ICIMOD

Remote sensing indices and their applications

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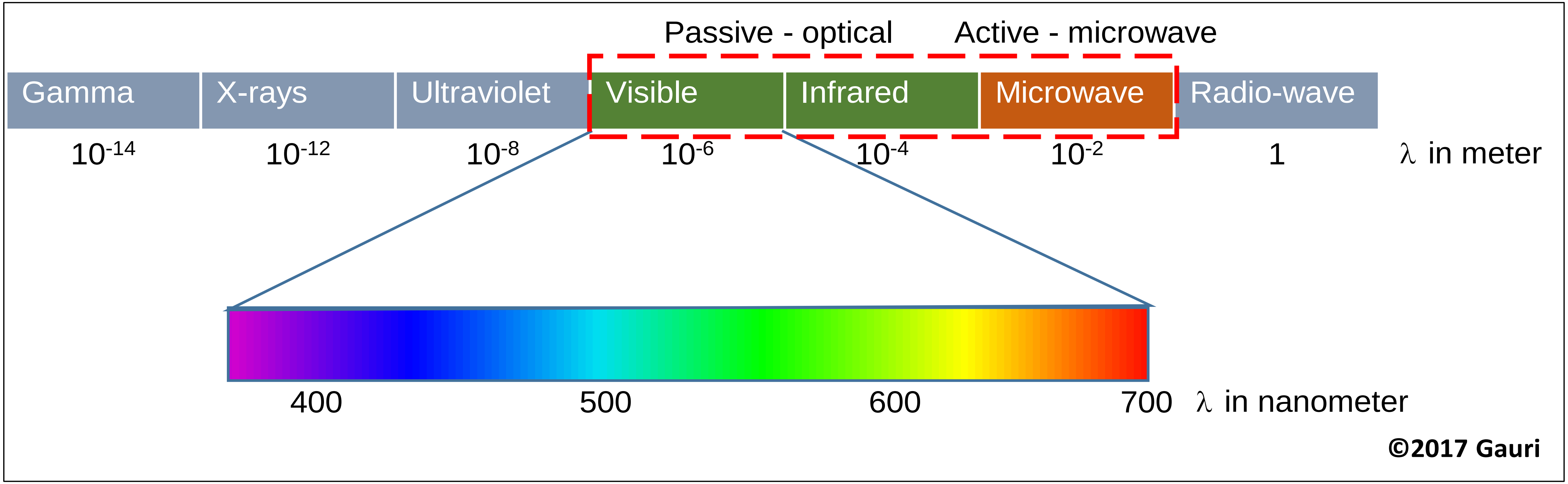
Electromagnetic spectrum (EMR)

From very short Gamma rays to very long radio waves



Blue (400 – 500), Green (500 – 600) and Red (600 – 700nm) bands

Features in Sentinel-2A satellite bands

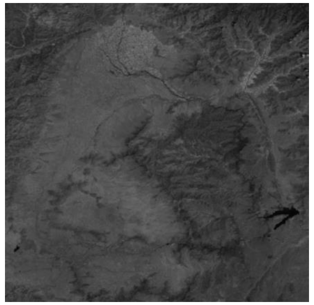
Kabul region of Afghanistan

Google Earth

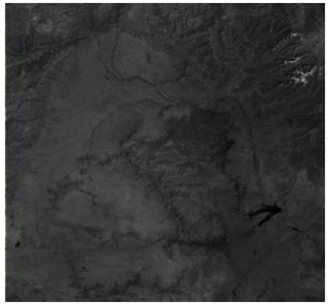
B2 (Blue)

B3 (Green)

B4 (Red)



B8 (NIR)



B9 (SWIR)

Band		Spectral /wavelength range (nm)	Objective	Spatial range (m)
B1	Coastal aerosol	433-453	Aerosol correction	60
B2	Blue	458-523	Aerosol correction, land measurement	10
B3	Green	543-578	Land measurement	10
B4	Red	650-680	Land measurement	10
B5	Red edge1 (RE1)	698-713	Land measurement	20
B6	Red edge2 (RE2)	733-748	Land measurement	20
B7	Red edge3 (RE3)	773-793	Land measurement	20
B8	Near infra red	785-900	Water vapour correction, Land measurement	10
B8a	Near infrared narrow	855-875	Water vapour correction, Land measurement	20
B9	Water vapour	935-955	Water vapour correction	60
B10	Shortwave infrared	1360-1390	Cirrus detection	60
B11	Shortwave infrared 1	1565-1655	Land measurement	20
B12	Shortwave infrared 2	2100-2280	Aerosol correction, land measurement	20

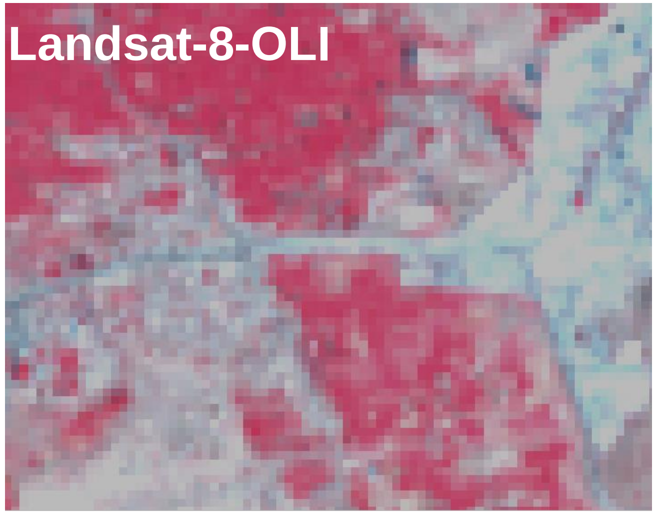
Features in Landsat satellite bands

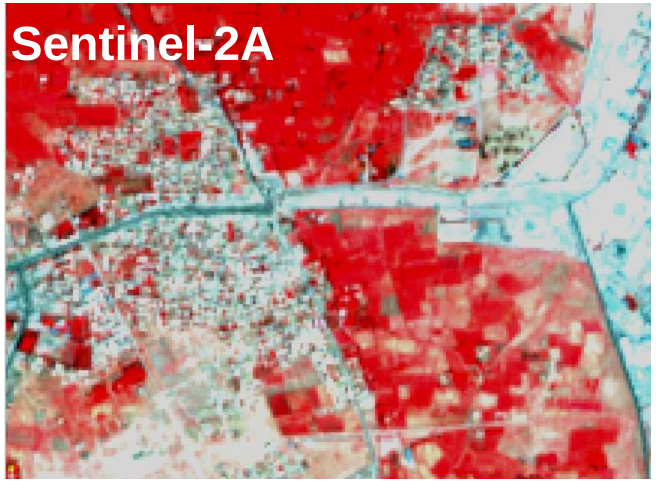
Band		Spectral range (nm)	Objective	Spatial range (m)
B1	New deep blue	433-453	Aerosol/coastal zone	30
B2	Blue	450-515	Pigments/coastal/scatter	30
B3	Green	525-600	Pigments/coastal	30
B4	Red	630-680	Pigments/coastal	30
B5	Near infra red	845-885	Foliage/coastal	30
B6	Shortwave infrared 2	1560-1660	Foliage	30
B7	Shortwave infrared 3	2100-2300	Mineral/litter/no scatter	30
B8	Panchromatic	500-680	Image sharpening	15
B9	Shortwave infrared	1360-1390	Cirrus cloud detection	30

1. https://www.sentinel-hub.com/develop/documentation/eo_products/Sentinel2EOproducts
2. https://modis.gsfc.nasa.gov/about/specifications.php
3. https://gisgeography.com/landsat-8-bands-combinations/

Difference between Landsat and Sentinel data

	Landsat-8-OLI	Sentinel-2A
Bands	9	13
Spectral range (µm)	0.435-1.384	0.44-2.22
Spatial resolution (m)	30	10,20,60
Temporal resolution	16 days	10 days
Sensor	Operational Land Imager (OLI)	Multi-Spectral Instrument (MSI)
Type	Multi-spectral	Multi-spectral
Satellite	Landsat-8	Sentinel-2A
Operator	U.S. Geological Survey (USGS)	European Space Agency (ESA)





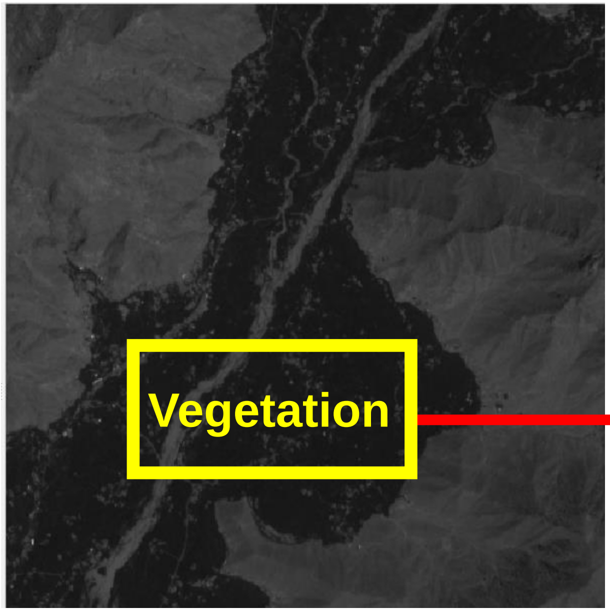
Why band ratio?

- Undesirable effects on recorded radiances (e.g. variable illumination) caused by **variation in topography**
- Differences in **brightness values** from identical surface material or vice versa are caused by topographic slope and aspect, shadows or seasonal changes
- These hamper the ability of interpreter to correctly identify surface material in image
- Ratio transformation can be used to reduce the effects of such environmental conditions

Why band ratio?

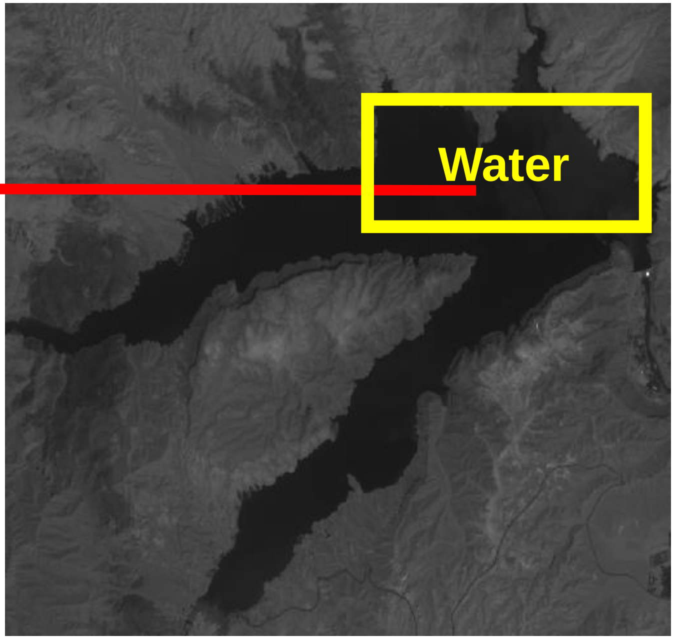
Spectral response and reflectance is similar from two different objects in RED band of Sentinel-2A

Google Earth



732

Red band

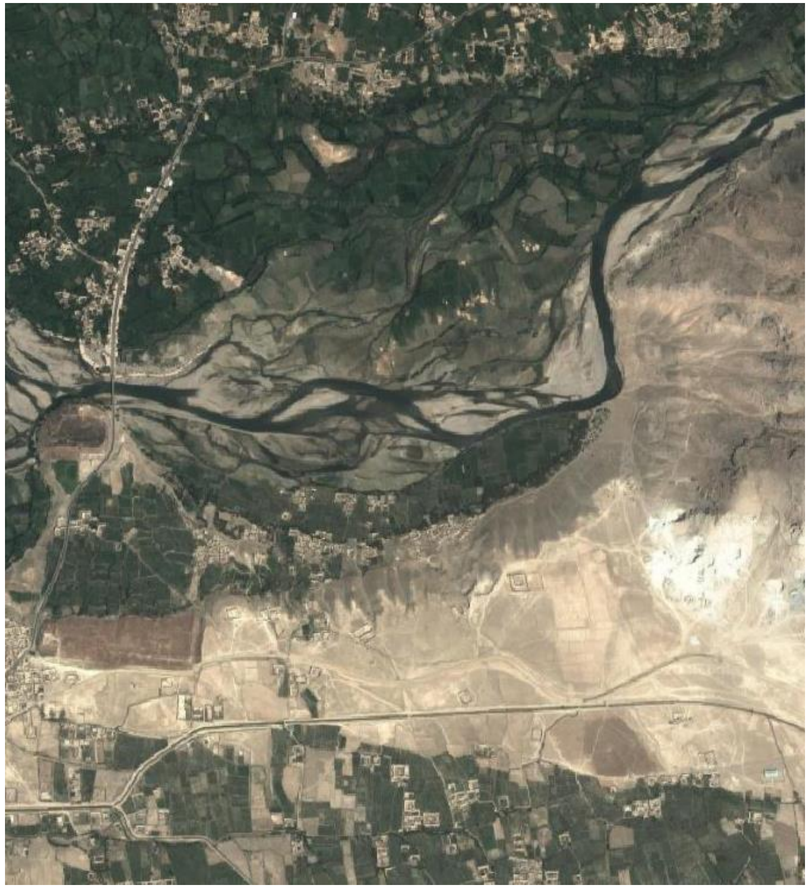


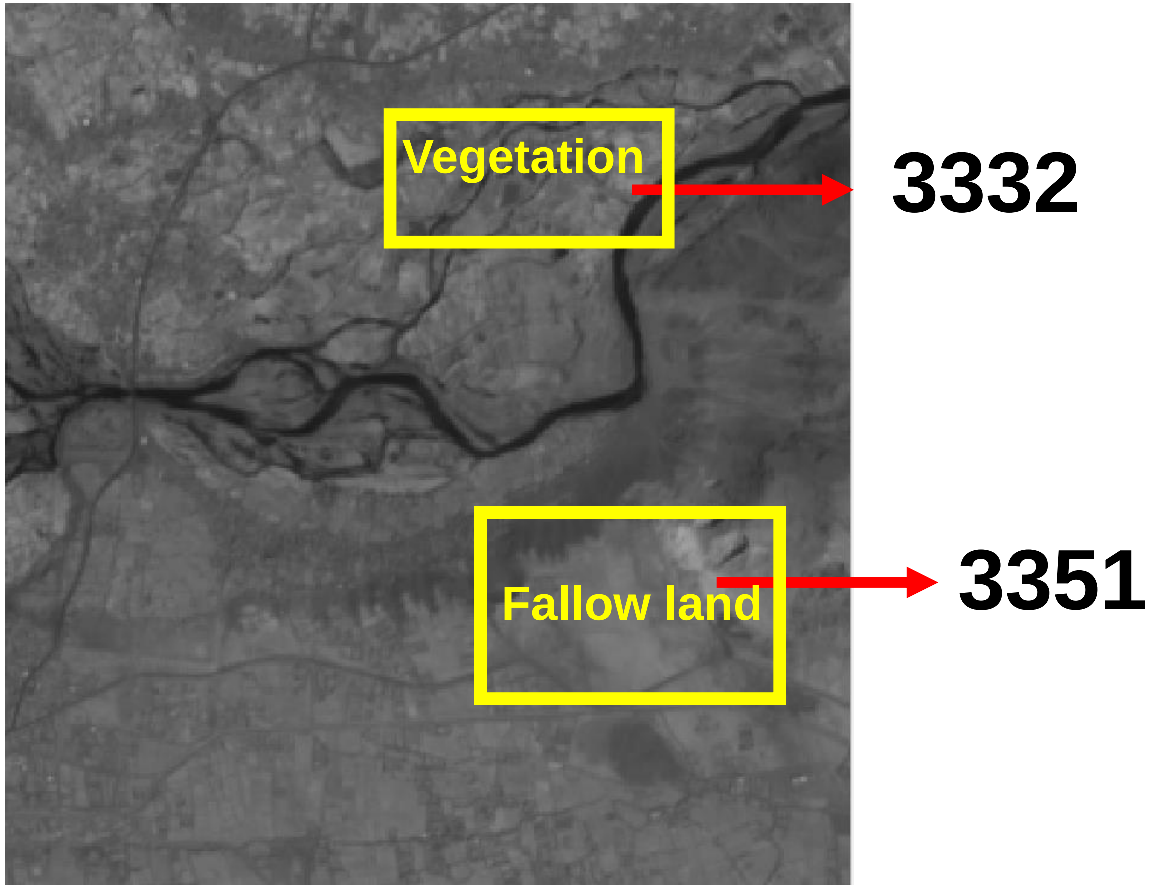
725

Red band

Google Earth

Why band ratio?



