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Monitoring Vegetation, Water, and Land Surface Temperature in Dubai and Muscat Over Three Time Periods

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Abstract **-** The goal of this study is to monitor the changes caused by climate change on vegetation's health, land surface temperature, and water bodies in Dubai, UAE, and Muscat, Oman, focusing on three different years: 2018, 2021, and 2024. The monitoring procedure is carried out using Landsat 8, which is known for its high-resolution imagery. The satellite was used to capture several images for the proposed years; then, the images will be processed using ERDAS Imagine software, which is an advanced remote sensing tool. The software was initially used to classify imagery using supervised algorithms. Subsequently, it was used to assess vegetation's health, land surface temperature, and water availability using the Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), and Normalized Difference Water index (NDWI), respectively. Results indicate that Dubai underwent a rapid increase in vegetation cover over the years, which perfectly aligns with the city's vision. On the other side, Muscat faced an inconsistent variation in vegetation cover; a rise occurred between 2018 and 2021, followed by a fall between 2021 and 2024. Additionally, both cities experienced a gradual decrease in LST values, which highlights the cooling effect of vegetation expansion. However, both cities faced a decrease in NDWI values, indicating lower water availability over the years. These findings show the critical role of satellite monitoring in future planning for urban development and vegetation expansion.

Keywords**:** Remote sensing, ERDAS Imagine, Climate change, Vegetation index, Water index, Land surface temperature

1. Introduction

Climate change poses critical challenges to environmental features, especially with the increased temperatures resulting from global warming [1]. These challenges are even more pronounced in arid regions like Dubai and Muscat, where high temperatures, fluctuating water availability, and vegetation shifts shape their unique ecosystems. Fortunately, the tracking of these environmental changes over time is possible with the use of satellite imaging. Monitoring vegetation is of high significance due to various reasons including, but not limited to, urban heat island effect reduction, water conservation, biodiversity boost, and the protection of sensitive environments [2]. Similarly, LST and water availability are clear indicators of thermal and hydrological stress in cities and their surroundings [3].

The utilization of Landsat satellites, particularly Landsat 8 and its predecessors, has been extremely beneficial for vegetation monitoring [4]. The 30-meter spatial resolution of Landsat images makes them ideal for recording localized vegetation dynamics [4, 5]. Moreover, trends in vegetation density, degradation, and recovery over time can be tracked using multispectral data from satellites like Landsat and Sentinel. Landsat can also use particular spectral bands to monitor water bodies, which aids in assessing water level changes [6, 7].

This study aims to utilize satellite imagery to monitor changes in Dubai and Muscat's vegetation, water resources, and LST over a period of three years. Furthermore, we aim to spot trends over time and evaluate their consequences by comparing data from these two cities, which have similar climates but different environmental regulations and urban design. Insights gained from this study can serve as a guide for generating sustainable urban design and while also advancing our understanding of how climate change appears in arid regions.

2. Methodology

To effectively achieve the objectives of this research, which focus on monitoring vegetation's health, land temperature, and water stress, the initial step is to acquire imagery from high-resolution satellites, the usage of Landsat 8 was utilized in this project. The study site of this paper is focused on both Dubai, UAE and Muscat, Oman. Hence, imagery data for both cities will be gathered to form the core of the analysis. These images will then be compared to determine the variations of chosen parameters over time. In this regard, the project focuses on three specific years, 2018, 2021, and 2024 within a six-year time frame. Furthermore, acquired images will be processed using the advanced features of ERDAS Imagine software. Firstly, supervised classification was employed using ERDAS Imagine to enhance the accuracy of the analysis. The software is then used to precisely measure vegetation health using NDVI, land temperature using LST, and water stress using NDWI.

