Analysis of Effects of Air Pollution on Mango and Custard apple Tree Leaves using ASD FieldSpec 4 Spectroradiometer and Spectral Indices

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ABSTRACT
This research aims to examine effects of Air pollution on chlorophyll content, water content, carotenoid content, anthocyanin content of Mango and Custard apple tree leaves using spectral indices. Samples are collected from Control Area (University Area) and Polluted Area (Bus Stand area). ASD FieldSpec4 Spectroradiometer machine is used for collecting spectral reflectance measurement of tree leaves. Spectral signatures are analyzed using spectral indices. Normalized Difference Vegetation Indices(NDVI) and Simple Ratio indices(SR), Red Edge Chlorophyll index ($CI_{Red\ Edge}$), Moderate Resolution Imaging Spectrometer (MERIS) Terrestrial Chlorophyll Index (MTCI), Double Difference Index (DD), Red-Edge Model (R-M) indices are used for estimate chlorophyll content. Water index (WI), Normalized water indices(NWI) are used for estimate water content. Carotenoid concentration index (CRI_{700}), Photochemical reflectance index (PRI), Plant senescencing reflectance Index (PSRI), Carotenoid concentration index ($RNIR*CRI_{550}$, $RNIR*CRI_{700}$) indices are used for estimate carotenoid content. Modified Anthocyanin Content Index (mACI), Anthocyanin Reflectance Index (ARI), Modified Anthocyanin Reflectance Index (mARI), Red/Green indices are used for estimate anthocyanin content. Chlorophyll content and Water content seemed inverse proportion with air pollution in Mango tree but directly proportion in Custard apple tree. Carotenoid Content are seemed directly proportion with air pollution in mango tree but inverse proportion in Custard apple tree. Anthocyanin content seemed inverse proportion with air pollution in both mango and Custard apple tree.

Keywords
Anthocyanin content, Carotenoid content, Chlorophyll content, Spectral Indices, Water content

1. INTRODUCTION
Air pollution is one of the most critical environmental and public health issues. Urbanization, economic development, transportation/motorization, rapid population growth and energy consumption are major driving impetuses of air pollution in many cities, especially in megacities. There are various solutions have been done for reduce or avoid pollution. Various strategies exist for controlling atmospheric pollution but vegetation provides one of the best natural way of cleaning the atmosphere. Plants not only helps in attenuation of air pollution but also in noise pollution reduction, controlling soil erosion and enhancing the aesthetic beauty of the area. Air pollutants effect plant growth adversely.

Most studies based on spectral indices have tried to establish semi-empirical relationships between laboratory-measured leaf pigments and remotely sensed data measured on the ground or extracted from satellite/airborne imagery [1], [2]. Knudson et al. state that chlorophyll content could be a good measure for the evaluation of damage prompted by pollutants. Hence, Chlorophyll content variation has been use as a part of various studies with a particular final objective to investigate the impacts of pollutants on plant [3]. Alex S. Olpenda and Enrico C. Paringit use vegetation indices namely the RVI, NDVI, DVI and REP for Bougainvillea Spectabilis for monitoring particulate air pollution in Metro Manila city[4]. Jan-Chang Chen et. al conduct study to examine variations of leaf chlorophyll content using remote sensing indices NDVI, modified normalized difference vegetation index (mNDVI), simple ratio(SR), and modified simple ratio (mSR) [5].

Sims and Gamon used a large experimental database composed of a vast range of functional types, leaf structure, and development stage (nearly 400 leaves). They compared their indices with commonly used ones and found that the indices mSR705 and mND705 were the best for correlation with chlorophyll concentration [6]. Interestingly, Broge and Leblanc compared different indices on large simulated spectra database at canopy scale. However, this model-based comparison is not related to experimental spectra, and no similar study at leaf scale exists [7].

Quantitative and rapid methods for assessing leaf water status are required for plant water stress management in forestry, agriculture, fire risk assessment and horticulture [8]. Several indices using the near-infrared region have been proposed as water stress indices with varying results depending on the species [9], [10]. Many researchers use spectral indices for estimate water content. Penuelas et al. use Water Index WI (R900/R970) for evaluation of plant water concentration (PWC). They state that a simple radiometer measuring plant reflectance at 680, 900, and 970 nm could speed up the estimation of PWC, and be useful in wild risk assessment and drought assessment [11].

Several researchers have successfully evaluated Carotenoid in vegetation using visible ratios [12], visible/NIR ratios [13], [14], [15], red edge reflectance-ratio indices [16], [17], spectral and derivative red edge indices [18] and for forest canopies, scaling-up and model inversion methods with narrow bands are used [19].

