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Standard course – Remote Sensing
Lesson SR4 – Basic derived products : spectral indices

CERTH CENTRE FOR RESEARCH & TECHNOLOGY HELLAS

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What is a spectral index?

What is a spectral index?

A spectral index is a mathematical equation that is applied on the various spectral bands of an image per pixel. They are, therefore a combination of the pixel values from two or more spectral bands in an image.

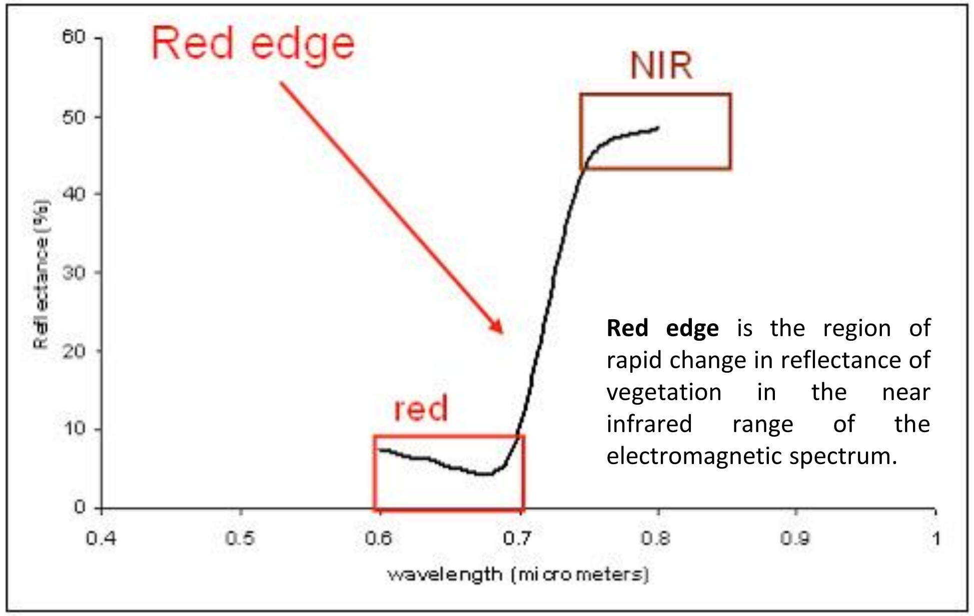
Spectral indices aim is to enhance spectral features that are not visible initially in the original input bands. The calculated spectral index is a « new » image that highlights pixels showing abundance or lack of a given variable of interest (greenness, humidity, aridity, etc...).

What is a spectral index?

There are several applications of satellite indices that include: agriculture, water resources, urban development, forest ecology, geology, soil sciences, vegetation,...

The spectral indices are developed based on the spectral properties of the object of interest.

- *Vegetation condition spectral indices*: based on the principle that the healthy vegetation reflects strongly in the Near Infrared spectrum while absorbing strongly in the visible red.
- *Water related spectral indices*: based on short wave infrared.
- *Snow cover and glacier monitoring spectral indices*: based on visual green and Short wave infrared spectra bands, since snow reflects most of the radiation in the visible bands while absorbing in the short wave infrared.

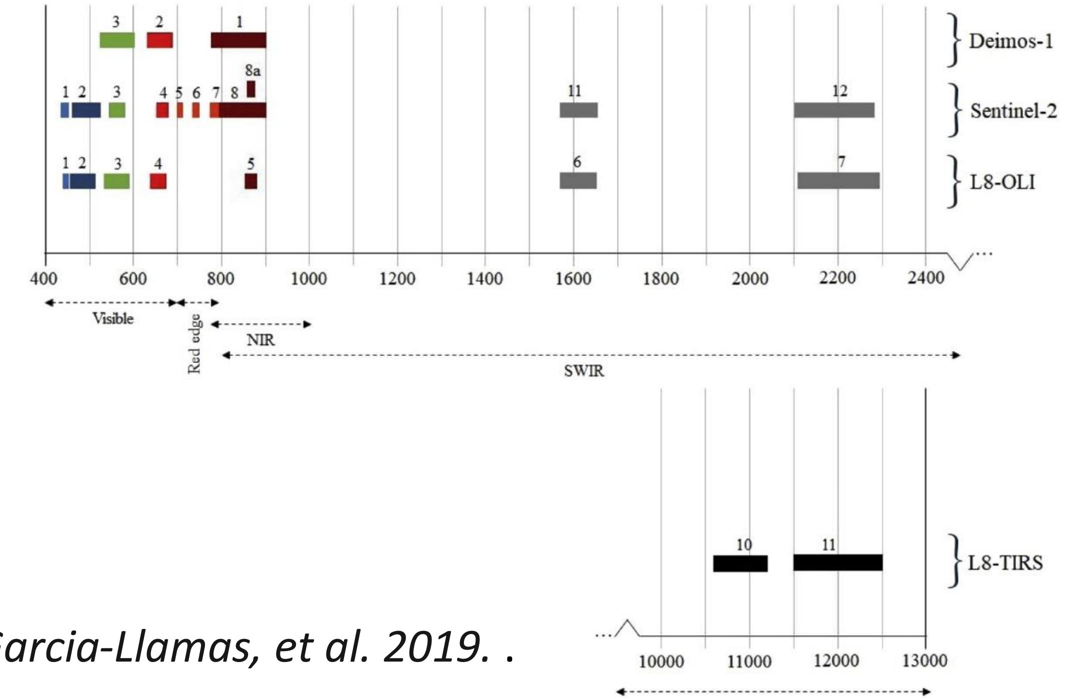


EUMeTrain

What is a spectral index?

The most common mathematical formula that is used is the <u>NORMALIZED DIFFERENCES,</u> but there are also more complex combinations of multiple bands.

$$(\text{Band}_X - \text{Band}_Y) / (\text{Band}_X + \text{Band}_Y)$$



Sources/Usage: Garcia-Llamas, et al. 2019. .

Vegetation condition indices

Vegetation condition: Simple Ratio

- The ratio of a NIR band to a red band (reflectance) can indicate vegetation status. That specific ratio is called Ratio Vegetation Index.

$$\boxed{RVI = \frac{\rho_{NIR}}{\rho_{RED}}}$$

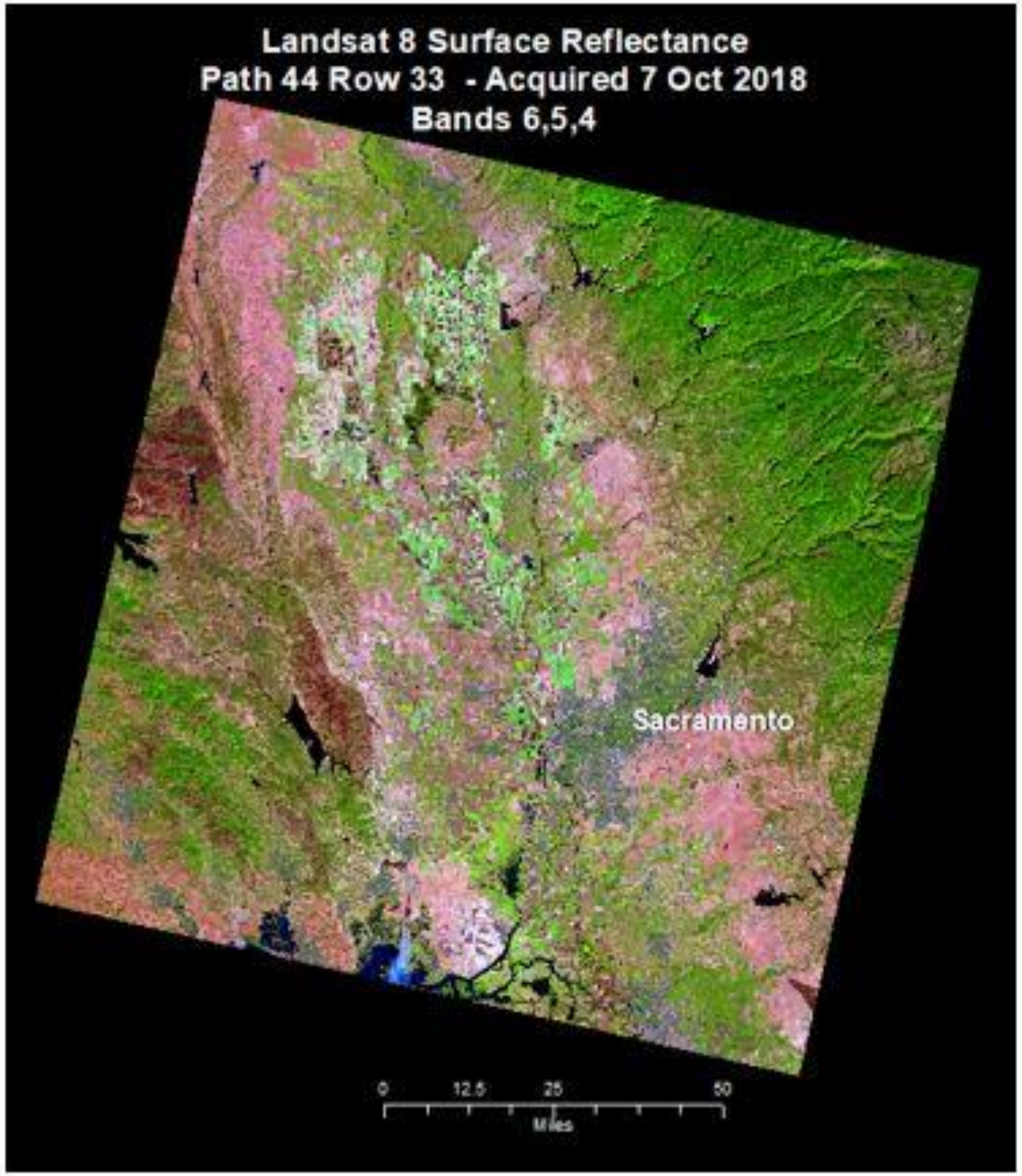
- The result of the ratio is greater when there is an increase of healthy green vegetation. This is because vegetation reflects more in the NIR than in the red spectral region.

