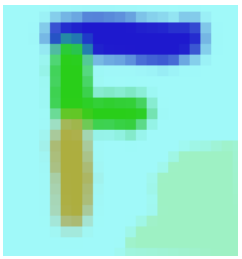
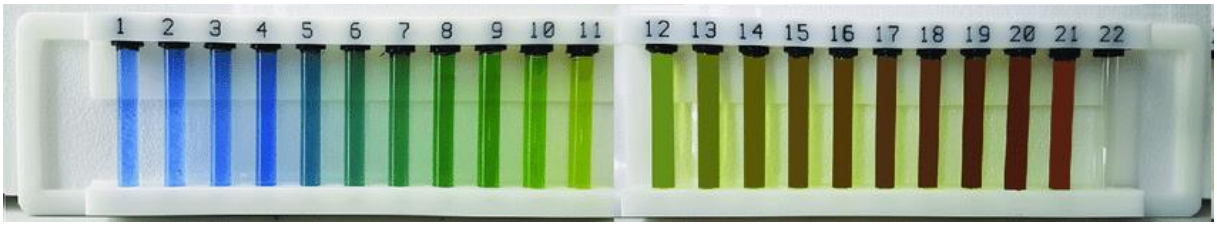
Sen2 Lake Watch QGIS Plugin

The plugin calculates the Forel-Ule index (FUI) from Sentinel 2 images



1. Forel-Ule index (FUI)

Classification of water masses into optical types is an old practice in limnology and oceanography. The first method (Forel-Ule index) was developed as a visual color comparator scale at the end of the XIX century. It uses 21 numbered vials with water colored by different chemicals. The visual comparison is made at half of Secchi's depth on the white background of the Secchi disk.



Natural waters absorb and scatter light in the presence of color-producing agents, thereby determining the apparent color of surface water masses. Primary agents include colored dissolved organic matter (CDOM, also called Gelbstoff), inorganic suspended particulate material (SPM or mineral solids), and phytoplankton chlorophyll-*a* (chl-*a*). These agents describe the trophic state of inland and coastal waters and are the main proxy of water quality.

2. FUI derived from Sentinel 2 images

The FUI can be derived from ocean color sensing products, including remote sensing reflectance R_{RS}. The algorithm for calculating FUI from MERIS remote sensing reflectance was presented first by Wernand et al. in 2013 and then successfully used for Landsat 8 and Sentinel 2.

The Sentinel 2 MSI products contain the following bands (in red bands in plugin input composite):

Sentinel-2 bands		Central wavelength (µm)	Resolution (m)
Band 1 – Coastal aerosol	B1	0.443	60
Band 2 – Blue	B2	0.490	10
Band 3 – Green	B3	0.560	10
Band 4 – Red	B4	0.665	10
Band 5 – Vegetation red edge	B5	0.705	20
Band 6 – Vegetation red edge	B6	0.740	20
Band 7 – Vegetation red edge	B7	0.783	20
Band 8 – NIR	B8	0.842	10
Band 8A – Vegetation red edge	B9	0.865	20
Band 9 – Water vapour		0.945	60
Band 10 – SWIR – Cirrius		1.375	60
Band 11 – SWIR	B10	1.610	20
Band 12 – SWIR	B11	2.190	20

The following workflow describes the application of an algorithm to Sentinel 2 images.

The preprocessing uses Sentinel 2 A,B S2MSI1C product and ACOLITE software for atmospheric correction. Then the composite of R_{RS} is created from 6 or 11 bands (in red in the table above).

The calculation starts with projecting R_{RS} (R) spectrum onto the CIE universal color space (X, Y, Z), representing the color spectrum visible to the average human. The X, Y, Z tristimulus system values for Sentinel 2 are determined as follows,

$$X = 11.756 * R(B1) + 6.423 * R(B2) + 53.696 * R(B3) + 32.028 * R(B4) + 0.529 * R(B5)$$

$$Y = 1.744 * R(B1) + 22.289 * R(B2) + 65.702 * R(B3) + 16.808 * R(B4) + 0.192 * R(B5)$$

$$Z = 62.696 * R(B1) + 31.101 * R(B2) + 1.778 * R(B3) + 0.015 * R(B4) + 0.000 * R(B5)$$

The chromaticity coordinates in CIE are normalized to 0 -1. Therefore, a new coordinate system is,

$$x = \frac{X}{(X + Y\,Z)}$$

$$y = \frac{Y}{(X + Y\,Z)}$$

The hue angle α can be expressed as:

