant identify errors already existing in the original data or appearing in the extracted results. As per the literature, and before attempting to use a dataset for any serious and sensitive research, all aspects should be checked for completeness, correctness, consistency, and compliance. Making decisions based on inaccurate data would definitely lead to non-objective results (Warner, 2014)

A group of researchers from Kenya, (Changwony et al., 2017), studied water scarcity in their own country where they collected rainfall data from eleven weather stations to examine the accuracy of the data provided by the Tropical Rainfall Monitoring Mission (TRMM) which is a collaborative project conducted by the National Aeronautics and Space Administration (NASA) and Japan Aerospace Exploration Agency (JAXA). The project, which operated between 1997 and 2015 had monitored and studied tropical rainfall. The project researchers found that TRMM rainfall data had a horizontal resolution of 0.25 degrees by 0.25 degrees area coverage with ground station data, root mean square error (RMSE) and correlation coefficient (R^2) methods being used as measures for error calculation (Changwony et al., 2017).

If any project contains a classification map, it must take the accuracy assessment into account by comparing the classified image to another accurate data source or truth samples, which can be collected from the field or high-resolution imagery. In more detail, one needs to create a set of random points from the aforementioned sources and compare them with the classified data in a confusion matrix. Hao et al. (2018) used this matrix to assess the quality of the annual cropland maps, including the producer's accuracy (PA), and user's accuracy (UA). A producer's accuracy is calculated by dividing the number of correctly classified pixels in each class by the number of reference pixels. User's accuracy is computed by dividing the number of correctly classified pixels in each category by the total number of pixels that were classified in that category. The classification image in this paper reached an accuracy of higher than 85%.

In addition to this, researchers in 2010 evaluated the accuracy of existing cropland layers, Finer Resolution Observation and Monitoring of Global Land Cover (FROM-GLC), and Globaland30. They applied McNemar’s test to evaluate the pairwise statistical significance of the difference in accuracy between FROM-GLC, Globaland30, and RBM-based maps (Hao et al., 2018). In the Mosian Aquifer (west of Iran) case study, the researchers evaluated the three years' classification maps via overall accuracy and Kappa coefficient (Ghazavi & Reza, 2016). The overall accuracy was defined as the total number of correctly classified pixels divided by the total number of reference pixels. The Kappa coefficient calculation ranges between 0 and 1, with the greater value indicating a better agreement between classified and references pixels. All maps indicate a satisfactory accuracy, with overall accuracies of 83.2% for 1991, 85.1% for 1999 and 85.1% for 2013, when the Kappa coefficient for 1991, 1999 and 2013 was 0.823, 0.836 and 0.87 respectively (Ghazavi & Reza, 2016). Hussein et al. (2020) applied the same accuracy assessment methods to evaluate LULC classification image along the eastern coast of the UAE between 1996 and 2016. A percentage of overall correctly classified pixels ranging from 73% to 78% was obtained.

There are many other researchers who used existing maps for the purpose of evaluating the accuracy of their work. For example, Oyedele and Akinola (2019) used existing land cover maps to validate the classified images that were used to produce crop water requirement model. Others used existing groundwater yield data to check the generated groundwater potential zone map.

Chapter 3: Methods

3.1 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. Groundwater is considered as one of the main sources of fresh water that needs protection from pollution and excessive use, especially in arid and semi-arid countries like the UAE where the rainfall distribution is not uniform in all seasons. Recently, the authorities in the Emirate of Abu Dhabi noticed that the amount of groundwater abstracted was increasing annually. It reached 2,013 million cubic meters in 2015, with daily water consumption in the Emirate being one of the highest rates in the world (590 liters per capita - Almadfaei, 2017). According to the Environmental Agency in Abu Dhabi, this rate continued to increase, currently reaching 2,100 million cubic meters annually. This is equal to about 20 times the quantities of natural feeding of underground reservoirs (EAD, 2020). 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, (Z. Hammami, ICBA, personal communication, December 28, 2021).

For that reason, the Emirate of Abu Dhabi introduced a wells inventory project and issued a law to control groundwater abstraction. The move aims at organizing the number of wells in farms which they are more than 100,000 wells across the Emirate. To explain the rationale behind these government's actions, it has been proven that groundwater is really decreasing, especially in the areas where alfalfa is grown. In this study, various remotely sensed data and remote sensing techniques were used to map alfalfa crop areas and measure the level of groundwater in the farms of the Emirate of Abu Dhabi.

3.2 Data

3.2.1 Remotely Sensed Data

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.

3.2.1.1 Landsat

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 (Figure 3). 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.

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

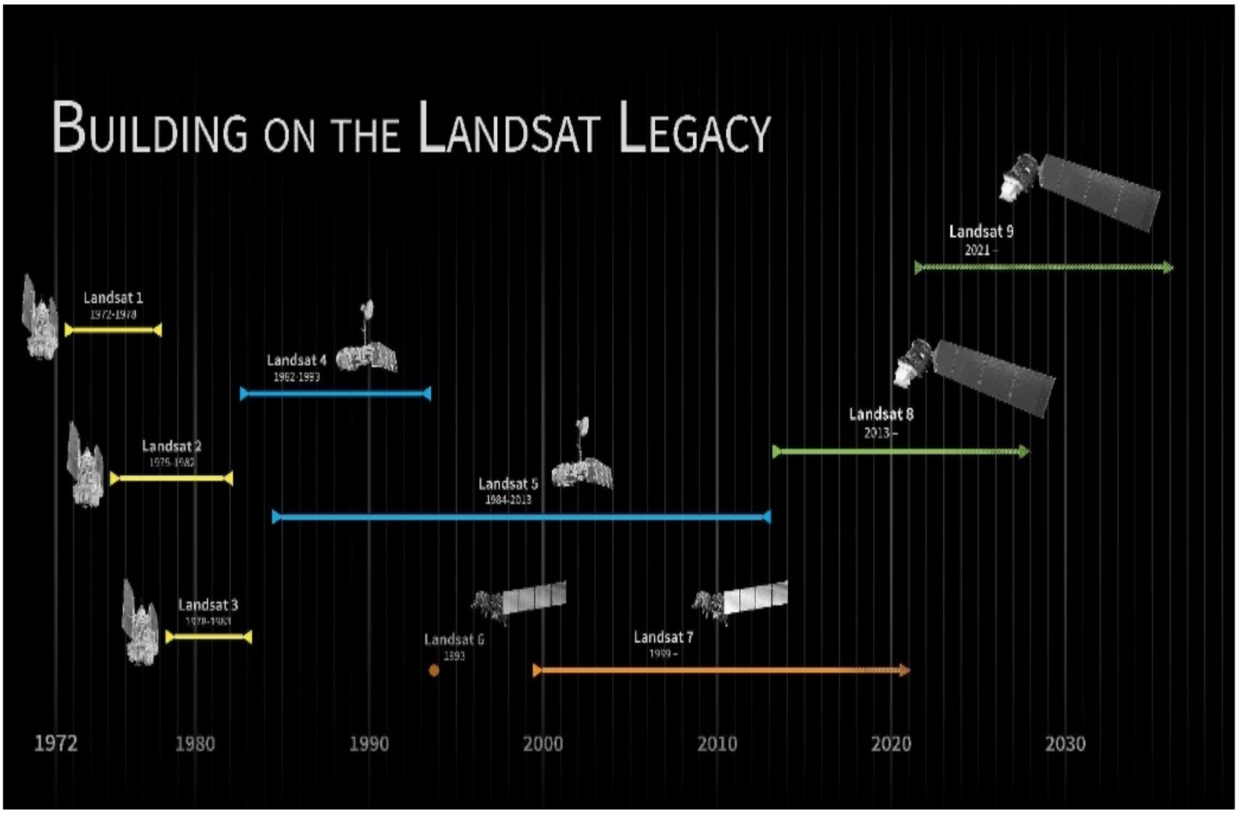

Figure 3: Landsat’s Launch and Expiration Dates. Source: NASA

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.

3.2.1.2 Worldview Data

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

3.2.2 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 4 and Figure 5. 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 6).

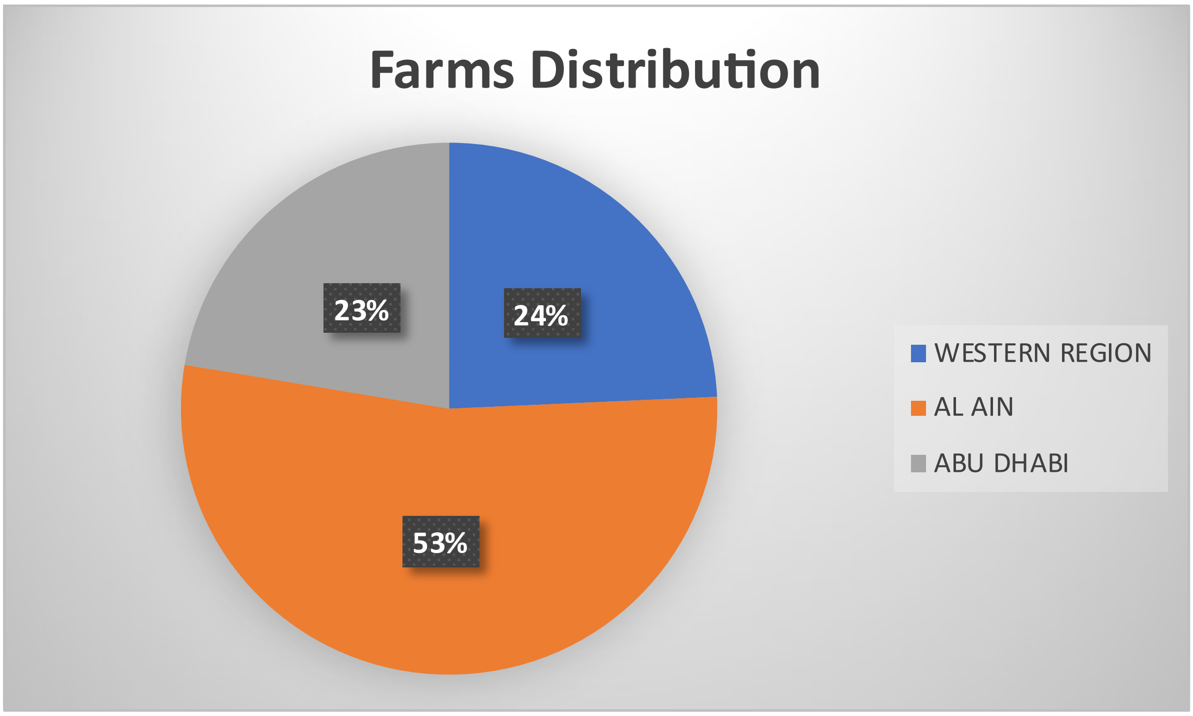

Figure 4: Percentage of Farms Distribution Over Emirate of Abu Dhabi.