3. Results and Discussion

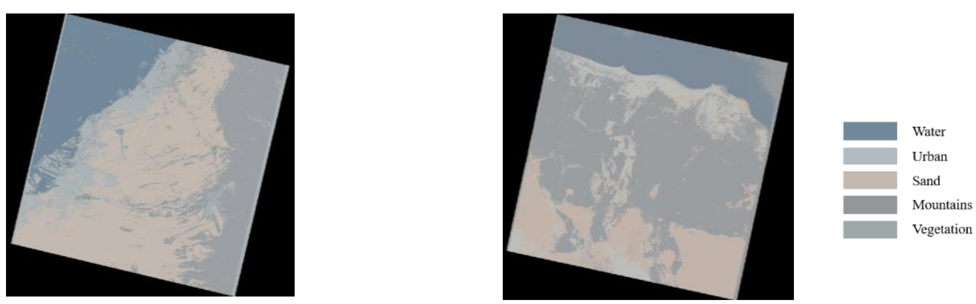
3.1. Supervised Classification

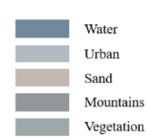
Supervised classification is applied to the satellite image to divide the landscape into different classes. In this study, each area investigated is divided into five distinct classes: water bodies, urban development, sandy regions, mountainous terrains, and areas covered with vegetation. Fig. 1 illustrates the change in Dubai and Muscat's area coverage in the years 2018, 2021, and 2024.

Most of Dubai's area is covered by sand. In 2018, sand covered 41% of the land in Dubai. This percentage dropped to 40% in 2021 and further decreased to 34.3% in 2024. The main reasons behind this decline in sandy regions are the ongoing process of urbanization, especially between the years 2021 and 2024, as well as the increased focus on vegetation. As shown in Fig. 2, the percentage of Dubai's area covered by vegetation increased from 6.4% in 2018 to 8.77% in 2021 and to 15.4% in 2024. As part of Dubai Municipality's goal to promote sustainable development, there has been a major focus on increasing vegetation and green areas. In 2023, Dubai Municipality planted over 185,000 trees across the Emirate, with an average of 500 trees being planted each day [8]. Moreover, Dubai is promoting the construction of green buildings, which are designed to be resource-efficient and have minimal impact on the environment throughout their lifecycle. In March 2014, Dubai Municipality mandated the adoption of green buildings for all new constructions [9]. This initiative is transforming Dubai into a green sustainable city. The area covered by water in Dubai remains constant at around 18.7% between the years 2018 and 2024. This could be due to the fact that most of the construction of Dubai's man-made islands has been done before 2018 as well as the focus on constructing manmade lakes after 2018.

Opposingly mountains make up most of Muscat's area. However, this area has decreased from 48.27% in 2018 to 42% in 2021 and finally to 41.15% in 2024. In contrast to the situation in Dubai, the vegetation area in Muscat did not experience a constant increase. The area covered by vegetation in Muscat increased from 3.85% in 2018 to 7.82% in 2021, then the percentage decreased to 4.64% in 2024. However, similar to Dubai, Oman has a 'Green Muscat' initiative, which was launched in January 2023 with the ultimate goal of planting 10 million trees. This initiative focuses on involving the community in protecting plants, combating desertification, and increasing green areas [10]. Similar to Dubai, there has not been a significant change in Muscat's water area between the years 2018 and 2024.

