Multitemporal Remote Sensing for Invasive Prosopis Juliflora Plants Mapping and Monitoring: Sharjah, UAE

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Abstract: Prosopis juliflora is one of the 'world's most invasive trees that negatively affects native species and their ecosystems. The main obstacle for controlling Prosopis juliflora pervasion is to accurately map location as well as the distribution pattern. Locating Prosopis juliflora is a strategic priority of countries to preserve the invaded local environment. Recent advances in remote sensing, geographic information system (GIS), and Machine Learning (ML) techniques provide valuable tools for producing tree distribution maps. In this research, a supervised classification method with Support Vector Machine (SVM) supported by GIS statistical analysis was developed to map Prosopis juliflora and their pattern analysis in Sharjah, one of the major cities in the United Arab. More than 5000-pixel labels taken from Landsat-7 and Landsat-8 imagery were used to train object-based Support Vector Machine to map Prosopis juliflora. The suggested algorithm resulted in 75% accuracy compared to ground truth samples. Furthermore, multi-temporal detection showed 'that's spatial clustering pattern of the trees is changing and increasing over time. The approach adopted in this study can be applied to any other location globally.

1 INTRODUCTION

Invasive species are organisms that are non-native and have been introduced due to their environmental and economic benefits, such as providing habitat for native plants and promote biodiversity due to global biotic environmental change (Essl et al., 2020). Nevertheless, the introduction of new species is not always successful. New species can establish themselves and dramatically spread in their new environment and become invasive (Jeschke et al., 2014). These invasive 'aliens' often reflect negative impacts, including reduction of grazing areas, reduction of crop yield, and risk of threat to biodiversity (Mwangi & Swallow, 2005).

An ideal example of invasive species is Prosopis juliflora, which is considered one of the world's worst woody invasive plants (Berhanu & Tesfaye, 2006). Prosopis juliflora (also known as mesquite) is a deciduous shrub with spreading cylindrical branches that can grow from 3-12 meters in height. The trunk of the tree is usually around 1.2 in diameter with compound leaves. Florets as usual, greenish-white, turning light yellow (Burkart, 1976). Prosopis juliflora is an evergreen tree native to the western hemisphere, including rangelands in South America, Central America, and the Caribbean (López-Franco et al., 2013), and have been introduced into several arid and semi-arid countries of Africa, Asia, and Australia over the last century due to their quality wood for fuel, timber and seeds for human and animal food. Despite their advantages, these plants are also highly invasive in new habitats creating dense thorny thickets (FAO, 2006).

The capability to grow under-stressed, drought and high-temperature conditions have been made them the most multipurpose tree in arid and semi-arid regions (George et al., 2017). Mesquite was also has been introduced to United Arab Emirates (UAE) in the 1970s from Central America (Environment Agency, 2020) on a large scale in the artificial forests due to its faster growth, soil-binding capacity, and desertification control. However, this invasive shrub, locally know as (Ghweif), has aggressively invaded the UAE environment causing severe damage. It prevents other species from growing in their vicinity, causing twofold-allelopathy. Moreover, there is a noticeable accumulation of litters underneath the Prosopis juliflora, compared with native species such as Prosopis cineraria canopies, With a significant negative influence on seed germination and growth of understory species (El-Keblawy & Al-Rawai, 2007).

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The aggressive behavior of Prosopis juliflora has prompted researchers to establish scientific efforts utilizing remote sensing data and Geographic Information System (GIS). Remote sensing data can cover more extensive areas than single plot studies (Joshi et al., 2016). Furthermore, remote sensing offers significant opportunities for providing timely information on the invasion of non-native species into native habitats.

Multispectral satellite images aid analyzing the spectral response of the vegetation. The analysis pattern of high and low spectral radiances introduced one of the most effective spectral measurement for vegetation known as the normalized difference vegetation index (NDVI), which have been widely and successfully used to provide surrogate indicators of canopy greenness (Melesse et al., 2007), in addition to ecologically map and classify vegetation (Mehner et al., 2004).