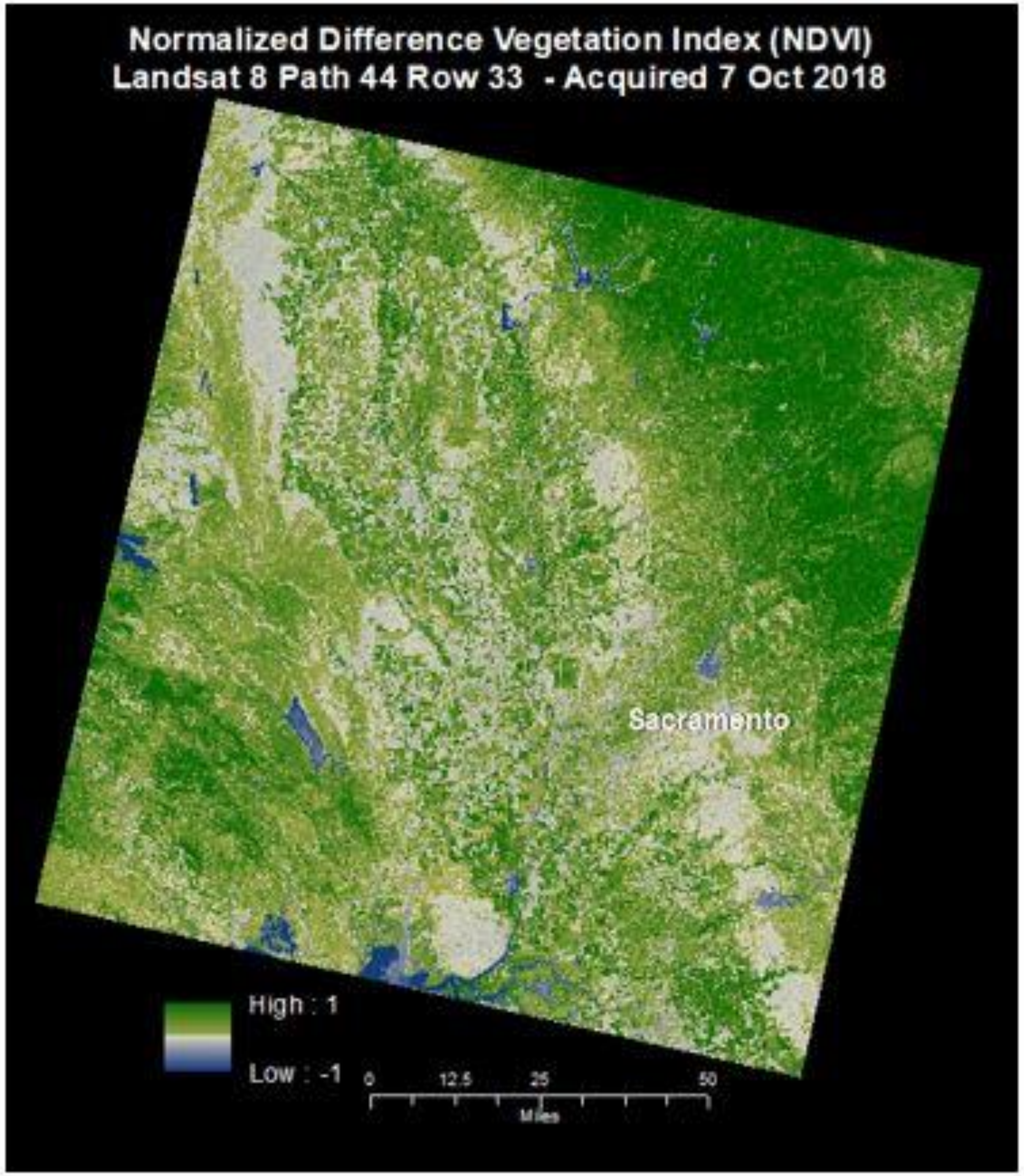
Vegetation condition: NDVI

- The most widely used index is the normalized difference vegetation (NDVI Normalized Difference Vegetation Index).
- NDVI is used to quantify vegetation greenness and it is useful in understanding vegetation density and assessing changes in plant health.
- It is used extensively to monitor vegetation on continental and global scales.
- Appears to be a poor indicator of vegetation biomass if ground cover is low (Huete and Jackson, 1987).
- Very low values of NDVI (0.1 and below) correspond to barren areas of rock, sand, or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate temperate and tropical rainforests (0.6 to 0.8). Values less than zero typically do not have any ecological meaning, so the range of the index is truncated to 0.0 to +1.0.

$$\boxed{NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}}$$

Valid range : [-1,1]





