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NDVI assessment versus two impact factors analysis (separate analysis based on chlorophyll content and leaf cellular structure): which method is more effective to detect declining health of an individual tree?

K. N. Au

ABSTRACT

In detecting the internal health of an individual tree, “two impact factors analysis” refers to evaluation of NIR and RED separately, instead of merging them together in one formula as in NDVI assessment. We use high resolution WorldView-2/-3 satellite data for our study. From our global case studies of stressed trees, we have found the following results: (1) NDVI works when the spectral reflectance in both NIR and RED bands deteriorates together/concurrently. (2) NDVI does not work when the spectral reflectance in NIR and RED bands varies. This will happen, as shown by our case studies of Tree 1 and Tree 2 of the removed stressed trees, and Tree 4 and Tree 5 of the collapsed stressed trees.

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NDVI; impact factors; leaf cellular structure; chlorophyll content

Introduction

NDVI (Normalized Difference Vegetation Index) is an indicator of vegetation health based on how plants absorb the red light by chlorophyll pigment and how they reflect the near-infrared (NIR) light by the leaf cellular structure derived from satellite data. A mathematical formula is used to calculate the NDVI as follows.

$$\text{NDVI} = (\text{NIR} - \text{RED}) \div (\text{NIR} + \text{RED})$$

The value of the NDVI will fall between -1.0 and $+1.0$, with 1 indicating the healthiest and 0 being the least healthy. It is widely used to estimate plant health in remote sensing.

The **two impact factors** derived from satellite data are also based on the spectral reflectance of these two bands, namely Red band produced by chlorophyll content

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and (b) Near-infrared (NIR) band produced by leaf cellular structure. More chlorophyll content will absorb more red light, so the spectral reflectance will drop in that band. On the other hand, firm leaf cellular structure will reflect more NIR light, so the spectral reflectance will rise in that band. But an important consideration has to be taken into account in the two impact factors method. If the rise in spectral reflectance is sudden and drastic over a short period, the situation is fluctuating which implies abnormal internal health condition. By comparing 3 or more sets of satellite data over a period, the two impact factors method will identify 4 categories of internal tree health, namely, (a) improving, (b) stable, (c) fluctuating and (d) declining. The former 2 categories indicate healthy internal condition, while the latter 2 categories imply unhealthy internal condition. **NDVI does not show these 4 categories of internal tree health.** These internal indicators are not discernible externally from onsite inspection. Therefore they provide important information to complement visual inspection to improve tree monitoring, maintenance and management.

Important difference between the two methods

As pointed out in the foregoing discussion, the two impact factors approach requires evaluation of the effects of changes in spectral reflectance of the two factors, namely (a) chlorophyll content (Red band) and (b) leaf cellular structure (NIR band) separately. On the other hand, NDVI assessment embraces both factors together in a single formula. In so doing, the different effect of the two factors in NDVI are merged. This will affect the assessment result of a single tree, as illustrated by the case studies of the 6 stressed trees in the following pages. This is the most important difference between the two methods. The two impact factors analysis provides more pertinent information than the NDVI assessment as illustrated in the following case studies.

The spectral reflectance we measure is the surface reflectance provided by the proprietary ACOMP (Atmospheric Compensation) data of WorldView-2/-3. It approximates what would be measured by a sensor held just above the Earth surface, without any alteration from the atmosphere. Hence the results are more reliable and consistent.

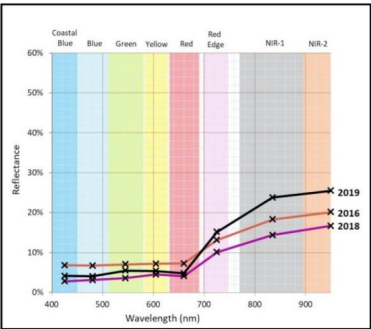
We have studied hundreds of individual trees globally over the past 9 years. Our methodology is to study the same tree over a period of several years and make comparison of the changes in spectral reflectance of the same tree. We do not compare a single tree with some other trees which may be of different species. Therefore we need not know the species of that single tree.

It should be noted that if the biotic and/or abiotic factors have not yet produced impact on the chlorophyll content and leaf cellular structure, there will be no changes in the spectral reflectance. Our methodology provides important information about the internal abnormal conditions of an individual tree not discernible externally from onsite inspection. Such internal abnormalities will develop earlier than appearance of external signs and symptoms. The internal abnormalities are indicated by fluctuating and declining spectral reflectance values which do not identify the causes. They have to be investigated by arborists through onsite inspection.