Remote sensing data and spectral analysis could be beneficial to map and detect Prosopis juliflora. Several attempts to map Prosopis juliflora in Africa are well acknowledged. For example, Normalized Difference Vegetation Index (NDVI) from multispectral, multi-temporal satellite imagery, combined supervised classification methods such as maximum likelihood classification (Rembold et al., 2015) and random forest classifier is used to quantify Prosopis juliflora during dry seasons in Somaliland (Meroni et al., 2017). Another study conducted in Ethiopia utilized spectral indices such as NDVI and Enhanced Vegetation Index (EVI) in addition to topo-climatic variables as input to correlative models to map both the current and potential distribution of P. juliflora (Wakie et al., 2014). Other spectral indices such as Normalized Difference Infrared Index (NDII) is used to retrieve the mesquite tree distribution area in Sudan through measuring foliar water content, where native plants have more water-stressed growing than the mesquite (Hoshino et al., 2011). In Kenya, a Land Use Land Cover (LULC) classification using random forest supervised classification was used to detect Prosopis juliflora, on 10–15 years study. The study showed that Prosopis has not stopped or slowed down (Mbaabu et al., 2019). In Asia, similar studies using remote sensing data were conducted as well. In India NDVI and Support Vector Machine (SVM) supervised classifications were used to map Prosopis juliflora (Vidhya et al., 2017). NDVI and NDII were also used to map Prosopis juliflora in Tirunelveli and Palayamkottai in India (Ragavan et al., 2015). A study in the United Arab Emirates (UAE) used onscreen digitizing of multi-temporal aerial images with the aid of statistical analysis to estimate percent cover, patch density, patch size, and mean patch shape index. The study helped to understand the spread of Prosopis juliflora in two areas in UAE (Filayah and Khut), where it showed a dramatic increase during 19 years of time (Issa, S. M. et al., 2008).

This study focuses on utilizing time serires analysis using Landsat-8 images with support vector machiene classification and NDVI to monitor Prosopis juliflora in Sharjah City, UAE, to obtain numerical analysis for the covered area every decade from 2000-2020.

2 STUDY AREA

The UAE is situated in the Middle East, and shares coastline with Gulf of Oman in the east and the Arabian Gulf in west, and boarders with Oman and Saudi Arabia (Figure 1). The UAE is located in an arid tropical region with an average annual rainfall of 80-140 mm (Sherif et al., 2014). This study consentrate on Sharjah city, one of the largest cities in the UAE with an area of 2590 km^2, located at 25.3463° N, 55.4209° E. The annual rainfall of Sharjah city is approximately 106.9 mm. Large parts of the emirate consists of desert areas, profound soil shaped in eolian sands, in addition to agriculture areas, and expansions of acacia woodlands. (Al-Ruzouq et al., 2019).

Figure 1: Study Area Sharjah City – UAE.

3 MATERIALS AND SATELLITE DATA

Ten years of satellite imagery were collected from Landsat 7 and Landsat 8 during the year 2010 to 2020 for yearly analysis. Furthermore, one image was collected in 2000 for decade analysis during 2000, 2010, and 2020 (Table 1). The images were collected during the dry season in UAE in August as the reflection of P. Juliflora appears brighter than other vegetation. Two scenes were required to cover the full Sharjah city. In addition, a high-resolution Khalifa-Sat image was acquired as well for visual inspecting areas of vegetation.

Table 1: Satellite Imagery Thematic Data Source.

