COMPARATIVE ANALYSIS OF SALINITY INDICES FOR MAPPING SABKHA SURFACES IN THE UNITED ARAB EMIRATES (UAE)

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ABSTRACT
Sabkha is an Arabic word for salt-flats found mainly in arid regions along the coastlines and inlands, within sand dunes. The sabkhas that form within the sand are relatively flat and very saline areas of sand or silt that forms just above the water-table where the sand is cemented together by evaporite salts from seasonal ponds. The UAE is home to some of the largest concentrations of both coastal and inland sabkhas. The coastal areas of Abu Dhabi includes several small shoals, islands, protected lagoons, channels and deltas, an inner zone of intertidal flats with algal mats and broad areas of supratidal sabkha salt flats.

Sabkha surfaces can in certain situations be a geotechnical hazard due to its high salinity and with adverse effects on concrete, asphalt, steel and other structures, in addition to their sporadic heaves and collapses. As the UAE continue to develop major urban infrastructure identifying the location of such habitats is of utmost importance in proper urban planning processes. Identifying sabkha surfaces from remotely sensed data is a challenging process. Traditional remote sensing mapping techniques of multispectral data, usually fail to properly identify sabkha pixels or provide lower rates of mapping accuracy for sabkha surfaces. The primary objective of this research is to assess the feasibility of using multispectral salinity indices for properly identifying sabkha surfaces from remotely sensed data.

Salinity indices have previously been developed for mapping saline soils within agricultural areas. These indices include the visible and near infrared parts of the spectral radiation in various mathematical combinations. This research applies a series of multispectral salinity indices, based on green, red and NIR parts of spectra, for identifying sabkha pixels on a DubaiSat2 multispectral image of western UAE. The preliminary results suggest that salinity indices based on green and red radiation, perform better in identifying sabkha pixels compared to a combination with NIR, as suggested in former literature. The index $SI=\sqrt{(R^2 + G^2)}$ comprising of red and green bands of the spectra, in this study, was able to identify sabkha pixels with very high accuracy. The comparison between actual sabkha pixels and index predicted pixels reveal an accuracy of more than 90%.

1. INTRODUCTION

Sabkha are salt flats associated with hot and arid climate, typically formed in shallow continental shelf/ marine environment (G. Evans .1970; Kendall et. al. 1994). They are classified as inland sabkhas, present within the sand dunes, or coastal sabkhas, found on shoreline. Coastal sabkha are further differentiated into three kinds based on their formation in varying tidal environments: 1) sub-tidal flats, 2) lagoons and intertidal flats, 3) supratidal flats (Pain & Abdelfattah, 2015; Shinn, 1983). Inland sabkha that form within the sand dune areas are relatively flat and highly saline areas of sand or silt formed just above the water table where the evaporite salts from seasonal ponds cement the sand together. Evaporite deposits associated with coastal sabkha may consist of carbonates or siliciclastics.

Sabkha habitats are under constant threat in the UAE because of rapid economic development, major urbanization projects, increased population, and environmental pollution. In the last 30 years these habitats have suffered significantly in UAE, and till date remain under constant threats and pressures caused by anthropogenic activities.

The primary objective of this research study is to develop a new technique for mapping inland sabkha habitats using multispectral remotely sensed data. Identifying sabkha pixels in remotely sensed images has been quite a difficult process (Allbed & Kumar, 2013). This is primarily due to the confusion of sabkha pixels with saline soils and the mixture of sabkhas with sand dunes making spectral separation a challenging process. This research uses the multispectral information provided by DubaiSat-2 data and tests various salinity indices for accurate identification of sabkha pixels from other land cover pixels.