Sources/Usage: USGS.Public Domain

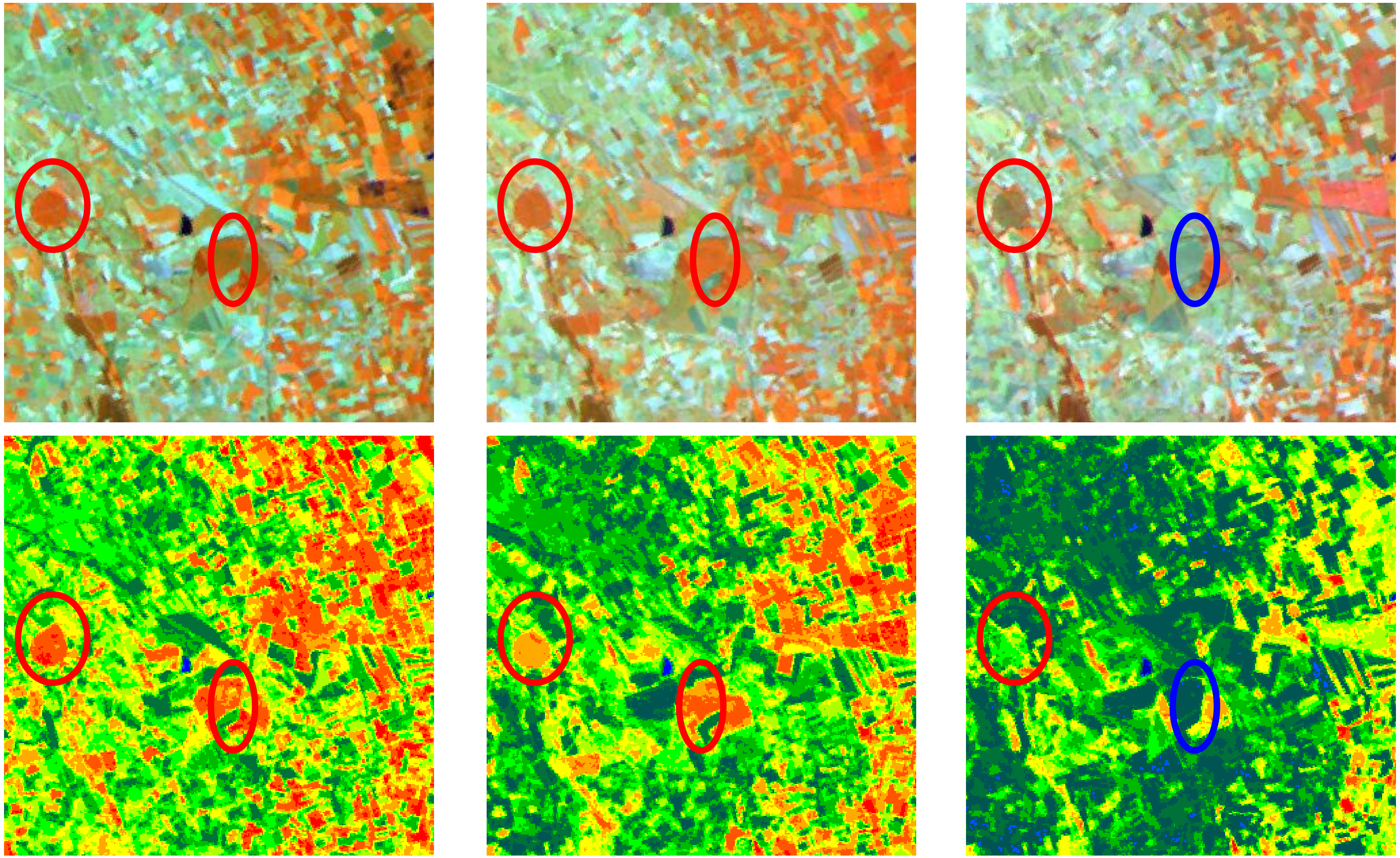
Vegetation condition: NDVI

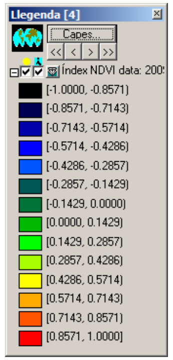
Mediterranean agricultural area

9/07 **10/08** **11/09**

Bands 4+5+3

NDVI





Active crops

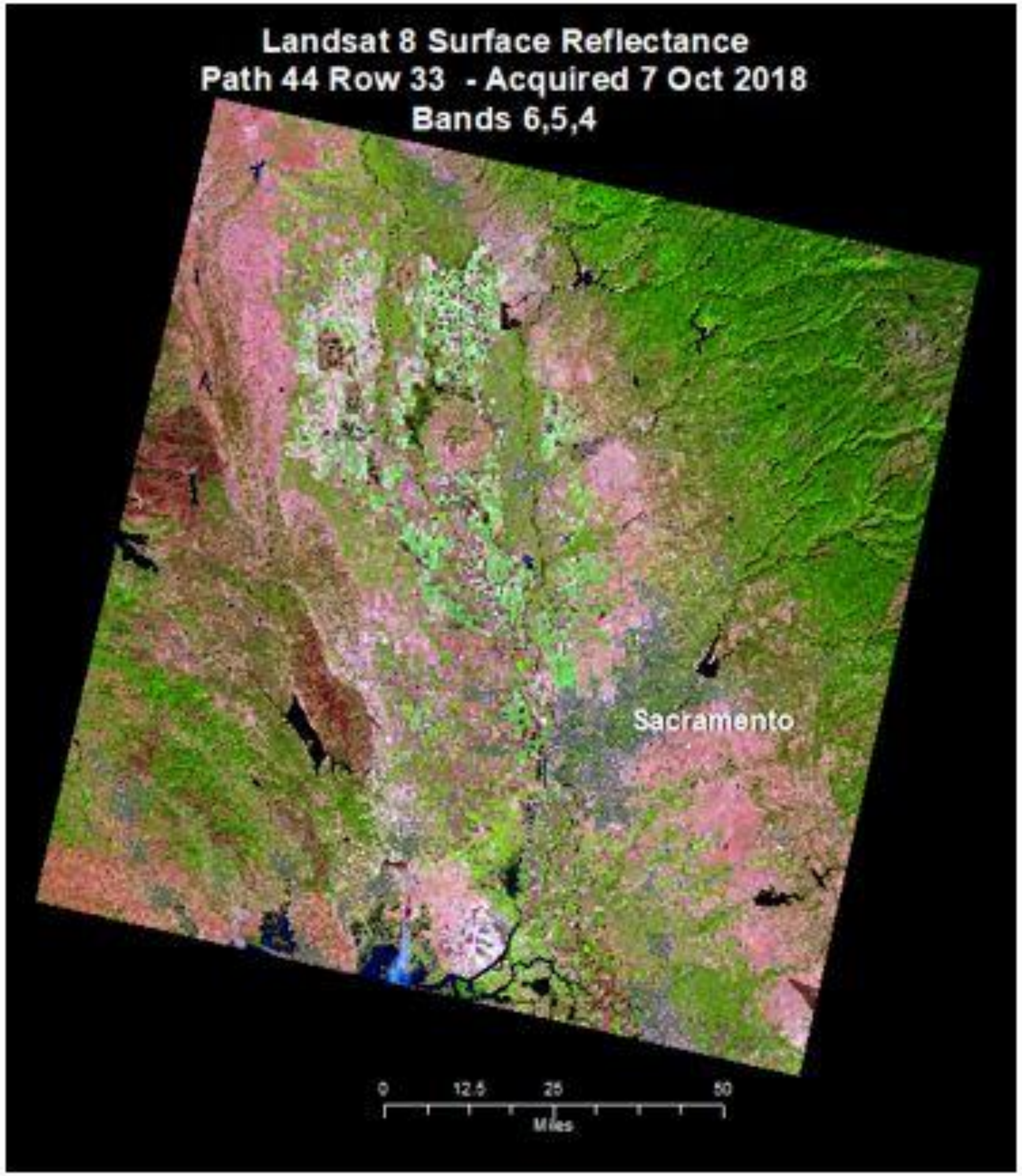
Mowed field

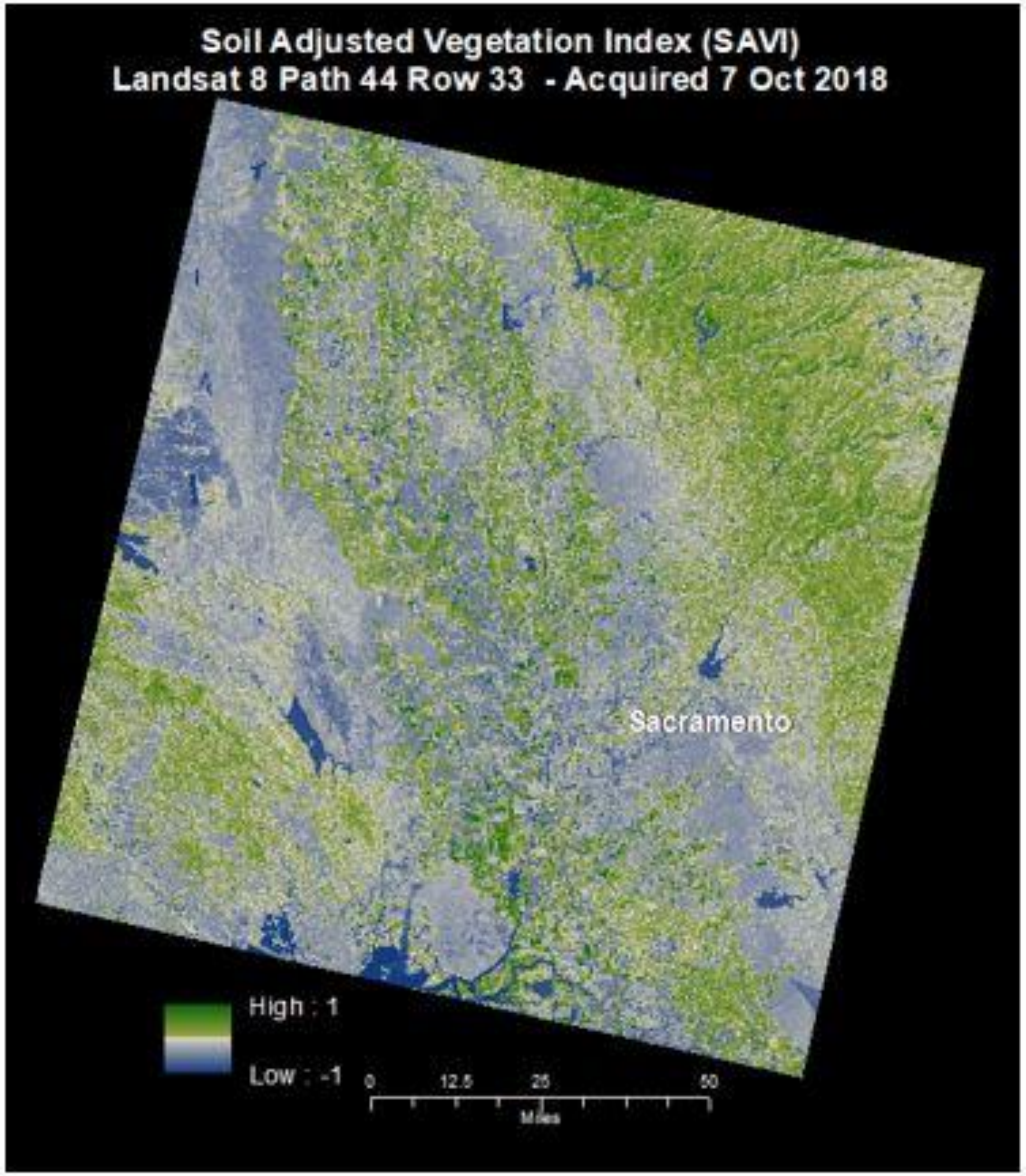
Vegetation condition: SAVI

- Soil Adjusted Vegetation Index (SAVI) is used to correct Normalized Difference Vegetation Index (NDVI) for the influence of soil brightness in areas where vegetative cover is low (Huete, 1988).
- Landsat Surface Reflectance-derived SAVI is calculated as a ratio between the R and NIR values with a soil brightness correction factor (L).
- The value of L varies by the amount or cover of green vegetation: in very high vegetation regions, L=0; and in areas with no green vegetation, L=1. Generally, an L=0.5 works well in most situations and is the default value used. When L=0, then SAVI = NDVI.
- Adjusting for the influence of soils comes at a cost to the sensitivity of the vegetation index. Compared to NDVI, SAVI is generally less sensitive to changes in vegetation (amount and cover of green vegetation), and more sensitive to atmospheric differences.

$$\boxed{\mathbf{SAVI = ((NIR - R) / (NIR + R + L)) * (1 + L)}}$$

Valid range : [-1,1]





