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Wildfire Effects on Vegetation Moisture, Using Remote Sensing Techniques: Case Study of Ain Marah Al-Jabal Al-Akhdar, Libya

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ABSTRACT

The Normalized Difference Moisture Index (NDMI) derived from Sentinel-2A, has been widely used to monitor moisture-related vegetation condition. It was applied to determine the actual impact of Ain Marah wild-fire on the moisture content of the area. Pre and post fire 10 metre Sentinel-2A images, were used to compare water content loss estimation as a result of the fire. NDMI values were tracked for ten months after the fire until 2 months after, in order to determine the moisture variation between the hot and dry seasons. Most recent free cloud Sentinel-2A on the 26th of December 2021, was compared with images taken a day before the fire to examine the moisture recovery over this period. The study results show the vegetation moisture content ranges from low to mid-high water content where vegetation exists, with NDMI values from 0 to 0.3. Whereas 5 months after the fire, the leaves water content represented through NDMI as -0.2 to -0.24 show high water stress over the burnt area. The area moisture content was tracked from August 2020 to August 2021 to examine the dynamics of the vegetation moisture in the burnt area. Although the area is characterized by moderate moisture in the hot season to high moisture in the rainy seasons, the fire caused a significant loss of the vegetation water content until the date of the current study.

آثار حرائق الغابات على رطوبة النبات، باستخدام تقنيات الاستشعار عن بعد دراسة حالة: حريق غابة عين مارة/الجبل الأخضر، ليبيا.

محمد طاهر حمد بوفروة

تم في هذه *الدراسة* تطبيق مؤشر الفرق الطبيعي للرطوبة (NDMI) المشتق من الصور الفضائية Sentinel-2A لتحديد التأثير الفعلي لحرائق غابات عين مارة على المحتوى الرطوبي للمنطقة. تم استخدام صورتي Sentinel-2A ذات الدقة المكانية 10 أمتار قبل وبعد الحريق ، لتقدير فقد محتوى الماء نتيجة للحريق. ومن ثم تم تتبع قيم NDMI لمدة عشرة أشهر بعد الحريق حتى شهرين بعد ذلك ، من أجل تحديد اختلاف الرطوبة بين الموسمين الحار والجاف. تمت مقارنة أحدث صورتين الأولى في 26 ديسمبر 2021 بالصورة التي تم التقاطها قبل يوم واحد من الحريق لفحص مدى استعادة الرطوبة خلال هذه الفترة. أظهرت نتائج الدراسة أن المحتوى الرطوبي للنبات يتراوح من محتوى مائي منخفض إلى متوسط مرتفع حيث توجد النباتات ، مع قيم NDMI من 0 إلى 0.3. في حين أنه بعد 5 أشهر من الحريق ، فإن محتوى الماء في الأوراق الذي يمثله مؤشر NDMI ‎-0.2 إلى ‎-0.24 يُظهر إجهادًا مائيًا مرتفعًا فوق المنطقة المحترقة. تم تتبع محتوى رطوبة المنطقة من أغسطس 2020 إلى أغسطس 2021 لفحص ديناميكيات رطوبة الغطاء النباتي في المنطقة المحترقة. على الرغم من أن المنطقة تتميز برطوبة معتدلة في الموسم الحار إلى رطوبة عالية في مواسم الأمطار ، إلا أن الحريق تسبب في خسارة كبيرة للمحتوى المائي للنباتات حتى تاريخ هذه الدراسة الحالية.

INTRODUCTION:

Wild fire is defined as uncontrolled large fire that is source of disturbance to people`s livelihoods and premises, regional climate, the land surface hydrology, biogeochemical processes, and wildlife habitats, as well as the terrestrial ecosystems. It is known to be a common cause of worldwide ecosystem degradation, an increment of nutrient and soil losses via leaching and erosion, which accordingly damage the vegetations (Hou & Orth, 2020). The increase in vulnerability of ecosystems to wildfires in a warming climate of the Mediterranean basin, is becoming a concerning issue, as they are increasing in severity, extension and the number of fires. That is due to the long hot and dry conditions, the regions have witnessed in the last decade. These fires are causing short and long term change at the soil quality, via the significant adjustment of the physical characteristics of soils and vegetation. Fires are a concerning topic in Mediterranean areas. They are increasing in number and extension, probably due to the anomalous dry and hot conditions experienced in this region in the last decade. Plant cover and litter layers are consumed, and mineral soil is heated, during the burning process. As a result, this causes changes in soil bulk density, porosity, texture, color, moisture content, and permeability. The soil and vegetation health recovery after being burnt is a very slow process.