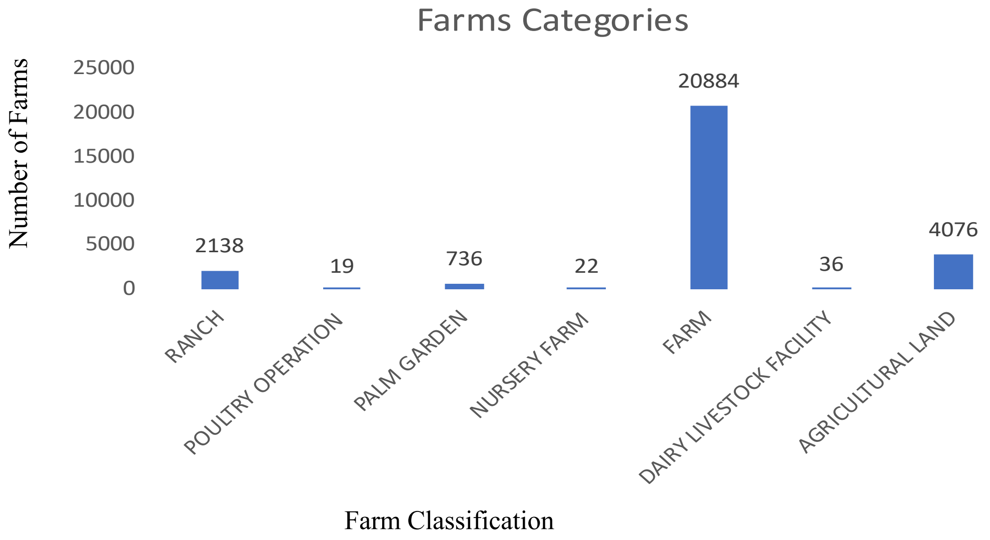

Figure 5: Farm Classification Based on Municipalities' Categorization.

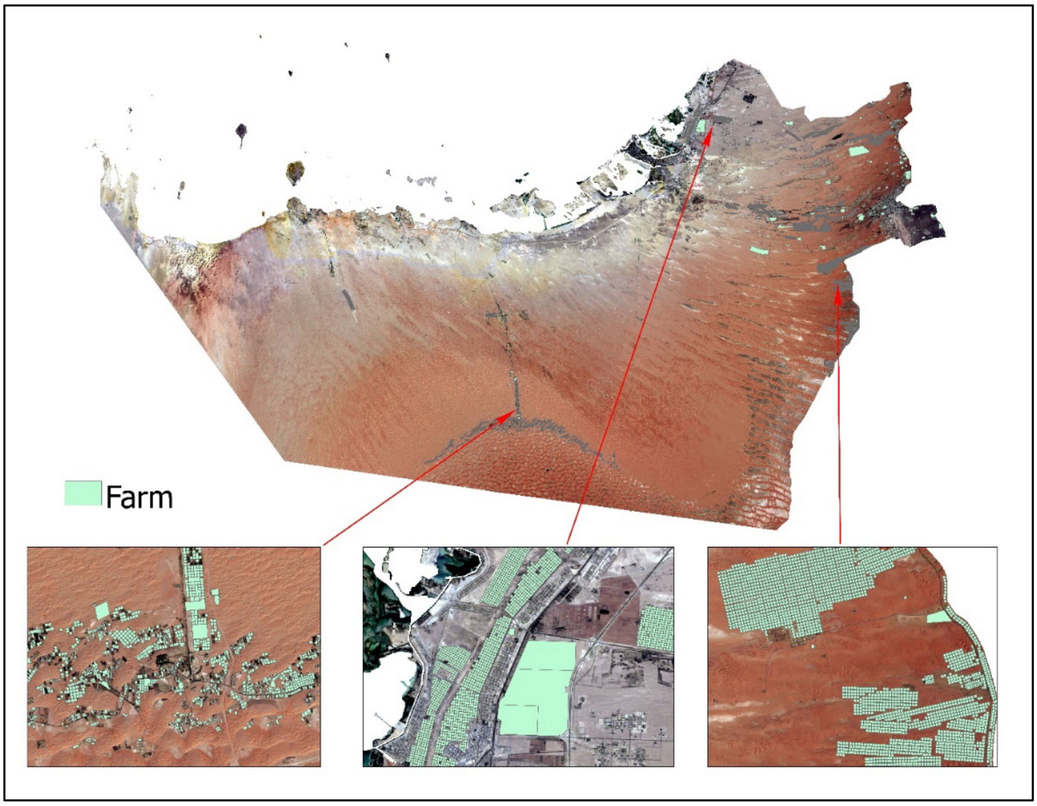

Figure 6: Farms' Locations in the Emirate of Abu Dhabi.

3.2.3 Field Data

3.2.3.1 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.

Figure 7: R10-2 Trimble Device.

R10-2 GNSS is a device commonly used for surveying (Figure 7). 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.

3.2.3.2 Wells Measurements

Water wells or water boreholes are terms referring to any narrow and deep shafts bored into the ground and tap into naturally occurring groundwater to extract water from the permeable rock below. In this study, wells data was used to monitor changes in groundwater levels. This kind of data was provided by field teams engaged in monitoring groundwater parameters such as water levels, pressure changes and water quality during aquifer tests. The annual water wells data between 2005 and 2017 was provided by the National Water and Energy Center (NWEC) of the Emirate of Abu Dhabi. It contains the elevation of water table for 53 wells within the study area as shown in Figure 8.

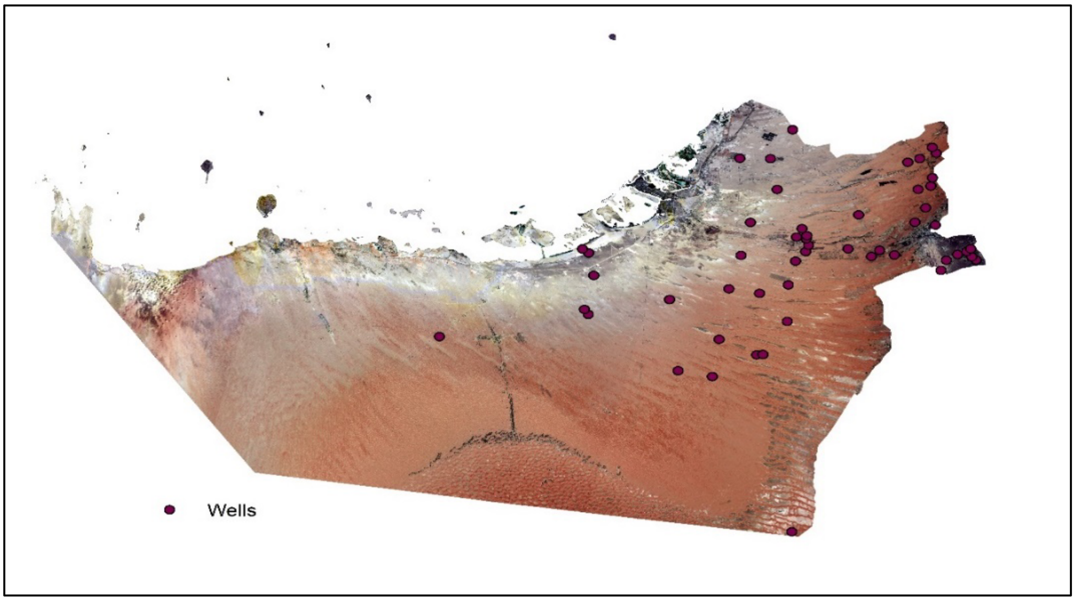

Figure 8: Locations of the Wells that were Used in the Study.

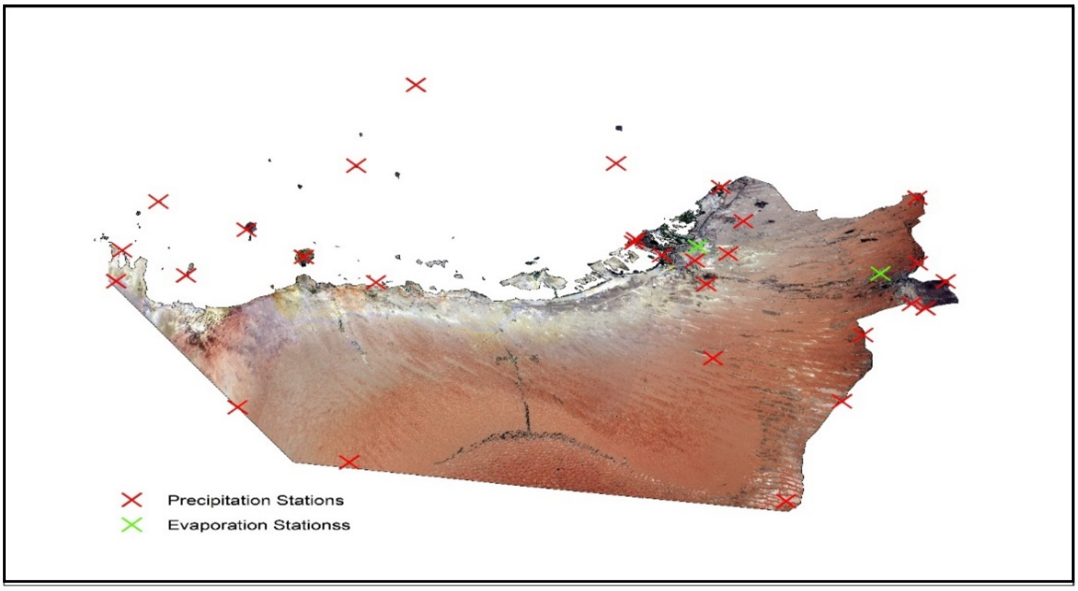

Figure 9: Locations of the Precipitation and Evaporation Stations in the Study Area.