Sources/Usage: USGS.Public Domain

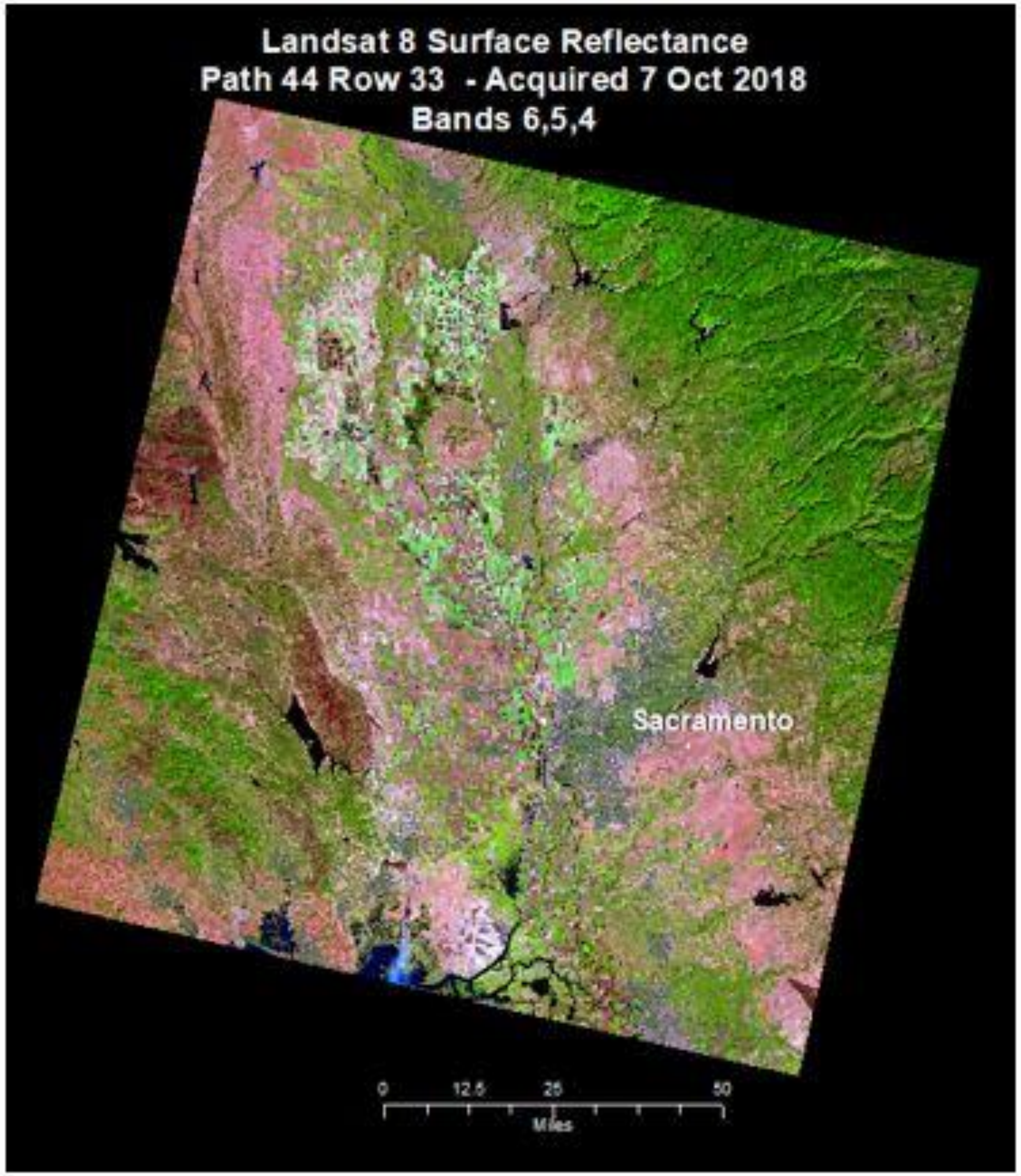
Vegetation condition: EVI

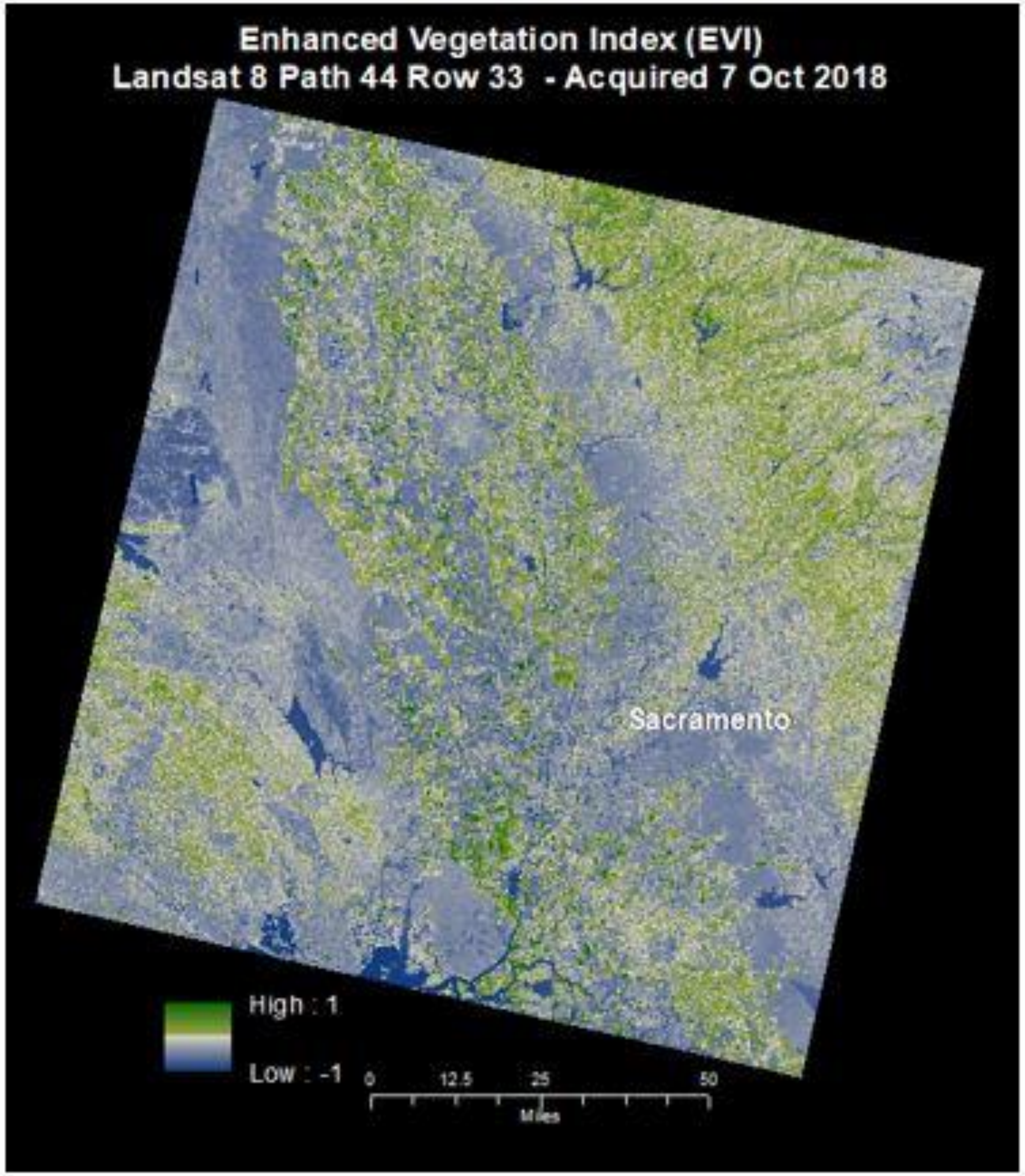
- Enhanced Vegetation Index (EVI) (Huete et al 2002) aims at addressing some of the limitations of the NDVI. The EVI was specifically developed to:
  - be more sensitive to changes in areas having high biomass (a serious shortcoming of NDVI),
  - reduce the influence of atmospheric conditions on vegetation index values (integrating the Blue band), and
  - correct for canopy background signals.
- One of the biggest current limitations to implementing EVI is that it needs a blue band in order to be calculated.
- However, there are also EVI versions that don't need the B band (EVI2)(Jiang, 2008).

$$EVI_{i,j} = G \times \frac{\rho_{i,j,IRP} - \rho_{i,j,R}}{\rho_{i,j,IRP} + C_1 \cdot \rho_{i,j,R} - C_2 \cdot \rho_{i,j,B} + L}$$

L=1; C1=6; C2=7.5; G=2.5

Valid range : [0,1]





Sources/Usage: USGS.Public Domain

Vegetation condition: NBR

- Normalized Burn Ratio (NBR) is used to identify burned areas and provide a measure of burn severity (Lopez Garcia et al, 1991).
- It is calculated as a ratio between the NIR and SWIR values in traditional fashion.
- Difference of Pre-fire and post-fire NBR images create a differenced (or *delta*) NBR image that indicates burn severity.

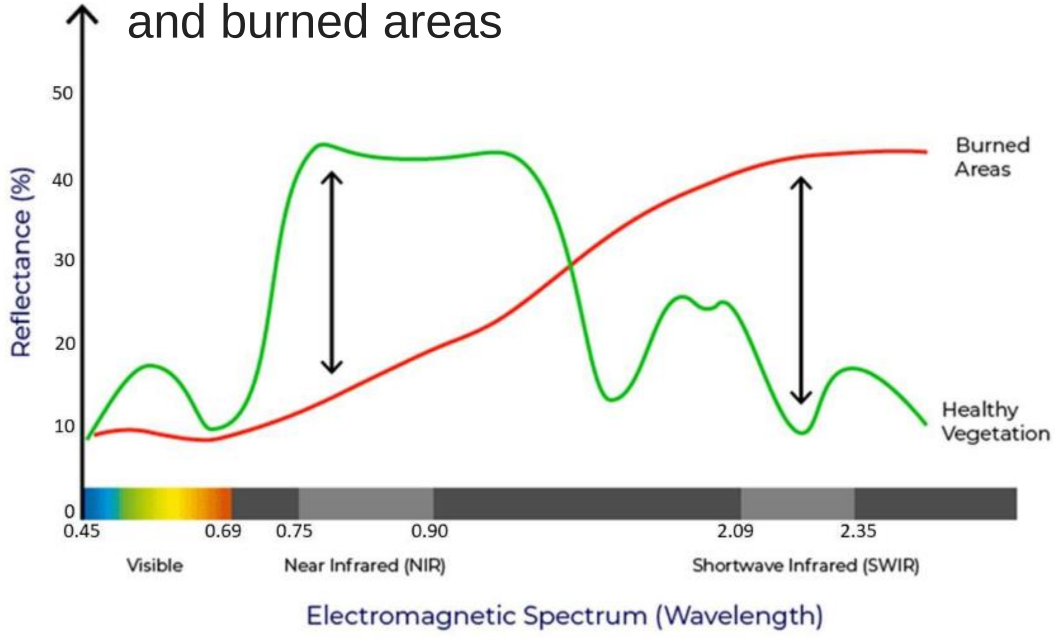
$$NBR = (NIR - SWIR) / (NIR + SWIR)$$

$$\Delta NBR = NBR_{pre\text{-}fire} - NBR_{post\text{-}fire}$$

Valid range : [0,1]

ΔNBR	Burn Severity
< -0.25	High post-fire regrowth
-0.25 to -0.1	Low post-fire regrowth
-0.1 to +0.1	Unburned
0.1 to 0.27	Low-severity burn
0.27 to 0.44	Moderate-low severity burn
0.44 to 0.66	Moderate-high severity burn
> 0.66	High-severity burn