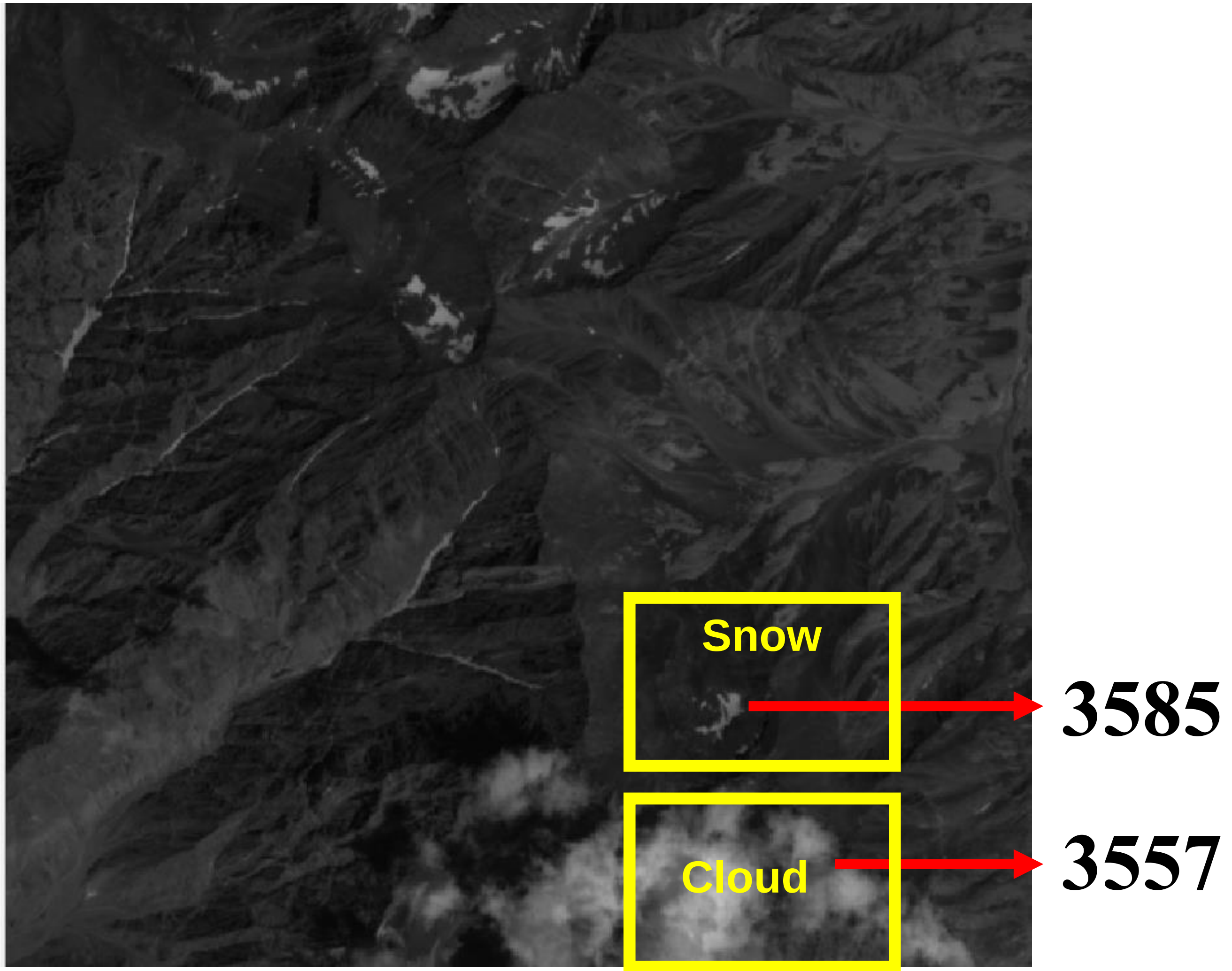


Spectral signature of two different objects are mixed in NEAR-INFRA RED band of Sentinel

Why band ratio?

Google Earth

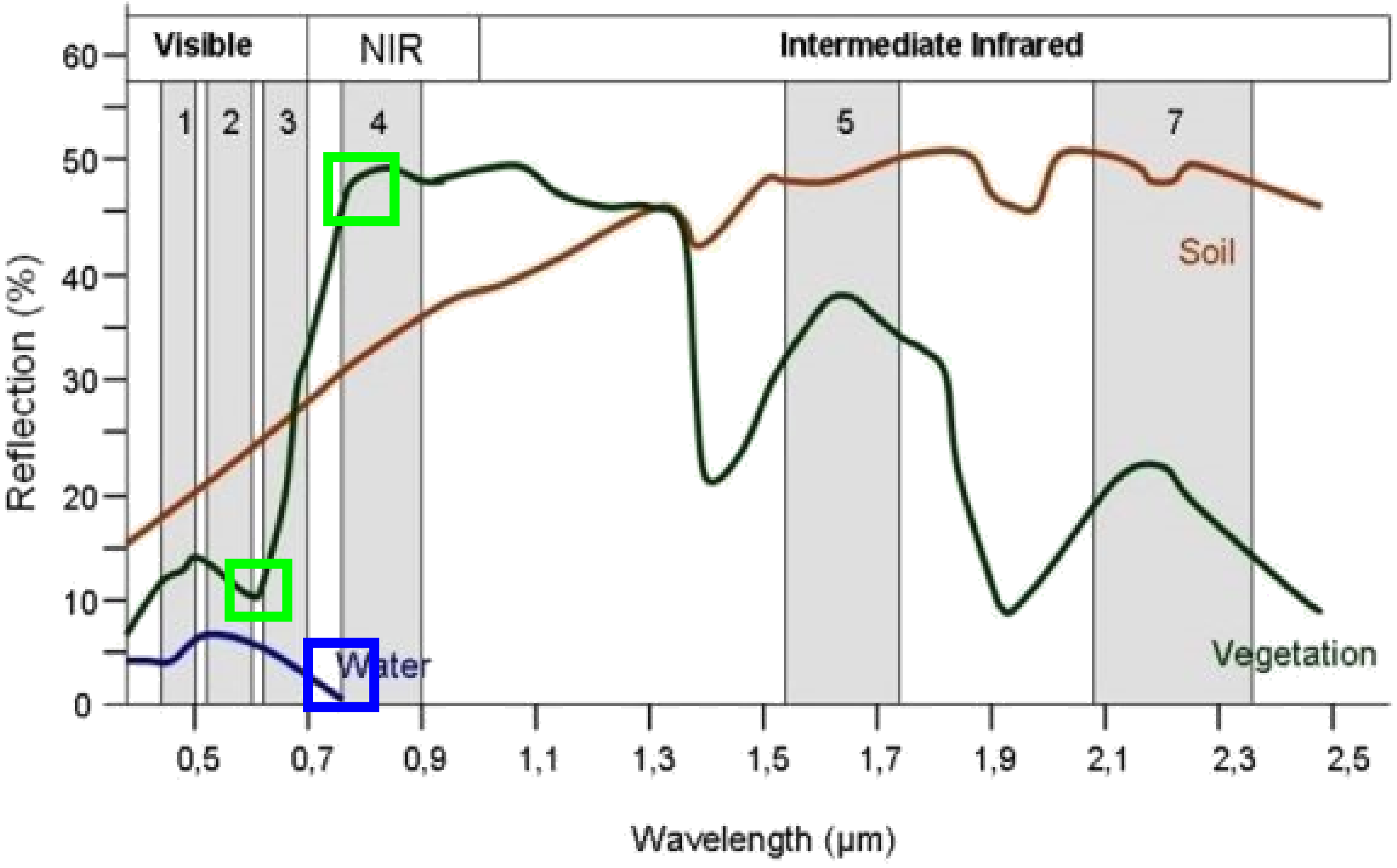
NIR band



Spectral signature of two different objects are mixed in NEAR-INFRA RED band

Why band ratio?

- Specific target has an individual and characteristic manner of interacting with incident radiation
- Interaction are described by the **spectral response** of the target in a particular wavelength of EMR



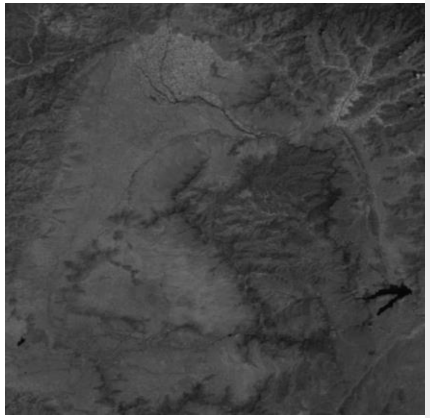
Spectral curves for various natural features

Differences between histogram

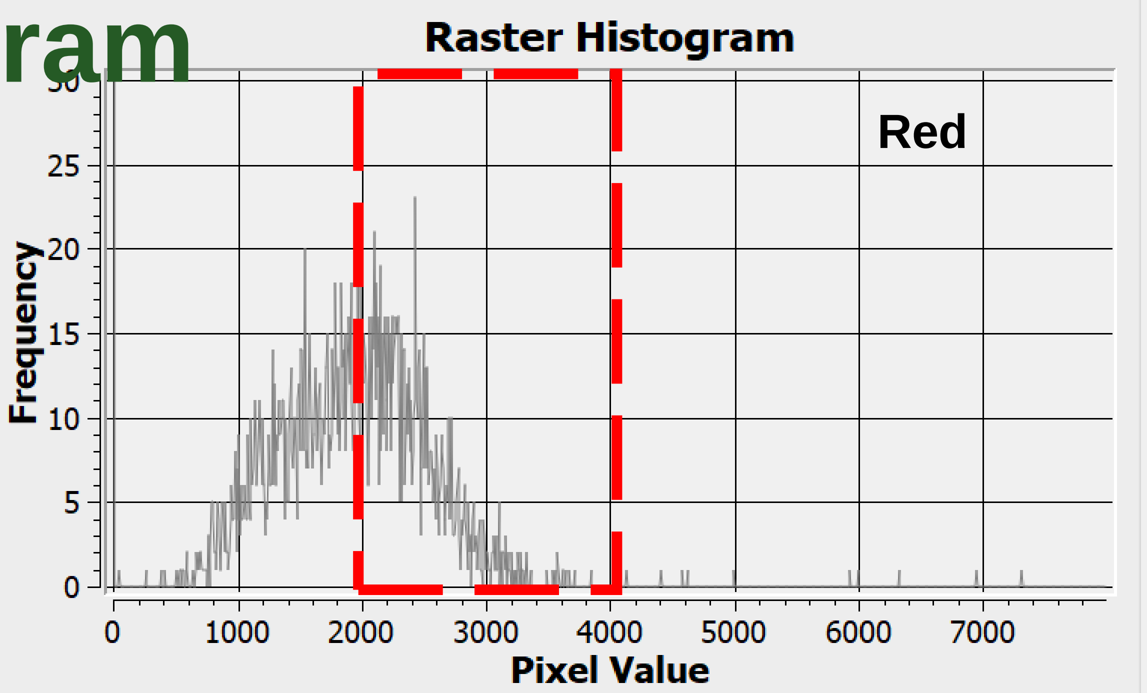
Histogram of Red and near-infrared reflectance representing more pixel frequency at higher reflectance in NIR of Sentinel-2A data

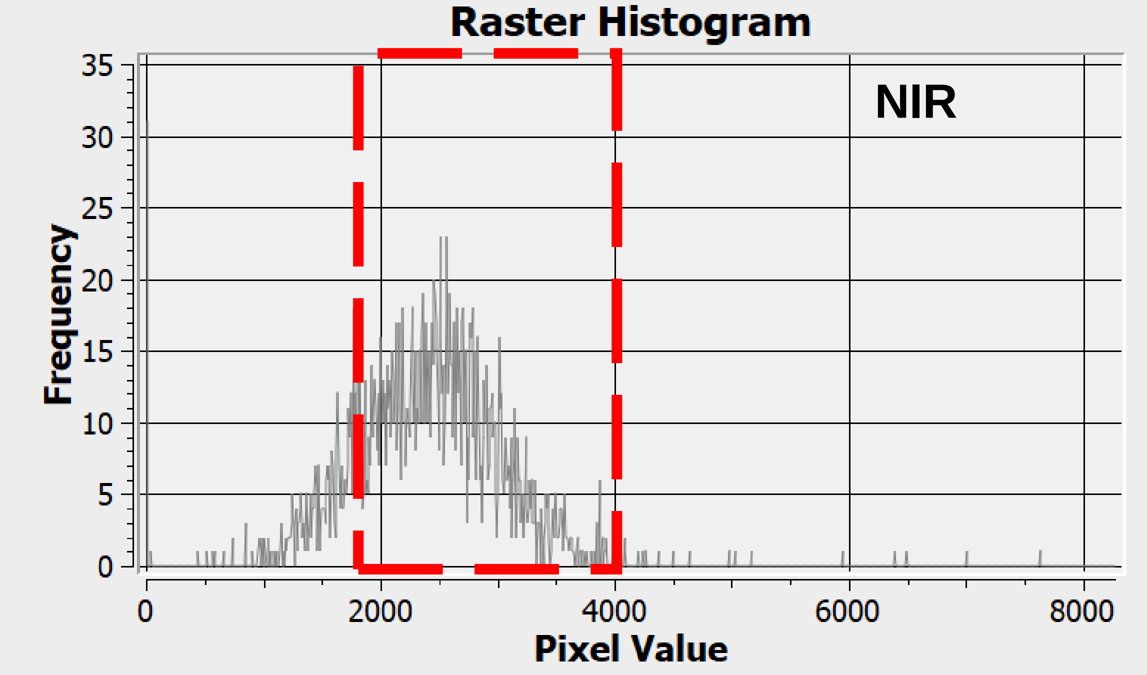
GEE

B4 (Red)



B8 (NIR)





Spectral indices

1. Spectral indices help in modelling, predicting, or infer surface processes
2. Developed to assess and monitor several land change processes
3. Computed from multiband images by adding and subtracting bands thereby making various band ratio
4. Emphasizes a specific phenomenon that is present, while mitigating other factors

- Vegetation health and status
- Burned area
- Fire severity etc.

