SENTINEL WATER MASK (SWM) - - NEW INDEX FOR WATER DETECTION ON SENTINEL-2 IMAGES

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ABSTRACT

Food is one of main natural disasters which struck Poland and Europe. Since the launch of Sentinel satellites we have more and more data, which can be used to monitor the extent of inland water.

The aim of the research was to recognize opportunities of water detection on S-2 imagery. A number of tests were carried out using indices selected from the literature. Based on the experience gained, a new index for water detection has been proposed, Sentinel Water Mask (SWM). It was specially adapted for S-2 images.

SWM provides quick and effective detection of water which is especially important in flood assessment for crisis management. The performance of SWM was tested on 5 research areas. It allows to obtain overall accuracy of water detection above 96%. The optimal threshold value should be included in value range between 1.4 and 1.6.

INTRODUCTION

The monitoring of inland waters extent is essential because it delivers basic information for crisis management, for determination of flood risk and evaluation of damage caused by inundation. Satellite remote sensing is one of the most effective methods for waterbody delimitation, especially on extensive or desolate and difficult-to-get areas.

A breakthrough moment for access to free, high resolution imagery was the launch of Sentinel constellation by ESA in the frame of Copernicus Programme.

This study was conducted on optical images from Sentinel-2 (S-2) satellite. It has Multispectral Instrument (MSI) which measures reflected radiation in 13 spectral bands with high spatial resolution: 10/20/60 m. Since March 2017, twin S-2 satellites can deliver new images every 5 days.

OBJECTIVE

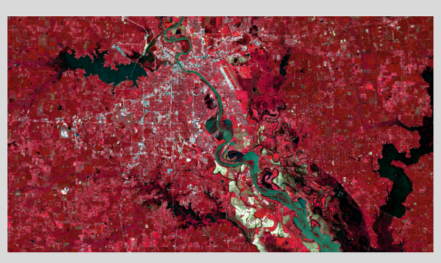
The indices which were found in literature, were developed, first of all, on the base of Landsat imagery. Although spectral range of Landsat 5/7/8 and Sentinel-2 sensors (TM/ETM+/OLI and MSI) is similar and enables to use those indices on S-2 data, a decision was made to check it and compare the obtained water masks with each other.

As a result of this comparison, a need arose to construct new water index for Sentinel-2 images and to evaluate and compare it with the existing indices.

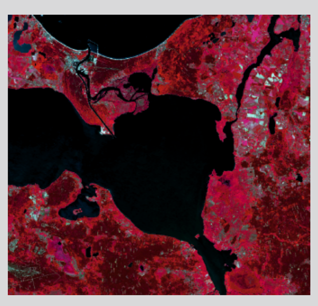
For the study purposes, five test areas were selected for which S-2 images were collected from March and June 2016:

1. North Ireland, surroundings of the Lough Neagh and Belfast, 14.03.2016, subset extent: 54 x 49 km

2. The Netherlands, Rotterdam and the Rhine-Meuse-Scheldt delta, 12.03.2016, 56 x 66 km
3. Poland, Zegrze Reservoir with Vistula and Narew rivers, 24.03.2016, 26 x 24 km



4. USA, Louisiana, flood on the Red River, 20.03.2016, 61 x 34 km
5. Poland, Bay of Szczecin, 08.06.2016, 45 x 42 km.



METHODS

Literature review enabled to select several water indices (Tab. 2): $NDWI_{McFeeters}$, NDII, $NDWI_{Rogers\&Kearney}$, $MNDWI_{Xu}$, $AWEI_{sh}$, $AWEI_{nsh}$, LSWI, MLSWI and MSI, which were calculated on pre-processed S-2 images. There were two datasets for each 5 test sites, one before atmospheric correction (Top of Atmosphere, TOA) and one after correction using Sen2Cor software (Bottom of Atmosphere, BOA).

Threshold values were determined on the base of detailed visual evaluation and histogram analysis. Water masks were validated using validation points distributed manually. Datasets consisted of 400-600 points for each test site.

The analysis of the class separability was performed using the Jeffreys-Matusita distance algorithm. The final threshold ranges for each index were determined after the analysis of Kappa coefficient values in relation to the different thresholds (Fig. 3).

The flowchart illustrates consecutive steps undertaken during the research (Fig. 1).