Comparison of the spectral response of healthy vegetation and burned areas



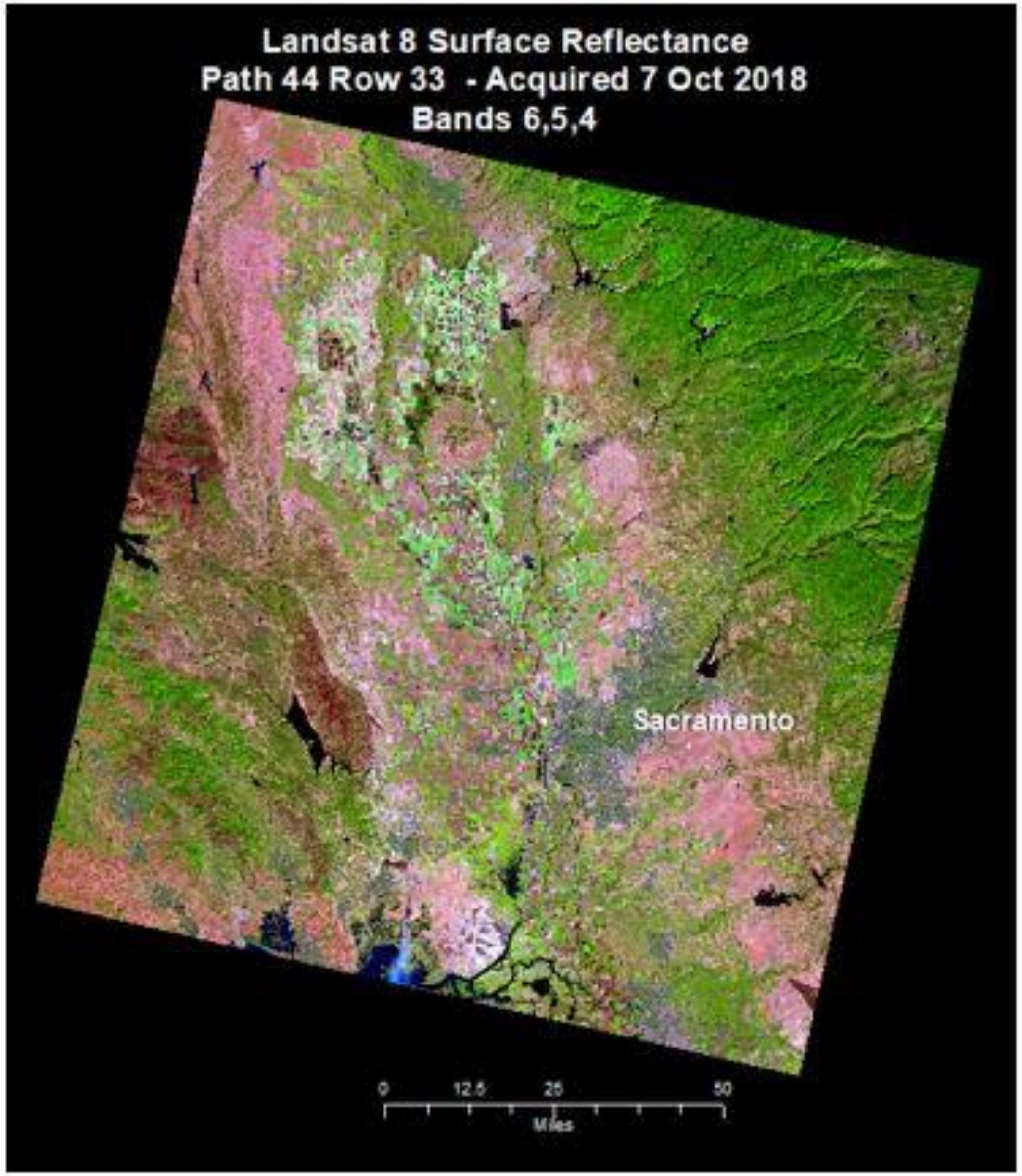
Sources/Usage: USDA forest Service

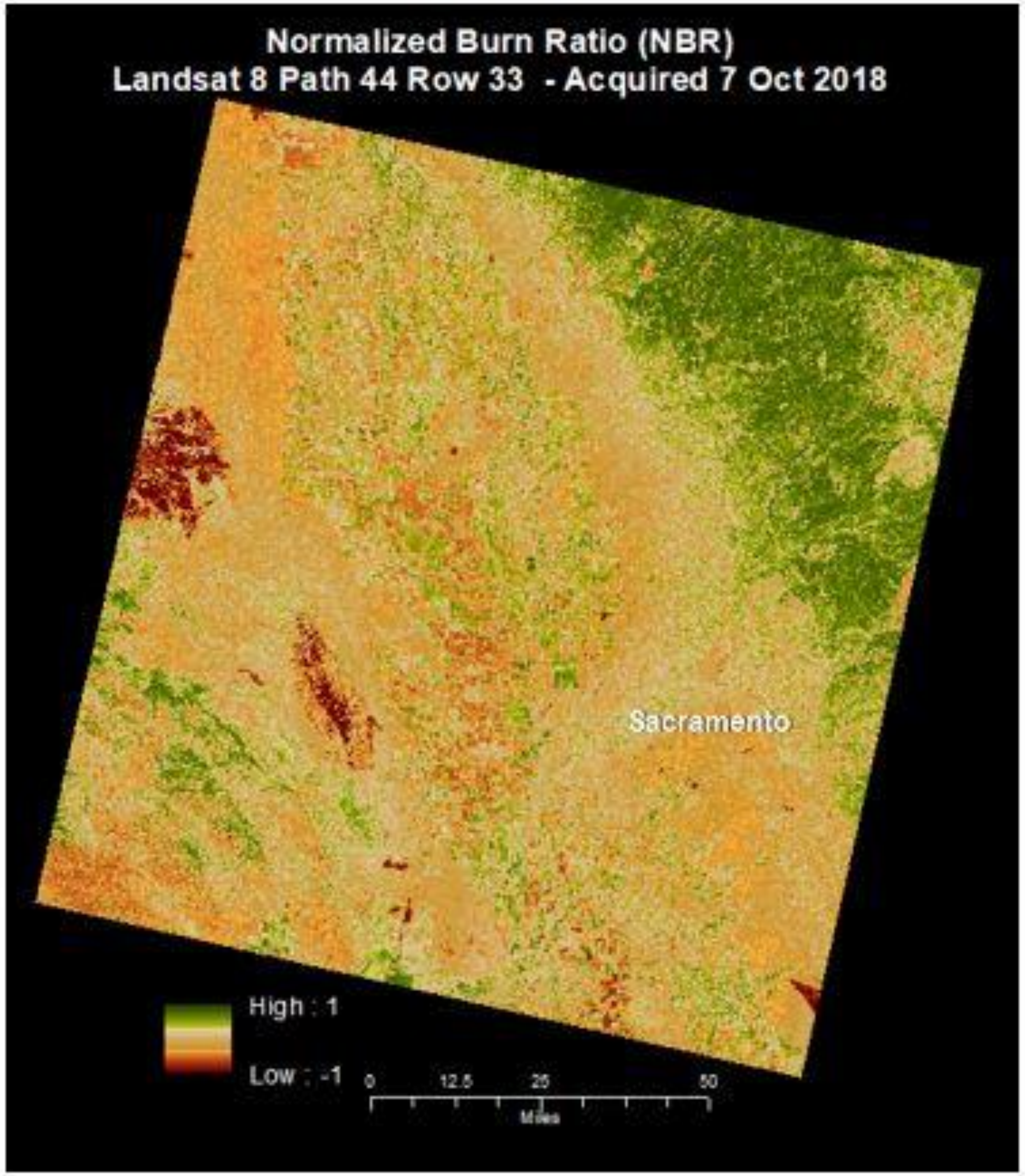
Vegetation condition: NBR+

- Normalized Burn Ratio + (NBR+) is an enhanced version of NBR that takes into account the reflectance of water (Alcaras et al 2022).
- This formula provides negative values for the clouds as they have the reflectance in the B12 band significantly lower than the sum of the other three bands.
- Values can vary in a range between −1 and 1, the pixels related to the clouds in the resulting NBR+ image present certainly low (negative) values and therefore cannot be confused with those related to the BA, which present high values and tend to white. So, values can vary in a range between −1 and 1, where the pixels with higher values represent the BA.

$$\mathrm{NBR}+ = \frac{(\mathrm{B12} - \mathrm{B8A} - \mathrm{B3} - \mathrm{B2})}{(\mathrm{B12} + \mathrm{B8A} + \mathrm{B3} + \mathrm{B2})}$$

Valid range : [-1,1]





Sources/Usage: USGS.Public Domain

Vegetation condition: BAI

- Burned Area Index (BAI) highlights burned land in the red to near-infrared spectrum, by emphasizing the charcoal signal in post-fire images (Chuvieco et al 2002).
- The index is computed from the spectral distance from each pixel to a reference spectral point, where recently burned areas converge.
- Brighter pixels indicate burned areas.

Valid range : [0,1]

$$BAI = \frac{1}{(0.1 - Red)^2 + (0.06 - NIR)^2}$$

Vegetation condition: BAIS2 (adapted to Sentinel-2)

- Burned Area Index for Sentinel-2 (BAIS-2) adapts the traditional BAI for Sentinel-2 bands, taking advantage of a combination of bands that have been demonstrated to be suitable for post-fire burned area detection (Visible (B4), Red-Edge (B6 and B7), NIR (B8A) and SWIR (B12) bands). (Alcaras et al 2022)
- The range of values for the BAIS2 is −1 to 1 for burn scars, and 1–6 for active fires.

$$\mathrm{BAIS2} = \left(1 - \sqrt{\frac{\mathrm{B6} \times \mathrm{B7} \times \mathrm{B8A}}{\mathrm{B4}}}\right) \times \left(\frac{\mathrm{B12} - \mathrm{B8A}}{\sqrt{\mathrm{B12} + \mathrm{B8A}}} + 1\right)$$

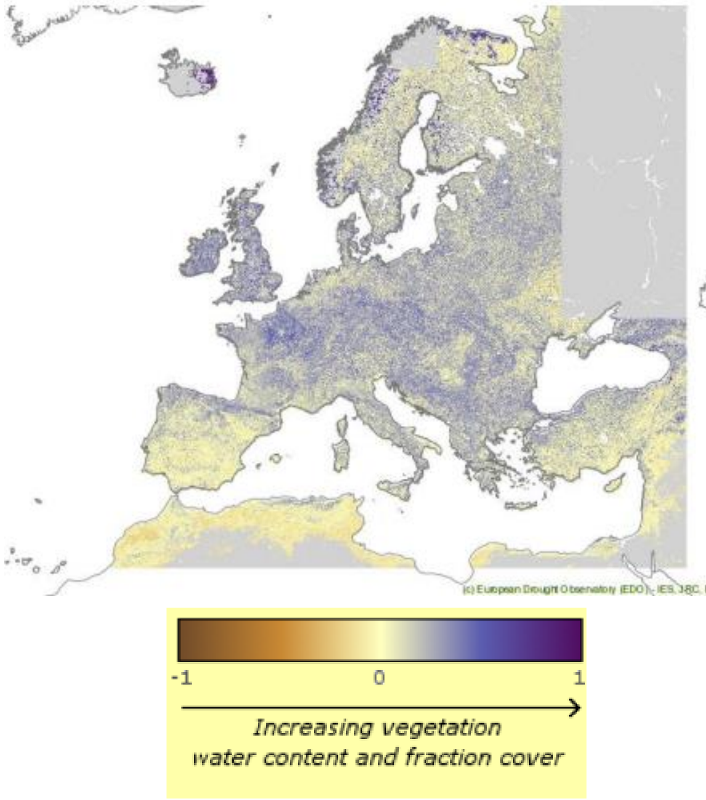
Valid range : [-1,6]

Vegetation condition: NDWI

- The Normalized Difference Water Index (NDWI) is sensitive to changes in vegetation canopy water content because reflectance at 857 nm and 1241 nm has similar but slightly different liquid water absorption properties (Gao, 1995).
- The scattering of light by vegetation canopies enhances the weak liquid water absorption at 1241 nm. Applications include forest canopy stress analysis, leaf area index studies in densely foliated vegetation, plant productivity modeling, and fire susceptibility studies.
- The common range for green vegetation is -0.1 to 0.4.

$$NDWI = \frac{NIR - SWIR}{NIR + SWIR}$$

Valid range : [-1,1]



NDWI (Source: JRC)

Hydrology related indices

Grant Agreement 952111, H2020 WIDESPREAD-05-2020 (Twinning)

Hydrology related: NDSI

- Normalized Difference Snow Index (NDSI) is the normalized difference between green (G) spectral bands and the shortwave infrared (SWIR) (Riggs et al 1994).
- Snow is not only very reflective in the visible parts of the electromagnetic spectrum but also highly absorptive in the NIR or the short-wave infrared part of the spectrum, while the most cloud reflectance remains to be high in the same parts of the spectrum, this allows good separation of most clouds and snow.

$$\boxed{NDSI = (G - SWIR1) / (G + SWIR1)}$$

Valid range : [-1,1]

Hydrology related: NDSI (Sentinel-2 algorithm)

- Normalized Difference Snow Index (NDSI) can be used to differentiate between cloud and snow cover.
- Snow absorbs in the SWIR, but reflects in the VIR, whereas cloud is generally reflective in these Bands.
- NDSI between -0.1 and +0.2 are clouds. NDSI negative pixels are Snow.

$$\boxed{NDSI = (VIR - SWIR1) / (VIR + SWIR1)}$$

Valid range : [-1,1]

Source: https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-2-msi/level-2a/algorithm

Data transformation

Vegetation condition: Tasseled Cap

- **Linear transformation** of originally Landsat MSS data that projects soil and vegetation information into a single plane in the multi-spectral data space (Kauth and Thomas, 1976).

- Its target is to **reduce the number of channels** to be considered, to provide a more direct association between signal response and physical processes on the ground, and to highlight the particular types of information of major interest to the user (Crist, Laurin & Cicone, 1986).

- **Extended to high-dimensional data** such as TM, ETM+, ASTER, MODIS, Sentinel…

Vegetation condition: Tasseled Cap

- It is an adjustment of viewing perspective (rotation of those data space) so that the concentrations of data within the total data volume are most readily observed (Crist and Laurin & Cicone, 1986).

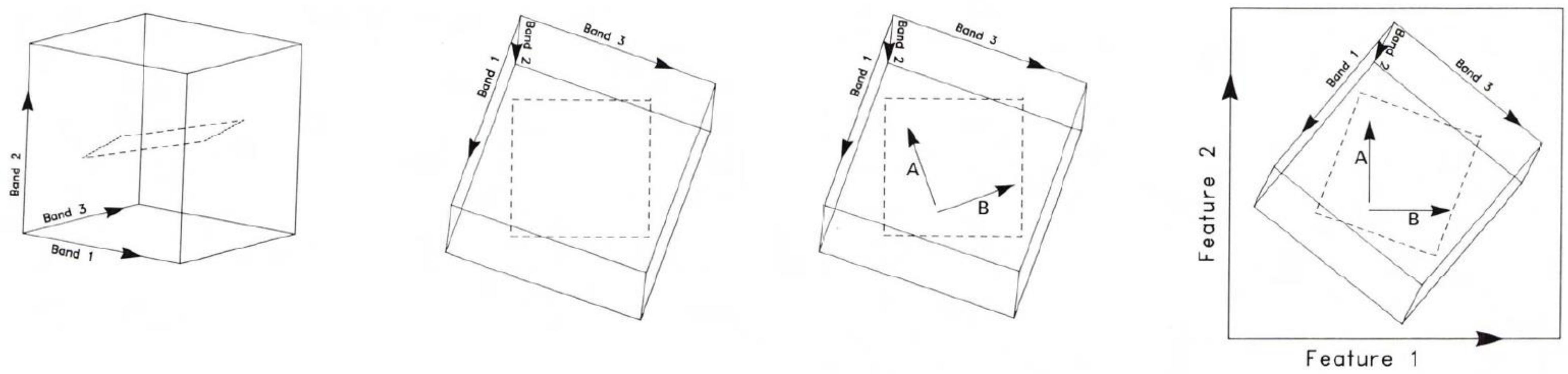
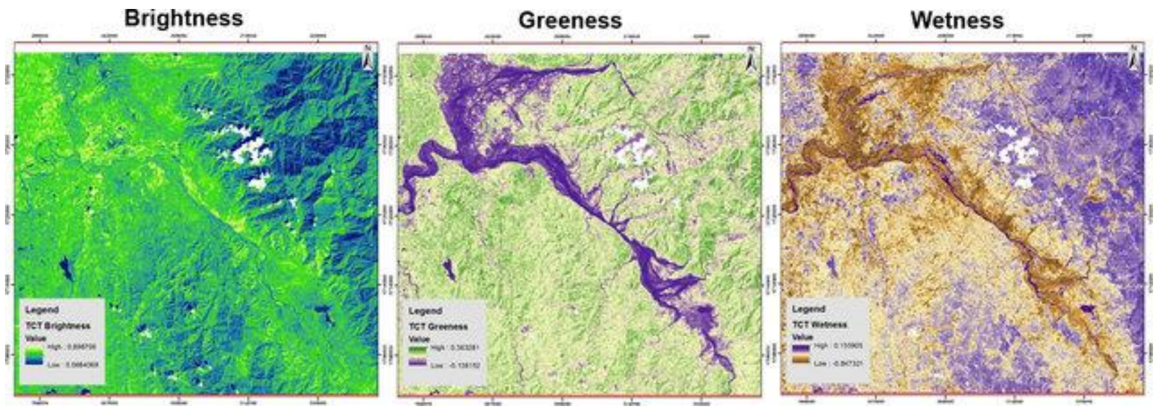