1.1 Studying Sabkha through Remote Sensing

Sabkha, as described earlier, develop in response to high evaporation rates, which result in supersaturated soils with insoluble salts (Al-Jaloud & Hussain, 2006). Remotely sensed satellite data uses this associated soil salinity to identify sabkhas: either directly by recognizing exposed salt topographies or indirectly by pinpointing the vegetation related to saline soils. Multispectral satellite imagery is the most commonly used and conveniently available technique for mapping saline soils for large geographic regions (Allbed & Kumar, 2013) in which maximum effectiveness is achieved with less than 5m pixel size (Ravi Shankar, Ramana Venkata, & Amarendra Narayana, 2008). In addition to multispectral sensors, there is also a more sophisticated alternative available for mapping the saline soils, in form of hyperspectral sensors. These sensors have better spatial and spectral resolution compared to multispectral sensors and they are able to capture variations in salinities much more comprehensively. However, this study utilizes DubaiSat-2 multispectral data, mainly because of data accessibility.

It is significant to note that salt reflectance is dependent of a number of factors such as salt type, mineralogy, color, and surface roughness (Mougenot, Pouget, & Epema, 1993); (Douaoui, Nicolas, & Walter, 2006). Normally, the more the amount of salt in soil the higher is the reflectance and vice versa. Spectral sensitivity of highly saline soils lies in the range of visible and near-infrared part of spectrum and this knowledge is the key for interpreting the salt features through multispectral data.

2. STUDY AREA

2.1 Climatology

The climate of UAE is hot, dry and arid with scarce amount of annual rainfall around 72 mm (Raafat, 2007) and rates of evaporation exceeding 2000 mm per year (Paul, Al Tenaiji, & Braimah, 2016). This high evaporation rate accounts for salinities ranging from 37% near Strait of Hormuz and 65% in the Arabian coastal lagoons (Alsharhan & Kendall, 2003; Bathurst, 1975) whereas in shallow depths of UAE coastal areas the average salinities vary from 40-50% and in lagoons and embayments they can reach up to 60-70%(Evans, Schmidt, Bush, & Nelson, 1969). The temperature 25cm below the sabkha go up to 17°C in winters and 43°C in summers respectively (Lokier, Knaf, & Kimiagar, 2013). The Shamal wind is the prominent climatic feature of the area, which blows in north-west direction. Storm outbreaks result in shallow inundation of the coastal area due to ramp geometry of coastline.

2.2 Geologic Setting of Sabkha

Main contributors to sabkha formation in the study area are the eustatic sea levels in the late Quaternery (Stevens, Jestico, Evans, & Kirkham, 2014) and north (Shamal) winds and currents which resulted in erosion of Pleistocene sand dunes some 7000 years ago (Evans et al., 1969). On northern coast of UAE, Sabkha emerged as a product of global sea-transgression and regression cycles during the latter part of Pleistocene time. About 12000-10000 years ago, (Kassler, 1973; Weijermars, 1999) sea level began to rise reaching a little above its present level around 4000 years ago, meanwhile flooding the depressions between coastline and dessert sand dunes.

Salt flats and depressions formed at the time of this fluctuating sea level and simultaneous erosion of late Quaternary(Al-Hurban & Gharib, 2004). Carbonates deposited on the seabed during phases of flooding and shriveled once the water retreated. Carbonate sand dunes evolved as the strong winds blew following the transgression-regression cycles. High evaporation rates made the soil, salt-concentrated, which eventually caused formation of a halite crust that expanded laterally as it desiccated and retained the shape of polygon, uplifting the margins. Fluids inside the sediments crystalized gypsum as they saturated with calcium sulphate. (Al-Farraj, 2005; Pain & Abdelfattah, 2015) has described the evolution of sabkha in the study area in 6 phases, based on different tidal environments including subtidal flats (khors) and intertidal channels, lagoons (intertidal flats) and supratidal flats (Pain & Abdelfattah, 2015) .

Coastal sabkha run for about 24 km inland between Abu Dhabi and Umm al Qawain and Sabkha Matti, the largest sabkha, extends for 150 km in the northern Rubal Khali Desert (Edgell, 2006). These inland sabkha exist in form of secluded interdunal plains, that flood during heavy rainfall and are characterized by intertwined polyhedrons of sand and gypsum (Brown, 2006). Coastal sabkha are dominated by carbonate sands, contrary to inland sabkha which are siliclastic in nature (Alsharhan & Kendall, 2003).