Soil moisture is a vital element in land surface hydrology cycle. It plays an important role for agriculture, ecology, wildlife, and public health, and it is most likely (after precipitation) the most important link between the hydrological cycle and life—animals, plants, and humans. It's also an important parameter in the hydrological, meteorological and agricultural vegetation statues. Pre-post fire Soil and vegetation moisture estimation has traditionally required intensive labour operations in the field as well as some complex post-treatment processes. This is not only time-consuming but also it is difficult to obtain a wide range of synchronous soil moisture information. The advancement of remote sensing technology has made it possible to gain access to regional scale soil moisture information. Recently, numerous studies have demonstrated the effectiveness of remotely sensed soil and vegetation moisture and vegetation optical depth products derived from the European Space Agency's (ESA), for drought monitoring, agriculture soil water monitoring and water stress. Because of this, satellite vegetation and soil moisture has been increasingly used in hydrological, agricultural, and ecological studies over the last decade due to its spatial coverage, temporal continuity, and accuracy (Lakshmi, *2013);* Garkusha. *et. al* (2017). In the current study, Normalized Difference Moisture index (NDMI) for Moisture Stress derived from Sentinal-2A images are used to determine the impact of wild fire of Ain Marah, Libya on the 30th of June 2021 on the hydrology and water stress of the burnt area on the soil and vegetation moisture.

Ain Marah wild-fire:

In the year 2021, the Mediterranean basin countries witnessed long heat-wave that has not accrued since long time, fed by dry hot air locally called (Ghibly), making destruction of soil and vegetation, which was a fuel for wildfires over the region. Several fires were reported as the worst fires that have happened since decades in each of Tunisia, Greece, Turkey , Morocco and Libya from June to September 2021. This accordingly led to a loss of people`s livelihood and premises (European Forest Fire Information System (Al Jazeera, 2021).

In 2021, Libya witnessed two massive wildfires in 2021 in the greenest region of Al Jabal Al Akhdar, which means the green mountains in English. This reflected a relative intensive vegetation cover in the region, one on the 30th of June near Ain Marah town approximately 70 km from East-south the biggest city of the region named Al Biyda city which is 500,000 population. The other forest fire was on the 12th of August in AL Bayada town which is 60 km West of Al Biyda city. According to The Libya Observer news agency on the , 2nd of July 2021, Libya is passing through the longest hot wave since 1987 which lasted for 9 days. The temperature levels have reached extraordinary levels in the North-West of Libya to be 45 degrees Celsius and in the North-East in Al Jabal Al Akhdar to record 39 degrees Celsius on the 26th of June 2021, which led to closing of schools for a week (The Libyan agency 2021).

The worst wildfire was in the North-East of Libya 4 km away from a rural town named “Ain Marah” Al Jabal Al Akhdar in 2021, which occurred in the early morning of the 30th of June 2021. The local citizens of Ain Marah woke up to smoke clouds a few kilometres off the town, they tried to stop the fire the whole day, but they were not able to. The preceding dry monsoon spell left plenty of flammable material in the under-story of the forest ranges. The fire kept spreading until the second day it went out of control, therefore citizens asked the civil defence to send firefighters to stop the fire. The support arrived on the 1st of June and they kept fighting the fire until the following day. The harsh topography and high temperature of the area, had made it difficult to control the fire easily. However the fire had stopped on the 2nd of July by the great constant effort of the safety authority supported by the local civilians from all cities and towns within the region. However, the fire sparked again to nearby ranges on the 3rd of July fed by moderate winds just few meters of the power station of the area, that made it very dangerous and destructive. The fire was officially stopped at the end of the same day leaving hectares of burnt environment including natural vegetations, farms and animals.

photo (1): A true seen of Ain Marah wild fire (local photographer).