Case study of six stressed trees

(a) Removed Stressed Trees

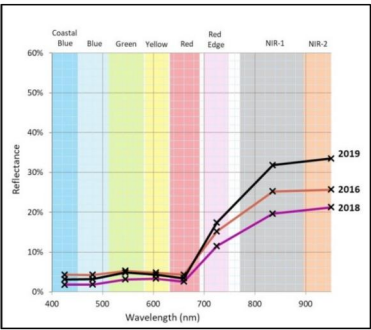
Tree 1
Wrong
NDVI
Result



Removed tree No.6 in Paramount Blvd. (Date of removal: June 2019)

Comparison		Leaf cellular structure and Chlorophyll content			$NDVI = \frac{NIR - RED}{NIR + RED}$		
		2016 (5/24/2016)	2018 (4/11/2018)	2019 (5/29/2019)	2016 (5/24/2016)	2018 (4/11/2018)	2019 (5/29/2019)
Leaf cellular structure (Average NIR)	%	18.27%	14.37%	23.78%	0.45	0.58	0.68
	Chlorophyll content (Red)	7.28%	4.09%	4.77%			
	Band	NIR1 18.27% NIR2 20.15% Average NIR 19.21% Red 7.28%	14.37% 16.68% 15.53% 4.09%	23.78% 25.49% 24.64% 4.77%			
Remarks		Fluctuating in both NIR and Red, indicating internal abnormality/ unhealthy condition			NDVI value rising continually, indicating healthy condition		

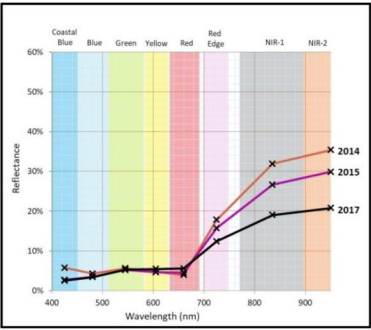
Tree 2
Wrong
NDVI
Result



Removed tree No.25 in Paramount Blvd. (Date of removal: June 2019)

Comparison		Leaf cellular structure and Chlorophyll content			$NDVI = \frac{NIR - RED}{NIR + RED}$		
		2016 (5/24/2016)	2018 (4/11/2018)	2019 (5/29/2019)	2016 (5/24/2016)	2018 (4/11/2018)	2019 (5/29/2019)
Leaf cellular structure (Average NIR)	%	25.24%	19.61%	31.84%	0.72	0.78	0.80
	Chlorophyll content (Red)	4.29%	2.58%	3.43%			
	Band	NIR1 25.24% NIR2 25.68% Average NIR 25.46% Red 4.29%	19.61% 21.23% 20.42% 2.58%	31.84% 33.51% 32.68% 3.43%			
Remarks		Fluctuating in both NIR and Red, indicating internal abnormality/ unhealthy condition			NDVI value rising continually, indicating healthy condition		

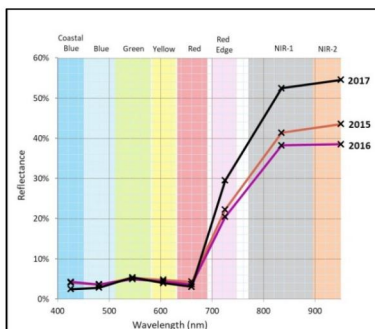
Tree 3
Correct
NDVI
Result



Removed tree in Lei Yue Mun Park, Hong Kong (Date of removal: February 17, 2017)

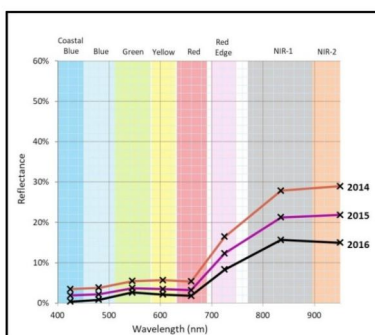
Comparison		Leaf cellular structure and Chlorophyll content			$NDVI = \frac{NIR - RED}{NIR + RED}$		
		2014 (19/11/2014)	2015 (9/1/2015)	2017 (21/1/2017)	2014 (19/11/2014)	2015 (9/1/2015)	2017 (21/1/2017)
Leaf cellular structure (Average NIR)	%	31.91%	26.66%	19.03%	0.79	0.72	0.56
	Chlorophyll content (Red)	3.99%	4.51%	5.59%			
	Band	NIR1 31.91% NIR2 35.37% Average NIR 33.64% Red 3.99%	26.66% 29.90% 28.28% 4.51%	19.03% 20.77% 19.90% 5.59%			
Remarks		Declining in NIR and decreasing absorption in Red, indicating internal abnormality/ unhealthy condition			NDVI value dropping continually, indicating unhealthy condition		