August
2018





August
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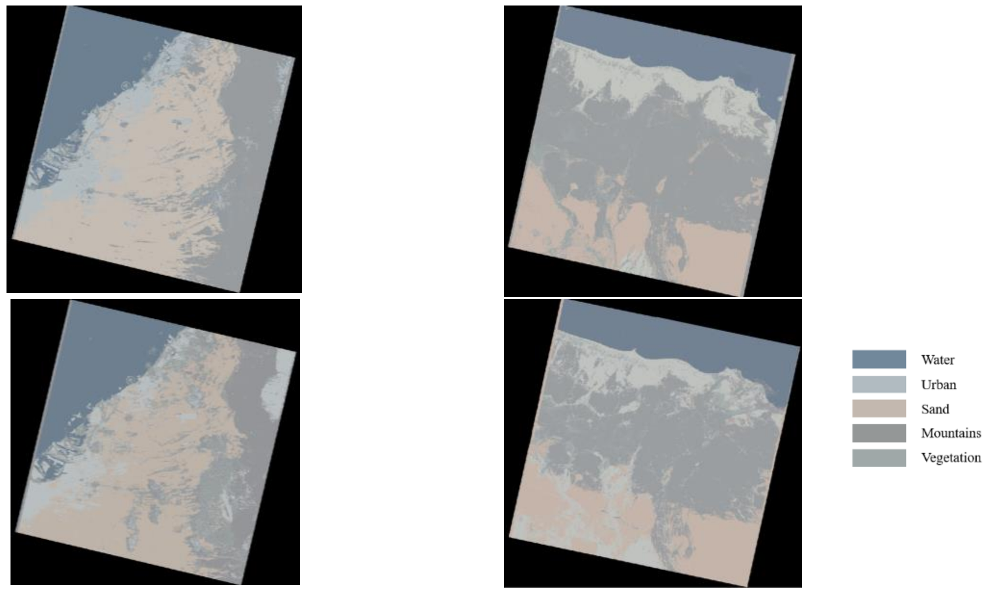


Fig. 1: Supervised Classification Images

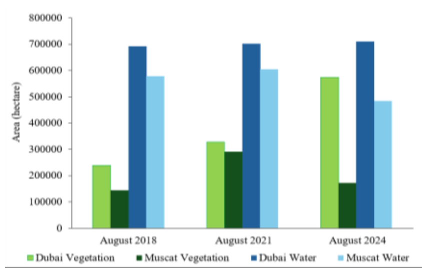


Fig. 2: Vegetation and Water Areas in Years 2018, 2021, 2024

3.2. Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) ranges between -1 and +1 and provides information about the vegetation cover in a certain region. A negative NDVI value signifies the presence of dead vegetation or an inanimate object. In contrast, the closer the NDVI value is to +1, the healthier the vegetation. In essence, as the amount of green vegetation increases, so does the NDVI value. NDVI is also sensitive to seasonal changes and other environmental factors. The NDVI for Landsat 8 is calculated using formula 4, where band 5 represents the near-infrared reflectance and band 4 represents the red reflectance.

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

Analysing vegetation health in Dubai, NDVI ranges between 0.142 and 0.344 in 2018. In 2021, NDVI fluctuated between 0.145 and 0.343 and in 2024 NDVI values range between 0.094 and 0.374 as seen in Fig. 4. This indicates the presence of unhealthy plant or plant that is moderately healthy throughout the studied area. In Muscat, NDVI values in 2018 ranged from 0.0458 to 0.291, from 0.0432 to 0.421 in 2021, and from 0.0375 to 0.365 in 2024 as displayed in Fig. 4. Similar to Dubai, vegetation in Muscat is unhealthy to moderately health. However, the large range of NDVI values in Muscat mean that there is vegetation that is less healthy than that in Dubai and vegetation that is healthier than Dubai's vegetation. The increase in mean NDVI in both Dubai and Muscat clearly seen in Fig. 5 indicates the increase in area covered by green vegetation.