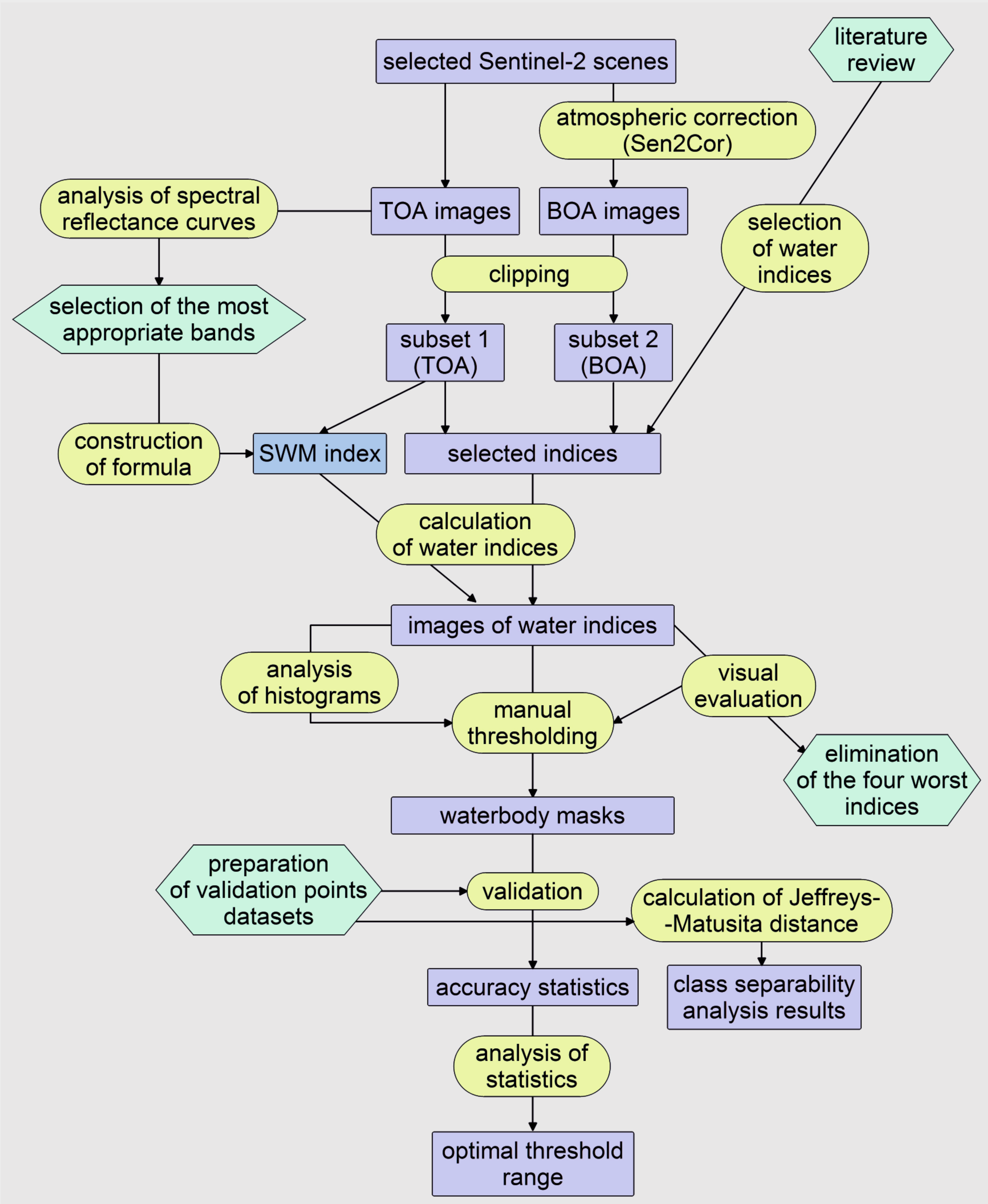


Fig. 1. Flowchart showing data processing steps during the research.

RESULTS AND DISCUSSION

The preliminary visual evaluation showed that some indices give poor results, so four of them (MSI, LSWI, MLSWI and NDII) were rejected at the initial stage of the study.

After analysis of spectral reflectance curves for water and other types of land cover (Fig. 2), two bands with the highest reflectance for water (B2, B3) and two with the lowest one (B8, B11) were selected and new index formula was developed:

$$\textbf{Sentinel Water Mask (SWM)} = (B2 + B3) / (B8 + B11)$$

where: B2 - Blue, B3 - Green, B8 - NIR, B11 - SWIR

The SWM index is dedicated for S-2 imagery without atmospheric correction (TOA). The aim of such index is to be useful when time has crucial role and analysis of water extent has to be prepared quickly. It takes positive values in the range of 0-12 and an optimal threshold lays within the range 1,4-1,6, when the index reaches overall accuracy of 96-99% depending on test area (Tab. 1).