(b) Collapsed Stressed Trees

Tree 4
Wrong
NDVI
Result

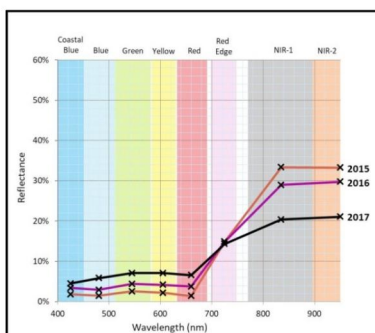
Collapsed tree in Central Park, New York (Date of collapse: August 15, 2017)

Comparison	Leaf cellular structure and Chlorophyll content			$NDVI = \frac{NIR - RED}{NIR + RED}$			
Year	2015 (7/6/2015)	2016 (22/7/2016)	2017 (28/6/2017)	2015 (7/6/2015)	2016 (22/7/2016)	2017 (28/6/2017)	
Leaf cellular structure (Average NIR)							
	Chlorophyll content (Red)						
	Band	NIR1 41.35% NIR2 43.54% Average NIR 42.45%	38.21% 38.49% 38.35%	52.45% 54.50% 53.48%	0.82	0.83	0.89
Remarks	Fluctuating in NIR and increasing absorption in Red, indicating internal abnormality/unhealthy condition			NDVI value rising continually, indicating healthy condition			

Tree 5
Wrong
NDVI
Result

Collapsed tree in Düsseldorf, Germany (Date of collapse: October 20, 2016)

Comparison		Leaf cellular structure and Chlorophyll content			NDVI = $\frac{NIR - RED}{NIR + RED}$		
Year		2014 (18/7/2014)	2015 (30/6/2015)	2016 (19/7/2016)	2014 (18/7/2014)	2015 (30/6/2015)	2016 (19/7/2016)
Leaf cellular structure (Average NIR)	%						
Chlorophyll content (Red)	%						
Band	NIR1	27.85%	21.28%	15.69%	0.68	0.74	0.79
	NIR2	28.98%	21.84%	14.97%			
	Average NIR	28.42%	21.56%	15.33%			
	Red	5.39%	3.18%	1.82%			
Remarks					Declining in NIR and increasing absorption in Red, indicating internal abnormality/unhealthy condition		
					NDVI value rising continually, indicating healthy condition		

Tree 6
Correct
NDVI
Result

Collapsed tree in Fanling, Hong Kong (Date of collapse: July 24, 2017)

Comparison		Leaf cellular structure and Chlorophyll content			NDVI = $\frac{NIR - RED}{NIR + RED}$		
Year		2015 (4/8/2015)	2016 (29/7/2016)	2017 (3/3/2017)	2015 (4/8/2015)	2016 (29/7/2016)	2017 (3/3/2017)
Leaf cellular structure (Average NIR)	%						
Chlorophyll content (Red)							
Band	NIR1	33.37%	28.95%	20.37%	0.92	0.77	0.52
	NIR2	33.27%	29.74%	21.06%			
	Average NIR	33.32%	29.35%	20.72%			
	Red	1.39%	3.74%	6.56%			
Remarks					Declining in NIR and decreasing absorption in Red, indicating internal abnormality/unhealthy condition		

Note: In NIR reflectance, rise implies improvement and fall indicates deterioration. But if it surges and declines drastically, it implies internal abnormality/instability. If it rises and falls or falls and rises, it means fluctuation.

In the Red band, higher reflectance implies less chlorophyll content to absorb Red light and lower reflectance implies more chlorophyll content to absorb Red light.

All these 6 trees were infected and diseased. The first 3 were removed before collapse, while the latter 3 collapsed unexpectedly, because they did not show obvious external warning signs and symptoms.

Tree 1 and Tree 2 were two removed trees from a retrospective study of 25 stressed trees in the Paramount Boulevard, Lakewood City, Los Angeles county, U.S.A. covering

the period from 2010 to 2019. They were Indian laurel fig trees (*Ficus Microcarpa*) infected by Bot Canker (*Botryosphaeria*) and were all removed in June 2019. Over the period from 2016 to 2019, the spectral reflectance in both NIR and Red band is highly fluctuating, being 9.11% in the NIR and 3.19% in the red band for Tree No. 6, and 12.26% in the NIR band and 1.71% in the Red band for Tree No. 25 in the Paramount Project. The relative low % variation in the Red band absorption for Tree No. 25 implies more consistent chlorophyll content to support green and dense canopy of that tree. Therefore Tree No. 25 was mistaken to be more healthy than Tree No. 6 from visual observation, but both trees were actually seriously stressed internally and were removed subsequently in June 2019.