The anthocyanin is common pigments in higher plants. For estimating leaf Anthocyanin content non-destructively, several vegetation indices were developed. These indices are depending on reflectance in a few spectral bands with different levels of sensitivity to changes in Anthocyanin content and also to the content of other pigments. Gamon and Surfus proposed using a red/green index, a ratio of reflectance in the red and the green spectral bands, to evaluate Anthocyanin content [20].

2. LITERATURE SURVEY

Researches [21], [22] [23] [24], use indices for chlorophyll estimation based on reflectance at 550 nm and/or around 700 nm and showed good result in Chlorophyll estimation. C. Lin et al. evaluate chlorophyll concentrations of fresh and water-stressed leaves. They state that estimation of chlorophyll concentration using only the remotely sensed reflectance will be seriously affected by the reflectance changes caused by a departure of water content from the non-water-stressed conditions. The significant uncertainty for the estimation of chlorophyll concentration is caused by the reflectance changes induced by variations of the foliar water content [25]. Jan-Chang CHEN1 et al. seemed index mNDVI705 is more sensitive to detecting chlorophyll content in a wide range of tree species across a terrain. They are shown that among the indices tested, mNDVI detects the best in different terrain vegetation reflection [26].

Driss Haboudane et al. was used several combined indices to test and estimate chlorophyll content using hyperspectral imagery. They state that Modified Chlorophyll Absorption Ratio Index/ Optimized Soil-Adjusted Vegetation Index (OSAVI), Triangular Chlorophyll Index/OSAVI, Moderate Resolution Imaging Spectrometer Terrestrial Chlorophyll Index/Improved Soil Adjusted Vegetation Index (MSAVI), and Red-Edge Model/MSAVI seem to be relatively consistent and more stable as estimators of crop chlorophyll content [27]. Qiu-xiang Yi et. al recognize that the optimal index for the estimation of cotton water content, i.e. EWT and FMC, Normalized Difference Vegetation Index (NDVI) and narrow band ratio type of vegetation index (RVI)[28].

E. Raymond Hunt and Barrett N. Rock show that indices derived from NIR and MIR reflectance cannot be used to remotely sense water stress [29]. M. A. Babar et al. show that the water-based indices WI and Normalized water index (NWI) have higher genetic correlations with grain yield compared to RNDVI, GNDVI and SR [30]. B. Prasad et al. suggest that use NWI-3 and NWI-4 as indirect selection tools for grain yield improvement in winter wheat breeding programs in Great Plains rain-fed environments [31].

Daniel A. Sims and John A. Gamon use SIPI, PSRI and PRI indices for evaluate carotenoid content in vegetation. They express that total carotenoid content was closely related to total chlorophyll content. Thus, the chlorophyll indices were also the best indicators of total carotenoid content [32].

Anatoly A. Gitelson et al. determine anthocyanin contents using mACI, ARI, mARI and Red/Green index. They express that Reflectance-based indices ARI and mARI were observed to be effective in the nondestructive estimation of anthocyanin content in the leaves of four irrelevant species despite broad differences in composition and pigment contents. Chlorophyll content was accurately estimated by the CI red edge indix that uses two spectral bands, the red edge and the NIR [33]. Gitelson, A. A et al. retrieve Anthocyanin content from reflectance over a wide range of composition and pigment contents. Anthocyanin reflectance index in the form ARI= $(R550)^{-1}$ - $(R700)^{-1}$, where $(R550)^{-1}$ and $(R700)^{-1}$are inverse reflectances at 550 and 700 nm, respectively, allowed an accurate estimation of Anthocyanin accumulation, even in minute amounts, in intact senescing and stressed leaves [34].

3. MATERIALS AND METHODOLOGY

3.1 Study Area

The leaf samples of two different trees are given in table 1 used in this study. These samples are collected from Bus Stand Area and Dr. Babasaheb Ambedkar Marathwada University of Aurangabad city which is one district of Maharashtra state in western India. Aurangabad is located at 19° 53' N and 75° 23' E. The annual mean temperature at the study area range from 17 to 33 °C and average annual rainfall is 710 mm. Aurangabad is connected by roads with various cities of Maharashtra and other states. From Dhule to Solapur, 211 National Highway passes through the city. Aurangabad has road connectivity to Pune, Ahmednagar, Nagpur, Jalna, Beed, Mumbai and the path are presently four lane street.

Table 1: Tree species used in this study

Tree Species		
Common Names	**Family**	**Botanical Names**
Mango	Anacardiaceae	Mangifera Indica
Custard apple	Annonaceae	Annona Squamosa

3.2 Plant Material and Reflectance Measurement

There are 2 species, namely Mango and Custard apple are used in this study. Two Areas are selected foe collect tree leave samples, Control Area (University Area) and Polluted Area (Bus Stand Area). From each area, 5 leave of each tree are taken for reflectance measurement. The ASD Fieldspec 4 Spectroradiometer machine is used for spectral reflectance measurement. Each leaf from polluted area is cleaned with dry cotton and then reflectance measurements are taken. The sampling interval at the spectral range (350-1000nm) is 1.4nm and at the spectral range (1000-2500nm) is 1.1nm.