Remote sensing data:

Water has unique thermal and dielectric properties which provides two options for remotely sensing soil moisture content. Due to water's high heat capacity and thermal conductivity, moist soils have a high thermal inertia. The diurnal range of surface temperature can be used to detect thermal inertia. As a result, the soil's surface emissivity and reflectivity are strong functions of its moisture content. The increased use of vegetation indices, such as NDVI, for crop control via remote sensing has resulted from the spread of digital technologies in farms. The sun emits different wavelengths and frequencies of radiation. The electromagnetic spectrum (EM spectrum) represents the totality of all electromagnetic radiation frequencies. The entire spectrum is divided into two parts: the visible spectrum, which produces light, and the non-visible spectrum, which produces light at longer and shorter wavelengths of the visible spectrum. Vegetation absorbs solar radiation in various bands, or frequency ranges and wavelengths, and emits a different percentage of it back into them. Plant health and water stress influence the percentage of refracted radiation in specific bands, such as near infrared (NIR), red (RED), and short-wave infrared (SWIR) [figure 1]. The vegetation indices are a sum of the percentages of refracted radiation in various bands. Sentinel-2A has a 5 day regular acquisition interval, so indices are available for multiple dates in the same season (Sara 2018). Several indices based on reflectance from near infrared (NIR) and shortwave infrared (SWIR) channels have been proposed for remote sensing of vegetation water content from space in the applications of spectral variation of water absorption bands. The most widely used NIR-SWIR vegetation water indices are the Normalized Difference Water Index (NDWI), which has recently been used to detect and monitor the moisture condition of vegetation canopies over large areas (Wang, & Qu 2007).

Figure 1: Vegetation indices with percentage of radiations emitted (Sara, 2018).

Sentinel-2A:

Sentinel-2 was officially launched in June 2015 as part of European Commission's Copernicus program. The satellite contain 13 spectral bands, ranging from the visible and the near-infrared to the shortwave infrared at different spatial resolutions ranging from 10 to 60-meters on the ground covering the globe every 5 days. Its mission is designed to provide Global Monitoring for Environment and Security, such as Generic land cover, land use, and change detection maps, in addition to Map of geophysical variables for leaf area index, leaf chlorophyll content, and leaf water content. It is the first optical Earth observation satellite in the European Copernicus program. Three Sentinel-2A images were used for the current study, the first one was taken on June 29th 2021 which was a day before the fire occurred which will be used as a generic view of the vegetation moisture state to compare with what was obtained from the one taken a day after the fire on July 4th 2021. This is in order to estimate the direct impact of Ain marah wild fire. In addition, the most recent free cloud Sentinel-2A image taken in December 2021 will be used to evaluate the moisture recovery 5 months after the fire.

In a study undertaken in Biebrza Ramsar Convention test site in the N-E part of Poland, Data of optical satellite images was obtained from the European space agency

(ESA) and was analysed to be compared to the detailed soil-vegetation ground truth measurements conducted during the satellite overpasses. Optical images have been used for classification of wetlands vegetation habitats and vegetation surface roughness for the aim of for the assessment of soil moisture. The correlation between the backscattering coefficient and soil moisture was examined, and the most combination of microwave variables (wave length, incidence angle, polarization) has been used for mapping and observing of soil moisture. The study resulted that there is a significant possibility to develop a water cycle model over wetlands ecosystems by adding vegetation and soil moisture derived from satellite images. Moreover, such information is efficient for better protection of the European sensitive wetland ecosystems (Dabrowska, *et. al* 2010)

In September 2019, a comparative analysis was applied in South-eastern of Kazakhstan to assess the vegetation indices (Normalized Difference Moisture Index) obtained from Landsat-8 data. It describes the effectiveness of several spectral indices in recognizing sparse desert vegetation and calculating the basic biophysical parameters of vegetation. Based on red and near infrared bands of satellite imagery, NDMI was comparatively tested with a various soil and vegetation indices. Pearson's correlation coefficients were calculated for three basic vegetation spectral indices and biophysical parameters. Based on the results of the study, NDMI demonstrated a high sensitivity and relevance than the traditional NIR RED-based vegetation indices when calculating biophysical parameters of vegetation in the conditions of heterogeneous desert vegetation in a desert and semi-desert of Southern Kazakhstan. Authors added that the NDMI has significant ability to recognise water content in up to eight leaf layers instead of the single uppermost leaf layer that is recognizable by NIR-RED-based vegetation indices). The index could successfully be adapted for the satellite platforms possessing appropriate spectral bands. They admitted that the NDMI has the potential for further studies and implementation in a variety of ecological agricultural applications. Moreover, its application either alone or with other traditional indices could provide more detailed and nuanced image of vegetation that one can obtain from satellite imagery (Malakhov, Tsychuyeva, 2020).

