

• Mapping water in dry flat environments: A study using Sentinel imagery in the northern Murray-Darling Basin

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Key Points

- Sentinel 2 image spatial, spectral and temporal resolution make it well suited to map wetland inundation events
- The modified normalised difference water index (MNDWI) performed best in this study of 2 large inland wetland systems
- The approximate twice weekly capture of Sentinel 2 imagery permits flood behaviour assessment with a time-step previously unachievable

Abstract

- Knowing where our water is as a function of flow, how far it extends and how it dries back is critical for managing environmental water and improving our environment.
- We used Sentinel-2 satellite imagery (twice weekly capture and 10 m pixels) to examine the accuracy and applications of water extent mapping in the northern Murray-Darling Basin. In the Warrego Western Floodplain and Gwydir wetlands, we mapped water extent using eight common water indices to determine mapping accuracies and choose the most appropriate index.
- All indices performed well with mapping accuracy generally over 90% when compared to georeferenced oblique aerial photography. The modified normalised difference water index (MNDWI) performed consistently better than the others and we noted that the normalised difference water index (NDWI) was particularly poor at detecting inundation when water was highly turbid. We also developed a set of maps/parameters or outputs on inundation persistence and duration that were previously impossible to create using lower frequency, or larger pixel, image sources such as Landsat or Modis.
- We can map surface water with a high degree of accuracy over large areas many times per year using opensource data. Having access to a simple map of water extent up to 50 times per year provides great insight into the outcomes of our environmental water management. We can target flow delivery more precisely to improve our environment, optimising our water use. In our dry and drying continent optimal water use is imperative for rebuilding our environment.

Keywords

Sentinel 2, inundation mapping, water indices, inundation duration, inundation frequency

Introduction

Knowing the relationship between channel flows and wetland inundation is critical to managing water for the environment to optimise environmental outcomes. In the Murray-Darling Basin, and especially the northern Murray-Darling Basin, the boundaries between channels and wetlands blurs. These low energy rivers with

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very flat slopes and relatively low rainfall totals can dissipate into multiple small channels with large flat wetlands that form features variously called: inland deltas, water courses, wetland-floodplain complexes etc. These areas are generally extensive, covering thousands or even tens of thousands of hectares and the relationship between gauged channel flows and inundation can be difficult to characterise.

This study examines the accuracy of using Sentinel 2 multi-spectral satellite imagery to map inundation extent in the Gwydir Wetlands and Warrego River Western Floodplain. Specifically, the project set out to:

- Compare water mapping accuracy and utility using 8 published remote sensing indices
- Explore methods of presenting high repeat frequency inundation

Methods

Sentinel 2 image spatial and spectral resolution is comparable to that provided by the Landsat series. Although, Sentinel provides finer spatial resolution with 10 m pixels in the Blue to NIR range and 20 m pixels in the Shortwave infrared range compared to 30 m pixels in the Landsat TM series. The frequency of Sentinel image capture is much higher than Landsat. Landsat provides a repeat pass every 16 days whereas Sentinel provides a repeat pass every 2-3 days in the mid-latitudes. The much higher capture frequency allows 'capture redundancy' that permits removal of cloud and rainfall affected scenes while maintaining sufficient data to analyse flow and inundation patterns.

Remote sensing of water

Historically, many projects have developed water mapping techniques for Landsat imagery. These include single band thresholding techniques (Frazier and Page 2000), normalised ratio forms (McFeeters 1996, Xu 2006, Gao 1996, Shen and Li 2010) and multi-band linear equation forms (Feysia 2014, Kauth and Thomas 1977, Fisher 2015).

Each of these approaches relies on the relatively high absorption of near and shortwave infrared electromagnetic radiation by water, meaning that open water on the land surface generally appears dark in most multi-spectral image displays and presents a tight cluster in multidimensional space. Since the Sentinel 2 image bands are similar to those present in the Landsat TM imagery the equations are either directly transferable or have been updated for the new band configuration.

For this study we selected eight commonly used water mapping approaches (**Error! Reference source not found.**) and applied them to the Gwydir Wetlands and Warrego River Western Floodplain.