The height of the light source is 44 cm, Gun height is 5.5 cm and distance between light source and the gun is 45 cm. Samples are collected on 15/06/2016 at 11.30 am and reflectance measurement are taken between 12.00 pm to 1.00Pm. 8^{o} Field Of View (FOV) is used and room temperature is maintained 24^{o}C when taking spectral reflectance. Length of Mango tree leave is 15-30 cm and width is 3-8 cm. Length of Custard apple tree leave is 5-10 cm and width is 3-5 cm. Spectral reflectance of samples are captured using RS^3 Software.

3.3 Spectral Indices

ViewSpecPro Software is used for Data Analysis. Spectral reflectance captured by RS^3 gives input to ViewSpecPro Software. Mean value calculated using 5 leave of every tree from each area. Table 2,3,4,5 shows the spectral indices used in this study. Spectral indices applied on Mean value.

Table 2: Spectral Reflectance Indices used for Chlorophyll content estimation

Index Name	Index calculation	Reference
$NDVI_{705}$	$\frac{(R_{750} - R_{705})}{(R_{750} + R_{705})}$	[5]
$mNDVI_{705}$	$\frac{R_{750} - R_{705}}{R_{750} + R_{705} - 2R_{445}}$	[5]
SR_{705}	$\frac{R_{750}}{R_{705}}$	[5]
mSR_{705}	$\frac{R_{750} - R_{445}}{R_{705} - R_{445}}$	[5]
$CI_{Red\ Edge}$	$\frac{R_{750}}{R_{710}}$	[35]
MTCI	$\frac{(R_{750} - R_{710})}{(R_{710} - R_{680})}$	[27]
DD	$(R_{750} - R_{720}) - (R_{700} - R_{670})$	[27]
R-M	$\frac{R_{750}}{R_{720}} - 1$	[27]

Table 3: Spectral Reflectance Indices used for Water content estimation

Index Name	Index calculation	Reference
WI	$\frac{R_{900}}{R_{970}}$	[10], [11]
NWI-1	$\frac{(R_{970} - R_{900})}{(R_{970} + R_{900})}$	[30]
NWI-2	$\frac{(R_{970} - R_{850})}{(R_{970} + R_{850})}$	[30]
NWI-3	$\frac{(R_{970} - R_{880})}{(R_{970} + R_{880})}$	[30]
NWI-4	$\frac{(R_{970} - R_{920})}{(R_{970} + R_{920})}$	[30]

Table 4: Spectral Reflectance Indices used for Carotenoid content estimation

Index Name	Index calculation	Reference
CRI_{700}	$\frac{1}{R_{515}} - \frac{1}{R_{700}}$	[12], [28],
PRI	$\frac{(R_{531} - R_{570})}{(R_{531} + R_{570})}$	[28]
PSRI	$\frac{(R_{680} - R_{500})}{R_{750}}$	28[28]
$RNIR * CRI_{550}$	$\frac{1}{R_{510}} - \frac{1}{R_{550}} * R_{770}$	[12], [28]
$RNIR * CRI_{700}$	$\frac{1}{R_{510}} - \frac{1}{R_{700}} * R_{770}$	[12], [28]

Table 5: Spectral Reflectance Indices used for Anthocyanin content estimation

Index Name	Index calculation	Reference
mACI	$\frac{R_{NIR}}{R_{Green}}$	[35]
ARI	$\frac{1}{R_{green}} - \frac{1}{R_{rededge}}$	[35]
mARI	$\left(\frac{1}{R_{green}} - \frac{1}{R_{rededge}}\right) * R_{NIR}$	[35]
Red / Green	$\frac{R_{red}}{R_{green}}$	[33]

4. RESULTS AND DISCUSSION

Figure 1 and 2 shows the Mean reflectance of all trees. The pink line shows reflectance of leave collected from Control Area (University Area) and blue line shows the reflectance of leave collected from Polluted Area (Bus Stand Area). The reflectance of mango tree leaves is higher in some regions of Control Area and reflectance of Custard apple tree leaves in Control Area is higher in all regions than Polluted Area.