3. METHODOLOGY

3.1 Study Area and Satellite Data

The study area lies in the western parts of the city of Abu Dhabi and the western extremities of the UAE. This area in particular is home to some of the largest sabkha habitats in the world. It includes both coastal sabkhas and inland sabkhas that reside within proximity of tens of kilometers from the coast. The multispectral data used in the study came from DubaiSat 2 data collected on September 14 2014. The study utilized DubaiSat 2 spectral bands ranging between 550-900 nm, which comprise of blue, green, red and near infrared (NIR) parts of spectrum. All these bands were tested in various combinations of band ratios during the course of this study, to identify the parts of spectrum that work better than others in pinpointing sabkha on satellite imagery. The spatial resolution of the data is 4m in the multi spectral detectors.

3.2 Methodology

The study used two overlapping satellite imageries, out of the entire DubaiSat-2 data of western Abu Dhabi, which visibly showed presence of Sabkha, after careful visual interpretation and correlation with geology and available maps, shown in Figure 1a (2441) and 1b (2442) . Both satellite images 2441 and 2442 show the same parts of Sabkha area, most of which is overlapping in both images with 2442 showing some extended sabkha towards the South East and East West. As per the definition of sabkha provided earlier in the paper, they are identified based on their high salinity content in this study. Salt characteristics distinguish sabkha from adjacent land cover on satellite images. (Elnaggar & Noller, 2009) showed that conventional remote sensing is able to differentiate between highly saline soil surface and non-saline soil surface due to high reflectance from the former. (Elnaggar & Noller, 2009; Everitt, Escobar, Gerbermann, & Alaniz, 1988) further stated that salt encrustations in saline soils generate high, smooth reflections in the visible and near infrared parts of the spectrum, which has been tested and verified in this study.

Digital image processing was performed on the two stated images using Envi 5.1 and ArcMap 10.1. Both images were subjected to the following salinity indices, Table 1, most of which were taken from the available literature known to show positive results with saline soils, followed by ‘band mask’ application in Envi to observe the number of Sabkha pixels highlighted or concealed by the respective index application.