Development of spectral indices

1. Initially intrinsic indices were developed from simple band ratios, which highlighted the spectral properties of vegetation at different stages of growth and senescence.
2. To compensate for background effects such as that caused in areas in which the soil response dominates over the vegetation.
3. To compensate for the effects of atmospheric distortion.
4. Development of new spectral indices to applications other than vegetation health. These include indices for burned area assessment and fire severity etc.

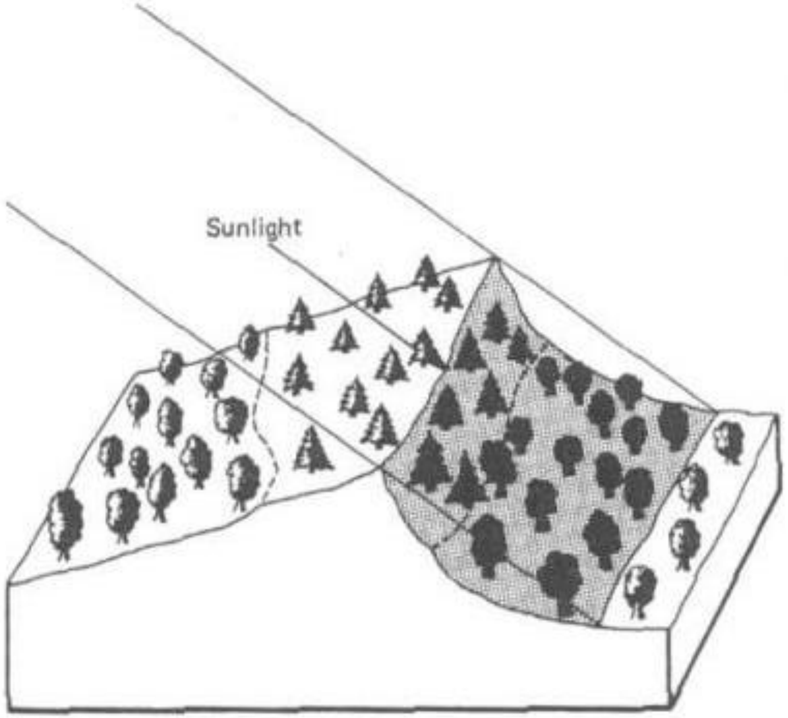
The criterion of a spectral index

- **Maximize the sensitivity** of certain surface feature (e.g. plant biophysical properties). Ideally, such responses should change linearly to allow both ease of scaling and use over a wide range of surface conditions.
- **Normalize or reduce effects** due to sun angle, viewing angle, the atmosphere, topography, instrument noise, etc., to allow consistent spatial and temporal comparisons
- Be linked to specific and measurable **surface processes** (e.g. biophysical parameter such as leaf area index (LAI), biomass, absorbed photosynthetically active radiation (APAR, etc.)) – i.e. be related to a measurable parameter or process

Source: *Jenson (RSE Book, 2000)*

Use of ratio to reduce topographic effects

Example 1



Land Cover/ Illumination	Digital Number Band A	Band B	Ratio (Band A/Band B)
Deciduous			
Sunlit	48	50	0.96
Shadow	18	19	0.95
Coniferous			
Sunlit	31	45	0.69
Shadow	11	16	0.69

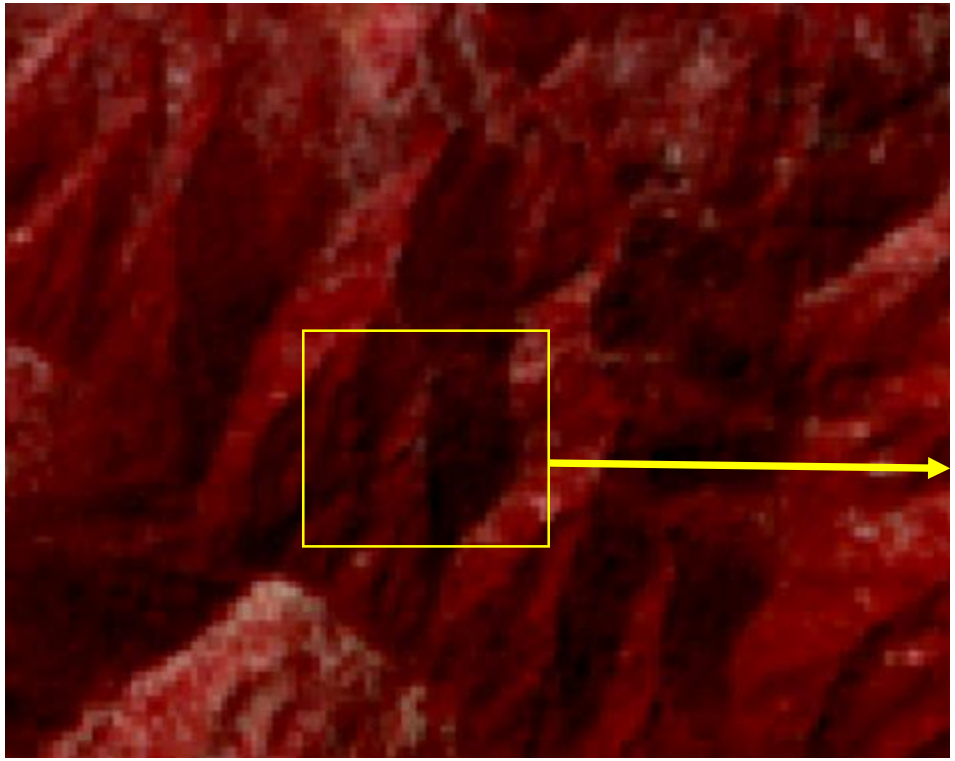
Figure 7.25 Reduction of scene illumination effects through spectral ratioing. (Adapted from Sabins, 1997.)

NB. The objective is to map 2 classes –coniferous and deciduous forest

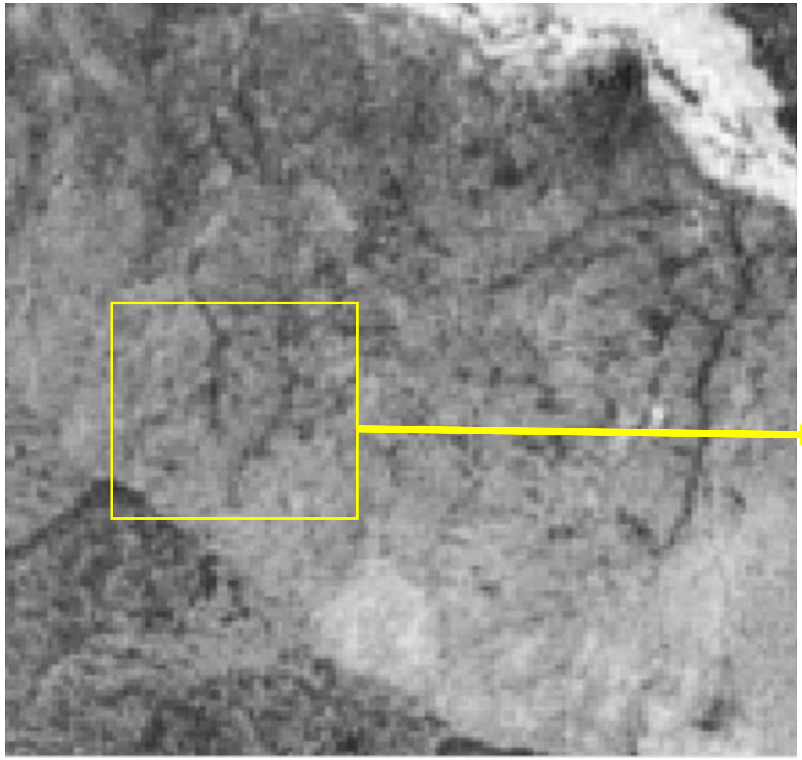
Use of indices to reduce topographic effects

Example 2 from Kabul

False color composite (FCC)



Normalized difference vegetation indices (NDVI)



R: 703
NIR: 1502
R:480
NIR:1018

Sunlit: 0.36
Shaded:0.359

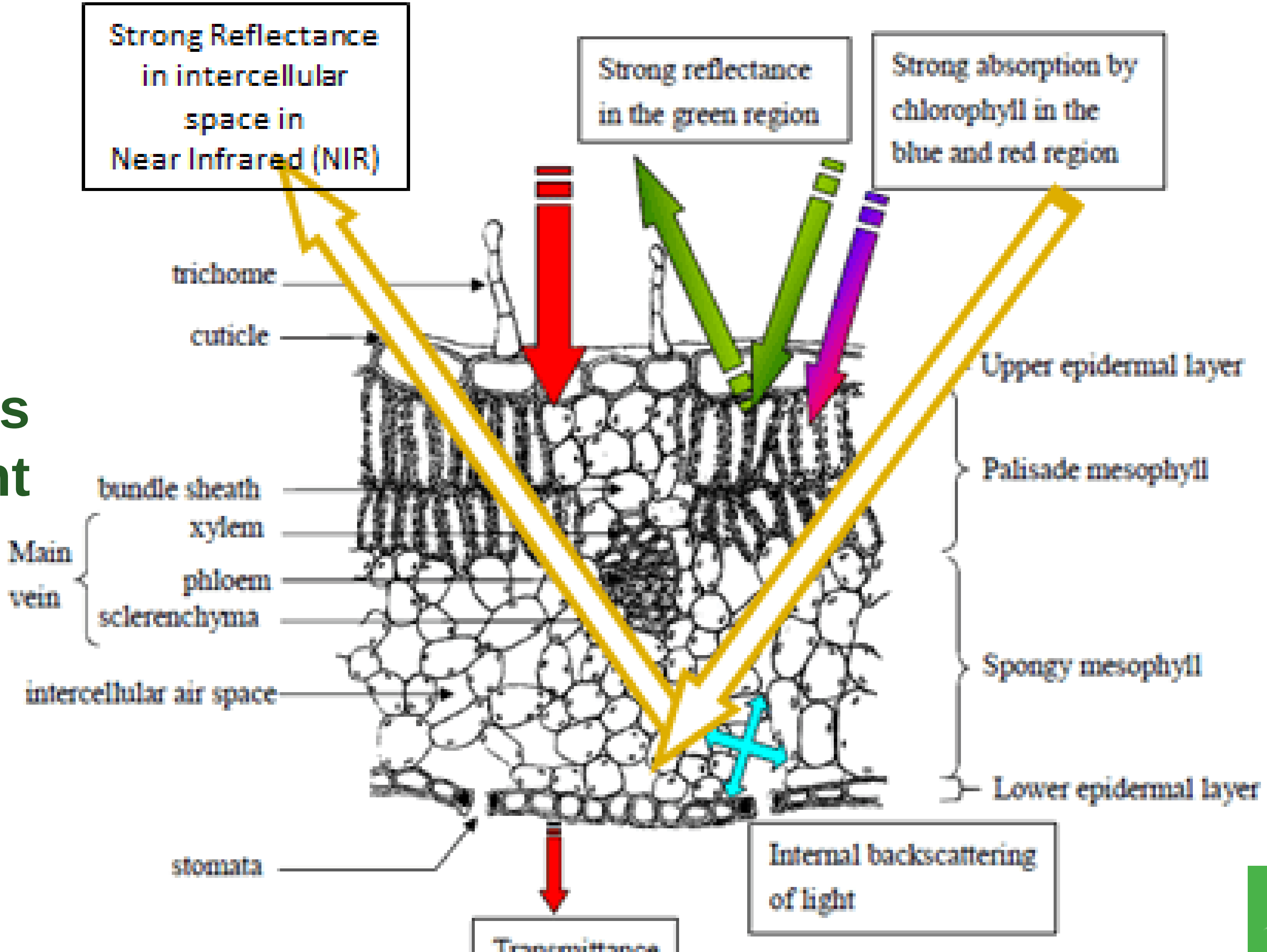
R and NIR represents the reflectance in red and near infra-red band of Sentinel for SUNLIT and SHADED region and their respective ratio in NDVI image

Vegetation indices

- **Enhances** green vegetation so that plants appear distinct from other image features
- Reflectance of light spectra from plants changes with **plant type**, **water content within tissues**, and other intrinsic factors
- Vegetation reflectance is determined by **chemical and morphological** characteristics of the surface of organs or leaves e.g. leaf structure, leaf pigments etc.

Vegetation indices

Leaf structure and its responses in different EMR region →



Vegetation indices

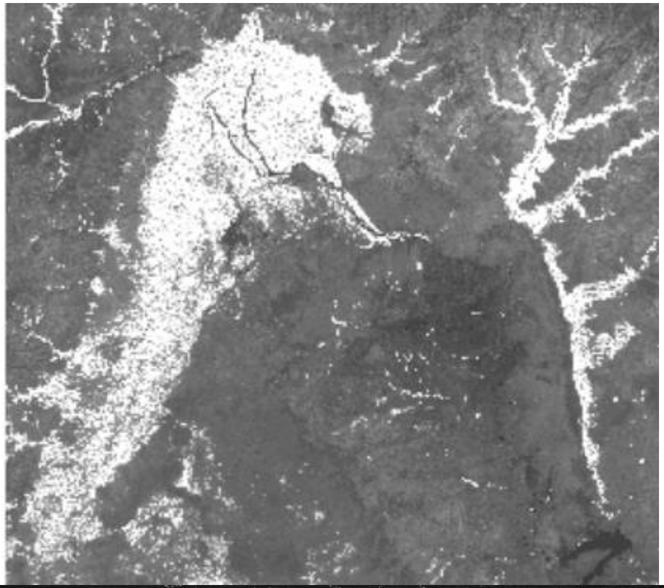
❖ Simple Difference Vegetation Index

DVI = NIR-R (*Richardson et al., 1977*)

– Distinguishes between **soil** and **vegetation**

– Does Not deal with the **atmospheric effects**

DVI



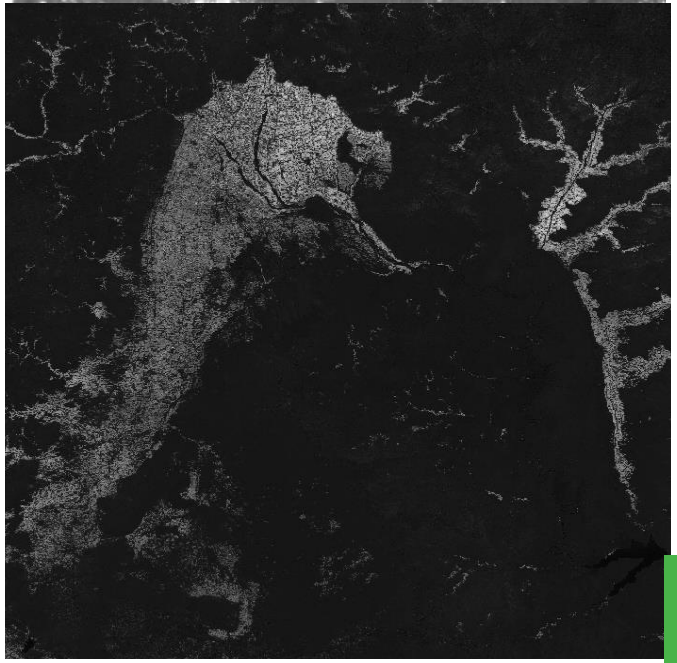
❖ Ratio-based Vegetation Index

RVI = R/NIR (Jordan 1969)

– Reduces the effects of **atmosphere** and **topography**

– **Low** for soil, ice, water, etc.