MATERIALS AND METHODS:

In this study, a forest fire that occurred in Ain Marah Town in Al Jabal Al Akhdar region, where natural trees, shrubs and agricultural lands are located. The forest fire started on 30th of June 2021 in the early morning hours and was under control by the 3rd of July late evening. During this period, the amount of burning area has not been given by an official authority. While the Maximum temperature reached to 39C° in the area. Sentinel-2 satellite data used for this study was obtained from Copernicus Open Access Hub, to estimate the vegetation water content of the affected area by the fire. 3 Sentinel-2A images were selected to be used for fulfil the main objectives of the current study. First pre and post fire eruption images dated (29th of June and 4th of July 2021), were used to detect the actual burnt area. The remotely sensed Normalized Burn Ratio index (NBR), was applied for both images to determine the burnt surface area. Once the burnt area of the selected images was found, it was extracted from the whole image extension to be used for vegetation moisture affection estimation using another index named Normalized Difference Moisture Index (NDMI). To detect the fire affection on the vegetation moisture, the NDMI mean values fluctuation was traced since August 2020 to August 2021 including the wild-fire period. To examine the latest vegetation moisture status, NDMI was applied on an up-to-date free cloud Sentinel-2A image on December, 26 2021 to be used for vegetation moisture recovery estimation 5 months after the fire.

Study area:

Al-Jabal Al-Akhdar is an upland area. It is located between 32° 00'- 32° 58'N with longitude 19° 56'- 23° 09'E. The total area of the region is about 7,800 km^2, which extends for a distance of over 300 km along the Libyan coast including the most vegetated part of the country. The wide region is characterized by a variety of natural environments that are caused by variation in geology, topography, climate, water resources, soil and natural vegetation. Distance from the sea and altitude cause important variations in climate. The natural vegetation in region varies between forests, shrubland, coastal plain and low vegetation in the semi-arid areas Ben Khaial, A., Bukhechiem, A. (2005); Bukhechiem, A. (2006). Ain Mara location as shown in figure 3, is located at the East-North of the region, 60 km to the East of Al Bida and 23 km the West of Derna City.

Normalized Burn Ratio (NBR):

The Normalized Burn Ratio (NBR) is a tool for identifying burned areas and determining burn severity in a large fire zone. In the traditional sense, it is calculated as a ratio of the NIR and SWIR values. According to Adagbasa *et. al* (2018); Cocke *et. al* (2005); Keeley, (2009) it is the most extensively used index to detect the burnt areas. Healthy vegetation in their normal statues show a low reflectance in the Short wave infrared (SWIR), while they highly reflect the Near Infrared (NIR) waves [Figure 2]. Adversely, the recently burnt vegetation indicate high reflectance in the SWIR and low reflectance in the NIR.

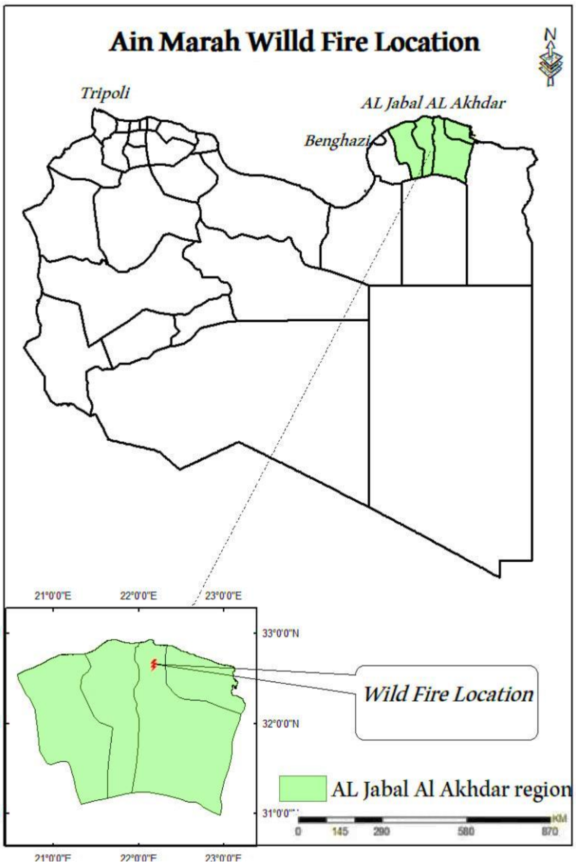

Figure 2: map of libya, Ain Marah wildfire.