Satellite	Spatial Resolution (meter)	Spectral Resolution (micro meter)	Data Acquisition Year
LANDSAT 7	30 m multi-spectral 60 m Thermal	- Band 1 Visible Blue (0.45 - 0.52 µm) - Band 2 Visible (0.52 - 0.60 µm) - Band 3 Visible (0.63 - 0.69 µm) - Band 4 Near-Infrared (0.77 - 0.90 µm) - Band 5 Short-wave Infrared (1.55 - 1.75 µm) - Band 6 Thermal (10.40 - 12.50 µm)	2000 2010 2011 2012
LANDSAT 8	30 m multi-spectral 15 m Panchromatic	- Band 1 Coastal aerosol (0.43-0.4530 µm) - Band 2 Visible Blue (0.45-0.5130 µm) - Band 3 Visible Green (0.53-0.5930 µm) - Band 4 Visible Red (0.64-0.6730 µm) - Band 5 Near Infrared (NIR) (0.85-0.8830 µm) - Band 6 SWIR (11.57-1.6530 µm) - Band 7 SWIR (22.11-2.2930 µm) - Band 8 Panchromatic (0.50-0.6815) - Band 9 Cirrus (1.36-1.3830 µm)) - Band 10 Thermal Infrared (110.6-11.19100 µm) - Band 11 Thermal Infrared (211.50-12.51100 µm)	2013 2014 2015 2016 2017 2018 2019 2020
Khalifa-SAT	0.7 m Panchromatic 2.98 m multi-spectral	- Panchromatic (0. 55-0.9 µm) - MS1: Visible Blue (0.450 – 0.520 µm) - MS2: Visible Green (0.520 – 0.590 µm) - MS3: Visible Red (0.630 – 0.690 µm) - MS4: Near Infrared (NIR) (0.77 - 0.889 µm)	2019

4 METHODOLOGY

The developed methodology to map P.Juliflora trees in Sharjah is represented in (Figure 2) throughout three stages. First, historical satellite imagery data is required to develop the thematic layers of the study area. The first stage is pre-processing to prepare the data for major processing in terms of band stacking and area coverage. Then data analysis using NDVI and Support Vector MAchiene. Finally mapping using ArcGIS software to map total Prosopis juliflora areas

4.1 Pre-processing

With LANDSAT-7, the Scan Line Corrector (SLC) failed On May 31, 2003. The sensor has acquired and delivered data with lined gap strips on each band (Loveland & Irons, 2016). Therefore, nearest neighbor (NN) resampling was used to fill the gap in each band for images from 2010-2012 (Figure 3).

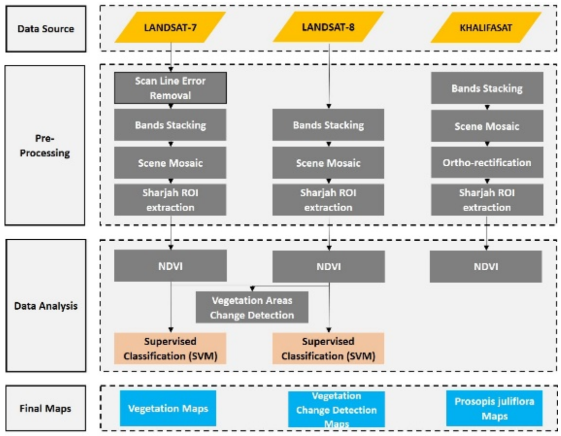

Figure 2: Proposed Methodology.

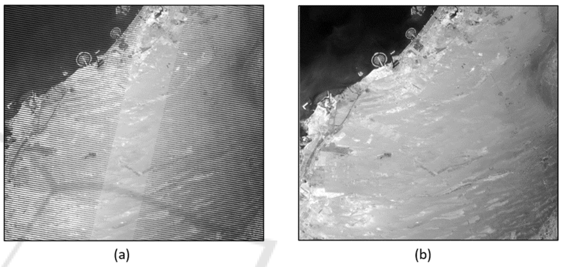

Figure 3: LandSat-7 SLC Using Nearest Neighbor (NN) Resampling.