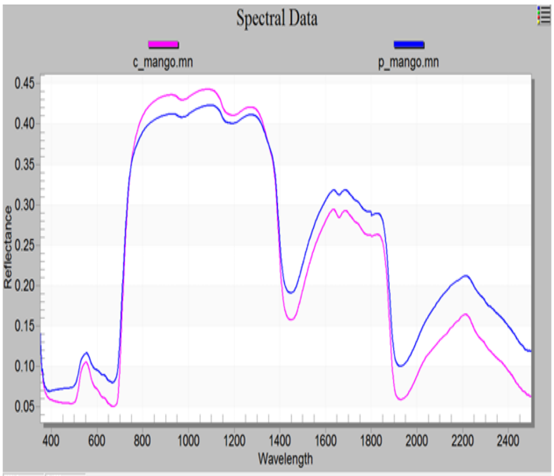

Figure 1: Mean reflectance of Mango Trees

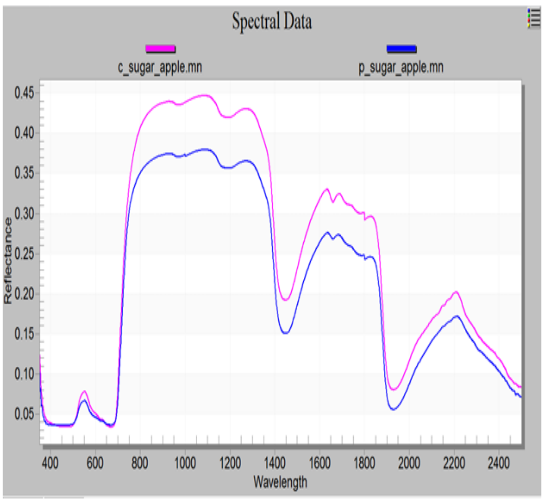

Figure 2: Mean reflectance of Custard apple Trees

4.1 Analysis of Chlorophyll Content

Table 6 shows chlorophyll content estimation using spectral indices. For Mango tree indices values are high in Control Area and low in Polluted Area. But in Custard apple tree indices values are low in Control Area and high in Polluted Area. mSR_{705} index have maximum value and DD index have minimum value.

Table 6: Chlorophyll content of trees

Tree Name	Spectral Indices	Control Area (University Area)	Polluted Area (Bus Stand Area)
Mango	$NDVI_{705}$	0.446	0.365
	$mNDVI_{705}$	0.576	0.507
	SR_{705}	2.607	2.147
	mSR_{705}	3.713	3.055
	$CI_{Red\ Edge}$	2.095	1.832
	MTCI	1.586	1.486
	DD	0.070	0.050
	R-M	0.530	0.429
Custard apple	$NDVI_{705}$	0.491	0.533
	$mNDVI_{705}$	0.582	0.652
	SR_{705}	2.930	3.283
	mSR_{705}	3.785	4.750
	$CI_{Red\ Edge}$	2.303	2.517
	MTCI	1.718	2.220
	DD	0.079	0.093
	R-M	0.621	0.706

For Mango tree using $NDVI_{705,}$ $mNDVI_{705,}$ $SR_{705,}$ $mSR_{705,}$ $CI_{Red\ Edge}$, MTCI, DD, R-M indices, it is found that Control Area has 0.081, 0.069, 0.460, 0.658, 0.263, 0.100, 0.030, 0.101 more chlorophyll content than Polluted Area respectively. For Custard apple tree using same indices, Control Area has 0.042, 0.070, 0.353, 0.965, 0.214, 0.502, 0.014, 0.085 less chlorophyll content than Polluted Area respectively. Figure 3 shows graphical representation of chlorophyll content using spectral indices.

4.2 Analysis of Water Content

Table 7 shows water content estimation using spectral indices. For Mango trees WI index value are high in Control Area and low in Polluted Area but for Custard apple tree WI index value are low in Control Area and high in Polluted Area. For mango tree $NWI_{900,}$ $NWI_{850,}$ $NWI_{880,}$ NWI_{920} indices have low values in Control Area and high values in Polluted Area but for Custard apple tree $NWI_{900,}$ $NWI_{850,}$ $NWI_{880,}$ NWI_{920} indices have high values in Control Area and low values in Polluted Area. WI index high value indicates high water content in tree leaf and low value indicates low water content in tree leaf but lowest values for $NWI_{900,}$ $NWI_{850,}$ $NWI_{880,}$ NWI_{920} indices indicates high water content and high value indicates low water content in tree leaf .

For Mango tree using WI, $NWI_{900,}$ $NWI_{850,}$ $NWI_{880,}$ NWI_{920} indices, it is found that Control area has 0.005, 0.002, 0.002, 0.002, 0.002 high water content than Polluted Area respectively. Using same indices, For Custard apple tree Polluted area has 0.001, 0.000, 0.004, 0.000, 0.000 high water content than Control area respectively. Figure 4 shows graphical representation of water content using spectral indices.