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Table 1 Remote sensing water indices

Index Group	Water Index	Formula	Author
Single band	SWIR threshold	Band 12	Frazier and Page (2000)
Normalised form	Normalised Difference Water Index (NDWI)	$(\text{Band 3} - \text{Band 8}) / (\text{Band 3} + \text{Band 8})$	McFeeters (1996)
	Modified Normalised Difference Water Index	$(\text{Band 3} - \text{Band 12}) / (\text{Band 3} + \text{Band 12})$	Xu (2006)
	Gao Normalised Difference Water Index	$(\text{Band 8} - \text{Band 12}) / (\text{Band 8} + \text{Band 12})$	Gao (1996)
	Water Ratio Index (WRI)	$(\text{Band 3} + \text{Band 4}) / (\text{Band 8} + \text{Band 12})$	Shen and Li (2010)
Multi-band	Automatic Water Extraction Index (AWEI)	$4 * (\text{Band 4} + \text{Band 12}) - (0.25 * \text{Band 8} + 2.75 * \text{Band 11})$	Feyisa (2014)
	Tasseled Cap Wetness (TCW)	$0.1509 * \text{Band 2} + 0.1973 * \text{Band 3} + 0.3279 * \text{Band 4} + 0.3406 * \text{Band 8} -$	Lastovicka et al. (2020) (from Kauth and Thomas
	Wetness Index (Fisher WI)	$1.7204 + 171 * \text{Band 3} + 3 * \text{Band 4} - 70 * \text{Band 8} - 45 * \text{Band 11} - 71 * \text{Band 12}$	Fischer (2016)

Methods

Image selection

The 2019-2020 water year saw significant inundation occurring in both the Warrego Western Floodplain and the Gwydir Wetlands. The Gwydir Wetlands received local heavy rain in February 2020 leading to a moderate inundation event in the wetlands and the Warrego Western floodplain experienced substantial inundation from upstream flow during March 2020.

These inundation events were both captured by a sequence of Sentinel 2 images and geotagged (GPS located) oblique aerial photographs. The aerial photographs were captured by NSW National Parks and Wildlife Service (NPWS) over the Gwydir from 11-15 May 2020 and by the Commonwealth Environmental Water Office (CEWO) over the Warrego from 25-27 April 2020 (**Error! Reference source not found.**). The overlap in satellite image and aerial photograph capture dates provided the opportunity to undertake reliable accuracy assessment for Sentinel 2 water mapping.

Table 2 Sentinel image and oblique aerial photography capture dates

Selected Area	Sentinel 2 Image date	Aerial photograph dates
Gwydir	12 May 2020	11-15 May, 2020
Warrego-Darling	25 April 2020	25-27 April, 2020

The eight water mapping indices described in **Error! Reference source not found.** were created for both images. To delineate (map) areas of water and areas of not-water, a threshold was selected for each output index (**Error! Reference source not found.**). Each threshold was set by closely examining each image histogram, image and index display and visually assessing the optimum value to separate water from not-water.

Table 3 Water mapping index thresholds

Index	Gwydir threshold	Warrego threshold
SWIR	0.52	0.57
NDWI	-0.20	-0.22
MNDWI	-0.30	-0.20
GMNDWI	0.56	0.25
WRI	0.59	0.80
AWEI	-0.30	-0.70
TC Wetness	-0.06	-0.15
Fischer	32.00	-30.00

Accuracy assessment

The geotagged aerial photographs were overlaid on the Sentinel images. Comparison of the photographs with the displayed image was used to locate points that could be allocated to either a water or not-water class. Water classification was assigned when areas of open water were clearly observed and areas of not-water were assigned where we were confident there was no water at that point. Each point was used to create a 10 m radius area with the allocated class. In total 117 points were assigned for the Gwydir area and 191 for the Warrego area.

These accuracy assessment points were compared to the water mapping outputs from each index with the comparison used to create mapping accuracy percentages.

Multi-temporal inundation characterization

The relatively high frequency of Sentinel 2 imagery provides the opportunity to interpret and examine flooding events using new approaches. We have undertaken preliminary exploration of methods using the 2019-2020 Warrego Western Floodplain image set to examine the uses of this high frequency data. These methods include map-based temporal representation of inundation frequency and duration. Given the high frequency of Sentinel 2 image capture we were able to remove cloud affected images and those affected by local rainfall events and retain sufficient data to document inundation patterns. Rainfall affected images were selected as those that were captured within 7 days of a significant event rainfall event and showed surface water in areas clearly not linked to main flow paths or channels.

Map-based temporal representation included:

- Percentage time inundated – create by calculating the percentage of times an image cell was shown as wet as a percentage of the total number of images analysed.
- Duration (wet and dry periods) – created by examining the longest continuous period each image cell was either dry or wet in the sequence.