FIG. 8. Hypothetical three-band sensor data.(a) The cube is the total possible data space (range of each band). The dashed line denotes a rectangular data structure (plane) within the cube.(b) Viewing perspective changed to view the rectangular data structure directly.(c) Direction of spectral variation associated with two distinct physical processes in scene classes.(d) Viewing perspective further adjusted to align the physically-related directions with the new coordinate axes (edges of the outer rectangle).

Source: Crist, Laurin & Cicone, 1986

Vegetation condition: Tasseled Cap

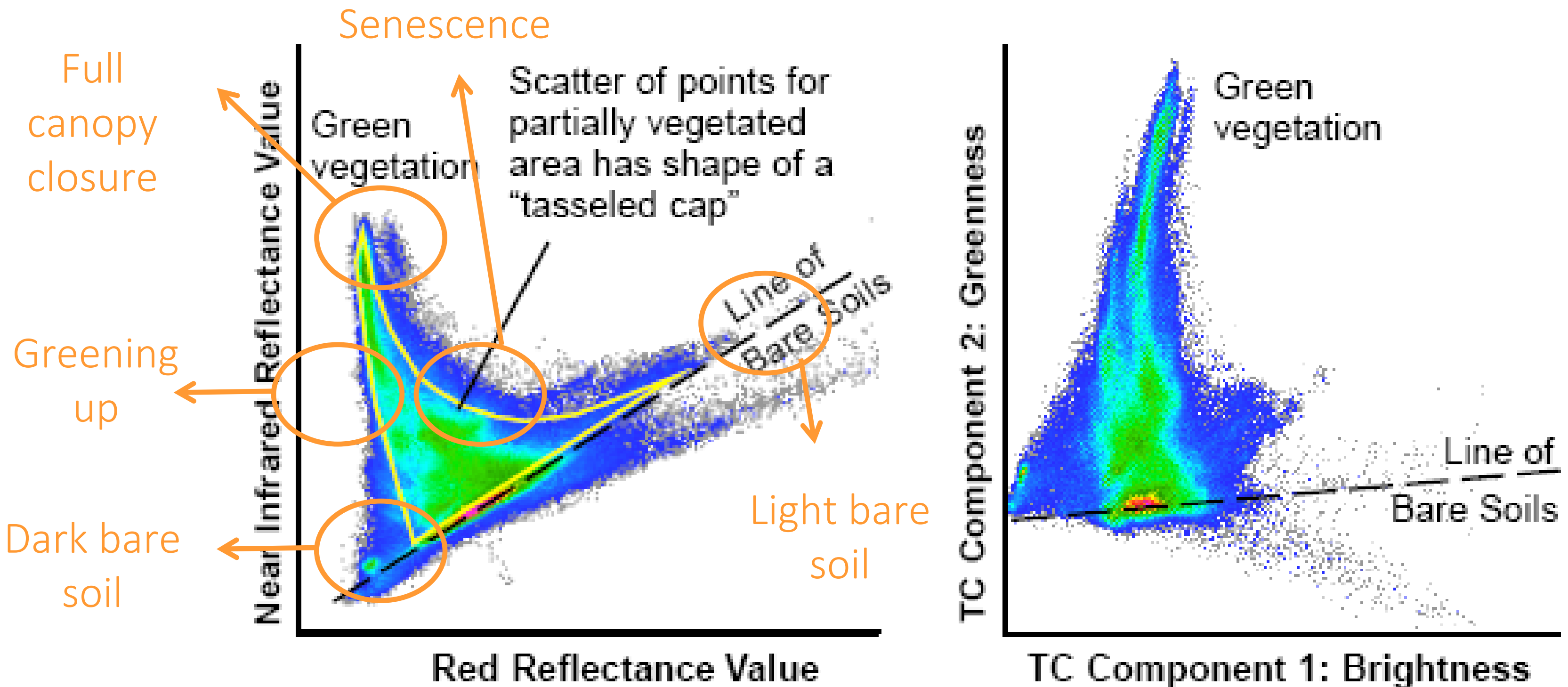
- The new dimensions for Landsat 8 are considered:
  1. **Brightness**: weighted sum of all six bands, a measure of overall reflectance (differentiating light from dark soils).
  2. **Greenness**: contrast between near-infrared and visible reflectance, a measure of the presence and density of green vegetation.
  3. **Wetness**: contrast between shortwave-infrared (SWIR) and visible/near infrared (VNIR) reflectance, providing measure of soil moisture content, vegetation density and other scene class characteristics. Water bodies, positive data.



Tasseled Cap Transformation indices for the 24 Oct Landsat 8 image. *Marie C. and Escape J.*

Vegetation condition: Tasseled Cap

	Landsat TM Tasseled Cap Coefficients for DNs (Crist, Laurin & Cicone, 1986)					
Component	Band1	Band 2	Band 3	Band 4	Band 5	Band 7
Brightness	0.3037	0.2793	0.4343	0.5585	0.5082	0.1863
Greenness	-0.2848	-0.2435	-0.5436	0.7243	0.084	-0.18
Wetness	0.1509	0.1973	0.3279	0.3406	-0.7112	-0.4572



Vegetation condition: Tasseled Cap

- Landsat 8 OLI Tasseled Cap Coefficients

Table 2. TCT coefficients for Landsat 8 at-satellite reflectance.

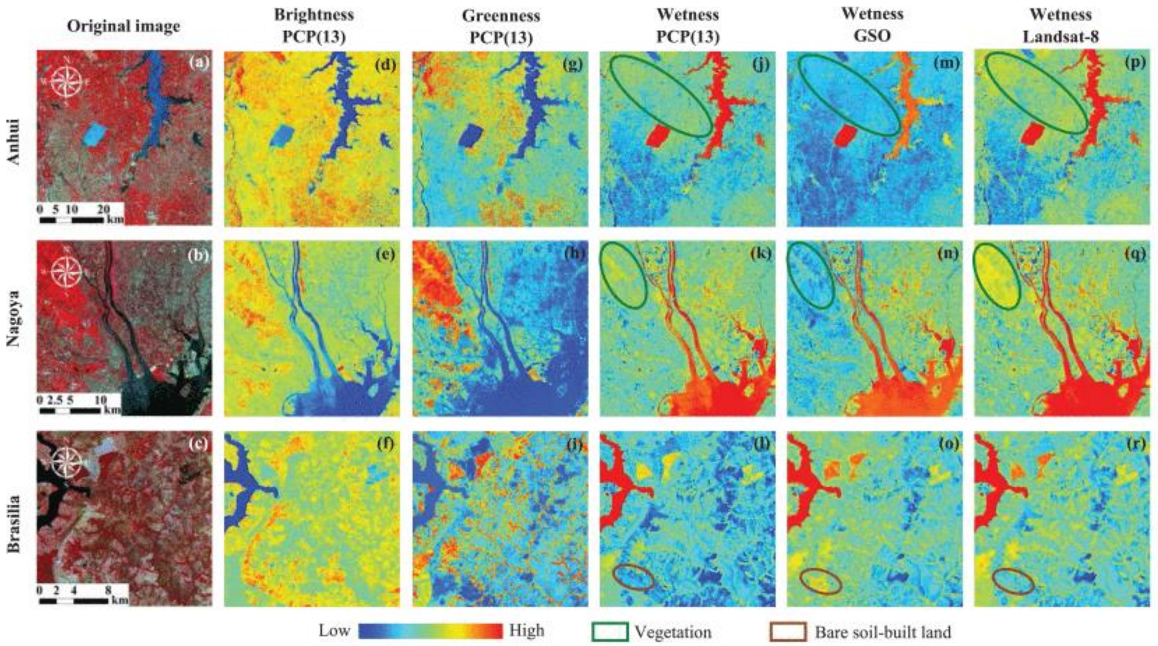
Landsat 8 / TCT	(Blue) Band 2	(Green) Band 3	(Red) Band 4	(NIR) Band 5	(SWIR1) Band 6	(SWIR2) Band 7
Brightness	0.3029	0.2786	0.4733	0.5599	0.508	0.1872
Greenness	−0.2941	−0.243	−0.5424	0.7276	0.0713	−0.1608
Wetness	0.1511	0.1973	0.3283	0.3407	−0.7117	−0.4559
TCT4	−0.8239	0.0849	0.4396	−0.058	0.2013	−0.2773
TCT5	−0.3294	0.0557	0.1056	0.1855	−0.4349	0.8085
TCT6	0.1079	−0.9023	0.4119	0.0575	−0.0259	0.0252

Source: Ali Baig et al , 2014

Vegetation condition: Tasseled Cap

- Sentinel-2 Tasseled Cap Coefficients

Type	TCT	Coastal	Blue	Green	Red	RE-1	RE -2	RE-3	NIR-1	NIR-2	WV	Cirrus	MIR-1	MIR-2
13 bands	B	0.2381	0.2569	0.2934	0.3020	0.3099	0.3740	0.4180	0.3580	0.3834	0.0103	0.0020	0.0896	0.0780
	G	-0.2266	-0.2818	-0.3020	-0.4283	-0.2959	0.1602	0.3127	0.3138	0.4261	0.1454	-0.0017	-0.1341	-0.2538
	W	0.1825	0.1763	0.1615	0.0486	0.0170	0.0223	0.0219	-0.0755	-0.0910	-0.1369	0.0003	-0.7701	-0.5293
6 bands	B		0.3510	0.3813	0.3437				0.7196				0.2396	0.1949
	G		-0.3599	-0.3533	-0.4734				0.6633				0.0087	-0.2856
	W		0.2578	0.2305	0.0883				0.1071				-0.7611	-0.5308



Vegetation condition: Tasseled Cap

- Considerations:
  - Original transformation derived for Midwestern agriculture. Several clusters selected as: soil and vegetation and Gram-Schmidt Orthogonalizal Process was carried out.
  - Original transformation not optimized for other areas and/or different climate, e.g., Mediterranean .
  - Each sensor needs a new adjustment and new coefficients.
  - It does not create information which was not present in the original data .