All tested indices gave better water masks when they were calculated on S-2 images before atmospheric correction. Pixels of water were mixing less with pixels of the other land cover types. The exception was $AWEI_{nsh}$ which gave similar results either on TOA or BOA images.

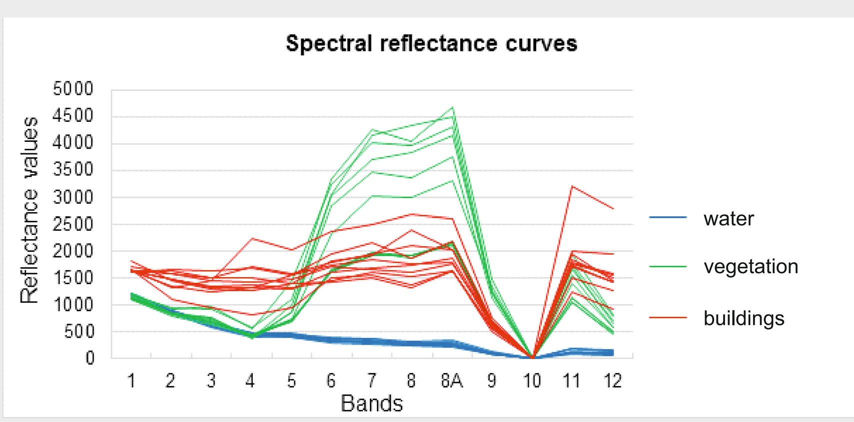


Fig. 2. Spectral reflectance curves of the main land cover classes.

Tab. 1. Accuracy assessment of SWM index water masks.

SWM index	Overall Accuracy (%)	Kappa Coefficient
Test site 1	98,00	0,96
Test site 2	96,75	0,94
Test site 3	98,50	0,97
Test site 4	98,11	0,96
Test site 5	99,80	1,00

Tab. 2. Water indices most common in literature.

Name	Formula
$NDWI_{McFeeters}$	$\frac{GREEN - NIR}{GREEN + NIR}$
NDII	$\frac{NIR\ (0{,}819) - SWIR\ (16{,}49)}{NIR\ (0{,}819) + SWIR\ (16{,}49)}$
$NDWI_{Rogers\&Kearney}$	$\frac{RED - SWIR\ (1{,}65)}{RED + SWIR(1{,}65)}$
$MNDWI_{Xu}$	$\frac{GREEN - SWIR\ (1{,}65)}{GREEN + SWIR\ (1{,}65)}$
$AWEI_{nsh}$	$4 * (GREEN - SWIR1) - (0{,}25 * NIR + 2{,}75 * SWIR2)$
$AWEI_{sh}$	$BLUE + 2{,}5 * GREEN - 1{,}5 * (NIR + SWIR1) - 0{,}25 * SWIR2$
LSWI	$\frac{NIR - SWIR\ (2{,}13)}{NIR + SWIR(2{,}13)}$
MLSWI	$\frac{1 - NIR - SWIR(2{,}13)}{1 - NIR + SWIR(2{,}13)}$
MSI	$\frac{SWIR\ (1{,}65)}{NIR}$

Tab. 3. Accuracy assessment of indices calculations for the TOA images.

	Test site 1				Test site 2				Test site 3			
Indices	Over. Accur. (%)	Kappa Coeff.	Prod. Accur. (%)	User Accur. (%)	Over. Accur. (%)	Kappa Coeff.	Prod. Accur. (%)	User Accur. (%)	Over. Accur. (%)	Kappa Coeff.	Prod. Accur. (%)	User Accur. (%)
NDWI McF	93,20	0,86	99,60	88,30	74,75	0,49	96,50	67,25	97,00	0,94	95,00	98,96
NDWI R&K	95,20	0,90	95,20	95,20	82,75	0,65	100,00	74,35	45,00	-0,10	72,50	46,77
MNDWI	93,60	0,87	97,20	90,67	70,25	0,40	100,00	62,70	90,00	0,80	87,00	92,55
AWEI nsh	94,40	0,89	97,60	91,73	97,75	0,95	99,00	96,59	92,25	0,84	85,50	98,84
AWEI sh	86,00	0,72	92,80	81,69	87,00	0,74	99,50	79,60	63,50	0,27	85,00	59,44