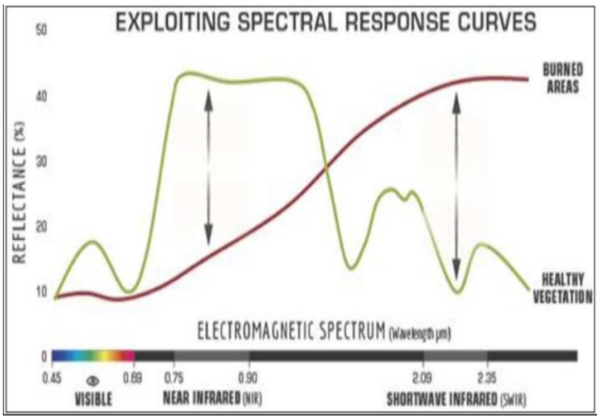

Figure 3. Comparison Of The Spectral Response Of Healthy Vegetation And Burned Areas (Keeley, 2009).

The NBR benefits of these spectral difference magnitude according to formula (1) below, it calculates the ratio between NIR and SWIR bands. Its values ranges from -1 to 1, a high NBR value express the healthy vegetation, while a low value indicates to a recently burnt vegetation [6] In order to visualize the fire extension in the current study, NBR is applied for two sentinel-2A images, one a day before the fire on June, 29th 2021, and the other one a day after fire was stopped on July 4th 2021.

$$NBR = \frac{(NIR - SWIR)}{(NIR + SWIR)} = \frac{(Band\ 8 - Band\ 12)}{(Band\ 8 + Band\ 12)}$$

Formula(1).

Basic visual analysis of the pre and post-fire NBR image in figures (4 & 5) show that we have two NBR bands each corresponding to the pre-fire (June 29th) on figure (4), which is a day before the fire, and post-fire date (July 4th) on figure (5) just two days of the fire stopped. To identify recently burned areas, it could be clearly seen that burned areas are visualized in darker, almost black colour and it is now easier to distinguish them from the rest of areas. The fire extension was calculated in a study published in May 2022 [4], various vegetation indices were used to gain the actual burnt area which was (103 ha).

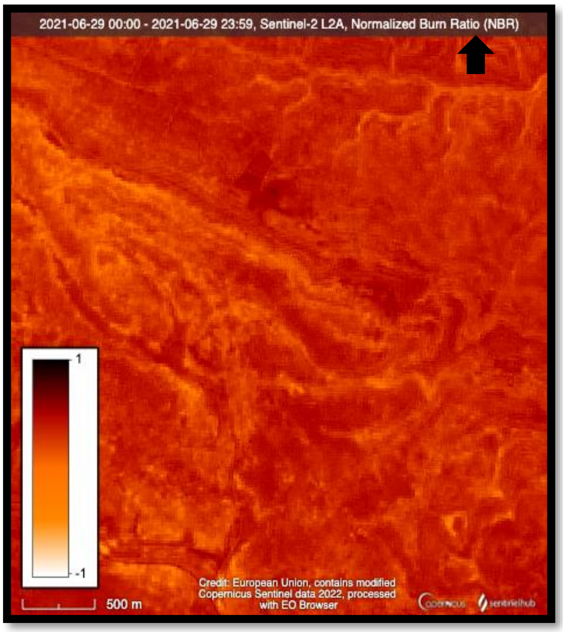

Figure 4. NBR of Pre (29th June) Ain Marah wildfire.