Table 7: Water content of trees

Tree Species	Indices	Control Area (University Area)	Polluted Area (Bus Stand Area)
Mango	WI	1.012	1.007
	NWI_{900}	-0.006	-0.004
	NWI_{850}	0.002	0.004
	NWI_{880}	-0.003	-0.001
	NWI_{920}	-0.007	-0.005
Custard apple	WI	1.007	1.008
	NWI_{900}	-0.003	0.003
	NWI_{850}	0.007	0.003
	NWI_{880}	-0.001	-0.001
	NWI_{920}	-0.005	-0.005

4.3 Analysis of Carotenoid Content

Table 8 shows carotenoid content estimation using spectral indices. For all trees, $CRI_{700,}$ PRI, PSRI, $RNIR*CRI_{550}$, $RNIR*CRI_{700}$ indices value are low in Control area and high in Polluted area. For all indices low values indicates high carotenoid content and high value indicates low carotenoid content in tree leaf. For Mango tree $CRI_{700,}$ PRI, PSRI, $RNIR*CRI_{550,}$ $RNIR*CRI_{700}$ using indices, it is found that Control Area has 1.034, 0.017, 0.006, 3.748, 0.006 less carotenoid content than Polluted Area respectively. For Custard apple tree using same indices, Control Area has 1.294, 0.025, 0.008, 3.204, 3.166 more carotenoid content than Polluted Area respectively. Figure 5 shows graphical representation of carotenoid content using spectral indices.

Table 8: Carotenoid content of trees

Tree Species	Indices	Control Area (University Area)	Polluted Area (Bus Stand Area)
Mango	CRI_{700}	5.121	4.087
	PRI	0.022	0.005
	PSRI	-0.003	-0.009
	$RNIR*CRI_{550}$	12.736	8.988
	$RNIR*CRI_{700}$	12.628	9.440
Custard apple	CRI_{700}	9.229	9.235
	PRI	0.015	0.026
	PSRI	-0.003	0.001
	$RNIR*CRI_{550}$	19.015	19.465
	$RNIR*CRI_{700}$	19.304	23.905

4.4 Analysis of Anthocyanin Content

Table 9 shows anthocyanin content estimation using spectral indices. mACI, ARI, and mARI, Red/Green, were calculated using average reflectance values in following bands Green = 540 – 560 nm, Red = 660 – 680 nm, Red Edge = 690 – 710 nm, NIR = 760 – 800 nm. For all trees mACI, ARI and mARI indices values are high in Control Area and low in Polluted Area. But Red/Green index have low values in Control Area and high value in Polluted Area. High value for mACI, ARI and mARI indices indicates high anthocyanin content and low value indicates low anthocyanin content in tree leaf but for Red/ Green index high value indicates low Anthocyanin content in tree leaf and low value indicates high anthocyanin content in tree leaf.

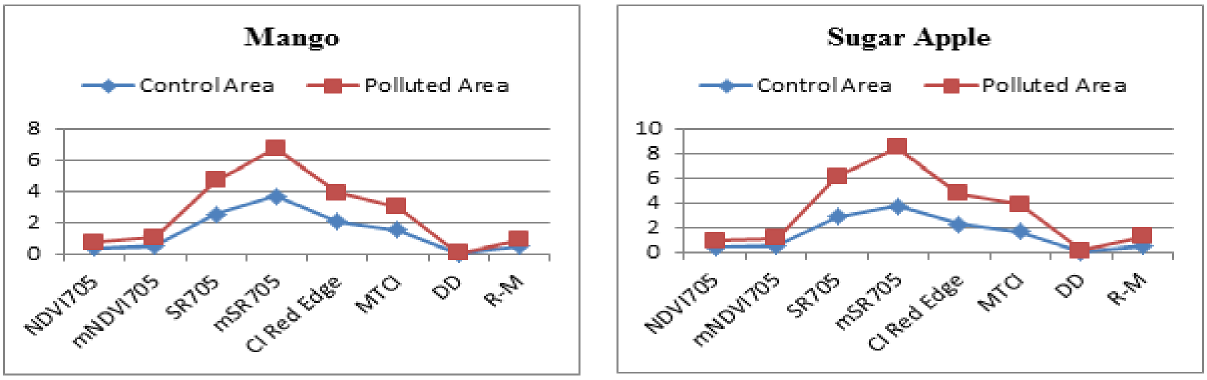

Figure 3: Graphical representation of Chlorophyll Content of Mango and Custard apple trees