3.2.4 Rainfall Data

Rainfall data refers to the amount of precipitation recorded by weather stations which are specialized agencies tasked with carrying out such measurements. The National Center of Meteorology (NCM) is the body responsible for monitoring rainfall amounts across the UAE and which is required to provide these measurements on a daily, monthly, and annual basis. In this study, monthly rainfall data from 29 NCM rain gauge stations. Figure 9 and Table 3 were used in the assessment for four different years, with five-year interval (2005, 2010, 2015, and 2020).

Table 3: Precipitation Data Provided by the National Center of Meteorology.

Station Name	**Data Availability**			
	2005	**2010**	**2015**	**2020**
Al Jazeera B.G.	√	√	√	√
Al Shiweb	√	√	√	√
Alarad	√	√	√	√
Alfoah	√	√	√	√
Algheweifat	√	√	√	√
Alqlaa	√	√	√	√
Alquaa	√	√	√	√
Jabal Hafeet	√	√	√	√
Mezyed	√	√	√	√
Khatam Al Shaklah	√	√	√	√
Mukhariz	√	√	√	√
Ras Ganadah	X	√	√	√
Ras Musherib	√	√	√	√
Um Azimul	√	√	√	√
Abu Al Bukhoosh	√	√	√	√
Abu Dhabi	√	√	√	√
Alwathbah	√	√	√	√
Makassib	√	√	√	√
Dalma	√	√	√	√
Qarnen	√	√	√	√
Rezeen	√	√	√	√
Sir Bani Yas	√	√	√	√
Al Ajban	X	X	√	√
Al Rass	X	X	√	√
ALReem Island	X	X	√	√
Ashaab	X	X	√	√
Arylah	X	X	√	√
Al Shawamekh	X	X	X	√
AL Musaffah	X	X	X	√

Table 4: Data Used in the Study.

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
Wells Measurements	The National Water and Energy Center (NWEC)	Vector	2005 - 2017
Rainfall Data	The National Center of Meteorology	Numerical	2005, 2010, 2015 & 2020

3.3 Calculation of Alfalfa Crop Area

3.3.1 Estimating 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 (Rasmus et al., 2007; Qiangzi et al., 2014; Dinelo et al., 2021). 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.

As Figure 11 shows, 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 5), 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 5: 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)	$\frac{(Red + SWIR) - (NIR + Blue)}{(Red + SWIR) + (NIR + Blue)}$

3.3.2 Image Classification

3.3.2.1 Unsupervised 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, as explained in chapter two (Section 2.4) (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).

3.3.2.2 Classification Enhancement

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.

3.3.3 Conversion of Classified Image

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.

3.3.4 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 10.

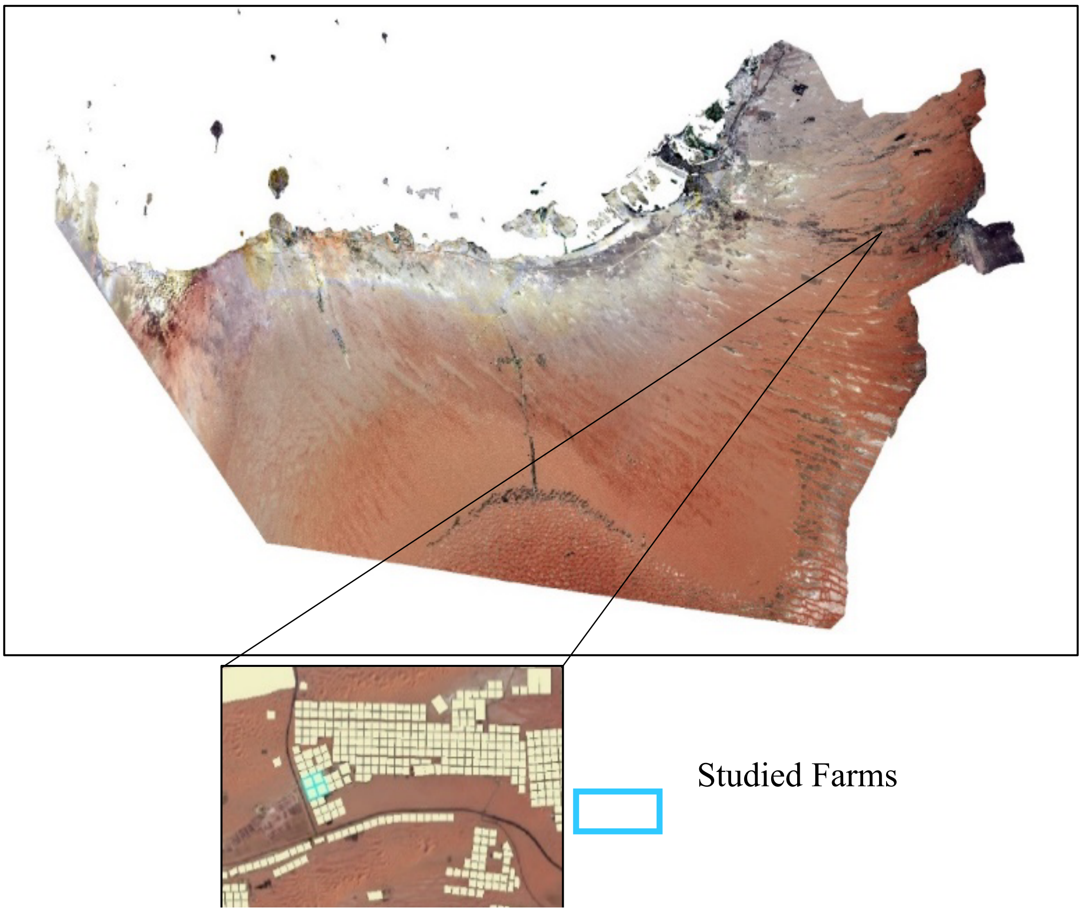

Figure 10: Farms from Which Data are Collected for Accuracy Assessment.

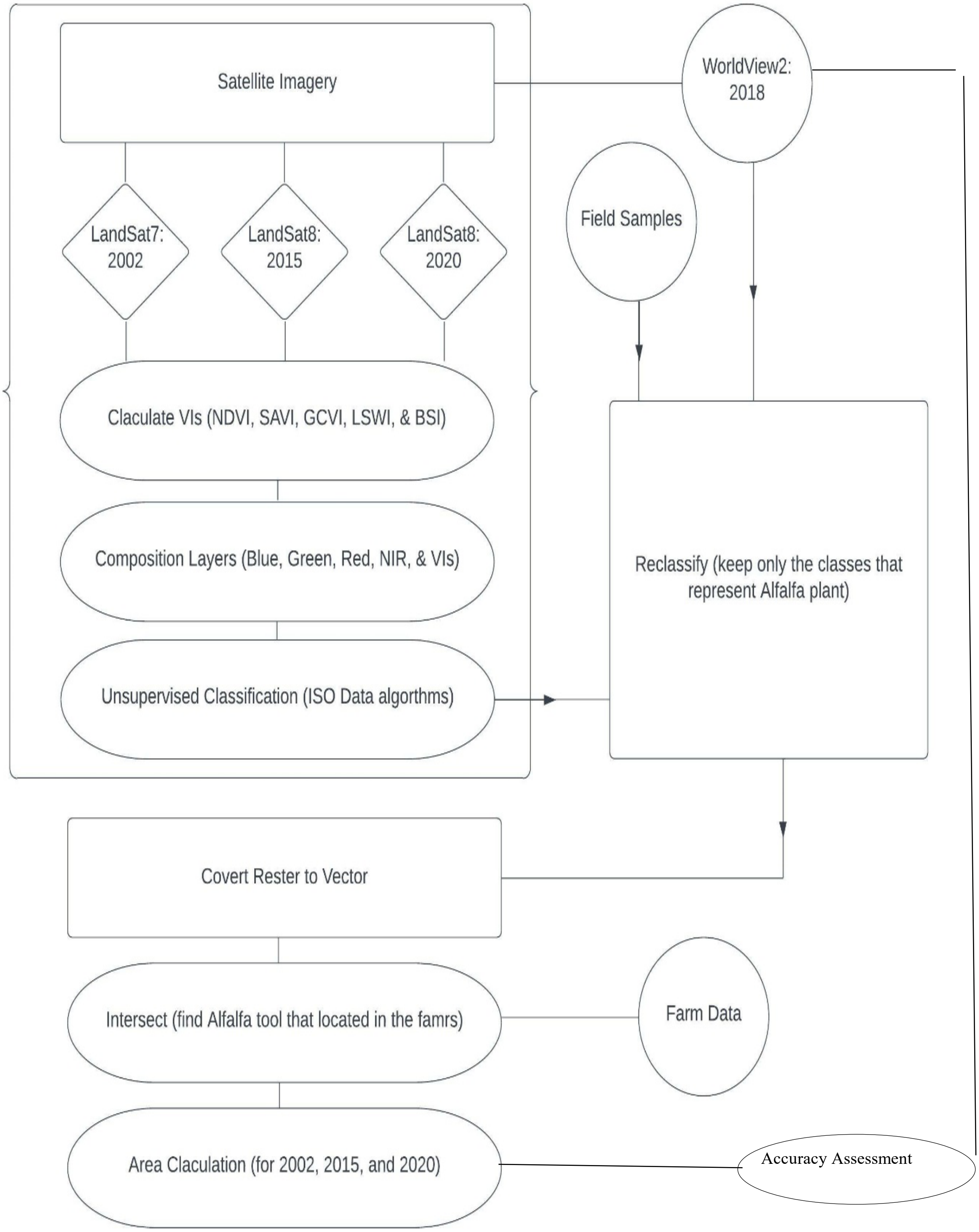

Figure 11: Functional Flow for Methodology Used for Mapping and Calculating the Areas Occupied by the Alfalfa Crop.