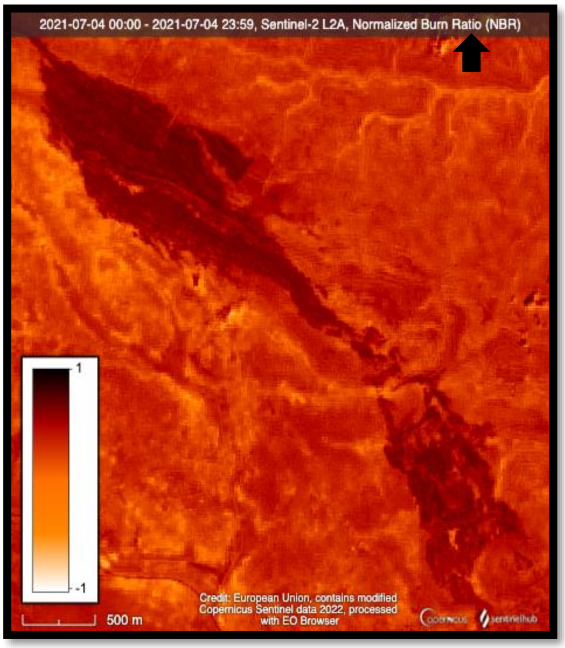

Figure 5. NBR of post Ain Marah wildfire (4th July). [procced by Copernicus 2021].

Normalized Difference Moisture Index (NDMI):

The NDMI detects soil and vegetation moisture using NIR and SWIR bands. The SWIR band reflects changes in vegetation water content as well as spongy mesophyll structure in vegetation canopies, whereas the NIR band is affected by leaf internal structure and leaf dry matter content but not by water content. Combining the NIR and SWIR removes variations caused by leaf internal structure and leaf dry matter content, improving the accuracy of determining vegetation water content. The amount of water present in the internal leaf structure has a large influence on the spectral reflectance in the SWIR interval of the electromagnetic spectrum. As a result, SWIR reflectance is inversely related to leaf water content. NDMI is used to monitor changes in the water content of leaves. It represents the crop's water stress level and is calculated as the ratio between the difference and the sum of the refracted radiations in the near infrared and SWIR, that is as (NIR-SWIR) /(NIR+SWIR). Its values vary between -1 and 1, and each value corresponds to a different agronomic situation, independently interpretation of the absolute value of the NDMI [Table 1]. The lowest NDMI values (yellow to dark brown) correspond to low leaves water content, and the highest ones (in blue) indicate to high water content. In other words, a decrease in NDMI will indicate water stress, while abnormally high NDMI values could signal waterlogging (Gao, 1996); (Wang & Qu, 2007); (Sara 2018).

NDMI = (NIR-SWIR)/(NIR+SWIR). ***Formula (1).***

Sentinel-2A NDMI = **(B 08 - B11) / (B 08 + B11).**

NDMI	INTERPRETATION
-1 to -0.8	Bare Soil
-0.8 to -0.6	Almost absent canopy cover
-0.6 to -0.4	Very low canopy cover
- 0.4 to -0.2	Low canopy cover, dry or very low canopy cover
-0.2 to 0	Mid-low canopy cover, high water stress or low canopy cover, low water stress
0 to 0.2	Average canopy cover, high water stress or mid-low canopy cover, low water stress
0.2 to 0.4	Mid-high canopy cover, high water stress or average canopy cover, low water stress
0.4 to 0.6	High canopy cover, no water stress
0.6 to 0.8	Very high canopy cover, no water stress
0.8 to 1	Total canopy cover, no water stress/ waterlogging

Table 1. NDMI index Sara 2018).

After determining the area affected by the wildfire using the NBR index. Accordingly, the burnt area of the image was extracted using the clipping tool of the sentinel-hub program to be used for moisture content estimation. NDMI is now applied on the same pre-post fire Sentinel-2A images in addition to the most recent resent free clouds cover Image on December 26th, 2021 to estimate the soil and leaf water content loss one day after the fire was stopped, as well as its status in 5 months' time, which is the time of writing the current research. Graphs are designed to numerally visualize the impact on the fire on the vegetation moisture in the area represented by the mean values of NDMI.