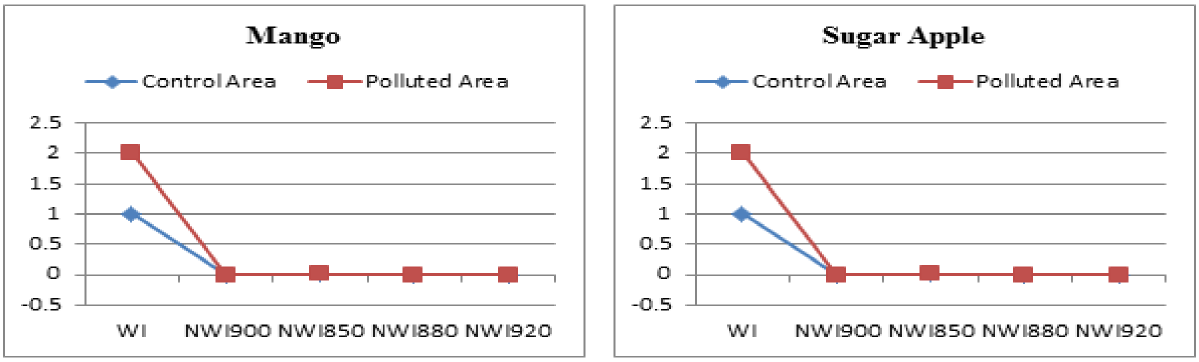

Figure 4: Graphical representation of Water Content of Mango and Custard apple tree

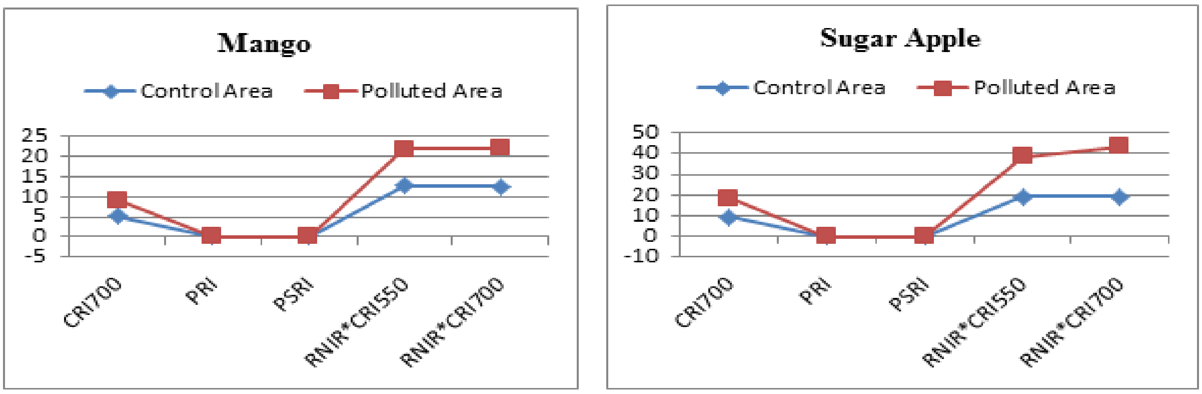

Figure 5: Graphical representation of Carotenoid of Mango and Custard apple trees

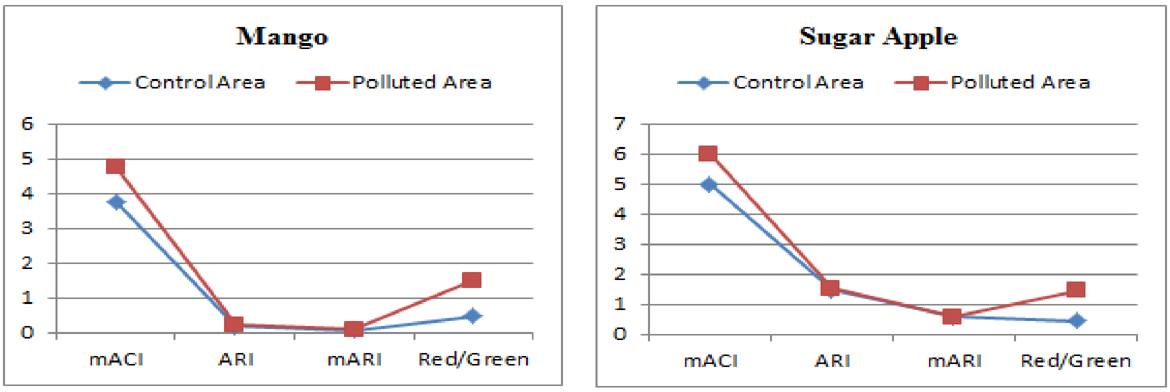

Figure 6: Graphical representation of Anthocyanin Content of Mango and Custard apple tree

For Mango tree using mACI, ARI, mARI, Red/Green indices, it is found that Control Area has 2.762, 0.129, 0.049, 0.522 more anthocyanin content than Polluted Area respectively. For Custard apple tree using same indices, Control Area has 4.013, 1.465, 0.566, 0.561 more anthocyanin content than Polluted Area respectively. Figure 6 shows graphical representation of anthocyanin content using spectral indices.