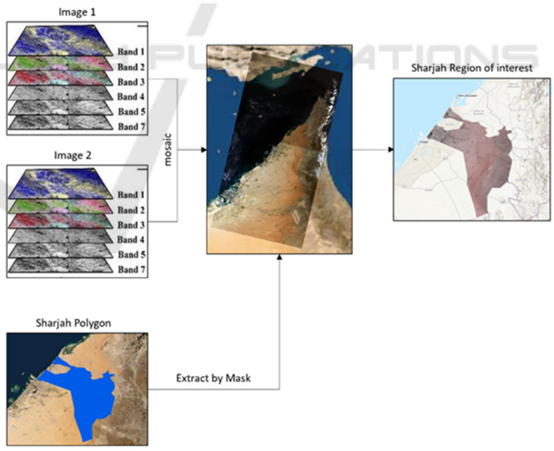

Figure 4: Common Pre-Processing Steps.

For each output point, the closest input detector sample must be identified and selected as the output image value.

Once Scan lines were corrected, both LANDSAT 7 and LANDSAT 8 were processed with common steps, including band stacking, scene mosaicking, and extracting the study area (Figure 4). These steps are necessary for time series analysis, using WGS 84 zone 40N UTM coordinate system, where areas in meters can be easily calculated to fulfill the need of this study. A further step is needed for KhalifaSAT, which includes geometric correction using 8 well-distributed ground control points (GCP) and projective transformation.

4.1 Data Analysis Processing

In the third stage, all the thematic layers were processed to map vegetation and Prosopis juliflora. Two approaches were used, Normalized Difference Vegetation Index (NDVI) and supervised classification using Support Vector Machine (SVM).

4.1.1 Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) synthesizes the information from two spectral channels: red and near-infrared. Vegetation tends to have higher reflectance in the red band and lower reflectance in the near-infrared band. Hence, this index can be repressed as simple mathematical expressions represented in equation (1) that combines spectral measurements used to identify the presence of vegetation in remotely sensed images (Leprieur et al., 1996)(Kefalas et al., 2018).

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

NDVI was measured for three years (2000, 2010 and 2020), in addition to a yearly measurement from 2010-2020. Further assessment of vegetation analysis was conducted using change detection over two periods from 2000-2010 and 2010-2020. Change detection analysis is conducted through equation (2).

$$CD = Image1 - Image\ 2 \quad (2)$$

4.1.2 Object-based-Support Vector Machine Classification

The Support Vector Machine classifier is promising in terms of vegetation classification as it can result in up to 80% overall accuracy assessment with Kappa 0.8 comparing to Maximum Likelihood Classification and Spectral Angular Mapper (Braun et al., 2010). P. Juliflora training samples were taken from the area behind Sharjah airport (ROI1) as shown in figure 5. The area is located within latitude and longitude (25° 20.61'N, 55° 31.64'E), with a total land area around 21.19 km^2, most of the land is vegetated with P. juliflora, with medium canopy sizes (5–10 m diameters) and different densities distribution[10], (Figure 6).

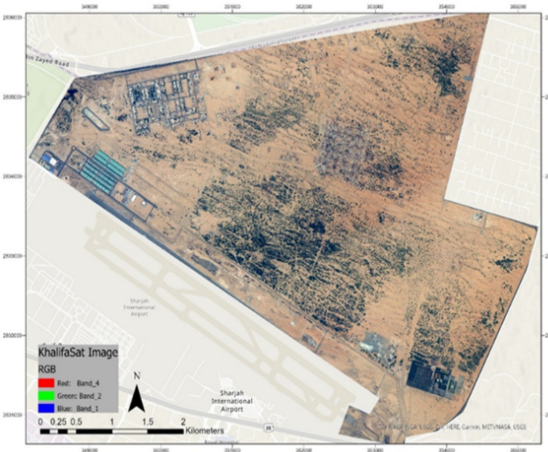

Figure 5: KhalifaSat image of ROI1 behind Sharjah Airport.

Figure 6: P. Juliflora as seen from satellite nadir view taken from Google Earth Image from ROI1.