	Test site 4				Test site 5			
Indices	Over. Accur. (%)	Kappa Coeff.	Prod. Accur. (%)	User Accur. (%)	Over. Accur. (%)	Kappa Coeff.	Prod. Accur. (%)	User Accur. (%)
NDWI McF	98,00	0,96	96,92	99,06	83,80	0,68	100,00	75,53
NDWI R&K	95,23	0,90	93,85	96,52	65,80	0,32	99,60	59,43
MNDWI	95,60	0,91	96,77	94,59	98,80	0,98	99,60	98,03
AWEI nsh	94,85	0,89	98,77	91,58	99,40	0,99	99,20	99,60
AWEI sh	96,46	0,93	98,92	94,28	85,80	0,71	100,00	77,88

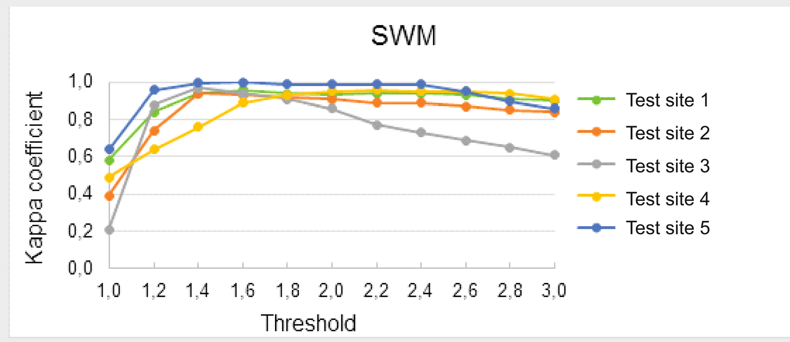


Fig. 3. Kappa coefficient values in relation to the different threshold values for SWM index.

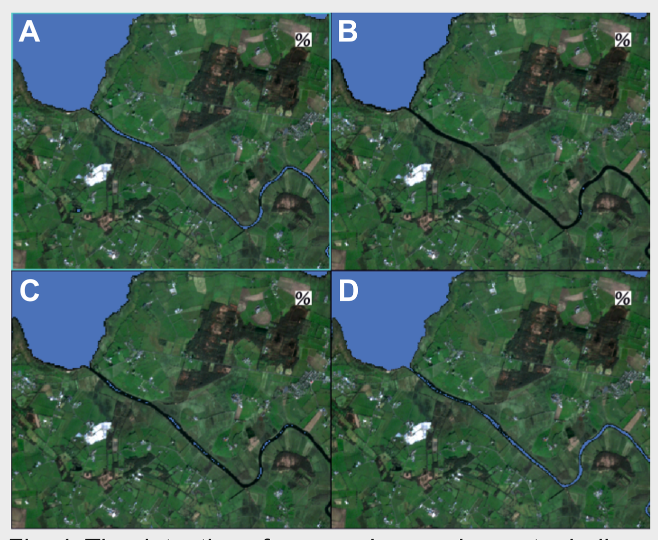


Fig. 4. The detection of narrow rivers using water indices: A - SWM, B - $AWEI_{nsh}$, C - MNDWI, D – $NDWI_{McFeeters}$.

CONCLUSIONS

Among analized indices the best one was $AWEI_{nsh}$ (Tab. 3). The analysis of Jeffreys-Matusita distance indicated that it provided the best land cover class distinction, however equally good results were achieved by SWM. $AWEI_{nsh}$ recognised correctly areas of water but it did not detect all narrow rivers. It reaches good results for a wide range of threshold values so it is time-consuming to determine an optimal threshold.

New water index was proposed - Sentinel Water Mask - for which very good results were obtained both as a result of visual evaluation and statistical analysis. Overall accuracy of water detection was over 96%. The SWM index was more contrasty in comparison with the other water indices, so it was easier to determine an optimal threshold between water and non-water area. It was good for detection of narrow rivers and small water bodies (Fig. 4). The SWM gave satisfactory water mask for flooded areas, dividing pixels of water from pixels of wet terrain, which could have been inundated earlier. The optimal threshold of water detection was set at a range 1,4-1,6.

Atmospheric correction is a time-consuming process which can be omitted when water indices are calculated on S-2 imagery and time of delivery of final analysis is important.

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