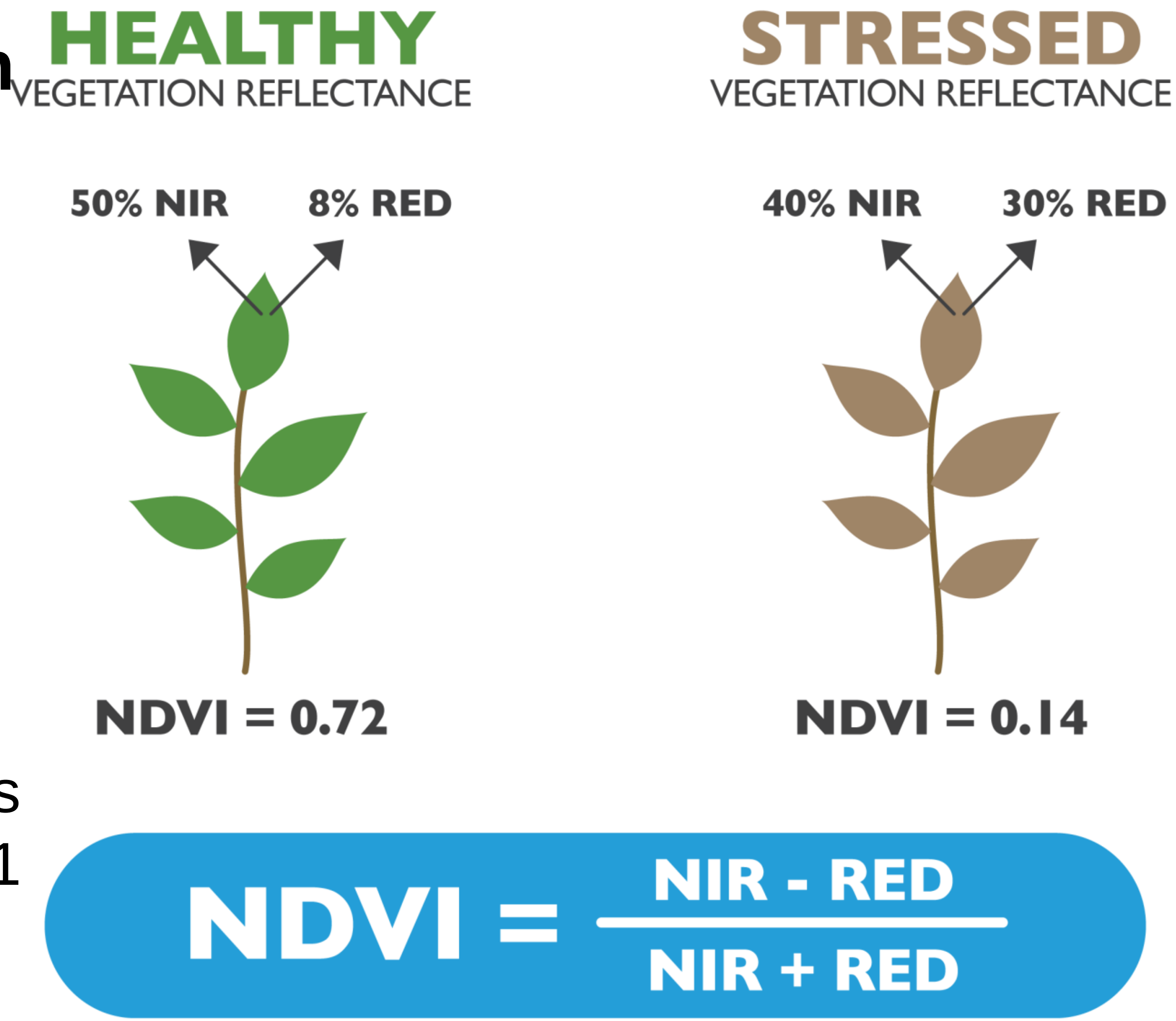
RVI



Vegetation indices

❖ **Normalized Difference Vegetation Index**

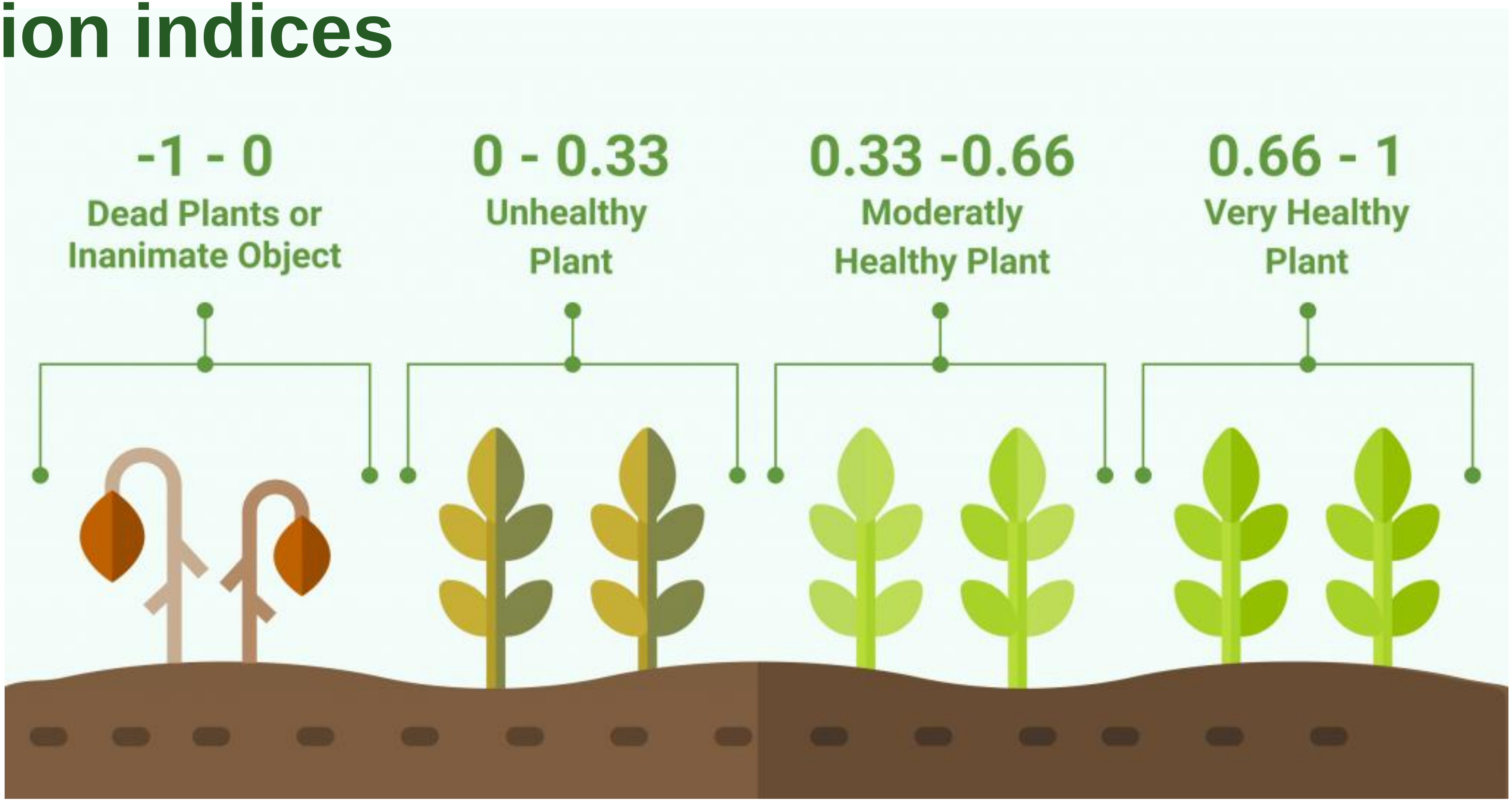
- Standard method for comparing the vegetation greenness from satellite
- NDVI = (NIR)-(RED)/ (NIR)+ (RED)
- Explains density of vegetation
- The NDVI values tentatively ranges between **-1 to +1**, the values close to +1 denotes the **good health** of vegetation



NDVI is sensitive to the effects of soil and atmosphere and saturates at high density of vegetation

Vegetation indices

NDVI



- **Negative values** correspond to areas with **water surfaces, manmade structures, rocks, clouds, snow**;
- Plants will always have positive values between **0.2 and 1.**

Vegetation indices

❖ Soil Adjusted Vegetation Index

- The concept of distinction of vegetation from the **soil background** was proposed by *Richardson and Wiegand., 1977*
- Soil background conditions exert considerable influence on partial canopy spectra and the calculated vegetation indices

❖ SAVI = ((NIR – Red) / (NIR + Red + L)) x (1 + L) *Huete, 1988*

- Minimizes soil brightness influence
- L is a variable ranges within **-1 to 1**, depending on the amount of green vegetation present in the area
- To run the remote sensing analysis of areas with high green vegetation, L is set to be zero (in which case SAVI index data will be equal to NDVI); whereas low green vegetation regions require L=1

Vegetation indices

- **Atmospherically Resistant Vegetation Index (ARVI;** *Kaufman and Tanré, 1992***)**
  - Relatively prone to atmospheric factors (such as aerosol)
  - Atmosphere affects significantly **Red** region compared to the **NIR**
  - Corrected for atmospheric scattering effects in the red reflectance spectrum by using the measurements in blue wavelengths.

ARVI = (NIR – (2 * Red) + Blue) / (NIR + (2 * Red) + Blue)

- Eliminates the effect of atmospheric aerosols
- Monitoring tool for tropical mountainous regions often polluted by soot coming from slash-and-burn agriculture

Vegetation indices

- **Land Surface Water Index (LSWI)**

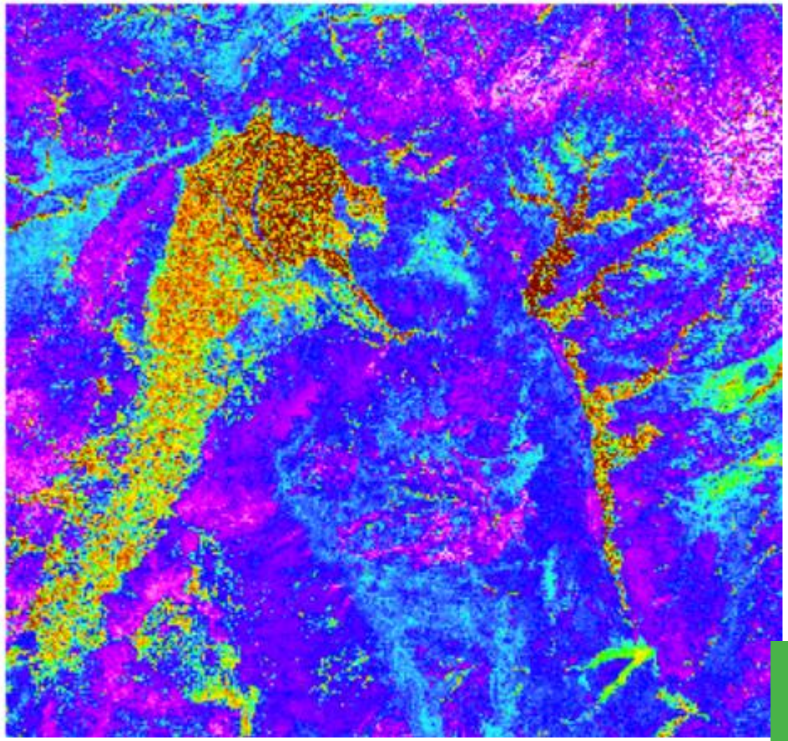
NIR-SWIR/NIR+SWIR

LSWI is sensitive to changes in vegetation canopy water content and indicates the water stress

- **Vegetation Condition Index (VCI)**

$$(NDVI-NDVI_{min}/NDVI_{max}-NDVI_{min})*100$$

Lower and higher values indicate bad and good vegetation state conditions



LSWI

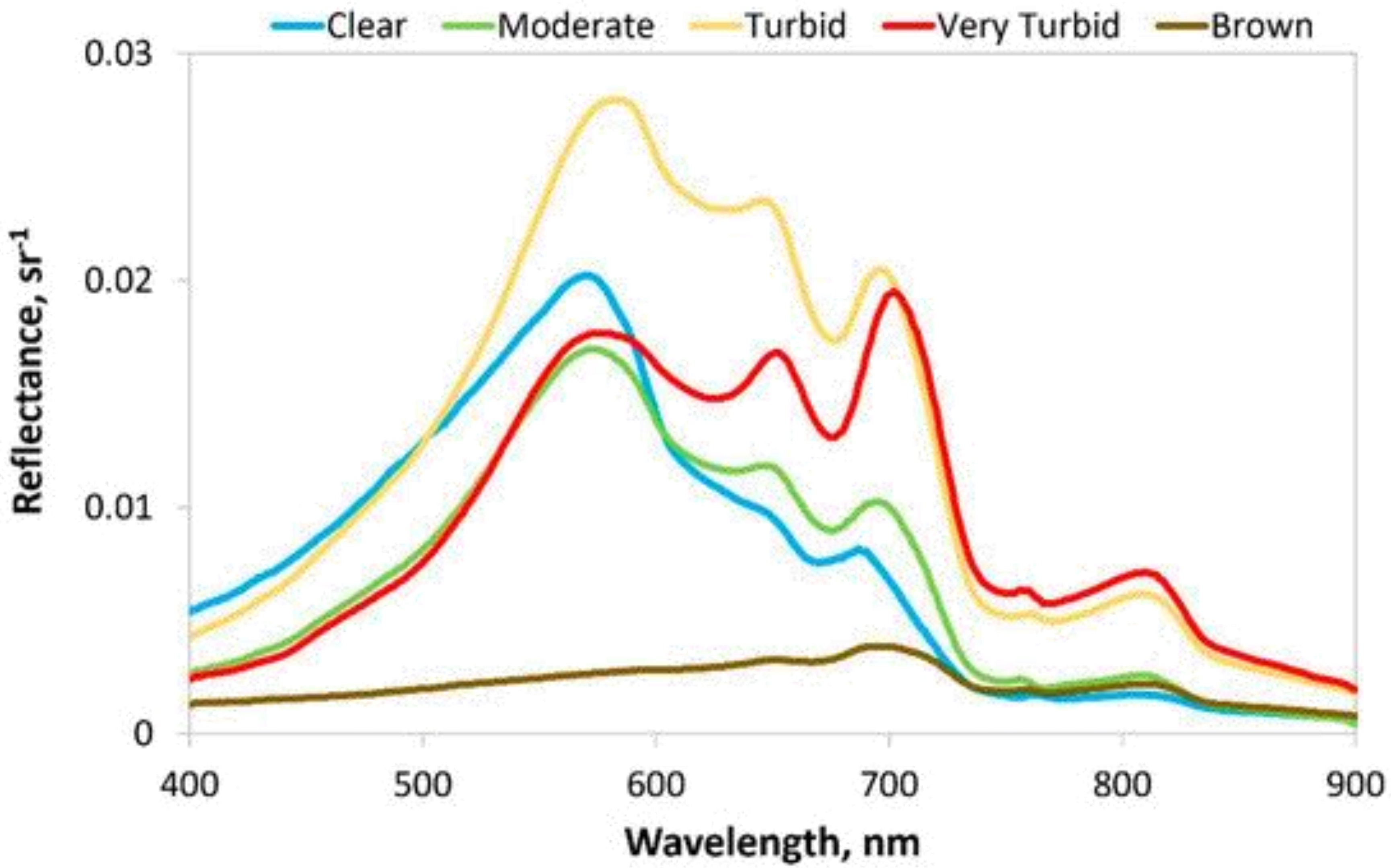
Water indices

- ➢ Used to highlight the water bodies while suppressing the other land cover
- ➢ Water **absorbs more energy** (low reflectance) **in NIR and SWIR** wavelengths
- ➢ Have the **greatest reflectance** in the **blue portion** of the visible spectrum
- ➢ Clear water has **high absorption** and virtually no reflectance in near infrared wavelengths range and beyond