Results

Mapping accuracy was high for all water mapping indices. Percentage accuracy values ranged from 71.79% to 98.29%. The MNDWI performed best in both environments with accuracy scores of 98.29% in the Gwydir Wetlands and 96.34% in the Warrego Western Floodplain (**Error! Reference source not found.**). Given that the MNDWI index is relatively simple to calculate and qualitative assessment of multiple images across the Murray-Darling Basin under varying flood conditions show that this index is broadly applicable we have chosen to use the MNDWI for ongoing water mapping needs.

Table 4 Water mapping accuracy percentage

Index	Gwydir (%)	Warrego (%)
SWIR	94.87	89.53
NDWI	89.74	88.48
MNDWI	98.29	96.34
GMNDWI	81.20	84.82
WRI	91.45	94.76
AWEI	95.73	90.58
TC Wetness	94.87	90.05
Fischer	71.79	79.58

For the Warrego River Western Floodplain in the 2019-2020 water year 119 Sentinel 2 images were captured, after assessment of image quality (cloudiness) and those that were clearly local rainfall affected, 37 images remained to assess surface water extent. Exploration of map-based temporal representation of the map series:

- Percentage time inundated (Figure 1)
- Dry and wet duration (Figure 2)

These results show that interpretation of more ecologically relevant metrics such as inundation frequency and duration are possible to assess with these data and as the dataset builds these inundation metrics become more meaningful. These outputs allow more detailed examination of inundation patterns and will assist to locate and extrapolate field survey data into the future.