$$\alpha = arctan\left(\frac{y - y_w}{x - x_w}\right) * \frac{180}{\pi}\ ;\ \ if\ \alpha < 0\ \ than\ \ \alpha = 360 + \alpha$$

where the coordinates of the x_w and y_w are (1/3, 1/3). The hue angle is corrected to compensate for the linear interpolation between the natural water spectrum and detector band by,

$$D = -65.74 * \alpha^5 + 477.16 * \alpha^4 - 1279.99 * \alpha^3 + 1524.96 * \alpha^5 - 751.59 * \alpha + 116.56$$

finally,

$$\alpha_{corr} = \alpha + D$$

The hue angles of FUI in degrees and boundary angles (if hue angle > boundary angle than index = FUI) are,

FUI	Hue angle	Hue boundary angle
1	229.94	227.68
2	225.41	219.27
3	213.13	205.19
4	197.25	189.20
5	181.15	165.71
6	150.26	133.96
7	117.66	109.85
8	102.05	95.14
9	88.24	83.38
10	78.53	74.62

11	70.71	69.60
12	68.49	67.93
13	67.36	65.98
14	64.60	63.35
15	62.11	60.37
16	58.62	56.64
17	54.65	52.09
18	49.53	46.75
19	43.96	41.82
20	39.67	36.98
21	34.28	

3. Indicators of water quality

The tool calculates FUI as an integer number (**FUL**) and its actual real type value (**FULc**) by interpolating between hue angle values. In addition, several indicators of water quality are calculated. Two algorithms are used for Chlorophyll-a calculation (**CHL**). The first is a three-band algorithm known as G99 which uses bands B4, B5 and B7,

$$CHL99 = \frac{\left(\frac{B5}{B4}\right) * (0.7 + bb) - 0.4 - bb^{1.05}}{0.015}$$

where:

$$bb = \frac{1.61 * B7}{0.082 - 0.6 * B7}$$

The second is a simple algorithm from Se2WaQ – Sentinel-2 Water Quality Script publish at Sentinel Hub.

$$CHL = 4.26 * \left(\frac{B3}{B1}\right)^{3.94}$$

Both algorithms unit is mg m^{-3}.

The tool also uses Se2WaQ formulas for calculating cyanobacteria (**CYA**), turbidity (**TURB**), colored dissolved organic matter (**CDOM**), and watercolor (**COL**).

$CYA = 115530.31 * \left(\frac{B3*B4}{B2}\right)^{2.38}$ 10^3 cell/ml

$TURB = 8.93 * \left(\frac{B3}{B1}\right) - 6.39$ NTU

$CDOM = 537 * e^{-2.93*\frac{B3}{B4}}$ mg/l

$COL = 25366 * e^{-4.53*\frac{B3}{B4}}$ mg Pt/l

The tool calculates the experimental formula for Suspended Sediment Concentration (**SSC**) in mg/l,

$$SSC = 4.53 + 0.86 * e^{1.579 - 15.273 * B2 + 16.9959 * B4 + 25.5141 * B8}$$

$$SSCplus = 1.44 * e^{33.0 * B4}$$

If SSC<10:

SSC=min(SSC, SSCplus)