3.4 Groundwater Estimation

3.4.1 Groundwater Level

Combined with some field monitoring data, RS can estimate the level of groundwater. Groundwater level is a term used to measure which elevation soil is saturated. Water table depths and the elevation for each borehole were recorded as part of well measurements explained earlier in this chapter (section 3.2.3.2). The water table describes the distance between water-saturated ground and unsaturated ground below the soil surface. In addition to the elevation, this data is needed to calculate the level of the groundwater. Equation 4 was used to calculate the groundwater level (GWL) for all studied wells using the height above mean sea level and the depth to groundwater (Figure 12).

$$\text{GWL} = \text{ground surface elevation} - \text{depth to groundwater} \quad (4)$$

The above Equation was applied to measure GWL in three different years, 2005, 2013, and 2017 to understand which direction the groundwater goes, i.e., whether the level is increasing or decreasing.

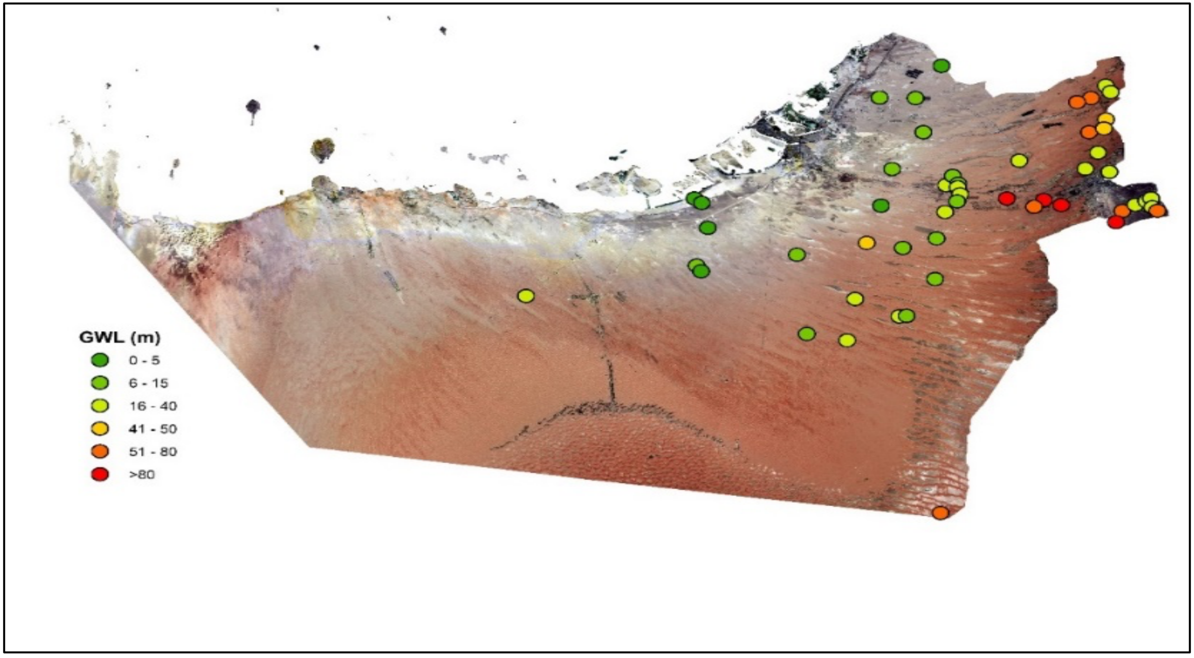

Figure 12: Groundwater Level in the Studied Wells in 2005.

3.4.2 Groundwater Level in Farms Wells

To adhere to the main objectives of the research, water had to be extracted from the wells located in or near the farms using farms and wells data. Table 6 shows 21 wells out of 53 located within the farms or at a maximum distance of 0.5 km. The MGWL of the 21 wells were calculated separately.

Table 6: Wells Located Within or Near the Farms.

Number	**Wells ID**	**Distract Name**
1	ADC0802998	Al Khaznah
2	ADC0814521	Al Khaznah
3	ADD0814653	Al Khaznah
4	ADD0814847	Al Khaznah
5	ADD0815144	Al Khaznah
6	ADD0815233	Al Khaznah
7	ADD0814858	Al Khaznah
8	ADD0814840	Remah
9	ADD0902607	Al Rawdha
10	ADD0814841	Al Rawdha
11	ADD0902599	Al Rawdha
12	ADE0700070	Zayed Milittary City
13	ADE0700069	Ajban
14	ADD0814843	Sweihan
15	ADD0902611	Airport East District
16	ADE0902990	Al Hayer
17	ADE0902904	Al Hayer
18	ADE0902981	Al Hayer
19	ADD0902632	Bida Bint Saud
20	ADD0902984	Masakin
21	ADE0902901	Masakin

3.4.3 Groundwater Recharge

There are two aspects that must be balanced in order to preserve groundwater resources: the rate of consumption and the rate of recharge. Groundwater recharge is a process where the water from the surface of the earth seeps downwards and collects in aquifers. The main source of groundwater recharging is rainfall. This study investigated whether the decrease in groundwater levels was related to a decrease in the amount of precipitation during the study period by comparing the percentage of changes regarding the GWL and precipitation. Monthly rainfall data provided by NCM were used to calculate the average precipitation for the whole year to find out the trend of the precipitation over the last two decades.

Chapter 4: Results

The results of this research were divided into two main sections: Alfalfa coverage and groundwater level calculation. In the first section, the results of the VIs showed in detail how the areas planted with alfalfa were expanding in the Emirate of Abu Dhabi, as well as showing the accuracy of these results. In the second section, the results of ground water levels computation (Equation 4) were presented and used to assess the changes in groundwater levels and where these changes occurred.

4.1 Alfalfa Crop Area Coverage

One of the objectives 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 (Figure 13).

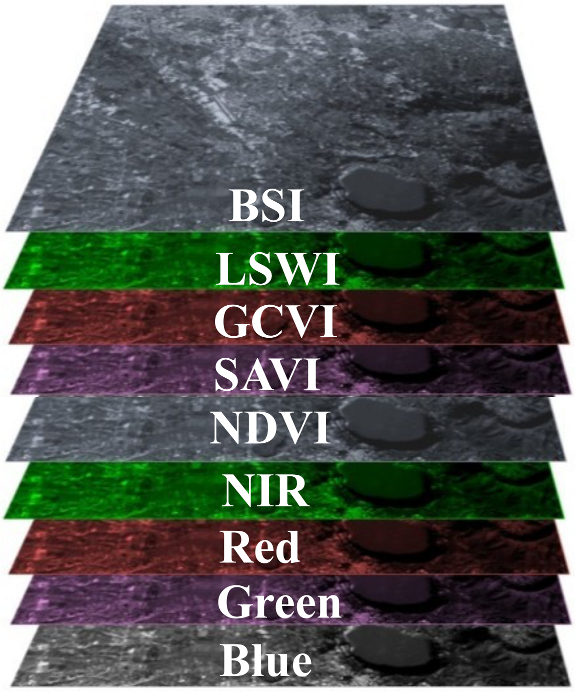

Figure 13: The Composite Image Used to Delineate Areas of Alfalfa.

4.1.1 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 14). 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.

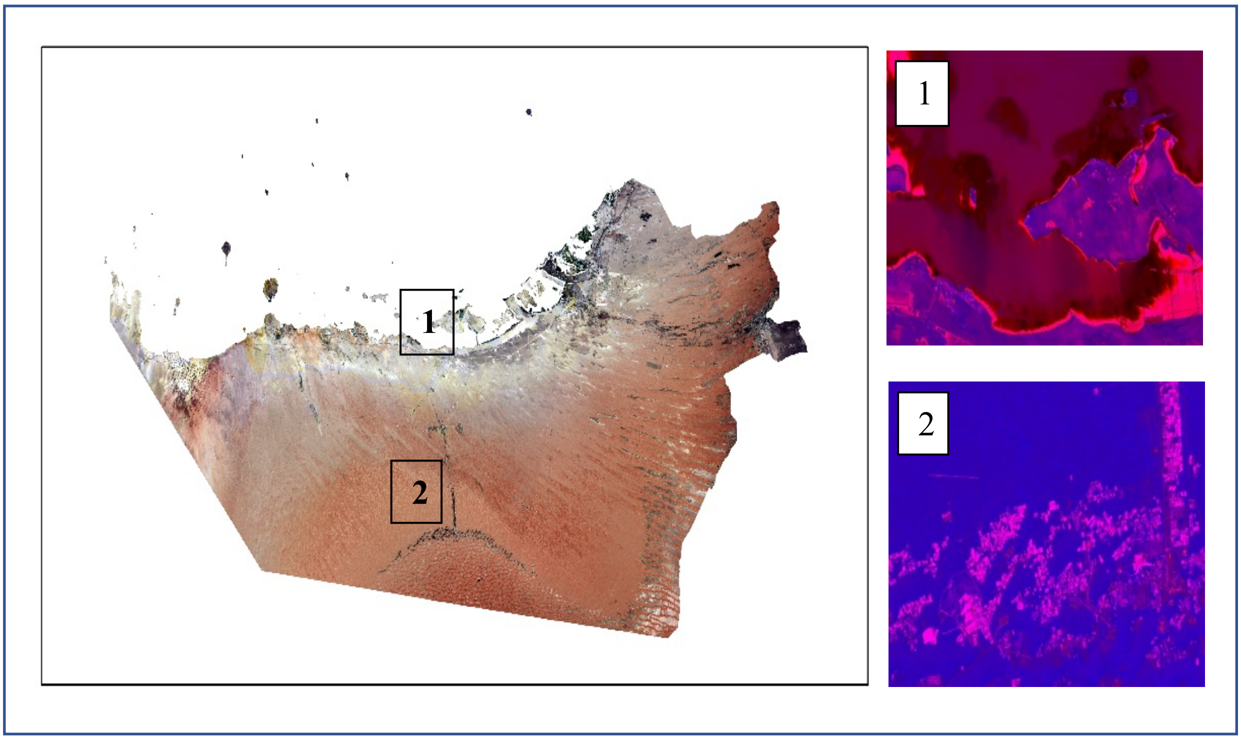

Figure 14: False Color Image of the Study Area Where Red = Land Surface Water Index (LSWI) and Blue = Green Chlorophyll Vegetation Index (GCVI).