Vegetation condition: Principal Components Analysis

- **Principal Components Analysis**:
  - Method for producing linear combinations of *p* variables with the object of summarizing the main aspects of the variation in the *p* variables with the variation of a smaller number of theses linear combinations.
  - The linear combinations are the **principal components**.
  - The 1st PC has the largest possible variance.
  - The 2nd PC has the larges possible variance while being uncorrelated with the first component.
  - Tasseled Cap components have physical significance while PC do not have an a priori known meaning.

Vegetation condition: Principal Components Analysis

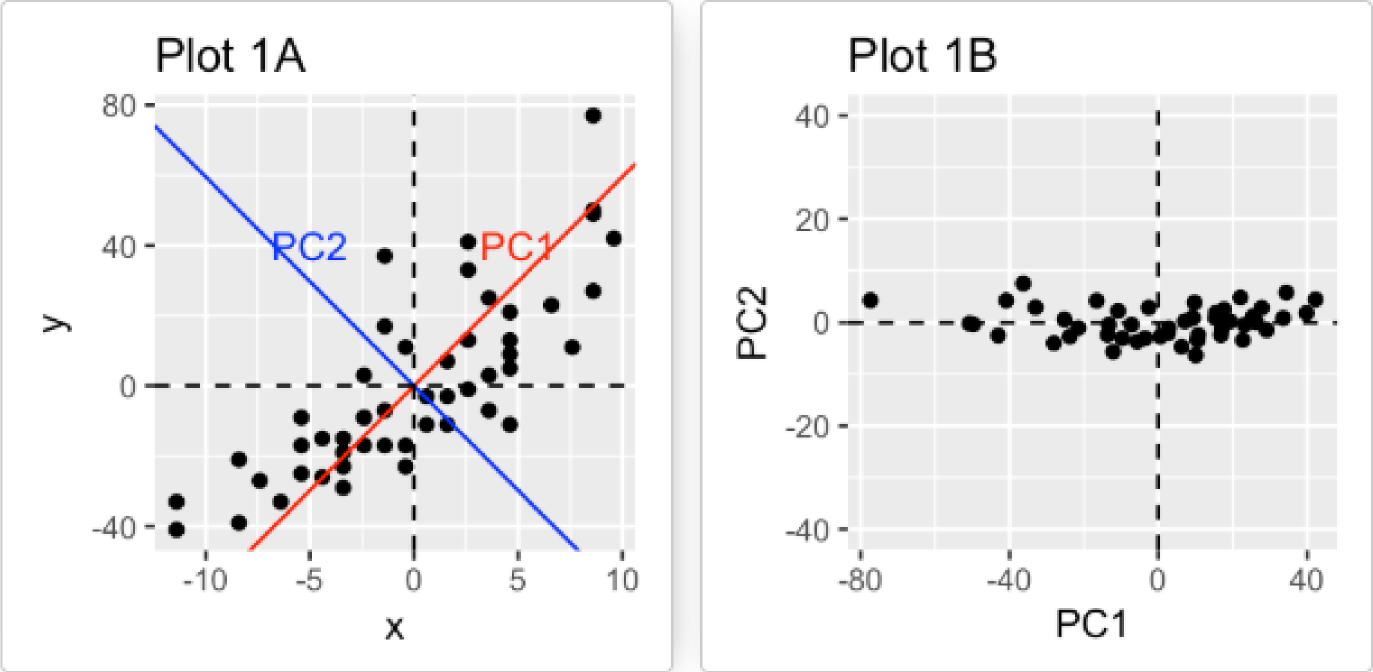
- **Principal Components Analysis**:
  - Each new variable (main component, CPi) is obtained by linear combination of all the original p variables (Xi):

$$CP_1 = a_{1,1}X_1 + a_{1,2}X_2 + \dots + a_{1,p}X_p$$
$$CP_2 = a_{2,1}X_1 + a_{2,2}X_2 + \dots + a_{2,p}X_p$$
$$\vdots$$
$$CP_p = a_{p,1}X_1 + a_{p,2}X_2 + \dots + a_{p,p}X_p$$

  - Each new variable is unrelated to the previous one.

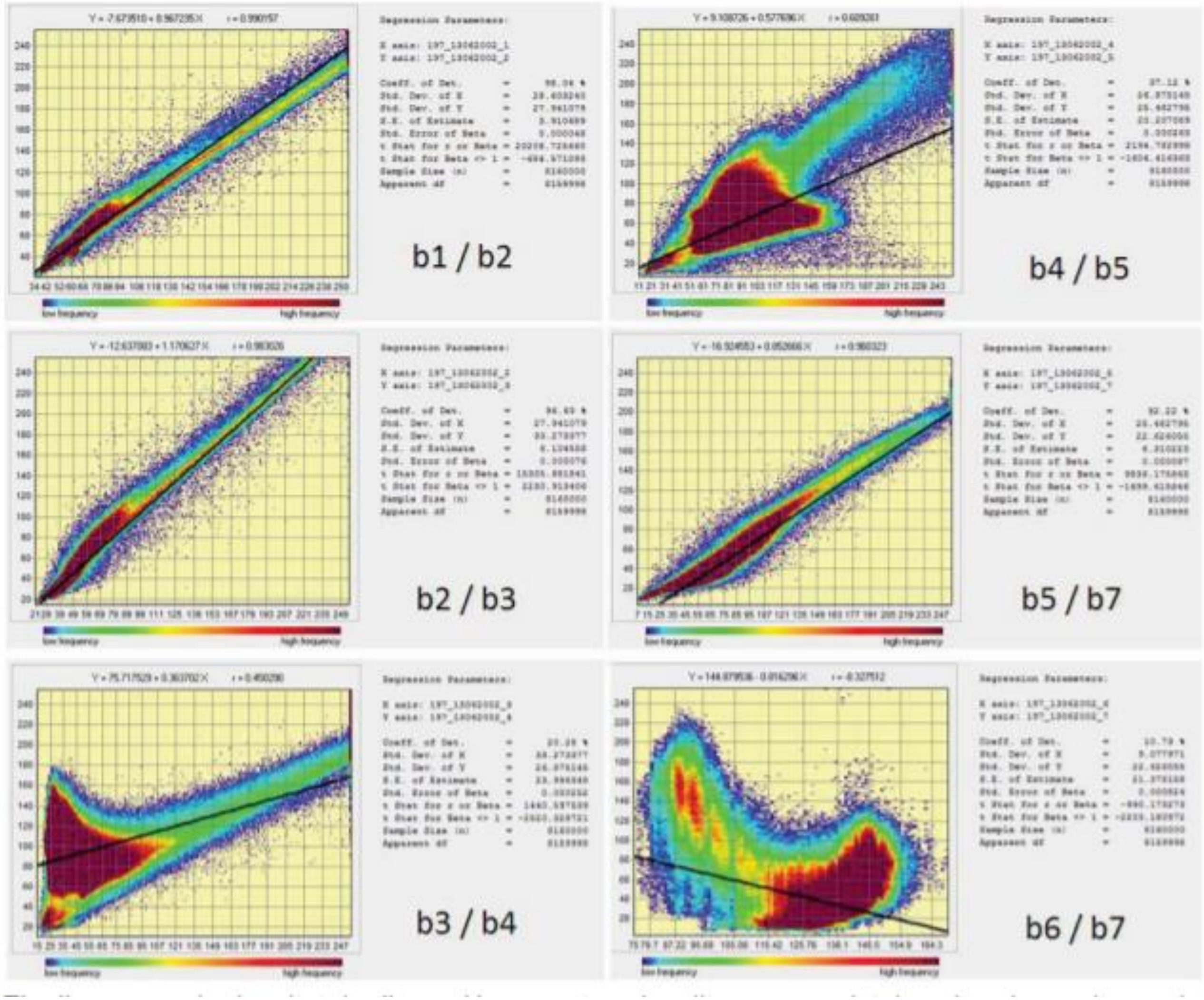
Vegetation condition: Principal Components Analysis

- **Principal Components Analysis**:
  - Each new variable explains a smaller (or equal) amount of the total original variation.



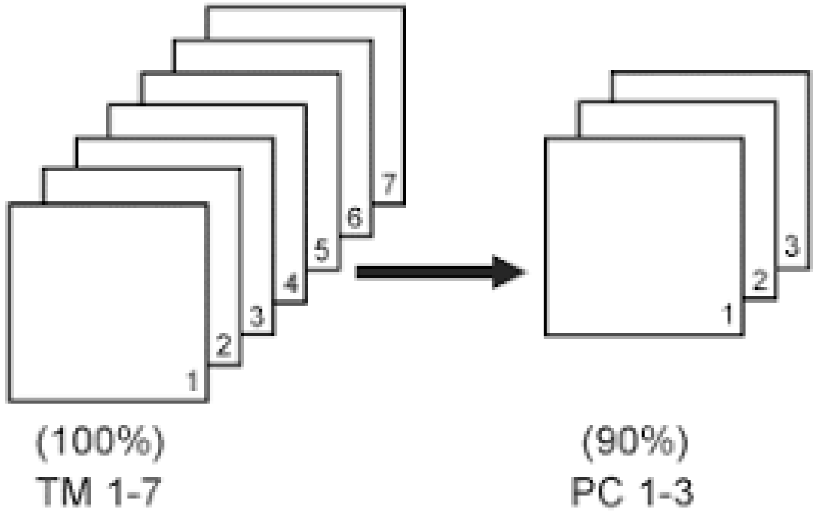
Vegetation condition: Principal Components Analysis

- Dispersion density diagrams show the possible high redundancy between bands.



Vegetation condition: Principal Components Analysis

- **Principal Components Analysis**:
  - If the variables used have very low or no correlation at all, PCA is useless.
  - Not all PCs are usually captured or used, this is the goal, to reduce the dimensions.



Vegetation condition: Principal Components Analysis

- **Principal Components Analysis**:
  - The sum of the variances of all PCs is equal to the sum of the variances of all the original variables (X).
  - The PCA is also interesting because it gives an idea of the intrinsic variability of our data (how many sources of variation there are).
  - The new variables lose their units and physical sense. In the case of Remote Sensing, the new components no longer have the radiometric sense of the original bands.