Two classes were identified in the training samples. The first one is P. juliflora taken from ROI1. Likewise other vegetation types, P. juliflora has a high reflectance from NIR band and low reflectance in the red band. However, this tree has distinguished spectral response where it has a minor peak and green band as well. More than 1000 pixel samples were taken from each year as training sample (Table 2). The second class is all other vegetation types taken from random distributed vegetated areas.

Table 2: Training samples were taken for SVM classifier.

Year	Total number of Pixels	Total Training Area (Km^2)
2000	3,598	3.25
2010	1,307	1.18
2020	5,386	4.86

4 RESULTS AND DISSCUSSION

4.1 Vegetation Analysis of Sharjah City

The multi-temporal analysis of the NDVI during (2000,2010,2020) for the vegetated areas in Sharjah city showed that the vegetation density increased during the past two decades. The highest density appeared in 2020 with 67.18km^{2,} followed by the year 2010 with a total area of 56.55 km^2, with increase of 0.188%. Finally, the year 2000 showed the least total vegetated area with 42.96 km^2 (Figure 7).

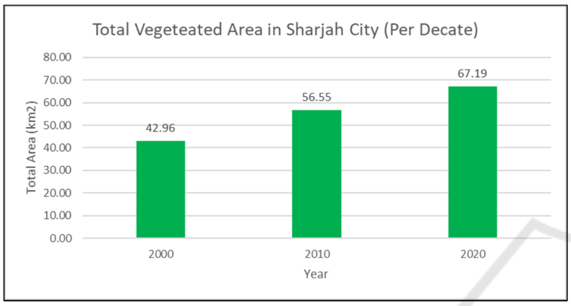

Figure 7: Total Vegetated Areas in Sharjah City in (a) 2000, (b) 2010, (c)2020.

The vegetation index during the period 2010-2020 showed that variations in vegetated areas per year were small as they did not exceed 0.25% of net change. The lowest vegetated areas were found to be in 2013 with 45.14 km^2 (Figure 8). The vegetation areas were mapped in (Figure 9)

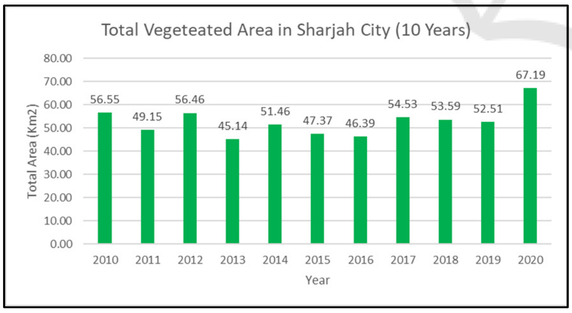

Figure 8: Bar chart of 10 Years Of Total Vegetation In Sharjah City From 2010-2020.

Vegetation cover change detection was implemented over two periods, from 2000-2010, and 2010-2020. In 2000-2010, vegetation cover increased by a total area of 32.18 km^2.The vegetation increase concentrated in city center area, university city area, and Sharjah-Ajman border farms area. In the same period, vegetation decreased by 30.43 km^2 , the decrease mostly found in the farmed eastern part of

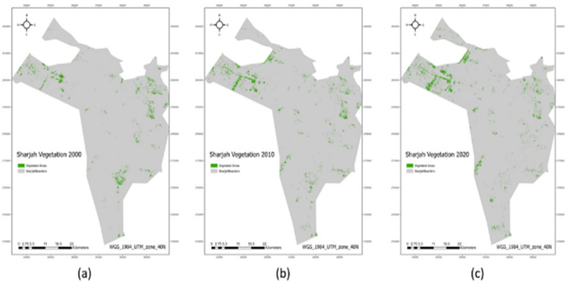

Figure 9: Vegetated areas maps in Sharjah City in (a) 2000, (b) 2010, (c)2020.

the city. In 2010-2020, vegetation cover increased dramatically, almost double by the total area of 75.28 km$^{2.}$ The vegetation increase distributed throughout the city and concentrated in the city center area, university city area, and Sharjah-Ajman border farms area, in addition to the farmed eastern part of the city. In the same period, vegetation decreased sharply by total area of 11.74km^2. The decrease is mostly found in farms in the eastern and southern parts of the city. (Figure 10) shows the maps of change detection in both periods.