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 15. Both of them have a disadvantage when giving soil and plants same values.

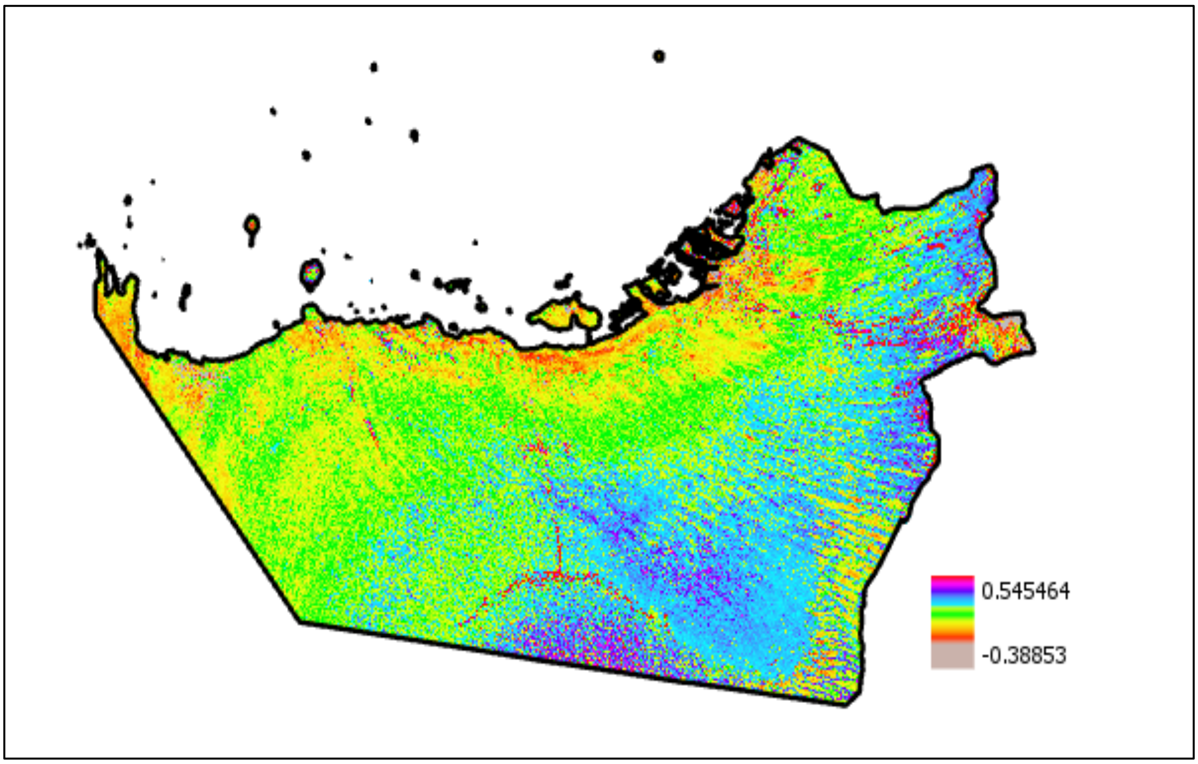

Figure 15: Normalized Difference Vegetation Index (NDVI) Map of the Study Area.

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 0.54 µm to 0.57 µm 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 (Can et al., 2021). 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 16. 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 17). Agricultural areas are shown in dark blue color.

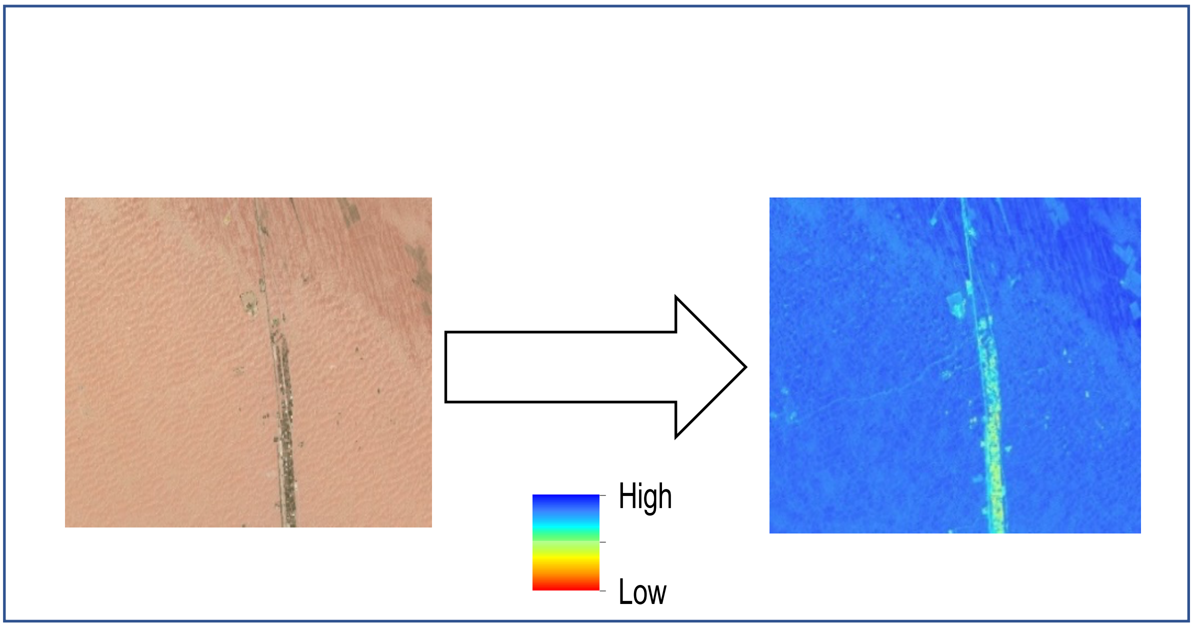

Figure 16: Bare Soil Index (BSI) Map of the Agricultural Areas in the Southern Part of the Emirate of Abu Dhabi.

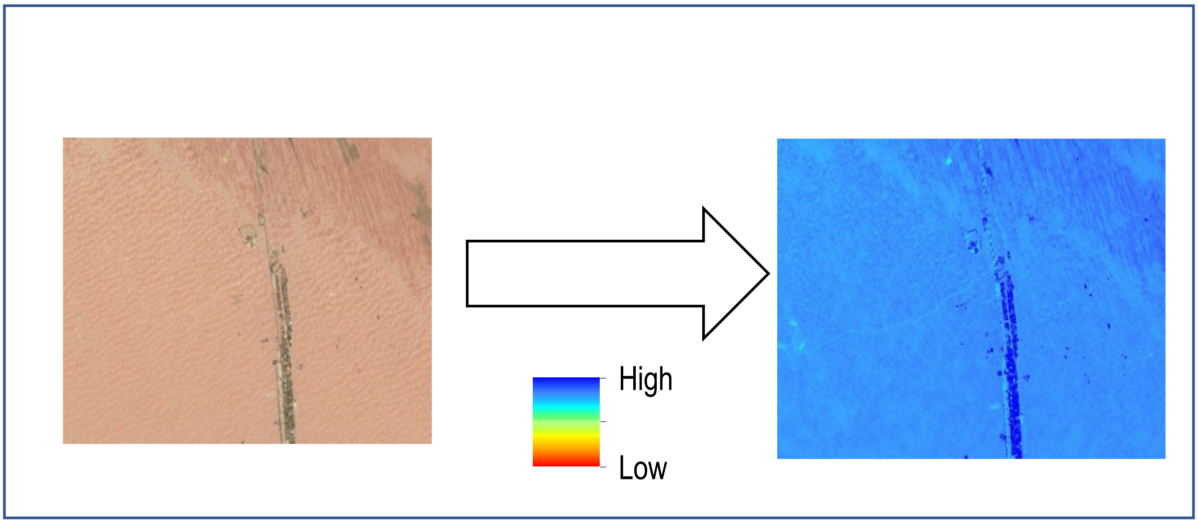

Figure 17: Soil Adjusted Vegetation Index (SAVI) Map of the Agricultural Areas in the Southern Part of the Emirate of Abu Dhabi.

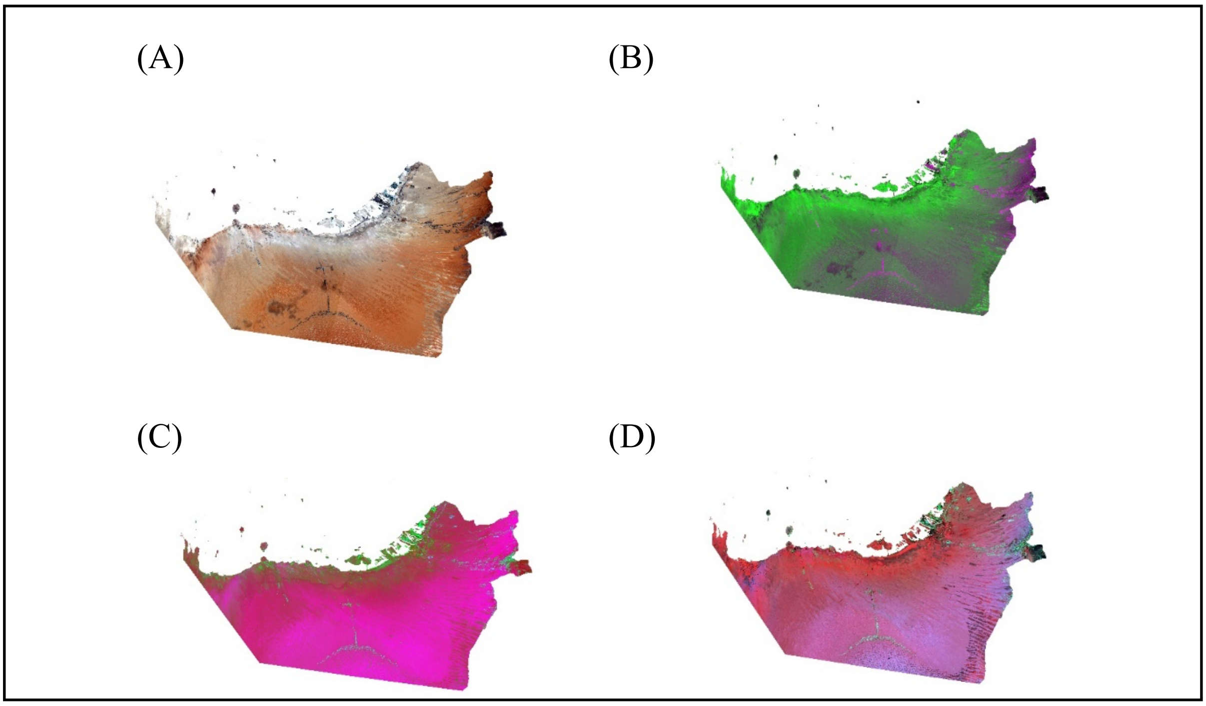

Figure 18: Different False Color Combination of Landsat Imagery (A) Natural Color; (B) Composite Image (B: Soil Adjusted Vegetation Index (SAVI), G: Green, R: Normalized Difference Vegetation Index (NDVI)); (C) Composite Image of (B: Bare Soil Index (BSI), G: Land Surface Water Index (LSWI), R: Green Chlorophyll Vegetation Index (GCVI)); (D) Composite Image (B: Near Infrared, G: Soil Adjusted Vegetation Index (SAVI), R: Green Chlorophyll Vegetation Index (GCVI)).