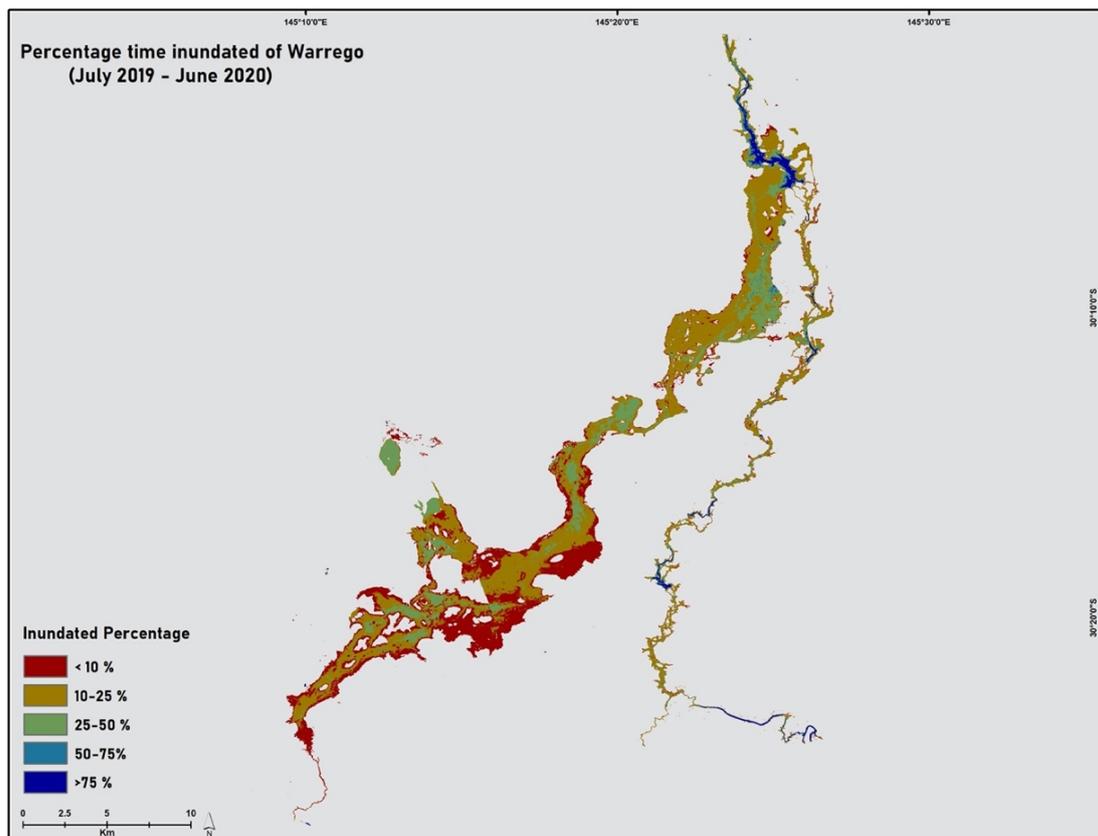


Figure 1 Percentage time inundated 2019-2020 water year

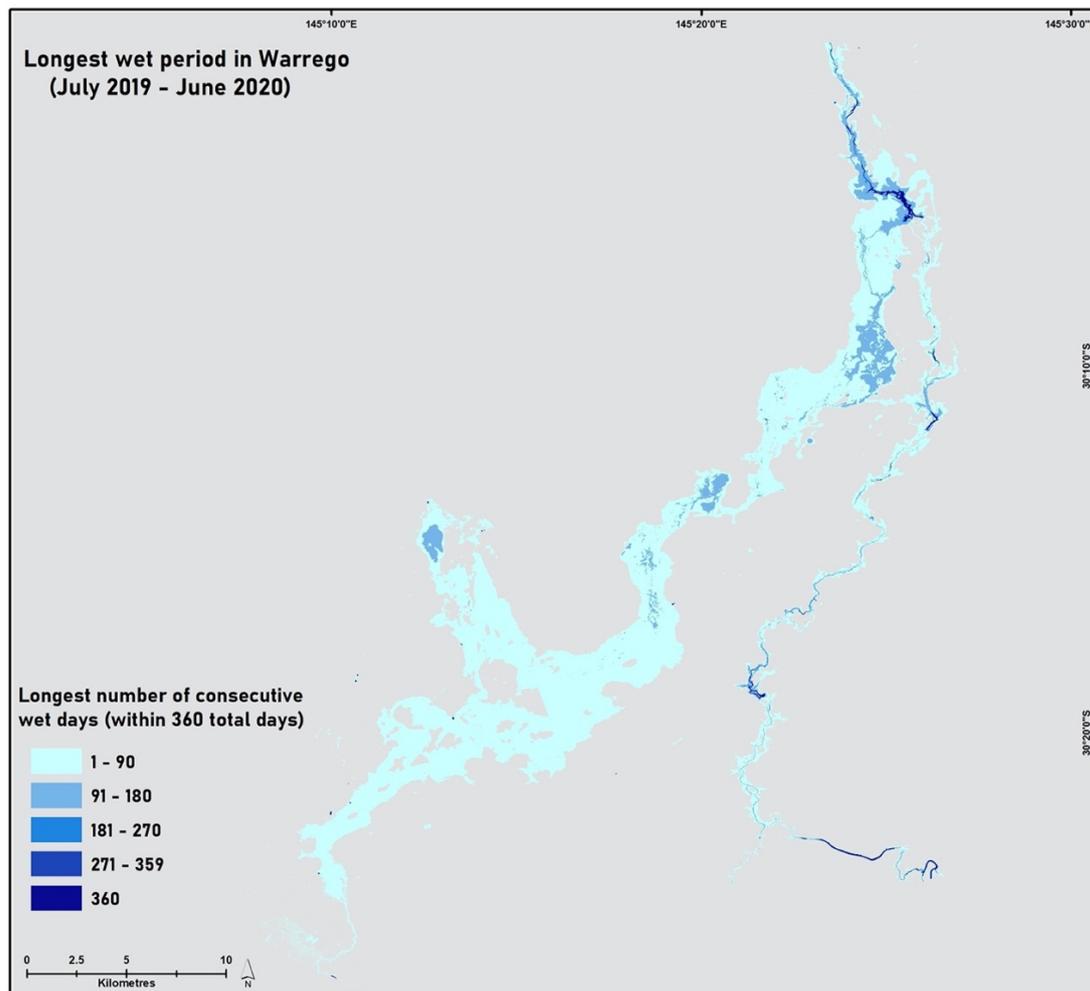


Figure 2 Longest consecutive days wet 2019-2020 water year

Conclusions

This study sought to examine the relative accuracy of 8 water mapping indices applied to Sentinel 2 imagery. Our results show that each index gave high accuracy results ranging from 71.79% to 98.29%. The MNDWI performed best in both the Warrego and Gwydir environments and was chosen for ongoing assessment.

The high frequency of capture of Sentinel 2 imagery provides opportunities to examine inundation patterns in a manner previously not possible with Landsat type data. These outputs enable the examination of inundation frequency and duration patterns that can potentially be linked to ecological process information to better direct field survey and extrapolate survey findings.

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