RESULTS DISCUSSION:

According to the NBR post-fire image result, the burnt area was clipped to be used for the current study. The obtained NDMI results illustrated in figures [5 & 6], demonstrate the vegetation moisture loss as represented by the NDMI and moisture stress. The region had witnessed long dry season since the beginning of May until the date of the fire, making the temperature reach to its highest level on the 26th of June 2021, which is 4 days before the fire started. The NDMI values obtained from the 29th of June pre-fire images in figures (5 i & ii), are ranging from 0 to 0.3 that represents the moisture content at the study area surface is ranging from mid-high to low water content, with low water stress and average canopy cover. When comparing it with post-fire images figures (6 i & ii) on the 26th of December 2021, the NDMI mean values had significantly dropped to from -0.2 to -0.24 which demonstrates very low moisture with dry and very low canopy cover. When visually analyzing the moisture stress images, on the left shows the water diminishing over the burnt area, it`s now mostly dry with NDMI lower than zero apart from some areas mostly at the edge of the burnt area space, when it used to be ranging from low to moderate water stress a few days before the fire.

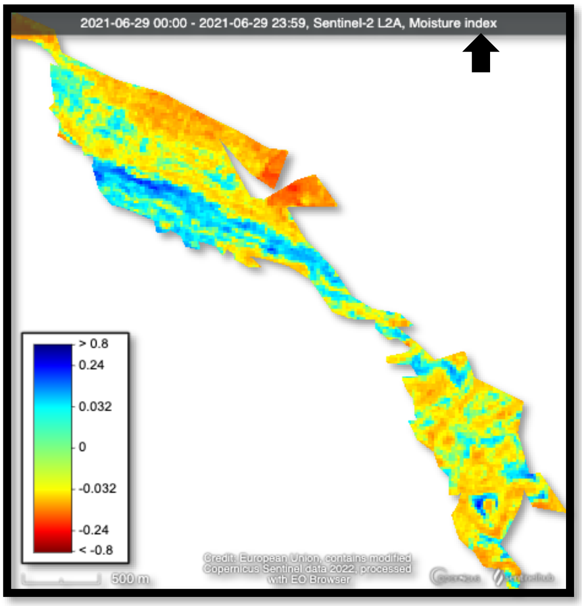

Figure 5 (i): NDMI of Pre (29th June) Ain Marah wildfire.

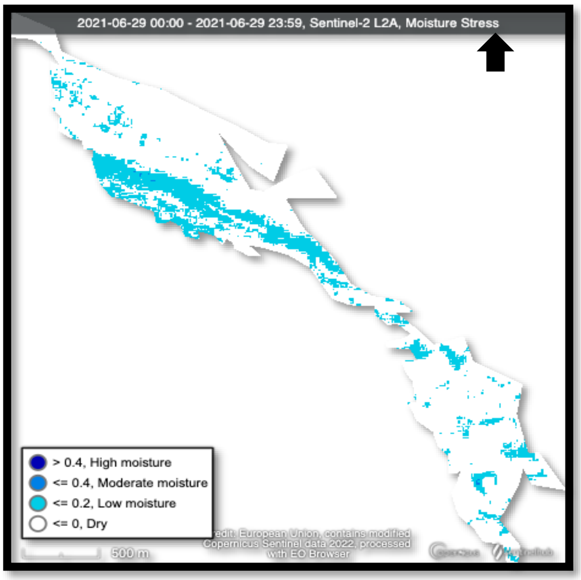

Figure 5 (ii): Moisture stress of Pre (29th June) Ain Marah wildfire [Copernicus 2022].

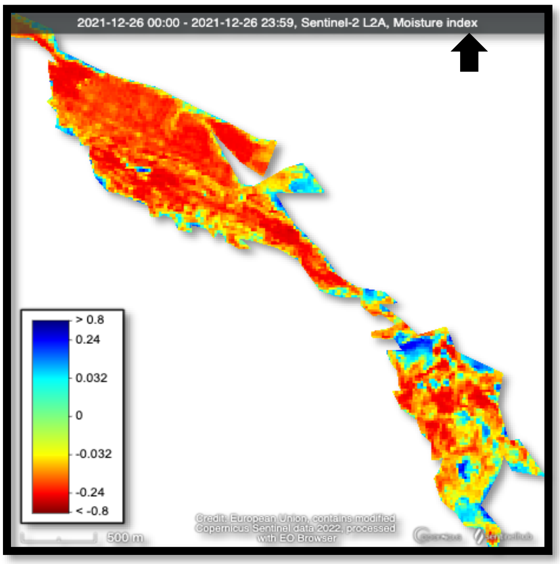

Figure 6 (i). NDMI of Post (26th December) Ain Marah wildfire.