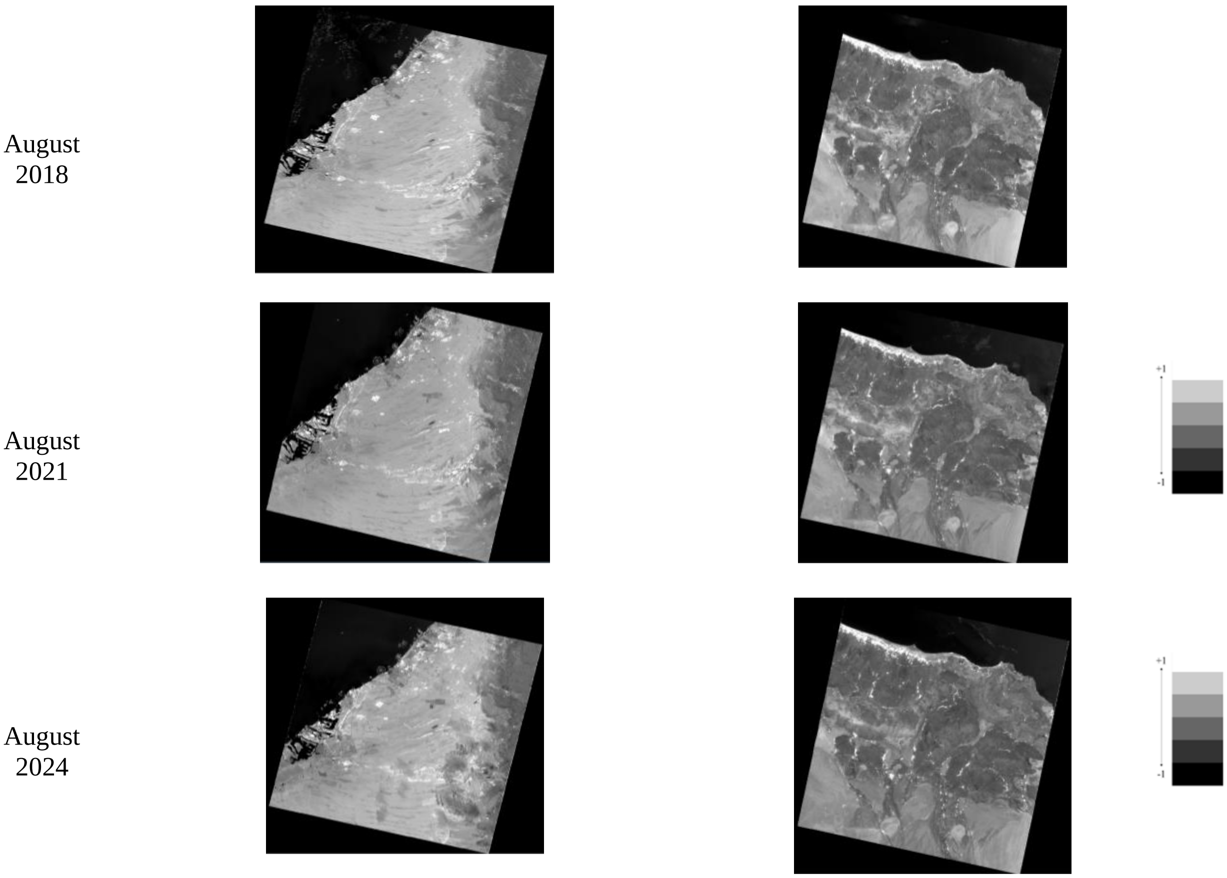


Fig. 3: NDVI Images

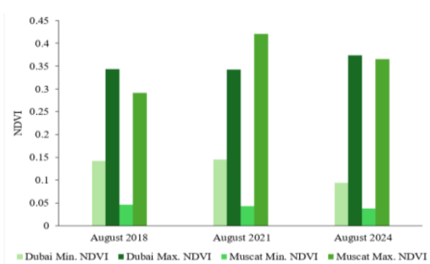


Fig. 4: Minimum and Maximum NDVI

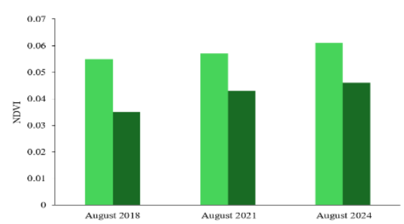


Fig. 5: Mean NDVI

3.3. Normalized Difference Water Index (NDWI)

The Normalised Difference Water Index (NDWI) ranges between -1 and +1 and plays a significant role in monitoring water content in a specified area. A negative NDWI value corresponds to a non-aquatic surface or a surface experiencing drought. The closer the NDWI value is to -1, the more severe the drought is. Opposingly, a positive NDWI value corresponds to the presence of water. The closer the NDWI index is to +1, the more water is present in that area. NDWI helps in monitoring changes in water resources over time. NDWI could also be used to monitor the health of vegetation by analysing their water content. Generally, healthy plants with high water content exhibit an NDWI value exceeding 0.5. Conversely, an NDWI value below 0.5 signifies the presence of less healthy vegetation with low water content. The NDWI for Landsat 8 is calculated using formula 5, where band 3 represents the green reflectance and band 5 represents the near-infrared reflectance.