4.1.2 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 18 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 19). In this classified image, the agricultural areas are presented in blue color.

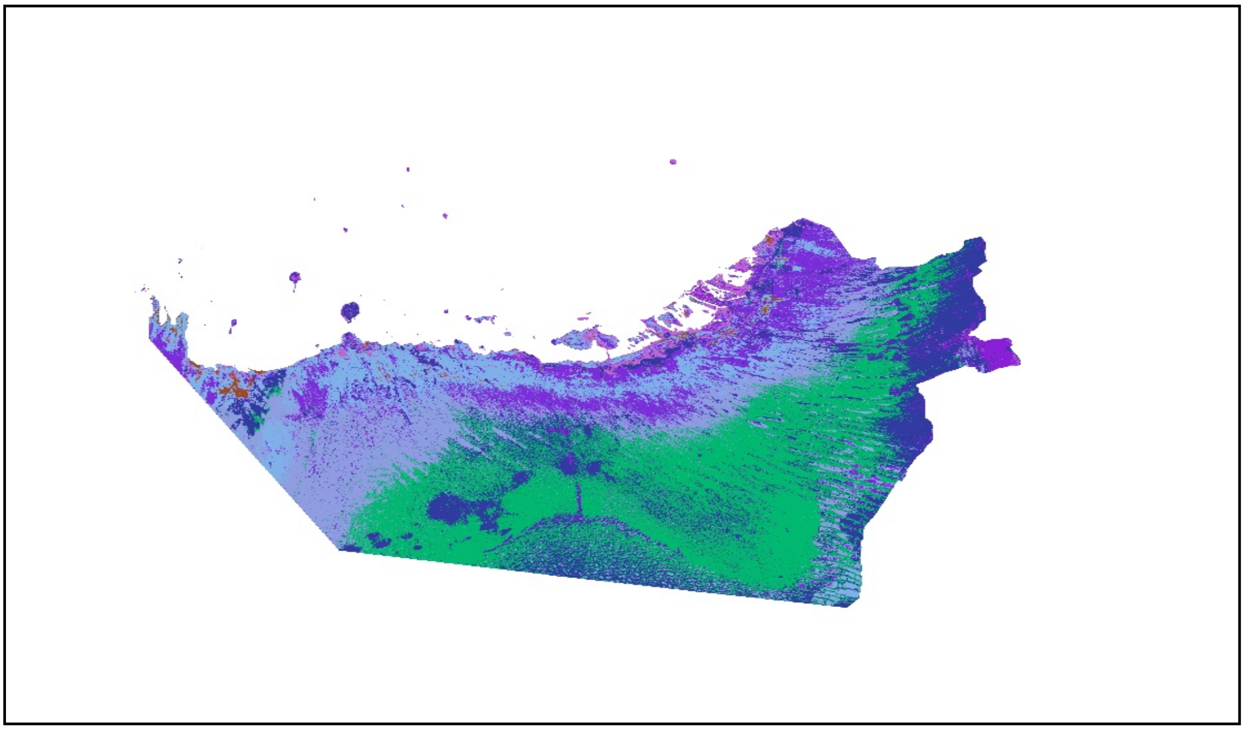

Figure 19: Land Use Land Cover Classes (40) Derived from the Composite Image Using Unsupervised Classification.

4.1.3 Alfalfa Crop Area 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 20).

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%.

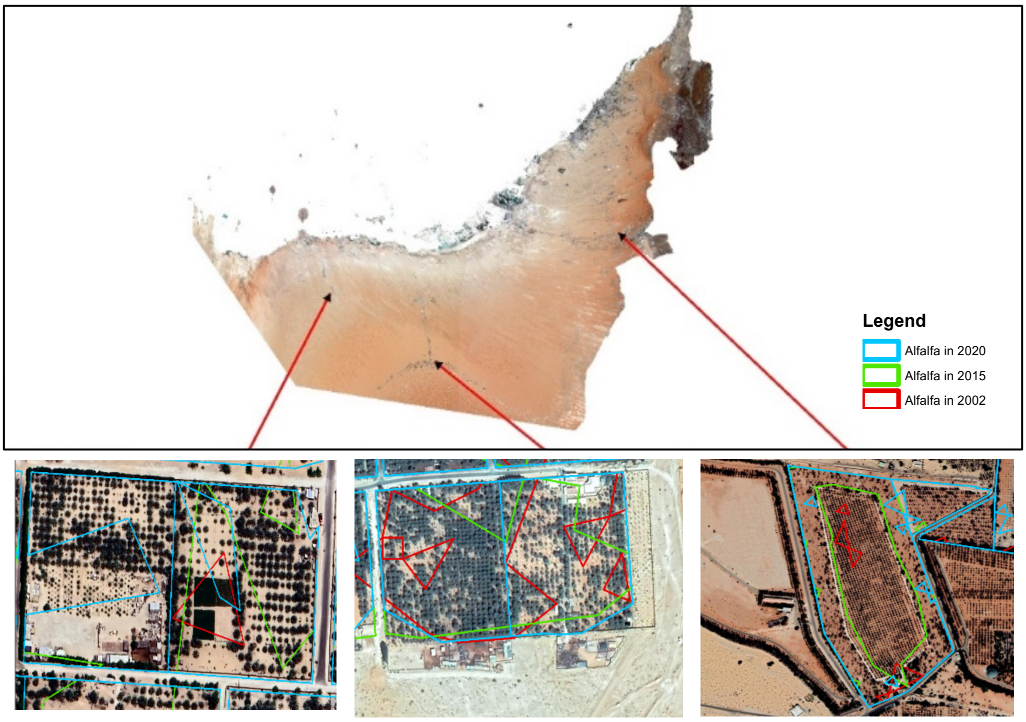

Figure 20: Alfalfa Crop Cultivated Areas in 2002, 2015, and 2020 in Different Farms in the Emirate of Abu Dhabi.

4.1.4 Accuracy Assessment

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 7).

Table 7: Accuracy Assessment of Alfalfa Crop Land in the Four Farms.

Farm Number	**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%**

4.2 Groundwater Estimation

4.2.1 Groundwater Level Calculation

The other objective of this research is to measure the level of groundwater in the wells of the Abu Dhabi Emirate, focusing particularly on those located inside or close to the croplands. To achieve this objective, the field data of the groundwater levels of 53 wells in the study area were used to measure the groundwater level. As described in the methodology, the groundwater level was calculated as the difference between the elevation from bare ground and the elevation from water-saturated ground.

Wells recordings analysis showed changes which occurred in groundwater level between 2005 and 2017. During this period, there was a slight reduction of 1.6 meters in the Mean Groundwater Level (MGWL) in the Emirate of Abu Dhabi. Based on the data regarding the studied wells, the decrease was approximately equal to 4.2%. According to the study, 41 of these wells - which were considered to constitute the vast majority of the total number of wells linked to the data - significantly contributed to this reduction (Figure 21). Most groundwater loss during that period was caused by Al Khatim well, which lost more than 38 meters in 12 years.

The results also showed an increase in 12 wells out of 53. These wells constitute only 22.6% of the total number of the studied wells, with the majority of them existing in non-agricultural areas. The well located in Jebel Hafeet is considered as the well which witnessed the biggest rise in groundwater level during the study period. This had been substantiated in an earlier study about groundwater level changes in Al Ain (Murad et al., 2013). While there are some areas in Al-Ain, especially near Jebel Hafeet, witnessing a noticeable rise in the groundwater level, this is not the case in the other parts of the country.