For these 2 trees, the NDVI values show improvement over that period as indicated by the rising value. The rising trend is shown in the green bars on the diagram. The result is contrary to the actual situation, because they were actually declining and subsequently removed. Hence NDVI assessment of these two stressed trees does not present the actual declining health condition.

The removed stressed **Tree 3** in Lei Yue Mun Park, Hong Kong, showed declining spectral reflectance in both NIR band and Red band (higher reflectance because of less absorption). Such condition matches the NDVI value of declining health. This means that NDVI assessment will agree with the two impact factors analysis, when the spectral reflectance of both the NIR band and Red band is deteriorating concurrently.

In the light of this finding, it is therefore inappropriate to use NDVI to detect the internal health condition of a single tree because of the possible discrepancy. This finding is further supported by the following case studies of 3 collapsed stressed trees.

Tree 4 was a stressed elm tree collapsed in the Central Park, New York on August 15, 2017, nearly killing a mother and her three young children. Over the period from 2015 to 2017, this tree was highly fluctuating in the NIR band with a range of 15.13%. But the red band absorption was improving by 1.23% which supported an apparent healthy appearance.

According to press reports, that collapsed tree had been inspected annually, but there were no external signs of decay or disease. Its internal abnormality might be overlooked because of its external apparent healthy look. The NDVI assessment of this subsequently collapsed tree showed continual improvement incorrectly.

Tree 5 was another stressed tree in Düsseldorf, Germany. It collapsed on October 20, 2016, damaging a residual building and buried several parked cars underneath. The two impact factors analysis had detected marked declining internal health condition from July 2014 to July 2016. The aggravation in the internal health condition was indicated by the continually declining spectral reflectance in the NIR band, although there was successive increase in red band absorption. The rise in chlorophyll content provided an apparent external healthy look for that tree, but it was actually seriously stressed internally due to continual deterioration in leaf cellular structure. But the NDVI value of this stressed tree shows improvement. It therefore does not convey the correct situation.

Tree 6 was another stressed tree collapsed in Fanling, Hong Kong on July 24, 2017, injuring one person and crashing two mini-buses, two buses as well as one private car.

This tree, like the other removed **tree 3**, revealed continually declining spectral reflectance in **both** the NIR band and the Red band (reduced absorption due to lower chlorophyll content). In this case, the two impact factors analysis agrees with the NDVI assessment.

Unique Advantages of the Two Impact Factors

1. It is straight-forward, time-saving and cost-effective, providing early warning not discernible from onsite inspection.
2. The analysis is pixel-based rather than polygon-based to avoid air spaces, leaf shadows and ground features to produce reliable and consistent results.
3. Pruning will not adversely affect the spectral reflectance, because it is based on the average, not the aggregated value.
4. No hyperspectral, LiDAR and UAV data are required.
5. Special instruments and invasive methods are not used.
6. Chlorophyll content and leaf cellular structure are analogous to blood and blood vessels in the human body. If either one is abnormal, there will be internal health problem.

Conclusion

It has been generally assumed that the internal health of a single tree will also follow the same pattern as the agricultural crops, namely when the NIR reflectance declines, the Red reflectance will also deteriorate (rise in reflectance due to lower chlorophyll content to absorb the red light). But the above case studies have shown that it is not always the case as demonstrated by the stressed **Tree 1**, **Tree 2**, **Tree 4** and **Tree 5**. The deterioration in **both** NIR and Red band reflectance is applicable only to the stressed **Tree 3** and **Tree 6**.

Therefore, NDVI could detect a stressed tree when both impact factors of leaf cellular structure and chlorophyll content are deteriorating concurrently. If the two factors differ in impact on tree health, the NDVI result would be erroneous. Due to the probability of such discrepancy, it may not be reliable in using NDVI to detect the internal health of an individual tree.

Hence there is a need to evaluate the spectral reflectance of NIR and Red separately instead of merging them together in the NDVI formula to generate one value to indicate the internal health condition of a single tree.

The two impact factors analysis is not designed to foretell when or whether a stressed tree will collapse. Instead, it provides objective and early information about the changes in internal health condition of a single tree.

Disclosure statement

No potential conflict of interest was reported by the authors.

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