Factors affecting water

- ➢ **Algae:** Water with higher algal density reflect more in **green** bands
- ➢ **Turbidity:** Turbid water has a **higher reflectance** in the visible region than clear water. This is also true for waters containing high chlorophyll concentrations

Water indices

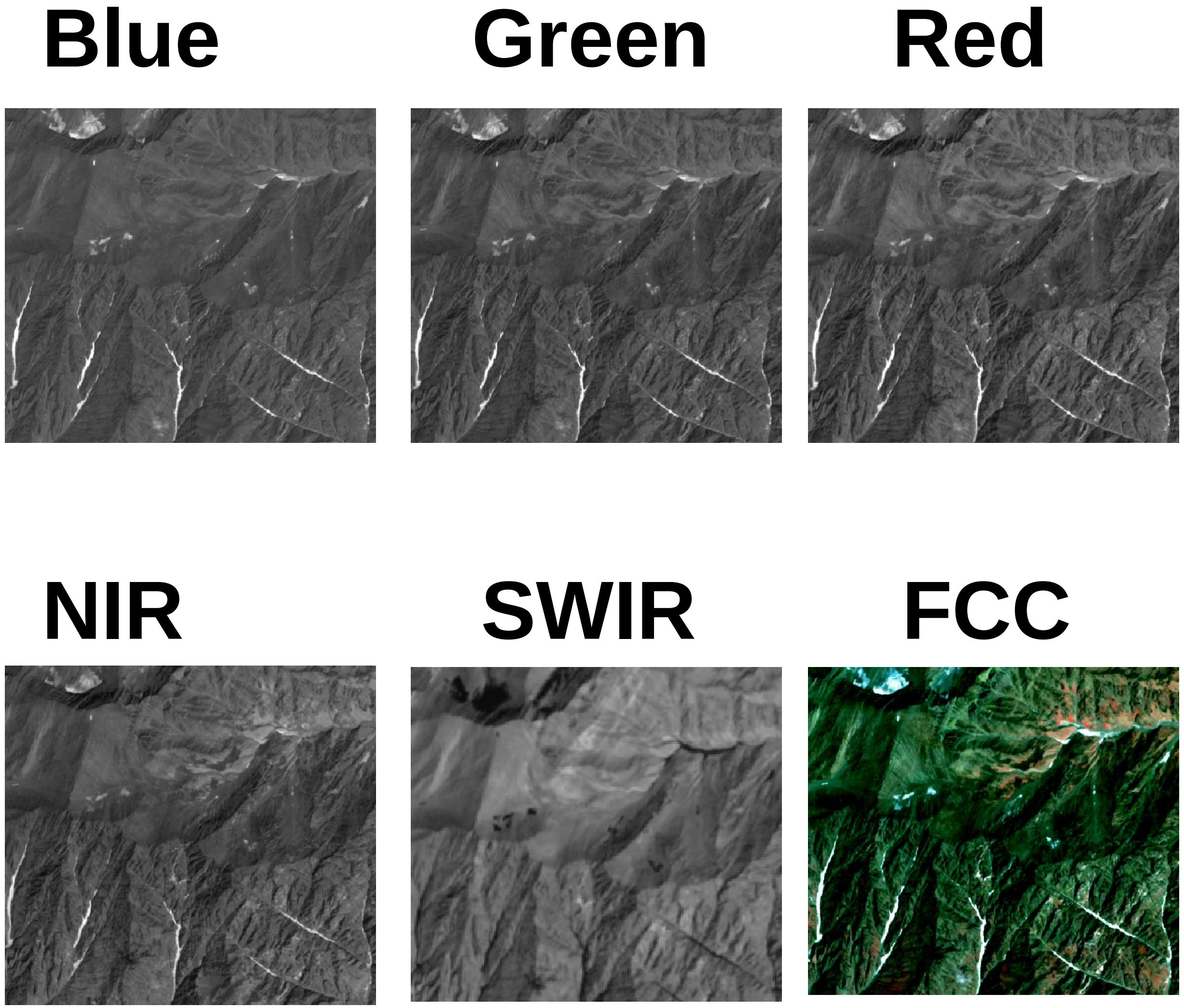


Adapted from *Kristi Uudeberg, 2019*

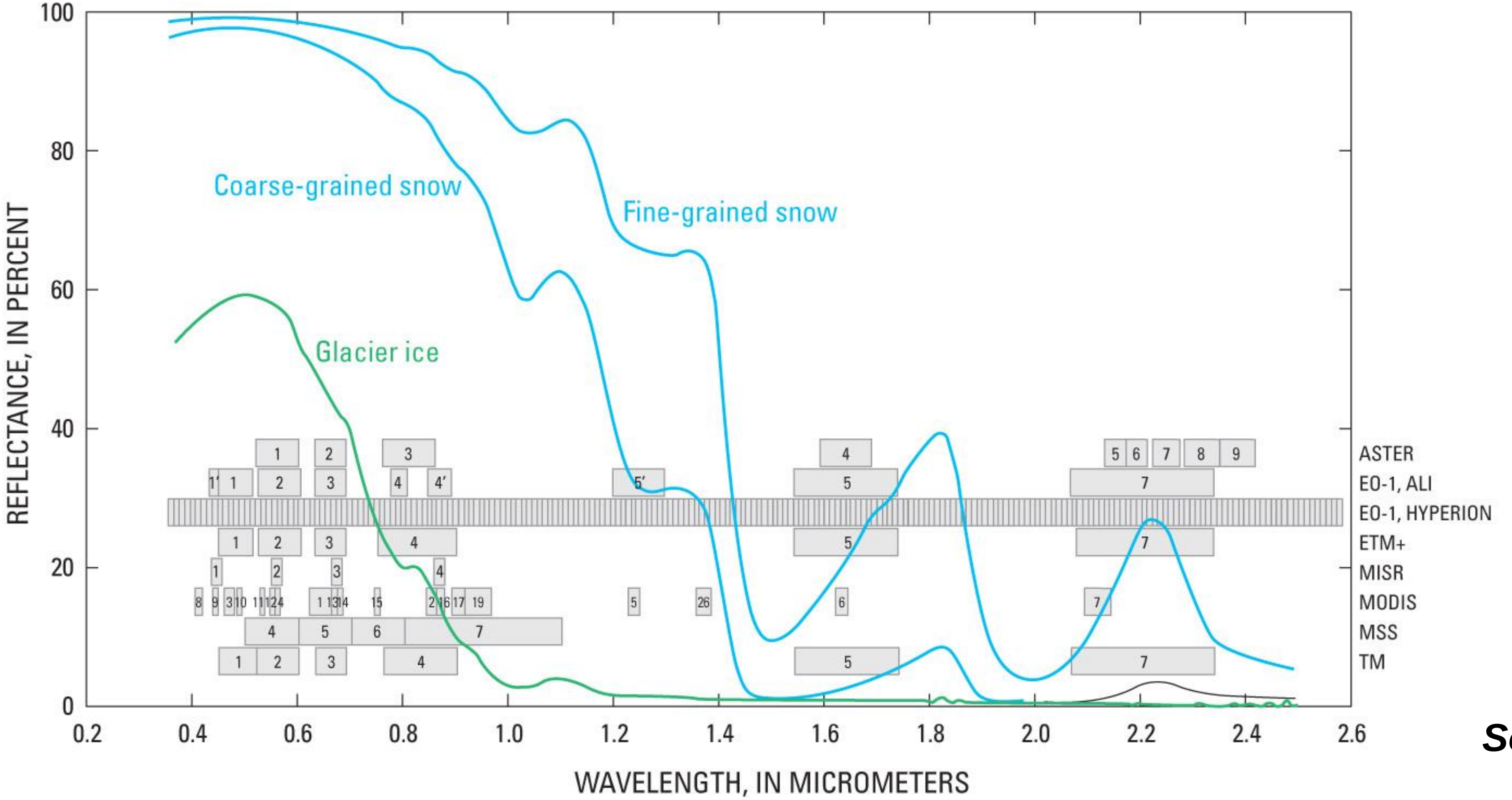
Reflectance response of water with different levels of turbidity

Snow indices

- Ice and snow generally have **high reflectance** across **all** visible wavelengths, thus bright white appearance
- The **low reflection** of ice and snow in the **SWIR** is related to their **microscopic liquid water content**



Snow indices



Source: USGS

Spectral reflectance curves of bare glacier ice, coarse-grained snow, and fine-grained snow. Spectral bands of selected sensor on Earth-orbiting satellites are shown in gray. The numbers in the gray boxes refer to the associated band numbers of each sensor

Water and snow indices

Indices	Formula
Normalized Difference Water Index (NDWI)	GREEN-NIR/GREEN+NIR
Modified Normalized Difference Water Index (MNDWI)	GREEN-SWIR/GREEN+SWIR
Normalized Difference Pond Index (NDPI)	MIR-GREEN/MIR+GREEN
Water Ration Index (WRI)	GREEN+RED/NIR+SWIR
Normalized Difference Turbidity Index (NDTI)	RED-GREEN/RED+GREEN
Automated Water Extraction Index (AWEI)	4*(GREEN-SWIR2-0.25*NIR+2.75*SWIR1
Normalized Difference Snow Index (NDSI)	GREEN-SWIR/GREEN+SWIR
Normalized Difference Snow and Ice Index (NDSII-1)	RED-SWIR/RED+SWIR
Snow Water Index (SWI)	GREEN (NIR-SWIR)/ (GREEN+NIR)(NIR+SWIR)

Applications

Application of vegetation indices

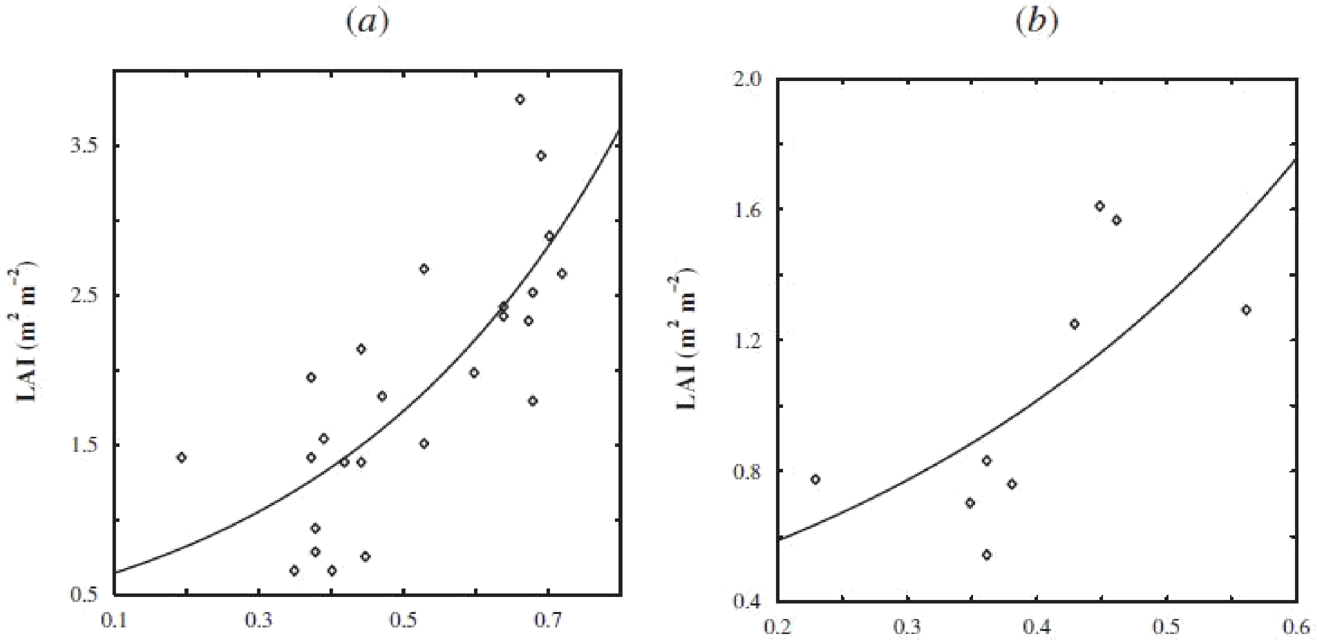
- Vegetation mapping and monitoring
- Biodiversity assessment
- Estimation of biophysical parameters (LAI, *f*PAR)
- Phenological assessment
- Vegetation health/stress
- Forest degradation
- Biomass mapping and modelling
- Productivity and carbon assessment
- Crop condition monitoring and predicting crop yield

Application of vegetation indices

Index	Wavebands	Application
Ratio	R_{NIR}/R_{red}	Biomass, LAI, cover
Normalized Difference Vegetative Indices		
Red NDVI	$(R_{NIR} - R_{red})/(R_{NIR} + R_{red})$	LAI, Intercepted PAR
Green NDVI	$(R_{NIR} - R_{green})/(R_{NIR} + R_{green})$	LAI, Intercepted PAR
Red Edge NDVI	$(R_{NIR} - R_{red\ edge})/(R_{NIR} + R_{red\ edge})$	LAI, Intercepted PAR
Soil Adjusted Vegetation Index		
SAVI	$(R_{NIR} - R_{red})(1 + L)/(R_{NIR} + R_{red} + L)$	LAI
Enhanced Vegetation Index		
EVI	$2.5(R_{NIR} - R_{red})/(R_{NIR} + 6R_{red} - 7.5R_{blue} + 1)$	LAI
Normalized Pigment Chlorophyll Ratio Index		
NPCI	$(Red_{660} - Blue_{460})/(Red_{660} + Blue_{460})$	Leaf chlorophyll
Chlorophyll Indices		
CI_{green}	$(R_{NIR}/R_{green}) - 1$	Leaf chlorophyll
$CI_{red\ edge}$	$(R_{NIR}/R_{red\ edge}) - 1$	Leaf chlorophyll
Plant Senescence Reflectance Index		
PSRI	$(Red_{660} - Green_{510})/NIR_{760}$	Plant senescence

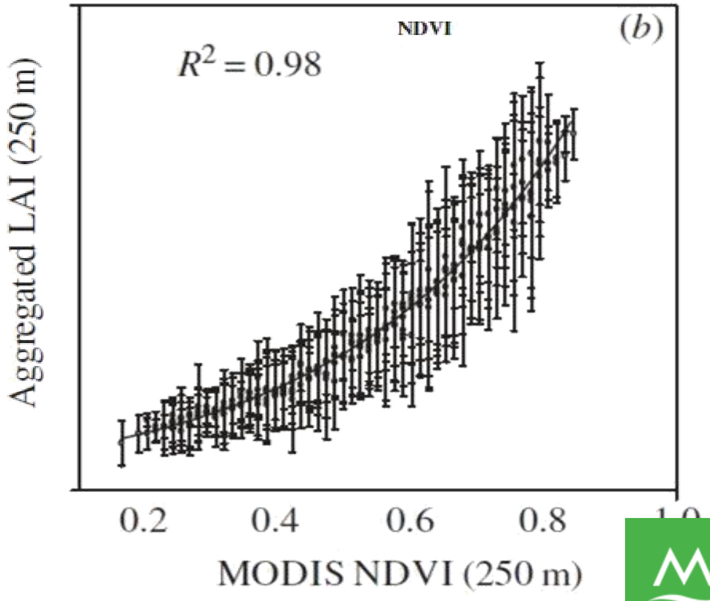
Source: Hatfield and Prueger (2010)