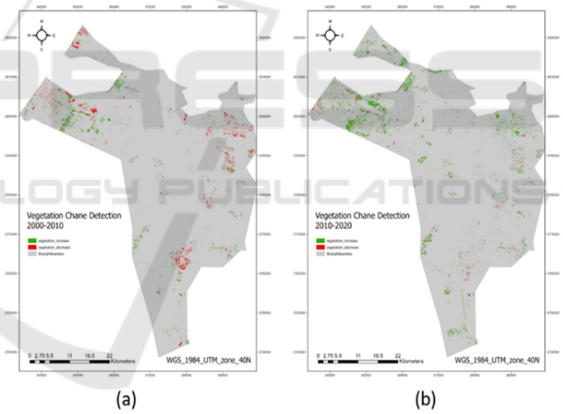

Figure 10: Change detection in Sharjah city in period (a) 2000-2010, (b) 2010-2020.

4.2 Vegetation Analysis of Mapped P. Juliflora

The multi-temporal analysis of the Support Vector Machine (2000,2010,2020) for the vegetated areas of P. Juliflora trees in Sharjah (Figure 11) showed that the highest density appeared in 2020 with 14.13 km^2 followed by the year 2000 with a total area of 11.99 km^2. Finally, the year 2010 showed the least total vegetated area with 9.26km^2 as shown in (Figure 12). The increase between 2010-2020 in the last decade was 0.525%.

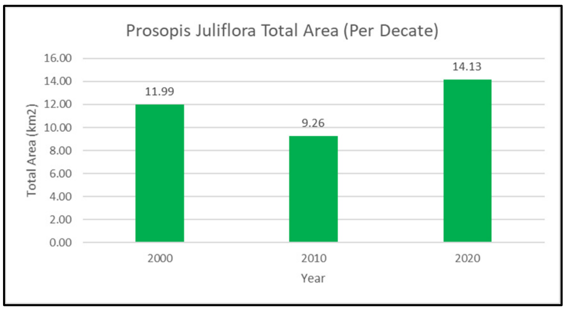

Figure 11: Total P. Juliflora Area In Sharjah City.

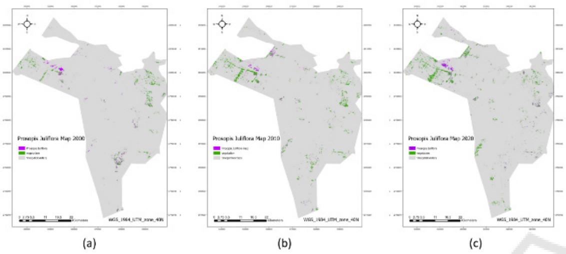

Figure 12: Total P. Juliflora Area in Sharjah City in (a) 2000, (b) 2010, (c)2020.

4.3 Vegetation Accuracy Analysis of Mapped P. Juliflora

Eight sites have been selected (Table 3) for visual accuracy assessment from high-resolution google earth (Figure 13). These sites are taken from the resulted P. Juliflora classification results (Figure 14).

Table 3: Inspection sites ID and their location.