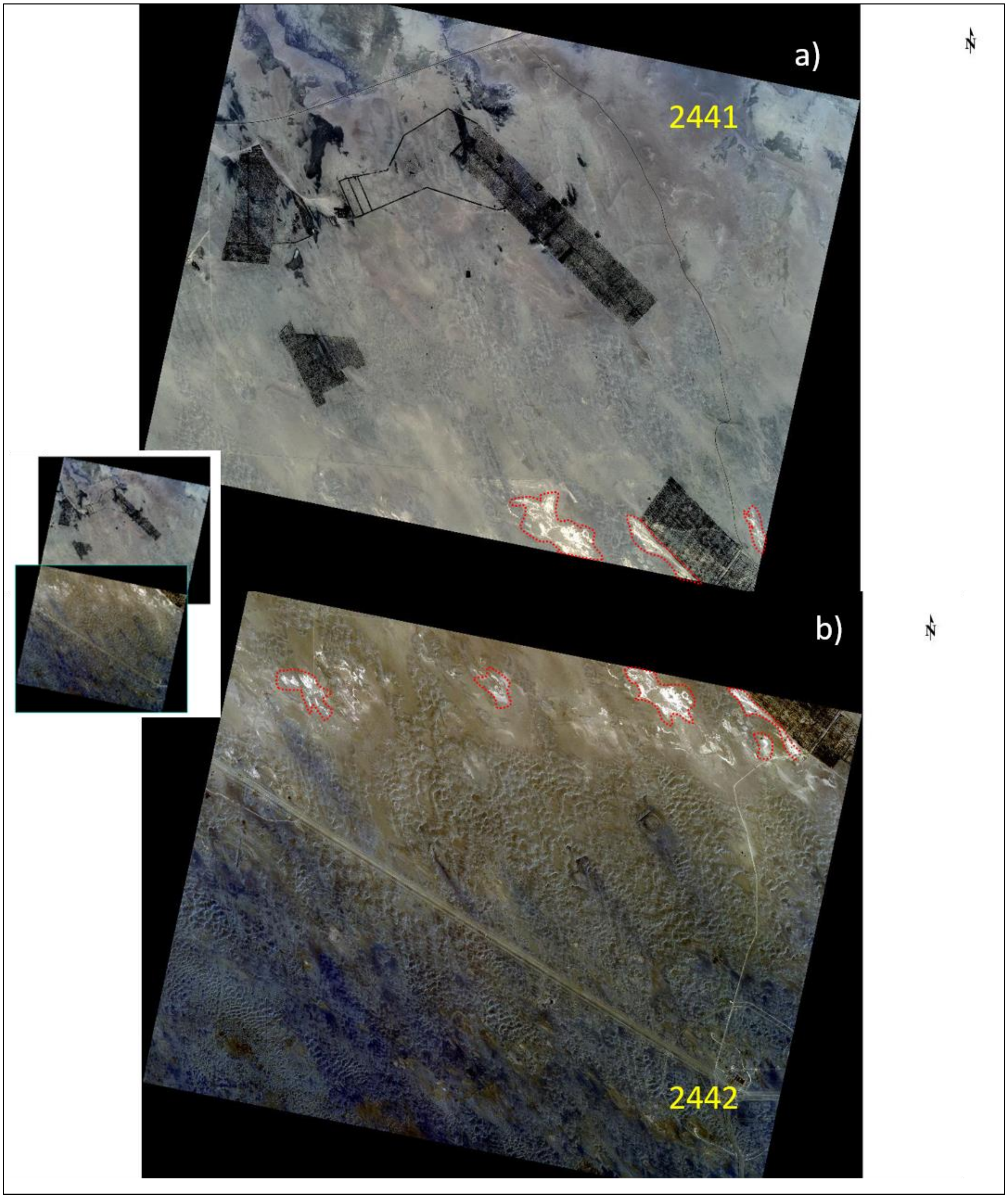

Figure 1 Figure 1a)(2441) and 1b)(2442): Two Adjacent Satellite Images with Highlighted sabkha (Whole Image)

Table 1 Salinity Indices for Identification of Sabkha on Satellite Image

SI 1	$\sqrt{R^2 + NIR^2}$	*(Khan, Rastoskuev, Sato, & Shiozawa, 2005)*
SI 2	$\sqrt{R \times B}$	
SI 3	$\sqrt{R \times G}$	
SI 4	$\sqrt{G^2 + R^2 + NIR^2}$	(Douaoui et al., 2006)
SI 5	$\sqrt{G^2 + R^2}$	
SI 6	B/R	(Abbas & Khan)
SI 7	$(B - R)/(B + R)$	
SI 8	$(G \times R)/B$	
SI 9	$(B \times R)/G$	
SI 10	$(R \times NIR)/G$	
SI 11	$(G - R + B)/R$	(Author)
SI 12	$(R \times NIR)/G$	
SI 13	$(R \times B)/G$	
SI 14	R/G	
SI 15	$(R \times G)/B$	
SI 16	G/R	

4. RESULTS & DISCUSSION

All the indices provided in Table 1 were applied to the images 2441 and 2442. The indices with red and green parts of spectrum indicated sabkha better than other indices. SI 5 showed best results for sabkha pixels, Figure 2. This index not only enhanced sabkha pixels but also depicted good separability between sabkha and non sabkha pixels.