$$NDWI = \frac{Green - NIR}{Green + NIR} \tag{2}$$

Fig. 7 represents the minimum and maximum NDWI values taken in water bodies in both Dubai and Muscat; therefore, all NDWI values taken are positive. In 2018 and 2021, NDWI in Dubai ranged between 0.0339 and 0.2639, in 2024 NDWI ranged between 0.0986 and 0.243. In Muscat 2018, the NDWI varied between 0.0635 and 0.0815, in 2021 NDWI varied between 0.07 and 0.1089. Finally, the minimum and maximum NDWI detected in water bodies in Muscat in 2024 are 0.0851 and 0.1051, respectively. Since all NDWI values detected are below 0.5, this indicates the presence of vegetation in the water, such as mangrove trees. Fig. 8 shows the overall mean NDWI values for Dubai and Muscat. In Dubai, the mean NDWI remains consistent at around -0.1077. However, the mean NDWI in Muscat decreased by nearly 13% in 2021 compared to 2018 from -0.062 to -0.07, it further decreased by another 4% to -0.073 in 2024. This decrease in mean NDWI could be a result of increased urbanization and droughts. In both Dubai and Muscat, a negative mean NDWI indicates the presence of minimal water bodies, low rainfall, and proves that Dubai and Muscat are desertified regions.