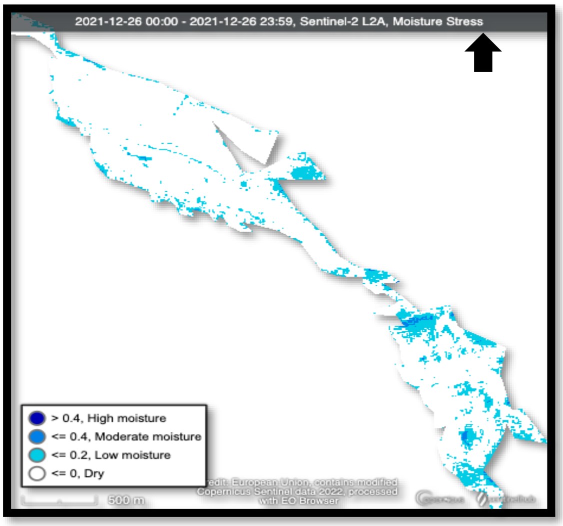

Figure 6 (ii): Moisture stress of Post (26th December) Ain Marah wildfire (Copernicus 2022).

To gain a broader view of the water content of the area, NDMI mean values were obtained from August, 18th 2020 to August 18th 2021 and illustrated in chart (1), over the dry and rainy seasons. Starting from the non-rainy months of August, September until the beginning of October show that the NDMI values had fluctuated from 0.10 to 0.15 expressing an average canopy cover, high water stress which is shortage of the leaves water content over the study area.

Since the 10th of October 2020 there had been gradual increments of the NDMI mean values, ranging from 0.17 to 0.39, that remained at the same fluctuation levels until mid-February 2021. This is obviously the precipitation that has taken place over this period. The NDMI values representing the vegetation cover is average canopy cover, low water stress. This variation instability continued until the beginning of end of April, which is the change from wet season to a dry hot period. That was the turning point to the gradual decline of the vegetation moisture to record 0.23 in the April 20 to 0.11 in June 29th 2021. As it could be clearly seen at chart (1), a day after this date the NDMI recorded a significant decline to record a ranged values from – 0.23 on the beginning of July to -0.28 mid-August 2021. This demonstrates the very low canopy cover with very high water stress at the vegetation cover of the area. That was clear evidence of Ain Marah wild-fire effect on the vegetation moisture of the burnt area.

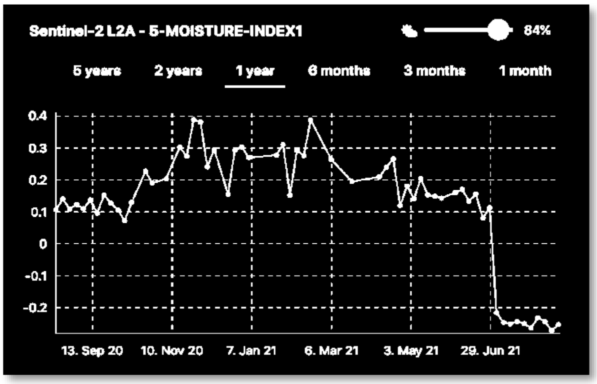

Chart 1: NDMI mean values variation from Aug 2020 to August 2021.

CONCLUSION

Remote sensing techniques were used to demonstrate the direct impact of Ain Marah wild-fire on the vegetation moisture. A new moisture index, the Normalized Multi-band Moisture Index (NDMI), is proposed for remote sensing of vegetation water content from space by using 10 metre spatial resolution with 5 days temporal resolution Sentinel-2A images . The preliminary results suggest that Ain Marah wild-fire had a significant negative impact on the vegetation and soil moisture. The area is characterized by moderate moisture content in the summer ranging from 0 to 0.3. While a day after the fire, these number had dropped to – 0.23 which represents a very high water stress. A recent Sentinel-2A image was used to detect the moisture states after 5 months of the fire, NDMI tracked that there had been a low recovery from July to December 26th 2021 to record a range of -0.2 to -0.24. However the results obtained from this is justified as the wild-fire has highly disastrous impact on the vegetation, thus the recovery process may take long time. Therefore, to gain the long term fire affect, more work is needed to be undertaken on the vegetation recovery after longer time.

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