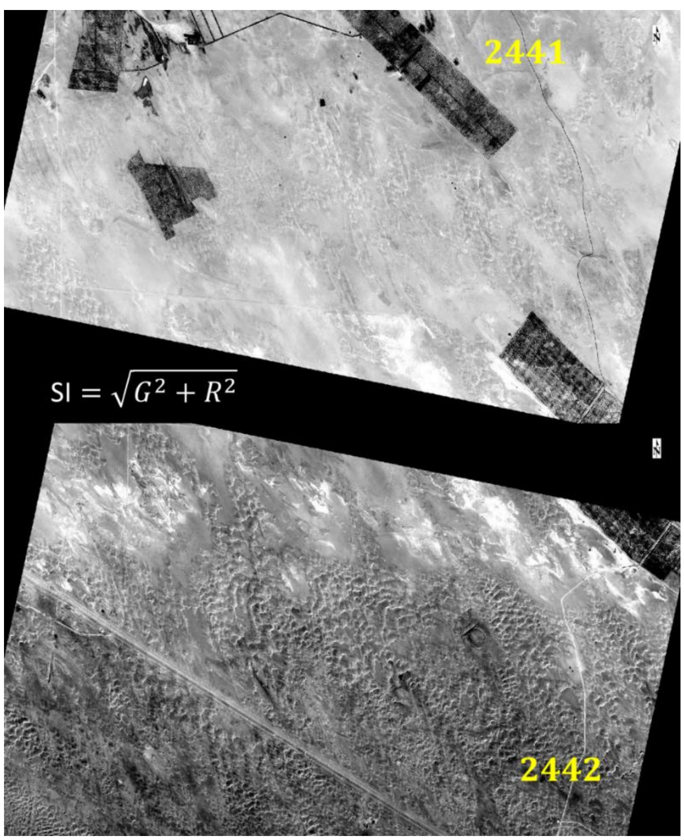

Figure 2 Images 2441 and 2442 applied with index SI 5
Brightest parts account for Sabkha (Image cropped to Sabkha extensive region)

To test the accuracy of the index, a number of regions of interest (ROI) were created on the original image, Figure 3, within the areas, which were identified as sabkha, through thorough visual interpretation of the satellite images and respective correlation with the known geology of the area and area maps.