Application of vegetation indices



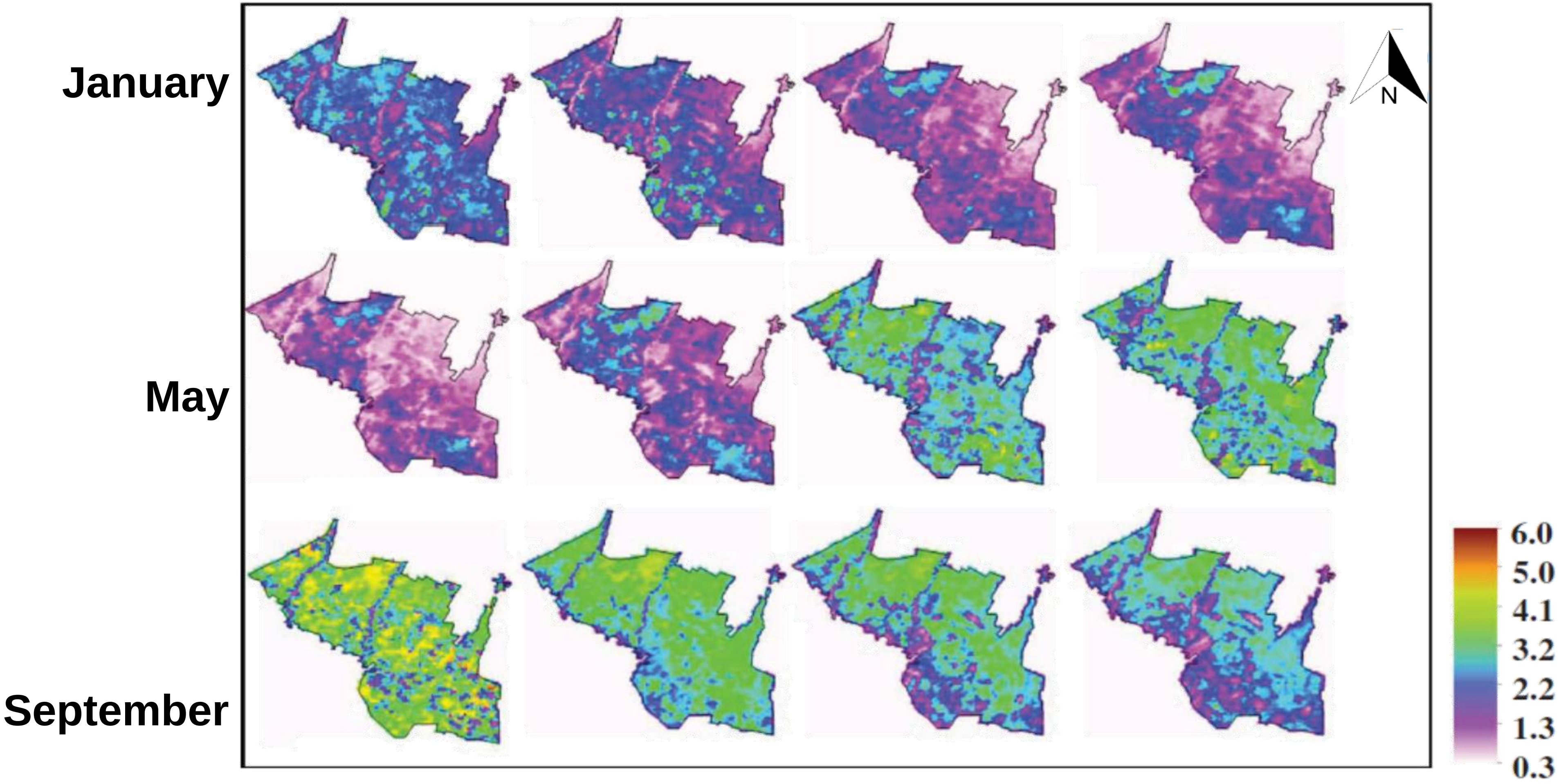
Leaf area estimation

Plantation	R^2	a	B	c	F-value
a) Mixed	0.59	0.06	2.47	2.13	49.8
b) Eucalyptus	0.47	0.07	2.73	1.52	21.6
c) Poplar	0.46	0.05	3.13	2.26	20.4
d) All plantation	0.62	0.05	2.73	2.01	63.3



Source: *Tripathi et al., 2014*

Application of vegetation indices



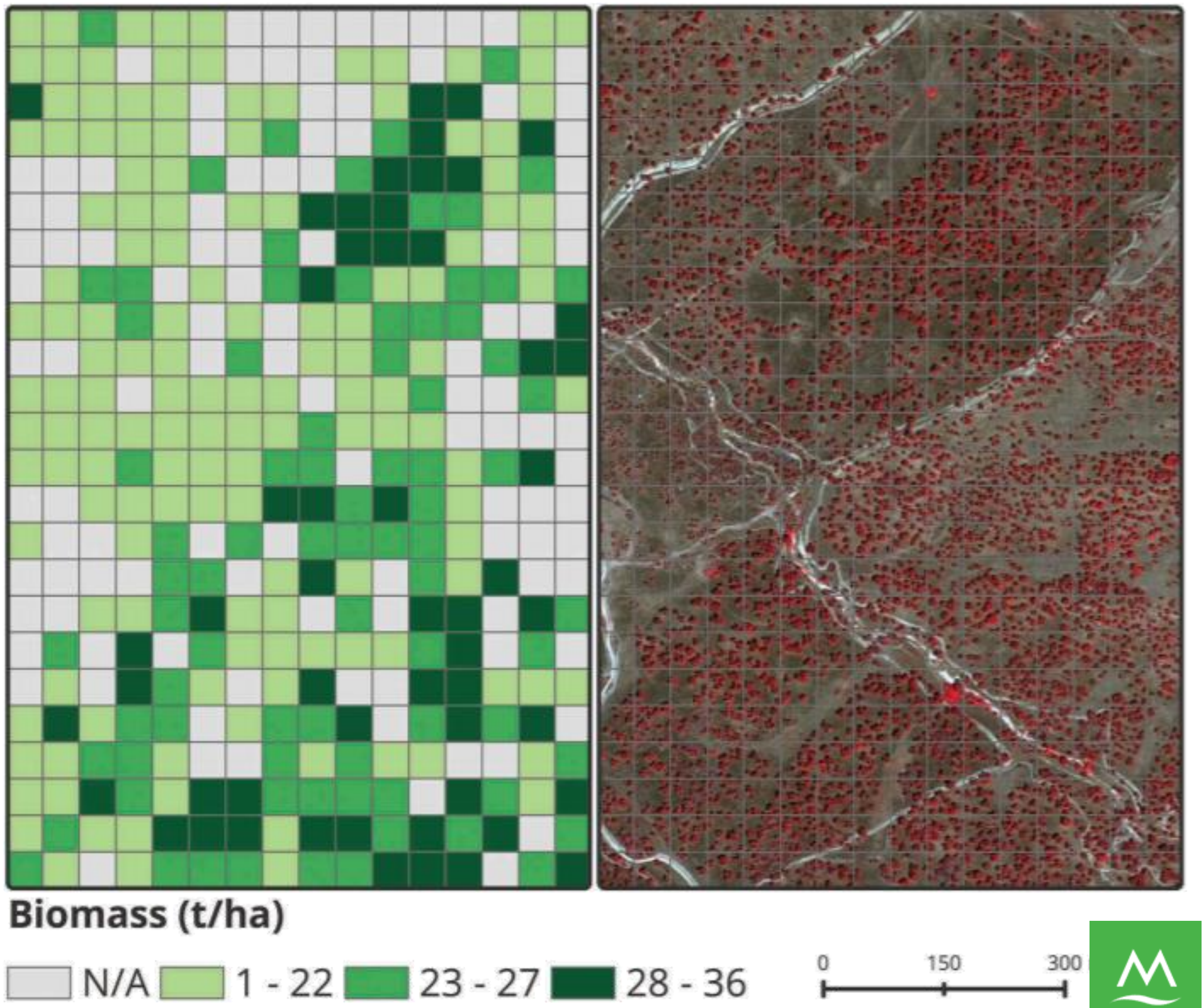
Monthly pattern (January- December) of leaf area index (LAI) derived from NDVI (exponential relationship)

Source: *Tripathi et al., 2014*

Application of vegetation indices

Biomass estimation

	AGB (t/ha)	CC (%)
AGB (t/ha)	1	
CC (%)	0.83	1
NDVI	0.85	0.95
EVI	0.75	0.91
SR	0.86	0.96
SAVI	0.70	0.84



Correlation between above ground biomass and vegetation indices for *Quercus rotundifolia*

Source: *Macedo et al., 2018, southern Portugal*

Application of vegetation indices

Drought Assessment

TABLE 1.
Remote sensing data, indices and thresholds relevant to drought assessment used in the study.

Drought index	Band or index used to compute the index		Range	Normal condition	Severe drought	Healthy vegetation
	AVHRR	MODIS				
1. Normalized difference vegetation index (NDVI)	Band 1 (0.58-0.68μm) Band 2 (0.73-1.10μm)	Band 1 (0.62-0.67μm) Band 2 (0.84-0.87μm)	-1 to +1	Depends on the location	-1	+1
2. Drought severity index (DEV_{NDVI})	NDVI NDVI long-term mean	NDVI NDVI long-term mean	-1 to +1	0	-1	+1
3. Vegetation condition index (VCI)	NDVI NDVI long-term minimum NDVI long-term maximum	NDVI NDVI long-term minimum NDVI long-term maximum	0 to 100 %	50 %	0%	100%

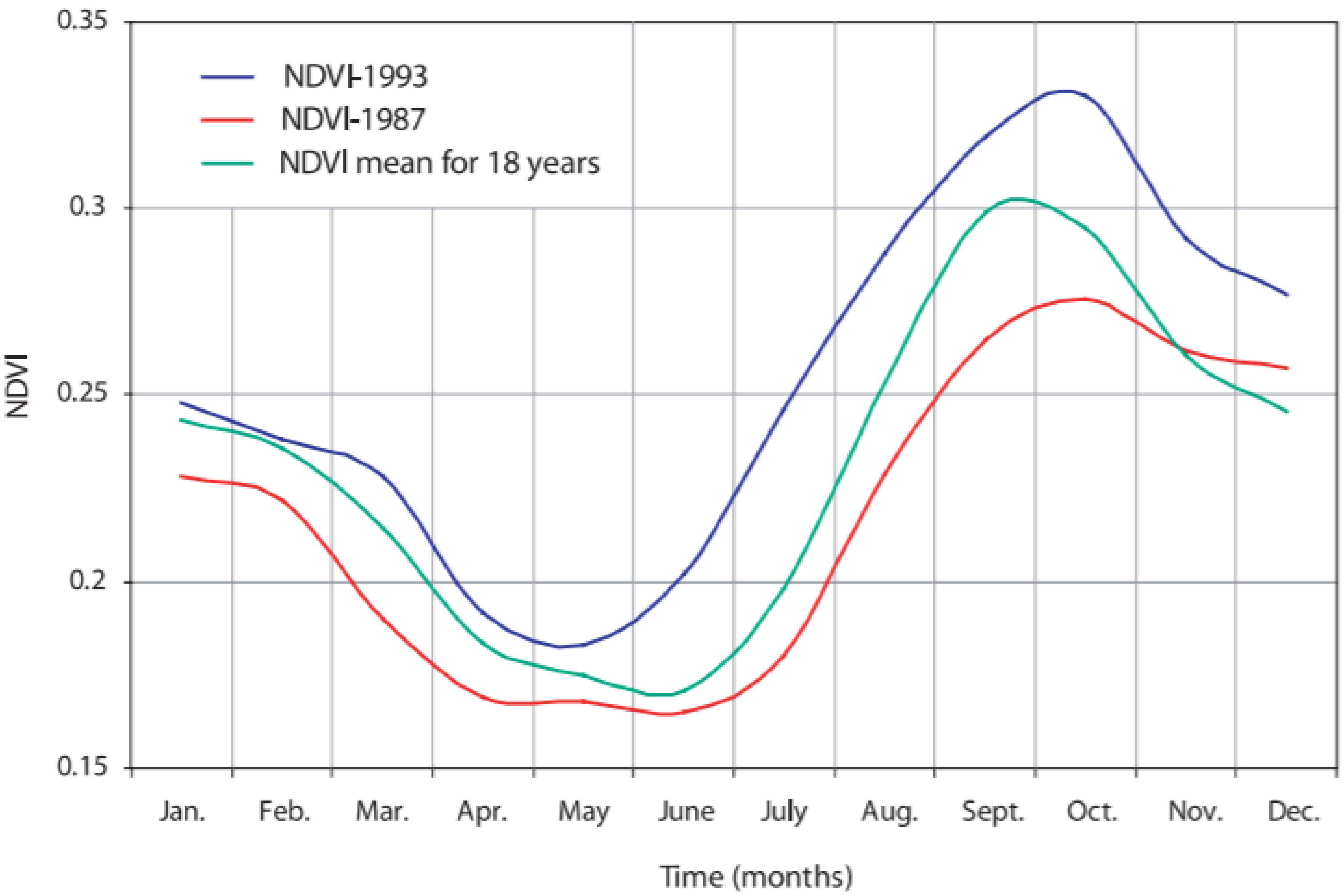
Source: *Thenkabail and Gamage, 2004*

Application of vegetation indices

Southwest Asia

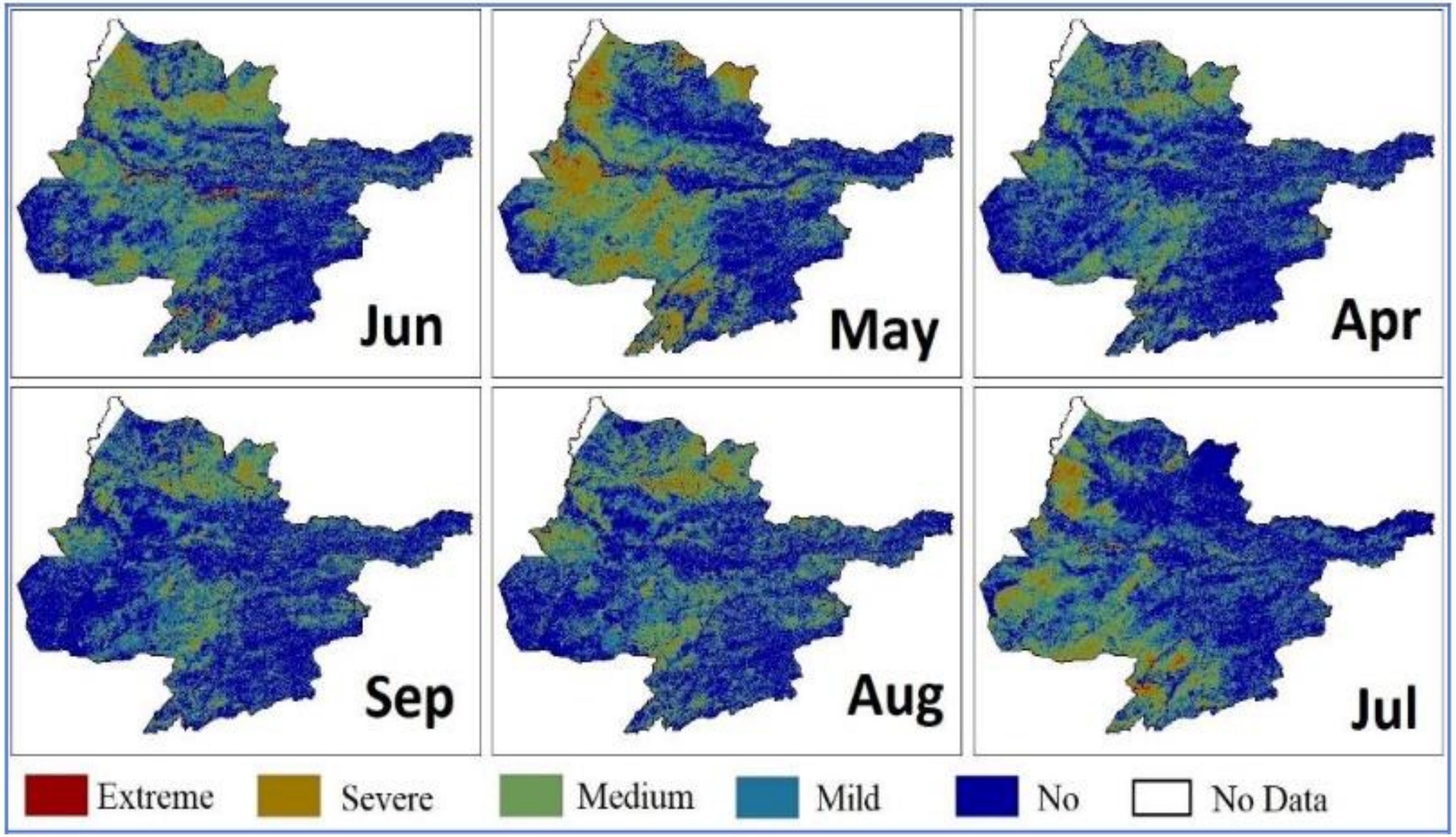
NDVI deviation

- A monthly NDVI time series for a drought year (1987) and a wet year (1993) compared to the NDVI long-term mean