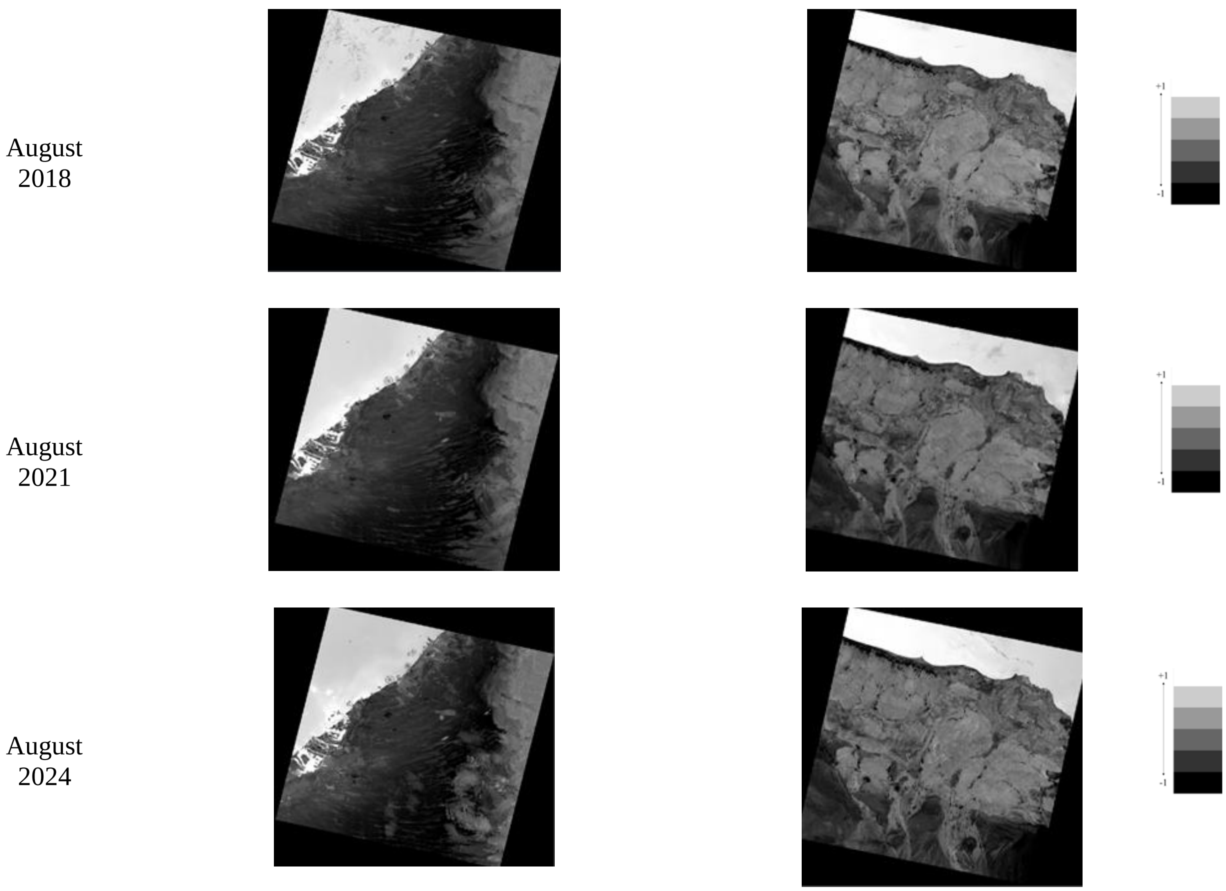


Fig. 6: NDWI Images

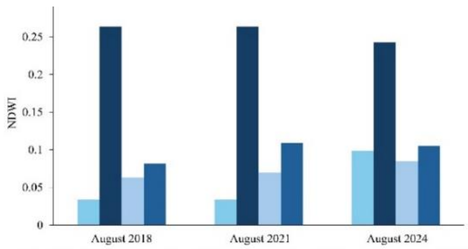


Fig. 7: Minimum and Maximum NDWI

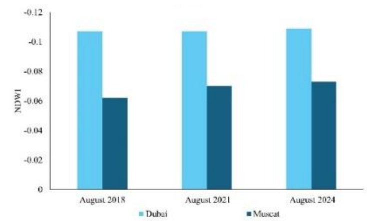


Fig. 8: Mean NDWI

The Normalised Difference Water Index (NDWI) ranges between -1 and +1 and plays a significant role in monitoring water content in a specified area. A negative NDWI value corresponds to a non-aquatic surface or a surface experiencing drought. The closer the NDWI value is to -1, the more severe the drought is. Opposingly, a positive NDWI value corresponds to the presence of water. The closer the NDWI index is to +1, the more water is present in that area. NDWI helps in monitoring changes in water resources over time. NDWI could also be used to monitor the health of vegetation by analysing their water content. Generally, healthy plants with high water content exhibit an NDWI value exceeding 0.5. Conversely, an NDWI value below 0.5 signifies the presence of less healthy vegetation with low water content. The NDWI for Landsat 8 is calculated using formula 5, where band 3 represents the green reflectance and band 5 represents the near-infrared reflectance.

$$NDWI = \frac{Green - NIR}{Green + NIR} \tag{3}$$

Fig. 10 represents the minimum and maximum NDWI values taken in water bodies in both Dubai and Muscat, therefore all NDWI values taken are positive. In 2018 and 2021, NDWI in Dubai ranged between 0.0339 and 0.2639, in 2024 NDWI ranged between 0.0986 and 0.243. In Muscat 2018, the NDWI varied between 0.0635 and 0.0815, in 2021 NDWI varied between 0.07 and 0.1089. Finally, the minimum and maximum NDWI detected in water bodies in Muscat in 2024 are 0.0851 and 0.1051 respectively. Since all NDWI values detected are below 0.5, this indicates the presence of vegetation in the water, such as mangrove trees. Fig. 11 shows the overall mean NDWI values for Dubai and Muscat. In Dubai, the mean NDWI remains consistent at around -0.1077. However, the mean NDWI in Muscat decreased by nearly 13% in 2021 compared to 2018 from -0.062 to -0.07, it further decreased by another 4% to -0.073 in 2024. This decrease in mean NDWI could be a result of increased urbanization and droughts. In both Dubai and Muscat, a negative mean NDWI indicates the presence of minimal water bodies, low rainfall, and proves that Dubai and Muscat are desertified regions.