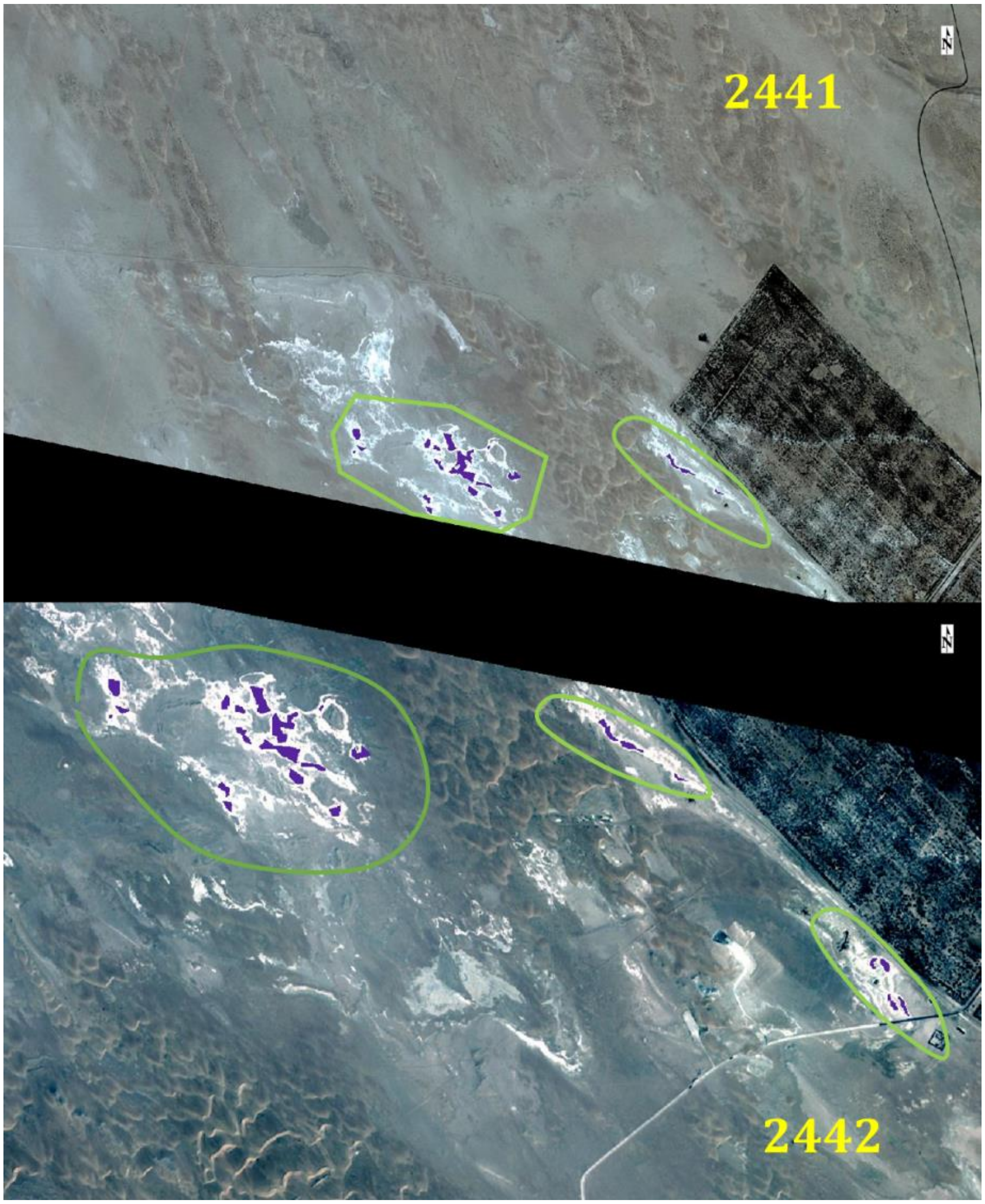

Figure 3 Highlighted ROIs Created On Original Images: 2441 & 2442, showing Sabkha With Maximum Confidence (Image cropped to Sabkha extensive region)

Further, these ROIs were overlaid on the index image (to simplify the process this paper will discuss image 2442 since it has extended Sabkha representation and it also covers almost 90% of Sabkha areas in image 2441). This is shown in Figure 4.

'Masking' technique in Envi was applied to get a minimum cutoff pixel value for sabkha which also masked the noise in the image. After numerous tries with various values, it was found that the pixel value of 1180 suited best in preserving the sabkha pixels and reducing the non-sabkha pixels.

Figure 5 shows 2442 image applied with SI 5 index and masked with a cutoff of 1180. To confirm further, the validity of the cutoff point, number of pixels covered below the 1180 in the index image was calculated using ROIs in Figure 4. This calculation revealed that only 55 pixels out of ROIs total pixels, 3798, created on the original image, were below the value of 1180. Hence, this result demonstrated that the index SI 5 with cutoff 1180, worked with an accuracy of 98% in delineating sabkha on satellite imagery along with minimizing the noise.

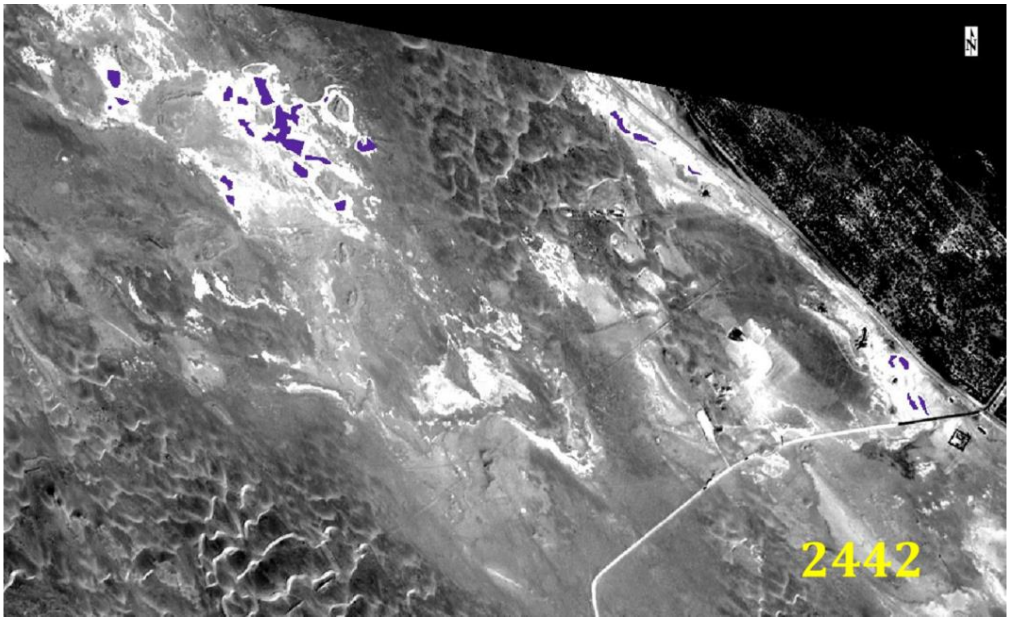

Figure 4 Index Image with Overlaid ROIs from the Original Image (Image cropped to Sabkha extensive region)