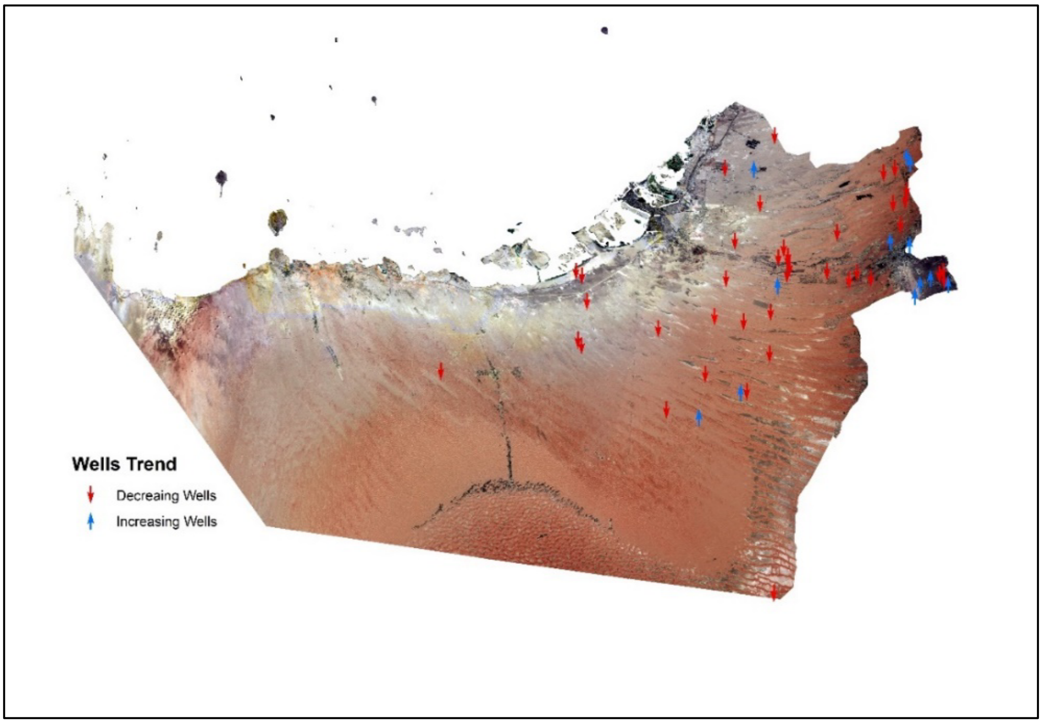

Figure 21: Well’s Groundwater Level Trend from 2005 to 2017.

4.2.2 Groundwater Level in Farm Wells

Calculating MGWL in all wells in the study area might not reflect a realistic picture of the relationship between cropland and groundwater. Therefore, the computation was subsequently restricted to wells located in agricultural areas. The MGWL of wells located near (~0.5 km) or inside a farm was calculated separately from other wells. There are 21 wells located inside or near farms in the Emirate of Abu Dhabi as noted previously in Table 6. It was noticed that there was a decrease in MGWL of all these 21 wells but with different scales. For example, while the Ajban well witnessed a small decrease estimated at 0.06 meter, in the Masakin wells the decrease exceeded 3 meters. Figure 22 shows some wells randomly selected in farm and mountain areas. It was clear that the groundwater in farm areas was depleting heavily, while the opposite was the case in mountainous areas.

Table 8 below shows that there is a big difference in MGWL between the wells near or inside the farms and the other wells. While the MGWL of these 21 wells had been

41.4 meters high, the descent became very steep (87.7%), reaching 5.11 meters, with the average MGWL of all wells becoming 29.5 meters. This significant difference between the two cases adequately explains the significant impact of the agriculture sector on groundwater storage.

Table 8: Average Groundwater Level (GWL) in the Wells Located in the Farms Area Compared to All Other Wells.

Year	2005	2017	Change (%)
Average GWL in all wells	30.8	29.5	Decrease (4.2)
Average GWL in the wells located inside or near the farms	41.4	5.11	Decrease (87.7)

In conclusion, the integration of the two factors (Alfalfa and groundwater) clearly showed a negative correlation between the increase in the area planted with alfalfa in farms and the decrease in groundwater levels in the wells located in the agricultural area during the same period (Figure 23). Obviously, the relationship between these two factors indicates that the more the area cropped with alfalfa, the less is groundwater level. However, other irrigated crops such as rhodes grass and date palm trees may contributed to observed decrease groundwater level as the overall accuracy alfalfa area delineation is approximately 80%. Al Tenaiji et al. (2019) studied the annual water consumption of 15 cultivated crops in Abu Dhabi. They found out that the annual average water consumption of alfalfa (~30,000 m^3/ha) is more than that of rhodes (~10,000 m^3/ha) and date palm (~20,000 m^3/ha).

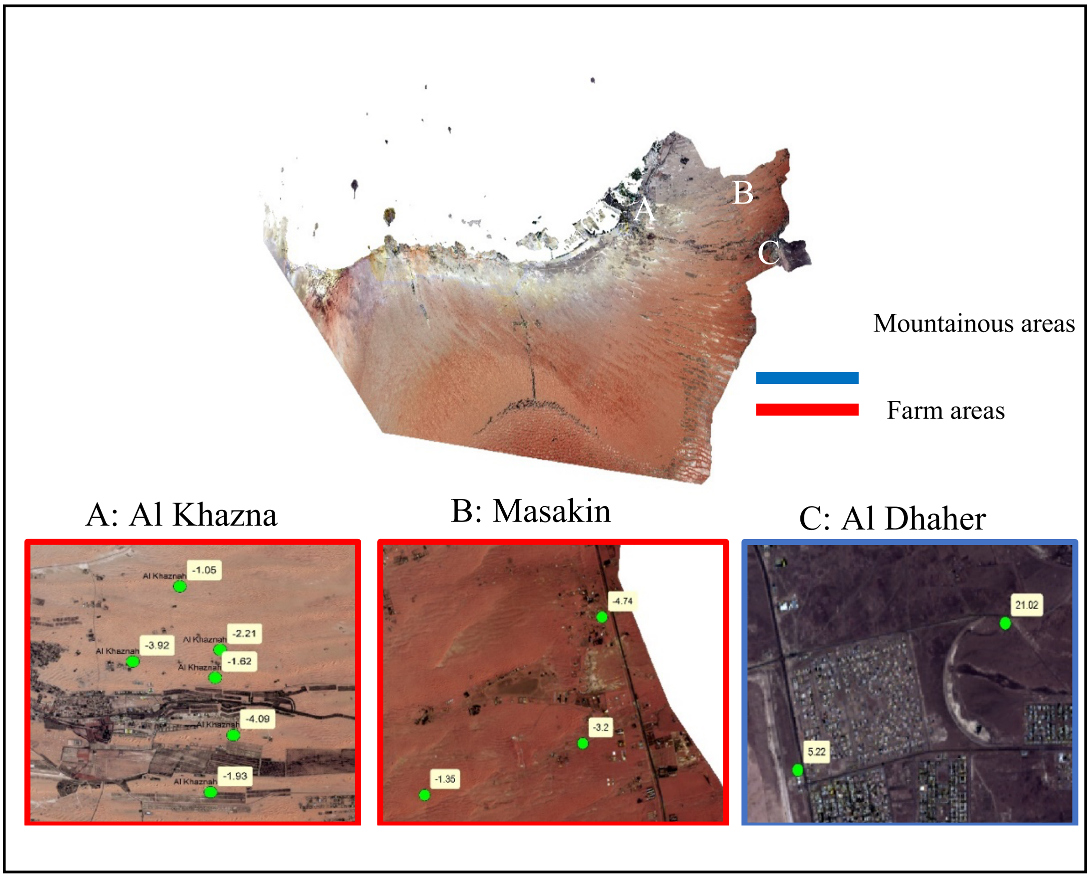

Figure 22: Groundwater Level (GWL) Changes in Wells Located in farm Areas and Mountainous Areas.

4.2.3 Groundwater Recharge

The rate of recharge must be taken into consideration in evaluating the impact of agricultural practices on groundwater storage. There are a number of other factors related to groundwater recharge. However, this study did not investigate the entire groundwater recharge process. It only looked into the main source of groundwater recharge - specifically precipitation. To assess whether rainfall had any impact on the decrease of GWL, annual rainfall totals during the study period had been looked into and compared with each other. Figure 24 shows the total annual precipitation across the UAE as estimated by the rain gauge networks. The yearly average of rainfall was very low, bearing in mind that in the UAE the rainfall is not evenly distributed in the various seasons and that rain in the UAE does not fall in most months of the year. Figure 24 shows the highest monthly average for each year, and it is used as a standard. Statistical results showed almost the same pattern. Generally, between 2005 and 2015, the amount of rainfall was almost stable. Subsequently, the rainfall in the following years (the study period) decreased.

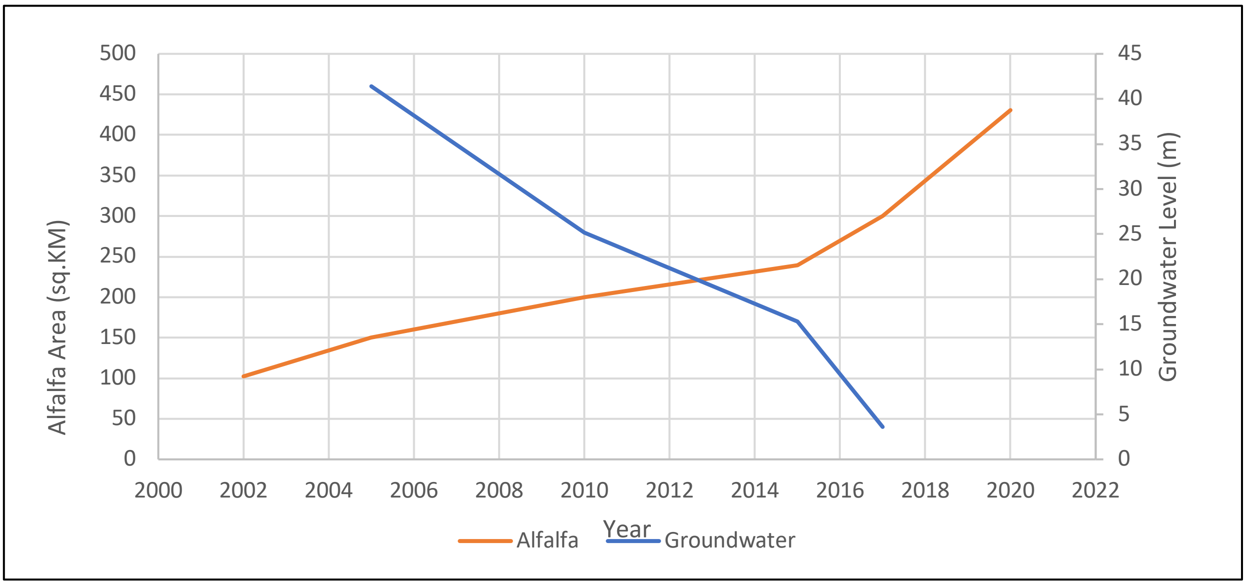

Figure 23: Relationship Between Groundwater Level and Alfalfa Cultivated Area.