Component	% Total Variance	Cumulative %
PC Band 1	89.971906	89.971906
PC Band 2	7.6096945	97.581601
PC Band 3	1.2901599	98.871762
PC Band 4	0.6295288	99.501288
PC Band 5	0.401309	99.902594
PC Band 6	0.097402	100.0

Vegetation condition: Principal Components Analysis

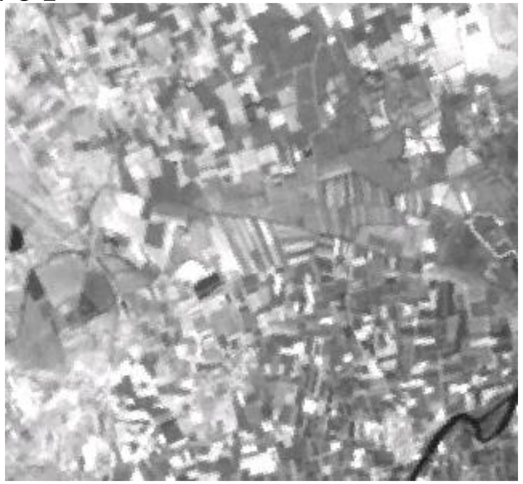
- **Principal Components Analysis**:
  - In order to prevent any of the variables from having an inappropriate weight in the analysis, it is usual to standardize the variables beforehand.
  - This is equivalent to performing the analysis based on the correlation matrix instead of the variance / covariance matrix.
  - There is no agreement on whether PCA is more effective based on the variance / covariance matrix or the correlation matrix.
  - Standardization (standardization):

$$z = \frac{x - \mu}{\sigma}.$$

New range of values with mean (μ) 0 and standard deviation (σ) 1

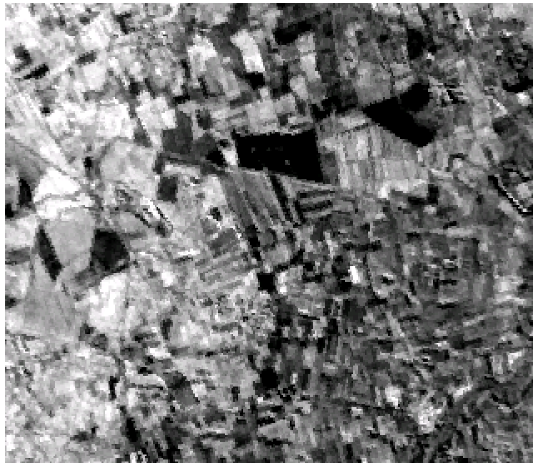
Vegetation condition: Principal Components Analysis

PC-1

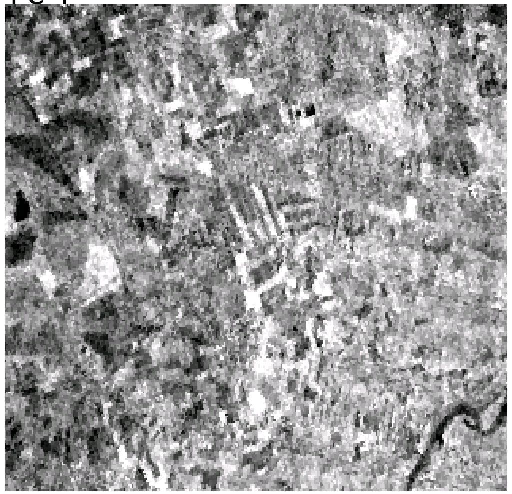


PC-2

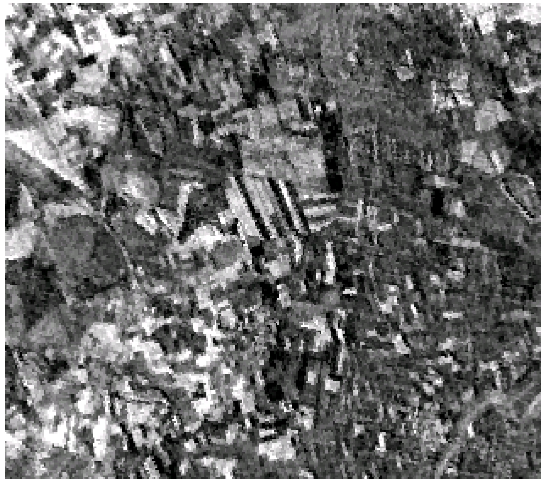
PC-3



PC-4



PC-5



PC-6

Vegetation condition: Principal Components Analysis

- **Principal Components Analysis- Variance/Covariance Matrix**:
  - The elements of the diagonal are the variances of the values of the pixels of each band; outside the diagonal are covariance's.
  - The matrix is symmetric: covar (Bi, Bj) = covar (Bj, Bi).
  - Bands with higher variances are the ones that contribute the most to CPs (except normalized variables).
  - If we identify large covariance's compared to variances between two variables, it indicates that there is a linear relationship between them.

	B02-B	B03-G	B04-R	B05-NIR	B06-SWIR1	B07-SWIR2	B10-LWIR1	B11-LWIR2
B02-B	**211204.17**	282001.48	379986.00	352684.62	662785.06	579909.24	232315.96	176908.91
B03-G	282001.48	**402282.39**	539510.41	665358.13	1018044.97	848310.20	336368.75	259073.56
B04-R	379986.00	539510.41	**773869.46**	666948.78	1462050.84	1249261.68	429120.45	332753.53
B05-NIR	352684.62	665358.13	666948.78	**4305056.45**	2299601.66	1234036.52	848934.95	651154.47
B06-SWIR1	662785.06	1018044.97	1462050.84	2299601.66	**3603727.36**	2679741.49	998048.52	772606.47
B07-SWIR2	579909.24	848310.20	1249261.68	1234036.52	2679741.49	**2191577.44**	740242.48	574982.68
B10-LWIR1	232315.96	336368.75	429120.45	848934.95	998048.52	740242.48	**605079.92**	463199.95
B11-LWIR2	176908.91	259073.56	332753.53	651154.47	772606.47	574982.68	463199.95	**359045.66**

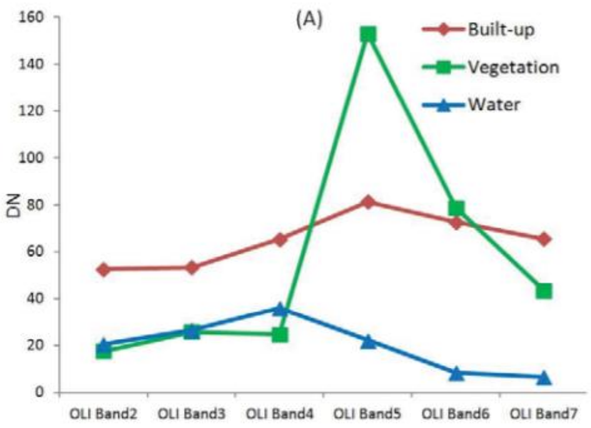
Urban areas indices

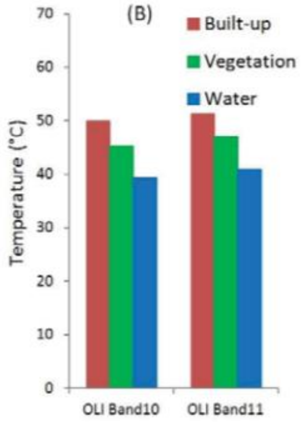
Urban areas: NDBI

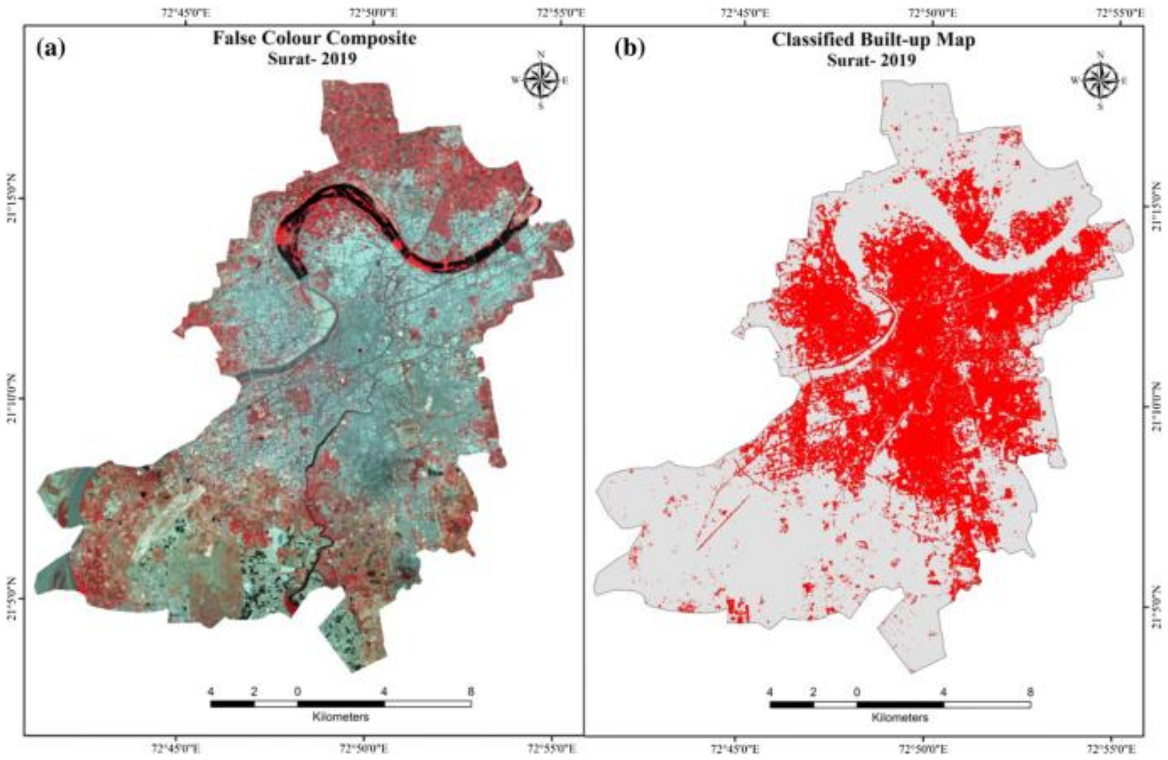
- The Normalized Difference Build-Up Index (NDBI) it takes advantage of the unique spectral response of build-up areas and other land covers. (Zha et al. 2003).
- All positive values show built-up area:

$$\boxed{NDBI = \frac{(SWIR - NIR)}{(SWIR + NIR)}}$$

SWIR 1.55-1.75 µm;
NIR 0.76-0.9 µm.







Source: Shahfahad et al, 2020

Urban areas: Other indices

$EBBI = \frac{(SWIR1-NIR)}{10\sqrt{SWIR1+TIRS1}}$	< 0.10 non-urban, 0.10–0.35 built-up and > 0.350 bare land
$UI = \frac{SWIR2-NIR}{SWIR2+NIR}$	All +ve values shows built-up area
$IBI = \frac{NDBI-(SAVI+MNDWI)/2}{NDBI+(SAVI+MNDWI)/2}$	< 0.018 non urban, 0.018–0.308 built-up > 0.308 bare land
$DBI = \frac{Blue-TIRS1}{Blue+TIRS1} - NDVI$	Higher values represents higher built-up area
$NDBaI = \frac{SWIR1-TIRS1}{SWIR1+TIRS1}$	> − 0.150 bare land

Source: Shahfahad et al, 2020

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