3.4. Land Surface Temperature (LST)

Land surface temperature (LST) opposite to air's temperature, is the earth's surface temperature measured in Kelvin. This measurement is an indication of how warm the earth's surface feels at a specific location. Earth's surface refers to the area observed through the satellite. The LST is obtained from Landsat 8's thermal infrared bands. The calculation of LST involves several steps. The raw digital numbers from band 10 are converted to spectral radiance using equation 1. Following that, the spectral radiance is converted to brightness temperature at sensor using Planck's equation. Lastly, corrections for surface emissivity and atmospheric effects are applied using equation 3 to obtain the LST.

$$L_{sensor} = M_L \times Q_{cal} + A_L \tag{4}$$

$$T_{sensor} = \frac{K_2}{ln\left(1 + \frac{K_1}{L_{sensor}}\right)} \tag{5}$$

$$T_s = \frac{T_{sensor}}{1 + \left(\lambda \times \frac{T_{sensor}}{\rho}\right) ln\varepsilon} \tag{6}$$

Where M_L is the radiance multiplicative factor, A_L is the Radiance additive factor, Q_{cal} is the pixel value in digital, K_1 is the first thermal constant, K_1 is the second thermal constant, λ is the wavelength of emitted radiance, ρ is the atmospheric correction factor (1.438×10^{-2} m·K), and ε is the emissivity from NDVI.

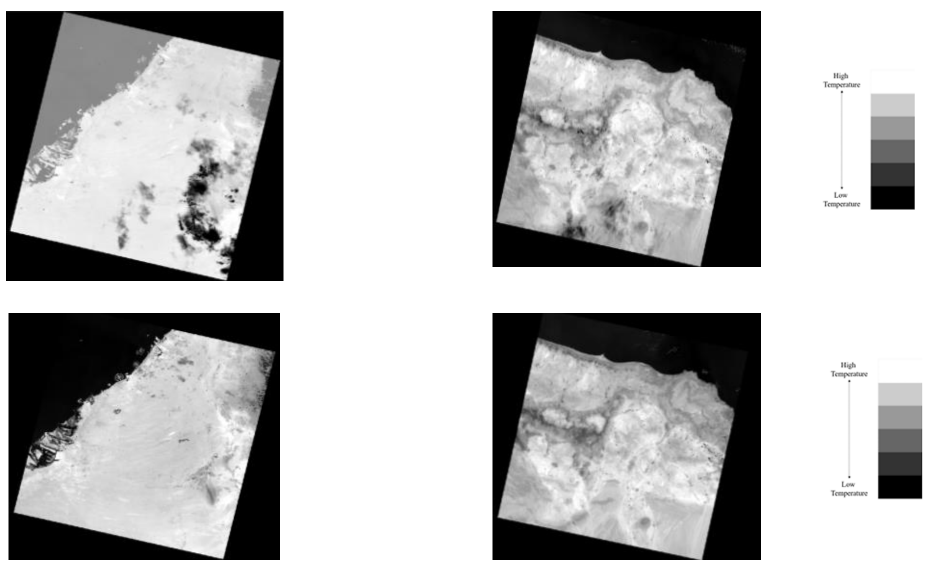
Fig. 10 shows the minimum and maximum LST measured at different points across the area. As it can be seen, there is significant changes in the LST of Dubai and Muscat between the years 2018 and 2024. In 2018, Dubai's LST ranged between 304.304 and 329.627 kelvin, in 2021 LST varied between 304.535 and 328.45 kelvin, and in 2024 between 274.537 and 316.667 kelvin. This shows that in Dubai, the maximum detected LST as well as the mean LST displayed in Fig. 11 decreased between the years 2021 and 2024. Opposingly, the maximum detected LST and mean LST of Dubai increased between the years 2018 and 2021.