ID	Year	location	correctly mapped
2020_1	2020	55.5587161°E 25.3250445°N	yes
2020_2	2020	55.5713399°E 25.4544956°N	yes
2020_3	2020	55.5570937°E 25.4715355°N	yes
2020_4	2020	55.5529439°E 25.3038846°N	no
2020_5	2020	55.9371005°E 25.1879427°N	no
2020_6	2020	55.4891707°E 25.2709255°N	yes
2020_7	2020	55.5530813°E 25.2568040°N	Yes
2020_8	2020	55.5876650°E 25.4609975°N	yes

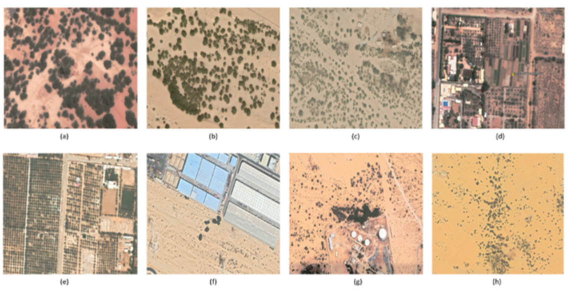

Figure 13: Inspection Sites Visually Inspected (a) 2020_1, (b) 2020_2, (c) 2020_3, (d) 2020_4, (e) 2020_5, (f) 2020_6, (g) 2020_7, (h) 2020_8.

The visual inspection showed that all vegetation in the inspection sites identified as P. Juliflora, except for site 2000_4 and 2000_5. The inspection sites also suggest that P. Juliflora density is higher at locations of lower altitude open fields sand-based areas. The visual inspection also showed that P. Juliflora showed minimum existence nearby other vegetation communities.

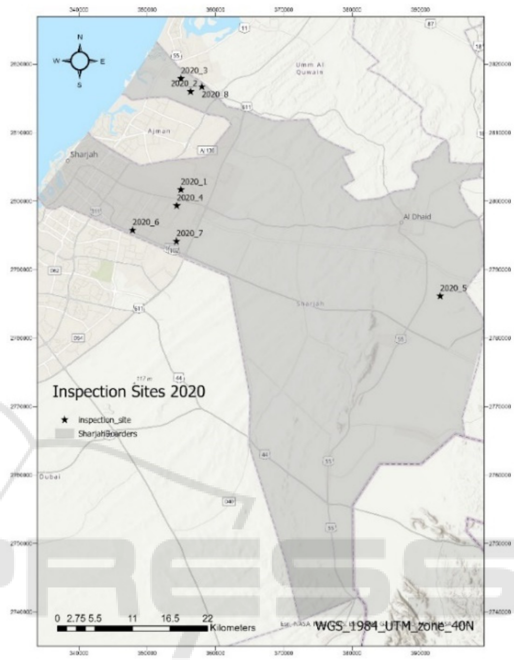

Figure 14: Map of Inspection Sites.

5 CONCLUSIONS

Identifying locations of Prosopis Juliflora is a significant environmental and ecological initiative for any arid region country. In this study, an algorithm that combines remote sensing data and GIS along with ML was developed to locate areas of Prosopis Juliflora. Eleven thematic layers from satellite imagery were collected from Landsat 7 and Landsat 8. Two approached were used. The first one is using vegetation index NDVI, and the second one is a combination of NDVI and supervised classification.

The NDVI maps all types of vegetation in Sharjah city using Red and NIR bands. Vegetation in Sharjah city showed an increment in the past two decades where it increased from 42.96 km^2 in 2000 to 67.19 km^2 in 2020. The second approach is using a Support Vector Machine (SVM) over vegetated areas from NDVI. Over 1000 pixels samples were taken to train the supervised classification with two classes:

P.Juliflora and other vegetation. Total area increased up to 14.13 km^2 in 2020 after it was 9.26 km^2 only in 2010. The vegetation analysis showed that P. Juliflora increase dramaticlly with 0.525% in the last decade between 2010 and 2020 comparing with other vegetation which increased by 0.1888% only. The visual inspection suggest that P. Juliflora density is higher at locations of lower altitude open fields sand-based areas. The visual inspection also showed that P. Juliflora showed minimum existence nearby other vegetation communities. Finally, the developed technique can be generalized and utilized over new arid-region locations.

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