In addition, three well-known indexes are included (**NDVI, NDWI**, **NDMI**),

$$NDVI = \frac{(B8 - B4)}{(B4 + B8)}$$

$$NDWI = \frac{(B3 - B8)}{(B3 + B8)}$$

$$NDMI = \frac{(B8 - B11)}{(B8 + B11)}$$

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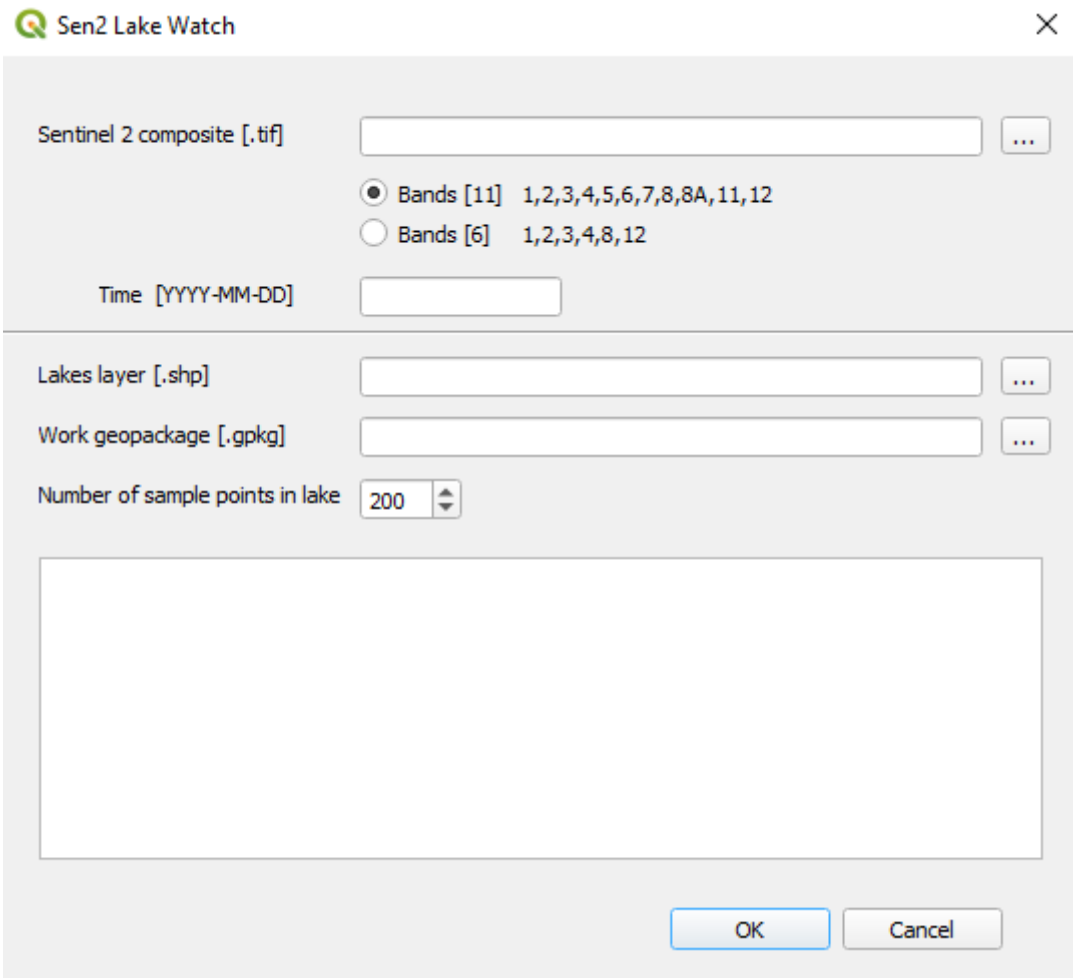

INPUT

The plugin has the following parameters:

Sentinel 2 composite image in .tif format (full path with image name has to be input)

Bands in composite (two options are possible: B1, B2, B3, B4, B5, B6, B7, B8, B8A, B11, B12 and B1, B2, B3, B4, B8, B12).

Time of image (in a proper format).

Lake layers in .shp format (layer of lake polygons with unique integer identifier LID).

Work geopackage (may be empty or with some files)

Number of sample points in lake (random points to calculate bands statistics).

OUTPUT

The output files are saved in two places, in the catalog of Sentinel 2 composite and the work geopackage.

In the catalog of the Sentinel 2 image, three files are created: raster (.tif) and vector (.shp) masks of the area of interest and text file (.csv) with all results for each lake. They have the name of the image plus '_mask' ending for mask files.

The text file with all results is an attribute table of lakes shapefile created in the work geopackage with the name lakes_sat11 or lakes_sat6 depending on the option. In adition several temporary files are saved there. The file lakes_points_sat is a point file of all samples for each lake with reflectance values in each point. The minimum distance between points is 20m.

All files in the work geopackage are overwritten, so they have to be export if needed.

The files with results contain all fields of the lake layer plus the following fields:

time	In YYYY-MM-DD format
lid	Lake id
b1_q1	First quartile (Q1) of reflectance for band 1
……	1-6 or 1-11 bands
bn_q1	First quartile (Q1) of reflectance for band n
CHL	Chlorophyll-a mg m^{-3}. CHL99 for 11 bands and CHL for 6 bands the in composite.
CYA	Cyanobacteria 10^3 cell/ml
TURB	Turbidity NTU
CDOM	Colored dissolved organic matter mg/l
SSC	Suspended Sediment Concentration mg/l
COL	Watercolor mg Pt/l
xx	X tristimulus
yy	Y tristimulus
zz	Z tristimulus
FUL	Forel-Ule index
FULc	Forel-Ule index (real value)
NDVI	NDVI
NDWI	NDWI
NDMI	NDMI