In 2018, Muscat's LST ranged between 300.774 and 326.977, in 2021 between 310.359 and 342.714, in 2024 between 270.061 and 326.895. Similarly, Muscat's LST experienced a significant increase in 2021 then decreased in 2024. Both Dubai and Muscat exhibit similar trends in the changes in LST, Muscat experienced a significant decline in its mean LST in 2024, with a decrease of approximately 5%. Similarly, Dubai's mean LST decreased by around 3.1% between 2021 and 2024. This difference could be due to different urbanization trends and variations in land use pattern.

Climate change and a soar in construction activities have consequently increased Dubai and Muscat's mean LST between 2018 and 2021. The increase in LST causes urban heat island effect which is a result of the presence of large urban areas whose temperature is significantly higher than rural regions. Urban areas have high temperatures because buildings and other infrastructure absorb solar radiation. Opposingly, vegetation and water are reflectors of solar radiation. As a result, a densely constructed urban area with minimal greenery develops into an island with elevated temperatures. However, in 2024, both Dubai and Muscat have been working on increasing vegetation and green spaces, particularly in urban areas. This has in turn caused a decrease in the mean LST. This is because by reflecting heat, vegetation cools its surrounding environment. Therefore, increasing the areas of vegetation and integrating more green spaces in urban areas helps mitigate the urban heat island effect and create a more sustainable environment.

August
2018

August
2021



August 2024

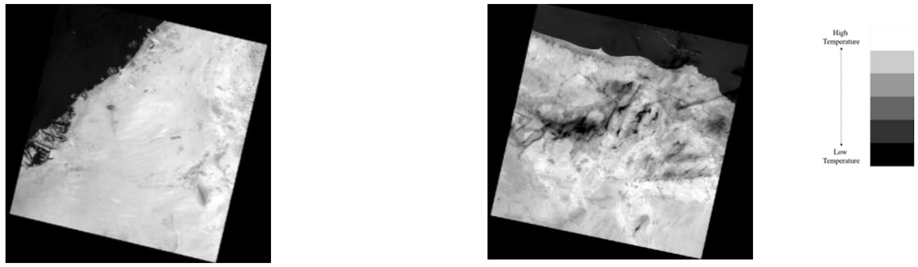


Fig. 9: LST Images

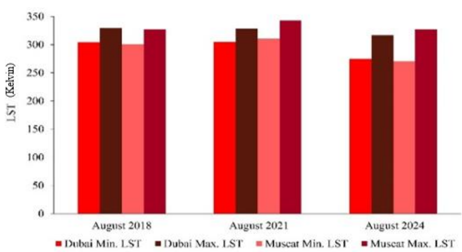


Fig. 10: Minimum and Maximum LST

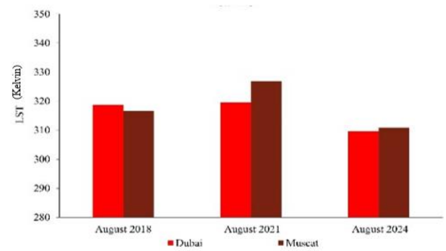


Fig. 11: Mean LST

4. Conclusion

This study critically highlighted the impacts of climate change and urban development on vegetation health, land surface temperature, and water availability in Dubai and Muscat. Due to Dubai's extreme focus on urban greening, results indicated that vegetation cover is increasing, resulting in a decrease in LST between 2021 and 2024. Whereas Muscat experienced vegetation growth between 2018 and 2021, followed by a drop between 2021 and 2024. However, both cities are facing challenges in maintaining water availability; results indicated decreased NDWI values throughout the research period. Lastly, this study identifies the importance of urban greening with effective water management to face climate change effects.

It is recommended that future research to use multiple satellites, such as Sentinel-2 and Landsat 9, to provide a comprehensive assessment of the imagery. Also, monitoring the mentioned parameters in a shorter interval of years would provide precise and insightful results.

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