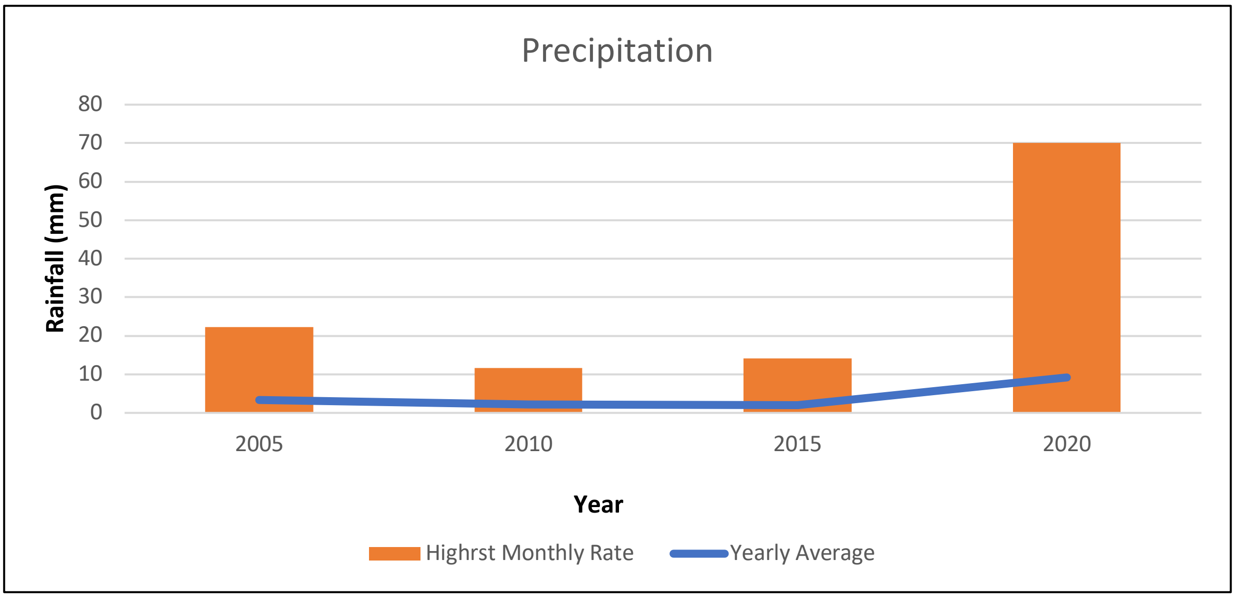

Figure 24: Highest Monthly Rate and Yearly Average for Precipitation in the Study Area Between 2005 to 2020.

Chapter 5: Discussion

The results presented in this research regarding annual groundwater measurements made it possible to obtain a clear picture on groundwater trend and link it to human activities. 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 as well as the investigation of the effect of agriculture on the depletion of groundwater, with a view to preserving this main source of fresh water in the UAE.

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. Therefore, three different years of groundwater measurements (2005, 2010, and 2017) were chosen in order to see whether groundwater levels were increasing or decreasing. NWEC provided annual data from 2005 to 2017. Three years were chosen in both datasets to maintain the same pattern, with the assumption that there would be no significant difference within a limited number of years.

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 (ICBA, 2020). 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 (Bauder, 2020). This study has proven a significant decrease in groundwater levels in areas where the alfalfa is cultivated. According to the study, groundwater levels had increased in wells located in areas far away from farms.

This study showed beyond any doubt that agriculture practices directly affected groundwater reserves. 21 wells out of 53 are located in farm areas. All of them witnessed a decrease in groundwater level. This calculation was carried out by applying the equation used by Hyun-Joo et al. (2010). It shows a big difference between MGWL of the wells located in the farms and other wells. MGWL in the wells located in farms areas decreased to 5.11 meters. Twelve years ago, the groundwater level was seven times the current value. It should be noted that the decrease in the groundwater level occurred even though the amounts of rainfall did not decrease.

Another evidence of the excessive withdrawal of groundwater in agricultural areas can be demonstrated by monitoring land deformation as El Kamali et al. (2022) did when they used Synthetic Aperture Radar (SAR) interferometry to study the land subsistence of the Ramah area. The study revealed that the height of Remah area decreased between 2013 and 2019. Actually, the districts lying between Al Ain and Abu Dhabi, including areas like Remah, Al Sad, Abo Samra and Al Khaznah, are home to more than 50% of the agricultural activities in the Emirate of Abu Dhabi, with all of relying on groundwater resources. The continued extraction of groundwater in these areas has led to water table drawdown.

It was always thought that groundwater was an infinite source but the results of this study showed how groundwater had become threatened with depletion and that other sources of water should be sought. Her Excellency Dr. Sheikha Salem Al Dhaheri, Secretary-General of Environment Agency – Abu Dhabi (EAD) said: “Now groundwater is considered a non-renewable resource in Abu Dhabi, and its natural recharge rate is extremely limited” (EAD, 2020). The problem is aggravated by the increasing rates of the ongoing pumping of groundwater in the emirate as a result of the expansion of the agricultural sector and its need for water.

Chapter 6: Conclusion

This study investigated the impact of planting alfalfa on groundwater levels in the last two decades using multiple GIS tools and remotely sensed data. It has been concluded that identifying and understanding the human activity that causes groundwater depletion is crucial for preserving water sources needed for food security. The study focused on the impact of farming practices on water resources, with alfalfa being used as an indicator of cropland expansion. The crop, which is widely cultivated in the UAE, has high water consumption. The findings of this study are useful not only for monitoring cultivated areas, but also for providing a clear picture of the rate of groundwater level decrease, particularly in wells located in farm areas.

The research answered all the questions raised in the introduction. RS and GIS techniques proved to be effective in mapping areas cropped with alfalfa, achieving an accuracy of 81% when a combination of multiple vegetation indices (VIs) were used. The analysis revealed that the area cultivated with alfalfa expanded significantly during the study period. The expansion of the agricultural areas led to a decline in ground water levels (GWL). The reduction in GWL was greater in the agricultural regions compared to other regions, which reflects the impact of human activities and particularly agricultural practices on groundwater storage.

This study has some limitations that can be addressed by expanding the size of the data as well as improving the method of result validation. The estimation of groundwater level was based on 53 wells only. Less than half of these are located in the targeted farm areas. With the presence of thousands of wells in the study area, the data on this limited number of wells (53) may be deceptive and might not give a comprehensive picture of the situation of groundwater in the Emirate of Abu Dhabi. Also, to obtain additional evidence of the research results, Synthetic Aperture Radar (SAR) can be used to monitor the depletion of groundwater over a wide area. Recently, this method was applied by many researchers to study land surface deformation and use it as an indicator of excessive withdrawal of groundwater. SAR has become useful in groundwater studies after it had been proven that groundwater pumping caused the land surface to uplift or subside. This type of data can fill some gaps in the data acquired through field visits, saving a lot of time and effort. Moreover, the recharging process should be investigated in more depth to support the study of the factors causing the depletion of groundwater.

The improvement process may also include alfalfa maps. 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. Moreover, further research could investigate the detailed relationship between groundwater and the alfalfa crop. In other words, calculating the amount of groundwater lost by the wells located inside farms at every meter in which the areas planted with alfalfa are extended will add great value to the research. There are always many ways to develop and improve.

In general, this research shows that there is a serious threat to the world's water resources as a result of agricultural practices—a threat that needs concerted efforts to confront and limit its consequences. Individuals, specialists, and the government are all responsible in this regards. Nevertheless, dependence on groundwater in the agricultural sector should decrease gradually by looking for alternative sources of water that do not affect the quality of crops. This, of course, requires a lot of effort and research.

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.

Recycled water, also known as treated sewage effluent (TSE), can be used for irrigating crops. TSE is a valuable source of water that is currently underutilized in the UAE. By using TSE for irrigation, the UAE can reduce its reliance on freshwater resources and alleviate the pressure on its limited water supply. The UAE government can invest in infrastructure and technology to treat and distribute TSE to farmers. Additionally, farmers can be incentivized to use TSE by offering them lower tariffs for using recycled water.

Another solution for the UAE's alfalfa shortage is to support research and development of drought-resistant alfalfa variants. Scientists can use genetic engineering and traditional breeding techniques to develop alfalfa varieties that are more tolerant to drought, heat, and salinity. Such varieties would require less water to grow and be better suited to the UAE's arid climate. The UAE government can collaborate with international research institutions and private companies to fund and support research and development efforts.

One of the practical steps to be implemented is to develop a national program to force farmers in all agricultural areas to use modern irrigation methods instead of the old ones which lead to water waste. Drip irrigation is an example of a modern irrigation system. It is a good method for water conservation as it allows water to drip slowly to the roots of the plants. Moreover, the government must ensure that all wells inside the farms are officially registered in the municipalities. For this purpose, it should create special files for each well to monitor groundwater levels on a daily basis with a view to controlling the quantities of withdrawn groundwater. In 2018, the Environment Agency-Abu Dhabi (EAD) completed the first inventory of groundwater wells in Abu Dhabi. In this inventory, over 100,000 groundwater wells were counted, classified, registered, and documented. Additionally, spreading awareness about groundwater sustainability among the public is an essential step to mitigate the decline in groundwater levels.

Groundwater sources are not only threatened by agriculture, but also by other factors such as climate change and global warming affect groundwater. There are many studies linking groundwater with climate change, including studies on sea level rise (SLR), which may lead to saltwater intrusion into coastal aquifers. Moreover, higher temperatures increase evaporation demand, limiting the amount of water needed to replenish groundwater. To sum up, groundwater is affected by natural and human factors. The focus of this research on the effect of agriculture does not mean that it is the only reason. However, this factor can be controlled by following the recommendations presented in this research.

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This research has been conducted with the objective of studying the impact of the alfalfa-cultivated areas on groundwater. It is based on calculating the groundwater level (GWL) in wells located near or inside a number of farms, with the end goal of generating a map that shows the areas planted with alfalfa in the same area. The study assessed in a detailed manner, the expansion of alfalfa-cultivated areas in the Emirate of Abu Dhabi using different vegetation indices (VIs). Moreover, GWL was calculated using two parameters: the height above mean sea level and the depth of groundwater in the wells. The aim was to study the effect of the cultivation alfalfa crop on groundwater storage.

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