Source: *Thenkabail and Gamage, 2004*

Application of vegetation indices



Monthly median of drought condition in Herat province during vegetation seasons of 2003-2014 based on VCI

Source: *Mohammad Ehsan Razipoor, 2019*

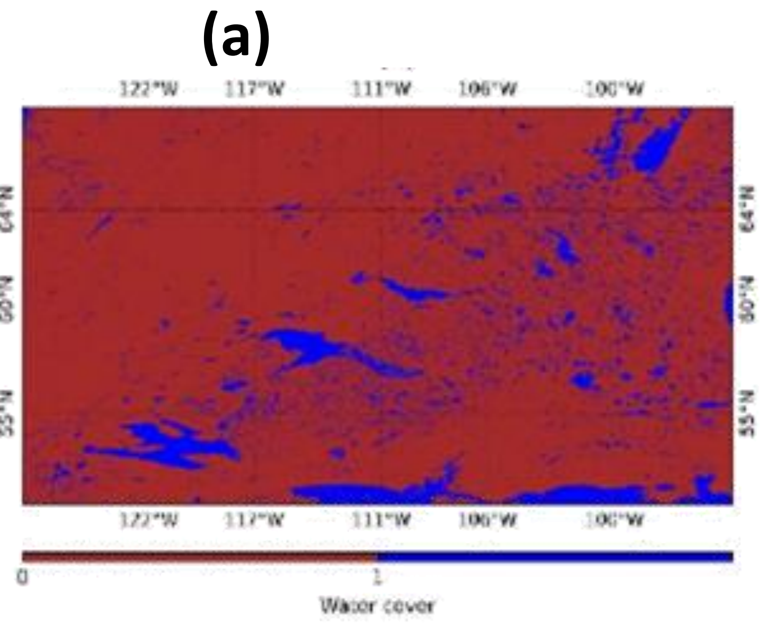
http://www.fao.org/giews/earthobservation/asis/index_2.jsp?lang=en

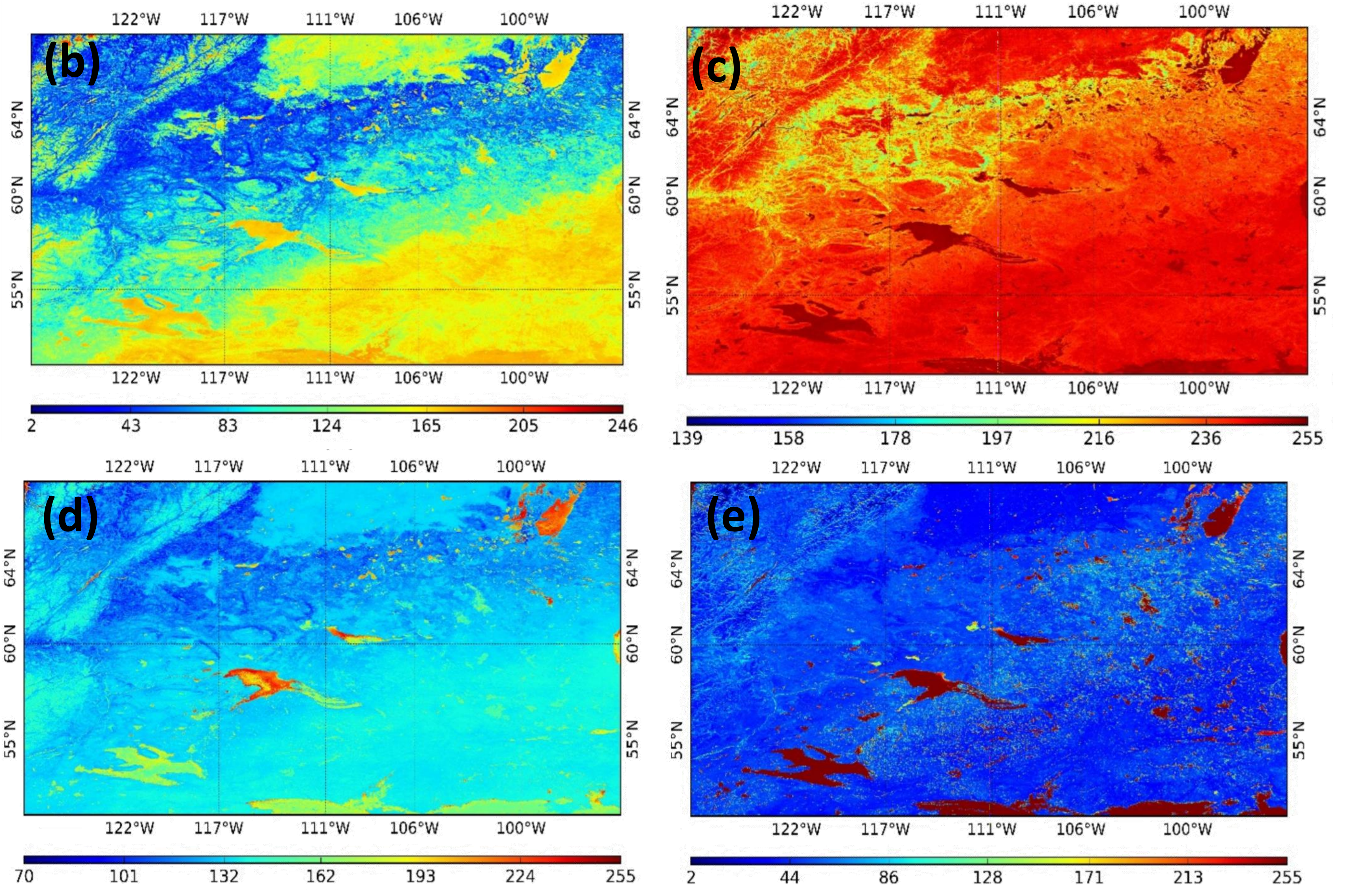
Application of water and snow indices

- Water Mapping and monitoring
- Change detection
- Water quality assessment
- Flood monitoring and damage assessment
- Algae assessment
- Snow and Ice mapping and monitoring

Application of water indices

Water mapping

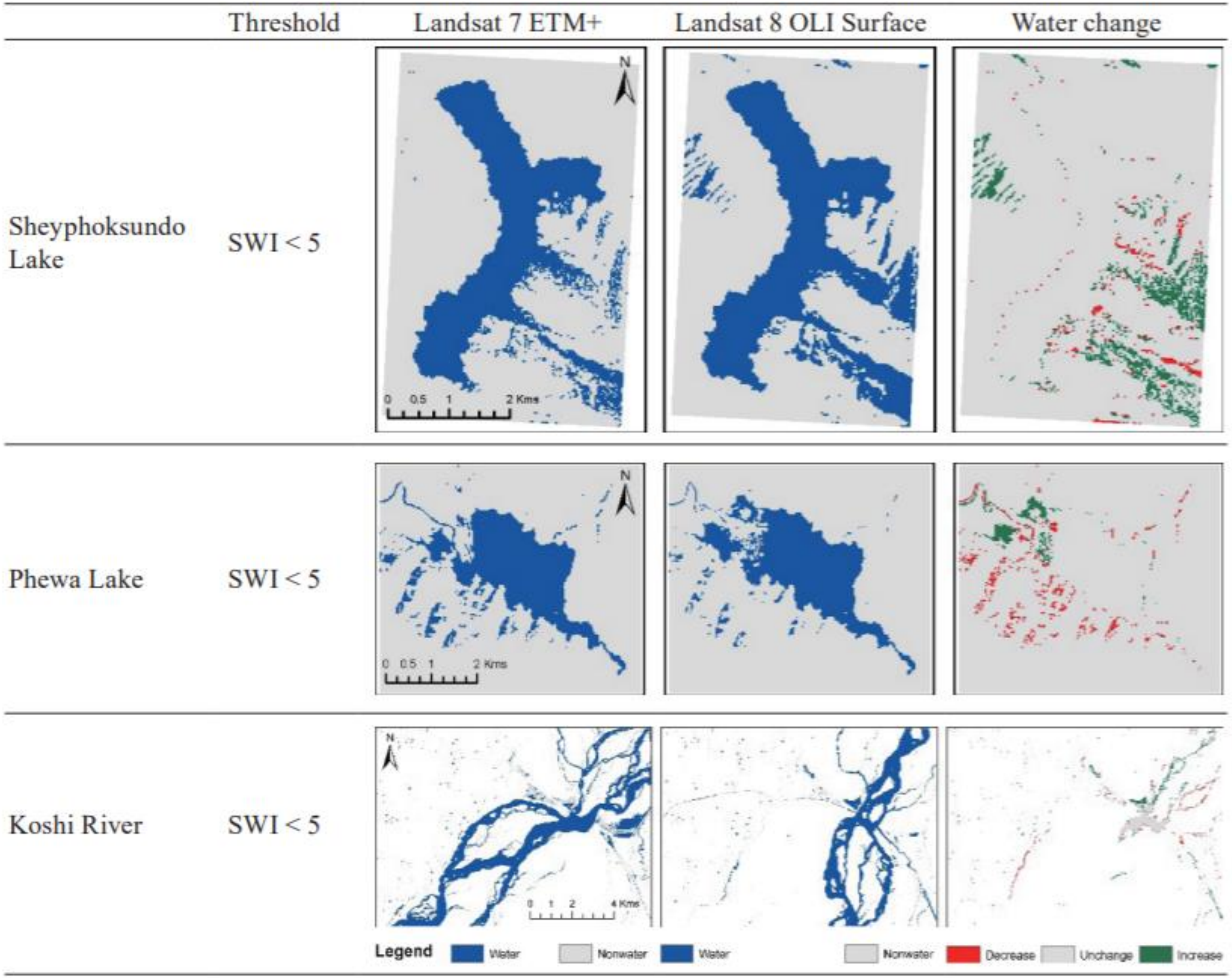




Source: *Sharma et al, 2015*

(a) Reference water cover map (b) Automated Water Extraction Index (AWEI), (c) Modified Normalized Difference Water Index (MNDWI) (d) Normalized Difference Water Index (NDWI), (e) Superfine Water Index (SWI)

Application of water indices



Water mapping and change dynamics

Simple water index (SWI)

$$SWI = 1/\sqrt{(Blue - SWIR1)}$$

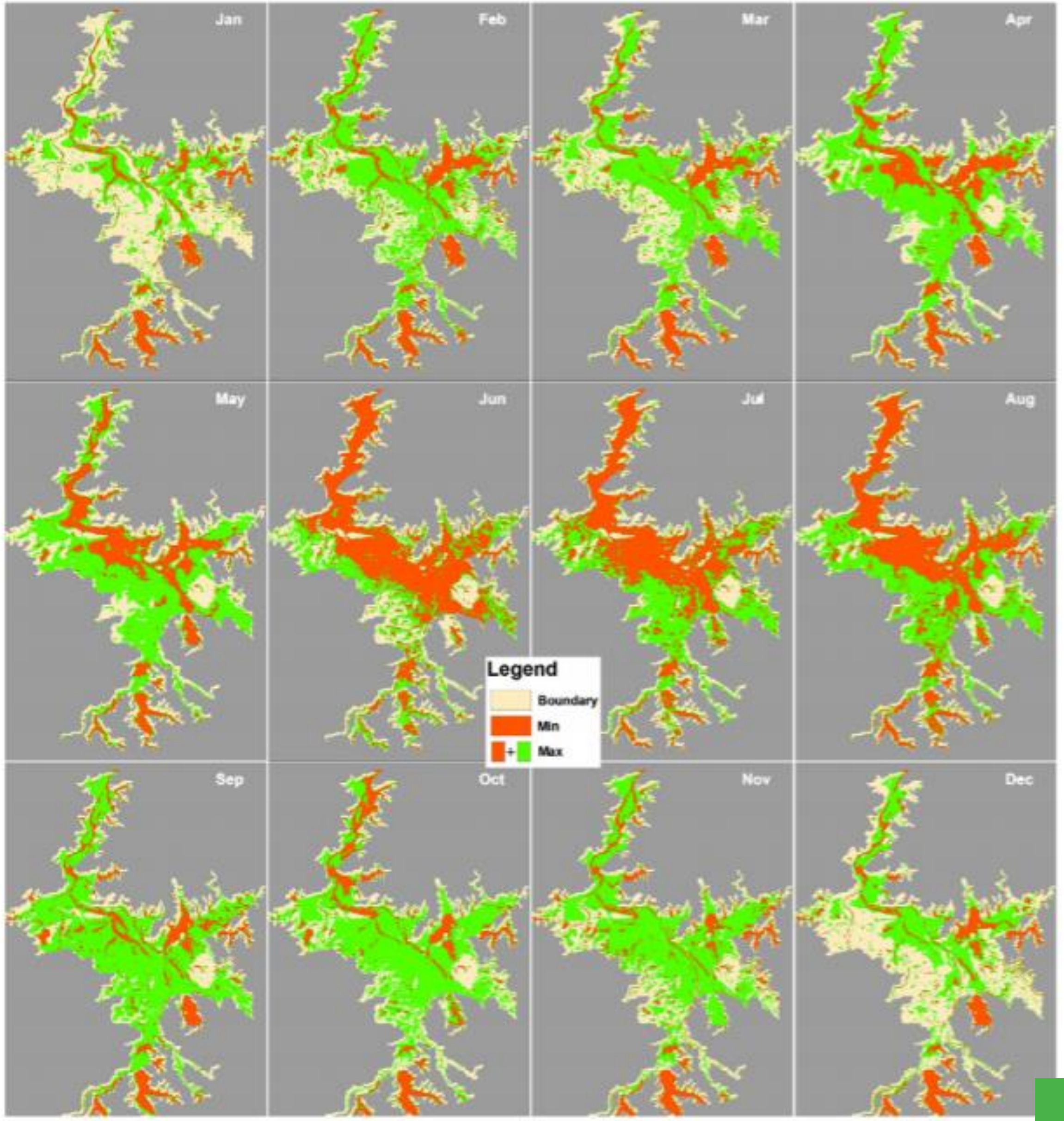
Source: *Acharya et al., 2019*

Application of water indices

Water inundation mapping

- Minimum and maximum inundation areas and their distributions during each climatological month between 2000 and 2010 for Poyang Lake, China