Table 9: Anthocyanin content of trees

Tree Species	Indices	Control Area (University Area)	Polluted Area (Bus Stand Area)
Mango	mACI	3.779	1.017
	ARI	0.181	0.052
	mARI	0.071	0.022
	Red/Green	0.490	1.012
Custard apple	mACI	5.013	1.000
	ARI	1.493	0.028
	mARI	0.576	0.010
	Red/Green	0.442	1.003

5. CONCLUSION

Chlorophyll content and Water content seemed inverse proportion with air pollution in Mango tree but directly proportion in Custard apple tree. Carotenoid Content are seemed directly proportion with air pollution in mango tree but inverse proportion in Custard apple tree. Anthocyanin content seemed inverse proportion with air pollution in both mango and Custard apple tree. mSR_{705} index is more sensitive to chlorophyll content, for water content WI index, for carotenoid content $RNIR*CRI_{700}$ index and for anthocyanin content mACI index is more sensitive.

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7. REFERENCES

[1] C. Lin1 , S. C. Popescu, S. C. Huang , P. T. Chang, and H. L. Wen, ”A novel reflectance-based model for evaluating chlorophyll concentrations of fresh and water-stressed leaves”, Biogeosciences, 2015, Vol. 12, pp.49–66.

[2] E. W. Chappelle, M. S. Kim, and J. E. McMurtrey, “Ratio analysis of reflectance spectra (RARS): An algorithm for the remote estimation of the concentrations of chlorophyll A, chlorophyll B, and the carotenoids in soybean leaves”, Remote Sensing of Environment, Mar. 1992, vol. 39, no. 3, pp. 239–247.

[3] Knudson, L. L., T. W. Tibbitts and G.E. Edwards, “Measuring of ozone injury by determination of leaf chlorophyll concentration”, Journal of Plant Physiology, 1977, vol. 60, pp. 606-608.

[4] Alex S. Olpenda1 and Enrico C. Paringit, ”Utilizing Spectral Reflectance And Vegetation Indices Of Bougainvillea Spectabilis For Monitoring Particulate Air Pollution In Metro Manila”, In proceedings of the 32nd Asian Conference on Remote Sensing (ACRS2011): Sensing for Green Asia, Taipei International Convention Center, Taipei, Taiwan, 2011.

[5] Jan-Chang CHEN, Chi-Ming YANG, Shou-Tsung Wu, Yuh-Lurng CHUNG, Albert Linton CHARLES, and Chaur-Tzuhn CHEN, ”Leaf chlorophyll content and surface spectral reflectance of tree species along a terrain gradient in Taiwan’s Kenting National Park”, Botanical Studies, 2007, vol. 48, pp. 71-77.

[6] Sims, D. A., & Gamon, J. A., “Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages”, Remote Sensing of Environment, 2002, vol. 81, pp. 337– 354.

[7] Broge, N. H., & Leblanc, E., “Comparing prediction power and stability of broadband and hyperspectral vegetation indices for estimation of green leaf area index and canopy chlorophyll density”, Remote Sensing of Environment, 2001, vol. 76(2), pp. 156–172.

[8] Inoue Y., Morinaga S., Shibayama M., “Non-destructive estimation of water status of intact crop leaves based on spectral reflectance measurements”, Japanese Journal of Crop Science, 1993, vol. 62, pp. 462-469.

[9] Carter, G. A., “Primary and Secondary effects of water content on the spectral reflectance of leaves”, American Journal of Botany, 1991, vol.78, pp. 916-924.

[10] Penuelas J., Filella I.,Serrano L., Save R., “ Cell wall elasticity and water Index (R970 nm/ R900 nm) in wheat under different nitrogen availabilitys”, International Journal of Remote Sensing , 1996, vol. 17, pp. 373-382.

[11] J. Penuelas, J. Pinol, R. Ogaya and I. Filella , ”Estimation of plant water concentration by the reflectance Water Index WI (R900/R970)”, International journal of remote sensing, 1997, vol.18(13), pp.2869-2875.

[12] Datt, B., “Remote sensing of chlorophyll a, chlorophyll b, chlorophyll a+b, and total carotenoid content in Eucalyptus leaves”, Remote Sensing of Environment, 1998, vol. 66, pp. 111–121.

[13] Gitelson, A. A., Gritz, U., & Merzlyak, M. N., “Relationships between leaf chlorophyll content and spectral reflectance and algorithms for non-destructive chlorophyll assessment in higher plant leaves”, Journal of Plant Physiology, 2003, vol. 160, pp. 271 –282.

[14] Gitelson, A. A., Keydan, G. P., & Merzlyak, M. N., “Three-band model for noninvasive estimation of chlorophyll, carotenoids, and anthocyanin content in higher plant leaves”, Geophysical Research Letters, 2006, vol.33, L11402.

[15] Haboudane, D., Miller, J. R., Tremblay, N., Zarco-Tejada, P. J., & Dextraze, L., “Integrated narrow-band vegetation indices for prediction of crop chlorophyll content for application to precision agriculture”, Remote Sensing of Environment, 2002, vol. 81, pp. 416–426.