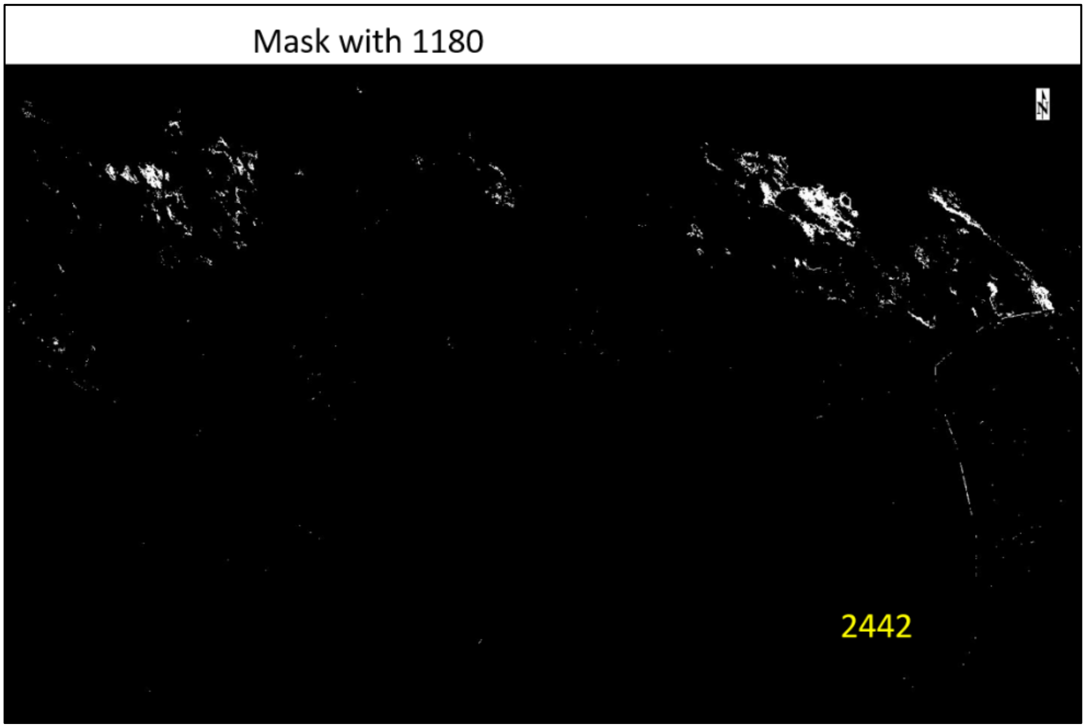

Figure 5 Masked Pixel Values Below 1180 with Minimum Noise (whole Image)

5. CONCLUSION

The present study disclosed that the salinity indices in literature, developed for saline soils, c effectively work for studying sabkha through satellite images by performing some image processing. In areas like the UAE, where urban development is augmenting at an unprecedented rate, geo-hazards like Sabkha pose a dire threat to the cause, especially when their existence largely distributed throughout the country due to the geologic setting. To be able to study the sabkha with the aid of satellite image, with high accuracy of over 90% is definitely a positive plus. This study indicated that salinity indices based on green and red parts of spectra, perform better in identifying sabkha pixels compared to a combination with NIR, as suggested in former literature. The index SI=$\sqrt{(R^2 + G^2)}$ comprising of red and green bands of the spectra, in this study, was able to identify sabkha pixels with very high accuracy. The comparison between actual sabkha pixels and index predicted pixels exhibited an accuracy of over 90% on a DubaiSat2 multispectral image of western UAE.

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