Source: *Feng et al. (2012)*



Application of water indices

Water quality assessment

Table 3. Correlation coefficient analyses between water quality and spectral indices

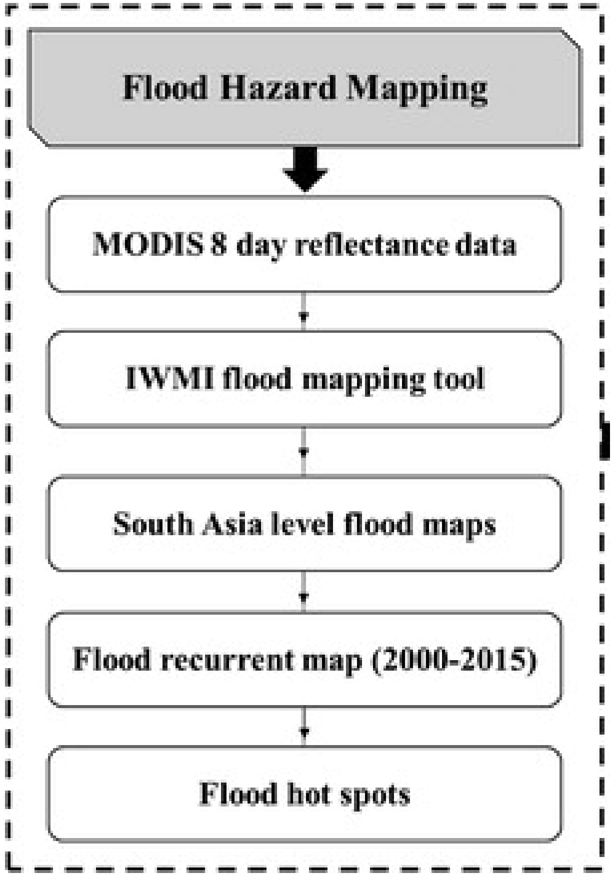
Parameter	EC	pH	Nitrate	Nitrite	Silicate	Phosphate	O.M	NDSI	NDVI	NDBI	N/P ratio
EC	1										
pH	0.192	1									
Nitrate	0.106	0.173	1								
Nitrite	0.292	0.144	0.806	1							
Silicate	0.827	0.229	0.46	0.721	1						
Phosphate	-0.016	-0.353	-0.28	-0.069	-0.002	1					
O.M	-0.02	-0.339	-0.086	-0.185	-0.044	-0.03	1				
NDSI	-0.273	0.033	-0.416	-0.517	-0.272	-0.085	0.246	1			
NDVI	0.273	-0.033	0.416	0.517	0.272	0.085	-0.246	-1	1		
NDBI	-0.355	-0.006	-0.332	-0.516	-0.392	0.032	0.488	0.744	-0.744	1	
N/P ratio	-0.221	0.329	0.897	0.738	0.334	-0.171	-0.096	-0.345	0.345	-0.135	1.000

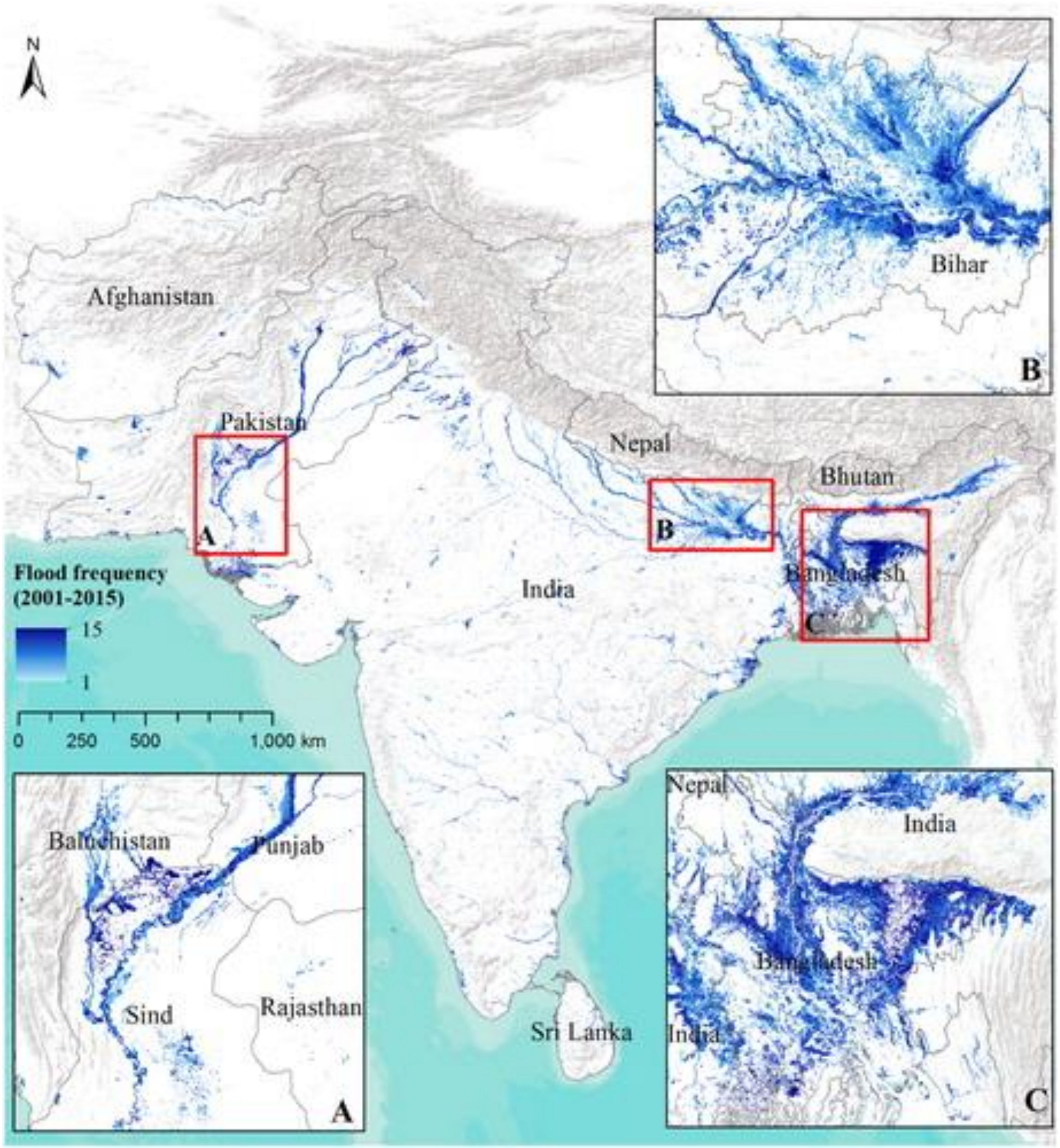
Source: *Ahmed M. El-Zeiny, 2018*

Application of water indices

Flood hotspot analysis

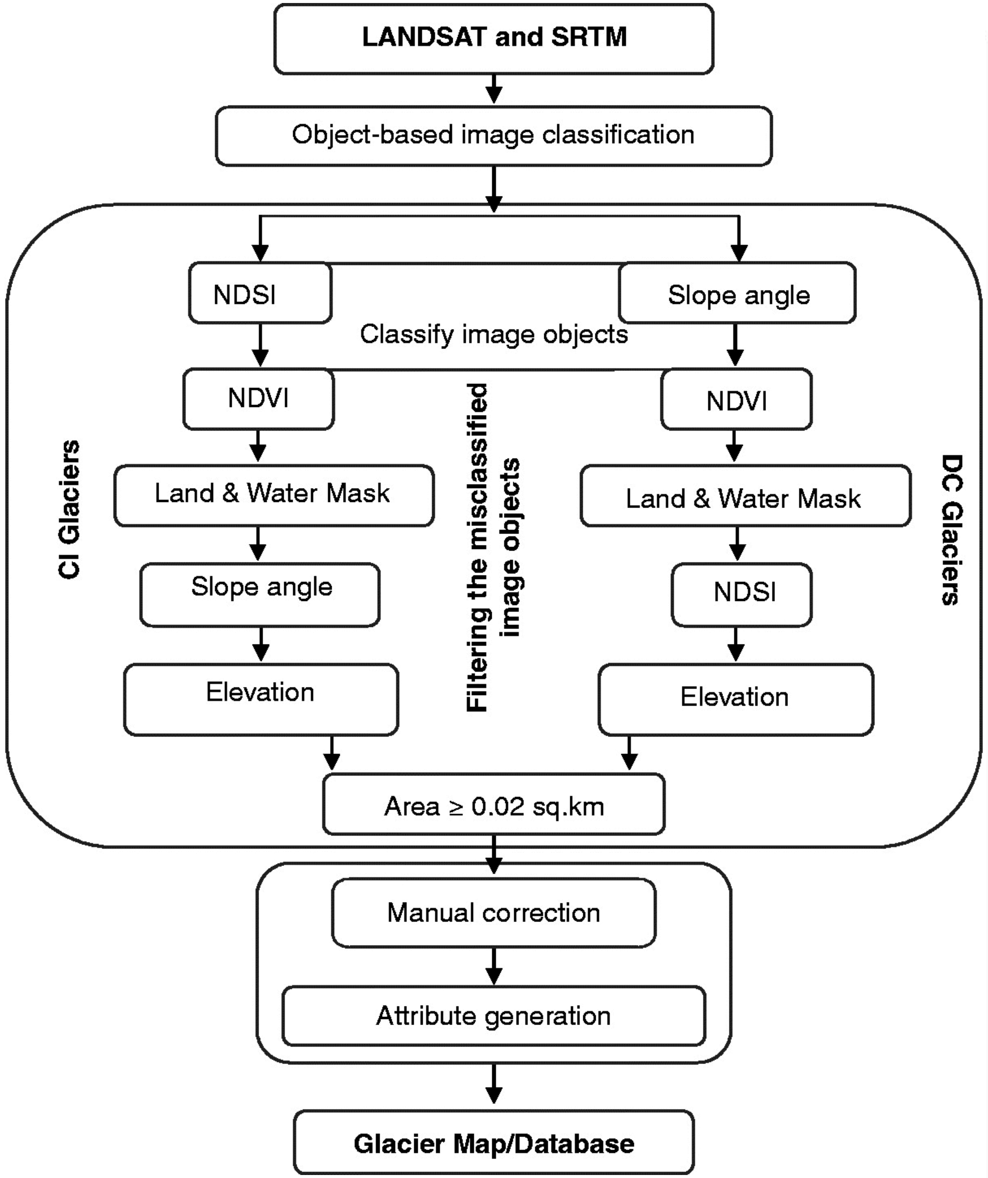
International Water Management Institute project

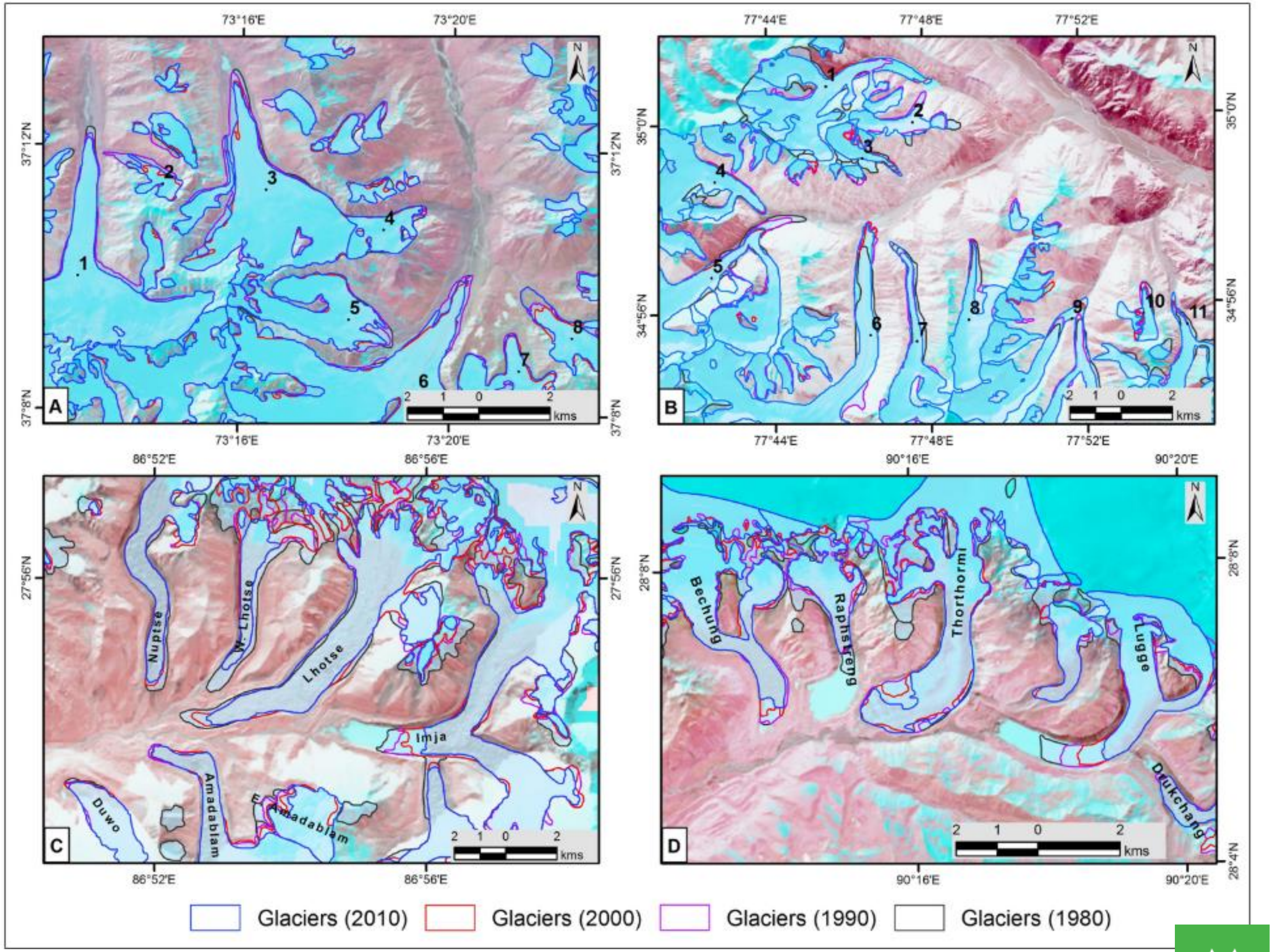




Source: *Matheswaran et al, 2018*

Application of snow indices





Source: *Bajracharya et al., 2015*

- Thank you