[16] Carter, G. A., & Spiering, B. A., “Optical properties of intact leaves for estimating chlorophyll content”, Journal of Environmental Quality, 2002, vol. 31, pp.1424–1432.

[17] Richardson, A. D., & Berlyn, P., "Changes in foliar spectral reflectance and chlorophyll fluorescence of four temperate species following branch cutting", Tree Physiology, 2002, vol.22, 499–506.

[18] Le Maire, G., François, C., & Dufrene, E., "Towards universal broad leaf chlorophyll indices using PROSPECT simulated database and hyperspectral reflectance measurements", Remote Sensing of Environment, 2004, vol. 89, pp. 1–28.

[19] Zarco-Tejada, P. J., Miller, J. R., Mohammed, G. H., Noland, T. L., & Sampson, P. H., "Scaling-up and model inversion methods with narrow-band optical indices for chlorophyll content estimation in closed forest canopies with hyperspectral data", IEEE Transactions on Geoscience and Remote Sensing, 2001, vol. 39, pp. 1491–1507.

[20] Gamon JA, Surfus JS, "Assessing leaf pigment content and activity with a reflectometer", New Phytol, 1999, vol. 143, pp.105–117.

[21] Aoki M, Yabuki K, Totsuka T, Nishida M, "Remote sensing of chlorophyll content of leaf (I) effective spectral reflection characteristics of leaf for the evaluation of chlorophyll content in leaves of dicotyledons", Environment Control Biology, 1986, vol. 24, pp. 21– 26.

[22] Carter GA, Knapp AK, "Leaf optical properties in higher plants: linking spectral characteristics to stress and chlorophyll concentration", American Journal of Botany, 2001, vol. 84, pp.677–684.

[23] Richardson AD, Duigan SP, Berlyn GP, "An evaluation of noninvasive methods to estimate foliar chlorophyll content", New Phytol, 2002, vol. 153, pp. 185–194.

[24] Sims DA, Gamon JA, "Relationship between leaf pigment content and spectral reflectance across a wide range species, leaf structures and development stages", Remote Sensing Environment, 2002, vol. 81, pp. 337–354.

[25] Gitelson A, Merzlyak MN, "Remote estimation of chlorophyll content in higher plant leaves", International Journal of Remote Sensing, 1997, vol. 18, pp. 291–298.

[26] Gamon JA, Surfus JS, "Assessing leaf pigment content and activity with a reflectometer", New Phytol, 1999, vol. 143, pp.105–117.

[27] Driss Haboudane, Nicolas Tremblay, John R. Miller, and Philippe Vigneault, "Remote Estimation of Crop Chlorophyll Content Using Spectral Indices Derived From Hyperspectral Data", IEEE Transactions On Geoscience and Remote Sensing, 2008, vol. 46(2), pp. 423-437.

[28] P. H. Sampson, G. H. Mohammed, P. J. Zarco-Tejada, J. R. Miller, T. L. Noland, D. Irving, "The bioindicators of forest condition project: A physiological, remote sensing approach", The Forestry Chronicle, 2000, vol. 76, no. 6, pp. 941–952.

[29] E. Raymond Hunt, Jr, and Barrett N. Rock, "Detection of Changes in Leaf Water Content Using Near- and Middle-Infrared Reflectances", Remote Sensing of Environment, 1989, vol. 30, pp. 43-54.

[30] M. A. Babar, M. P. Reynolds, M. van Ginkel, A. R. Klatt, W. R. Raun, and M. L. Stone, "Spectral Reflectance Indices as a Potential Indirect Selection Criteria for Wheat Yieldunder Irrigation", Crop Science, 2006, vol. 46, pp. 578-588.

[31] B. Prasad, B. F. Carver, M. L. Stone, M. A. Babar, W. R. Raun, and A. R. Klatt, "Genetic Analysis of Indirect Selection for Winter Wheat Grain Yield using Spectral Reflectance Indices", Crop Science, 2007, vol. 47, pp. 1416- 1425.

[32] Daniel A. Sims, John A. Gamon, "Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages", Remote Sensing of Environment, 2002, vol. 81, pp. 337– 354.

[33] Gitelson, A. A., Keydan, G. P., & Merzlyak, M. N., "Three-band model for noninvasive estimation of chlorophyll, carotenoids, and anthocyanin content in higher plant leaves", Geophysical Research Letters, 2006, 33, L11402.

[34] Gitelson, A. A., M. N. Merzlyak, and O. B. Chivkunova, "Optical properties and non-destructive estimation of anthocyanin content in plant leaves", Photochemistry and Photobiology, 2001, vol. 74, pp.38 – 45.

[35] Anatoly A. Gitelson, Olga B. Chivkunova, and Mark N. Merzlyak, "Nondestructive Estimation of Anthocyanins and Chlorophylls in Anthocyanic Leaves", American Journal of Botany, 2009, vol. 96(10), pp. 1861–1868.