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Integrating Satellite-Derived Vegetation Indices and Field Observations for Monitoring Seasonal Wetland Changes

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Abstract: The wetlands in monsoon environments experience rapid changes in water cover, aquatic plants, and bare substrate, although systematic monitoring programs fail to record such events on a management scale. In this study, the combination of vegetation and water indices derived from Sentinel-2 images was linked with repeated field observations in order to analyze the intra- and inter-annual variability of the Vedanthangal tank wetland in a monsoon-driven environment in India. The monthly timeseries of the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Soil-Adjusted Vegetation Index (SAVI), and Modified Normalized Difference Water Index (MNDWI) were constructed using 76 satellite images without clouds, together with field sampling conducted 12 times throughout the year and involving 24 fixed plots that collected data on vegetation cover, height of macrophytes, leaf chlorophyll, and water depth. Wetland condition showed a clear annual pattern that was regulated by the northeast monsoon: maximum water cover occurred in December and January, while the development of floating and emergent vegetation took place in the post-monsoon drawdown period. The MNDWI index captured field water depths well, while NDVI, SAVI, and EVI largely accounted for variability in vegetation cover. The NDVI index alone was affected by the presence of water under the plant canopy cover as well as saturation in thick floating vegetation cover; the combination of NDVI with MNDWI gave more accurate vegetation maps. The dry 2022-23 hydrological year caused delayed filling and shortened the inundation period by one month, resulting in a delay in the vegetation peak. The combination of multiple indices from time series of satellite images and a limited number of field measurements provides a reliable framework for monitoring changes in wetlands.

Keywords: Seasonal Wetland; Sentinel-2; Vegetation Indices; MNDWI; Field Validation; Hydroperiod; Wetland Monitoring.

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I. Introduction

Wetlands are some of the most productive and most endangered ecosystems in the world. Wetlands provide storage for and purification of water, act as buffers against floods, replenish groundwater sources, sequester carbon, and host an unusual amount of biodiversity, particularly migratory waterbirds. It was calculated in a meta-analysis of long-term inventories that the extent of natural wetlands has decreased by more than half since the start of the twentieth century, possibly as much as 87 percent since 1700, with this rate of destruction accelerating in the twentieth and early twenty-first centuries (Davidson, 2014). Given the dependency of the ecological role of wetlands on the seasonal cycle of flooding events, it is clear that conservation of wetlands demands not just data on the location of wetlands, but also on seasonal changes in wetlands' hydrology and vegetation.

Temporary wetlands in monsoon areas show this requirement explicitly. Thousands of irrigation tanks and floodplain depressions in Southern India are filled during monsoon season and retain water for a few months before drying up again. Such systems function as temporary wetlands whose habitat quality depends on their hydroperiods. When water retreats from such wetlands, the fringes become occupied by floating and emergent macrophytes, invertebrates and fish species in the water change their compositions, and birds which use the wetland as a place of feeding and breeding respond to changing proportions of open water and vegetation. Minor variations in rainfall, inflow channel management or agricultural water withdrawal can affect the duration of the wet period and consequently the habitat condition of the wetland. Early detection of such processes is important for adaptive management, but standard methods of field survey are resource intensive, localized and usually too infrequent.

Remote sensing via satellite provides the capability for synoptic, repetitive and ever finer resolution measurements which could complement the field campaigns. Reviewing the literature on wetlands remote sensing indicates that optical, radar and multi-sensor techniques have been employed successfully in the mapping and monitoring of wetlands extent, wetlands classification and change, and at the same time some problems that continue to persist in terms of spectral confusion between wet soils, shallow waters and vegetation and lack of adequate ground reference data (Ozesmi & Bauer, 2002; Mahdavi et al., 2018). Comparisons done using just two dates are especially susceptible to natural variation; in other words, wetlands that have been photographed in wet months and subsequently in dry months could give an indication of change whereas actually there has been no change at all in the state of such wetlands over a period of time (Kayastha et al., 2012).

The spectral indices have become popular tools for capturing this information. NDVI, calculated from the difference between red absorption and near-infrared reflection by green plants, is the most commonly used index for calculating vegetation greenness and has been widely used in monitoring changes in ecosystems due to environmental changes (Tucker, 1979; Pettorelli et al., 2005). However, NDVI is vulnerable to the effects of background brightness and saturates in case of dense canopies. To minimize the effect of soil background, the Soil Adjusted Vegetation Index (SAVI) was developed. In addition, the blue band was included in the EVI to minimize the effect of atmosphere (Huete, 1988; Huete et al., 2002). In the case of water, the Normalized Difference Water Index (NDWI) that is based on the combination of green and near-infrared bands, was introduced as an index for mapping open water features; a shortwave-infrared version of this index was created to estimate the liquid water content in vegetation; in addition, MNDWI (Modified NDWI) is used to increase discrimination between open water and impervious surfaces using shortwave instead of near-infrared bands (McFeeters, 1996; Gao, 1996; Xu, 2006). On a global scale, seasonal and permanent surface water, as well as long-term changes in this water, were identified by analyzing the whole Landsat archive; however, at a resolution of 30 m, only the presence of water is detected, not vegetation status (Pekel et al., 2016).

Two major gaps therefore remain. The first is that there are not many studies that use several vegetation and water indices at 10 m resolution during an entire hydrological cycle in monsoon-driven small wetlands, where shallow water is often located under floating/emergent vegetation and creates a spectral mixture that cannot be separated using one index only. The second gap is that the satellite flight path is rarely calibrated to a set of field measurements of variables that wetland managers need to know, such as water depth, vegetation coverage, and vitality of macrophytes.

These gaps are addressed in the context of the Vedanthangal Tank Wetland, Tamil Nadu, India, one of the oldest bird nesting waterbodies in India and a representative case of a seasonal, monsoon-fed tank wetland. Specifically, the goals are to (i) establish seasonal time series of satellite vegetation and water indices for three hydrological years; (ii) determine the relationship of these indices with field observations of water depth, vegetation coverage, macrophytes' height and leaf chlorophyll content; (iii) examine whether a vegetation-water index rule is better able to characterize seasonal coverage than individual indices; and (iv) consider annual differences in hydroperiod and vegetation dynamics and their implications for the ecological health and management of such ecosystems.

II. Materials and Methods

Study Area

The experiment was done at the Vedanthangal tank wetland (near 12.545° N, 79.856° E), in Chengalpattu district, Tamil Nadu, located about 75 km southwest of Chennai. This wetland is a shallow irrigation tank covering an area of 30 ha, having water spread across its uppermost part. Water accumulates in the tank due to an earthen bund, supplemented with surface run-off and inflowing channels. The climate of the area is tropical, wherein the northeast monsoon (October to December) accounts for most of the rainfall in the year, followed by southwest monsoon (June to September). The pre-monsoon months

(March to May) are generally dry and hot. The tank consequently remains full from late October to December and stays inundated till January-February.

The vegetation in the tank bed consists of sporadic stands of Barringtonia acutangula tree, which provides nests for the colonies of water birds, along with floating and emergent macrophytes including Ipomoea aquatica, Ipomoea carnea, Nymphaea species, and sedges that grow in the shallow margins as the water levels recede. Grasses and annual herbaceous plants grow on the bare tank bed during the dry season. The catchment area of the wetland is made up mainly of rice fields, villages, and shrub lands. Large colonies of herons, egrets, cormorants, ibises, and storks breed in this wetland during the wet season.

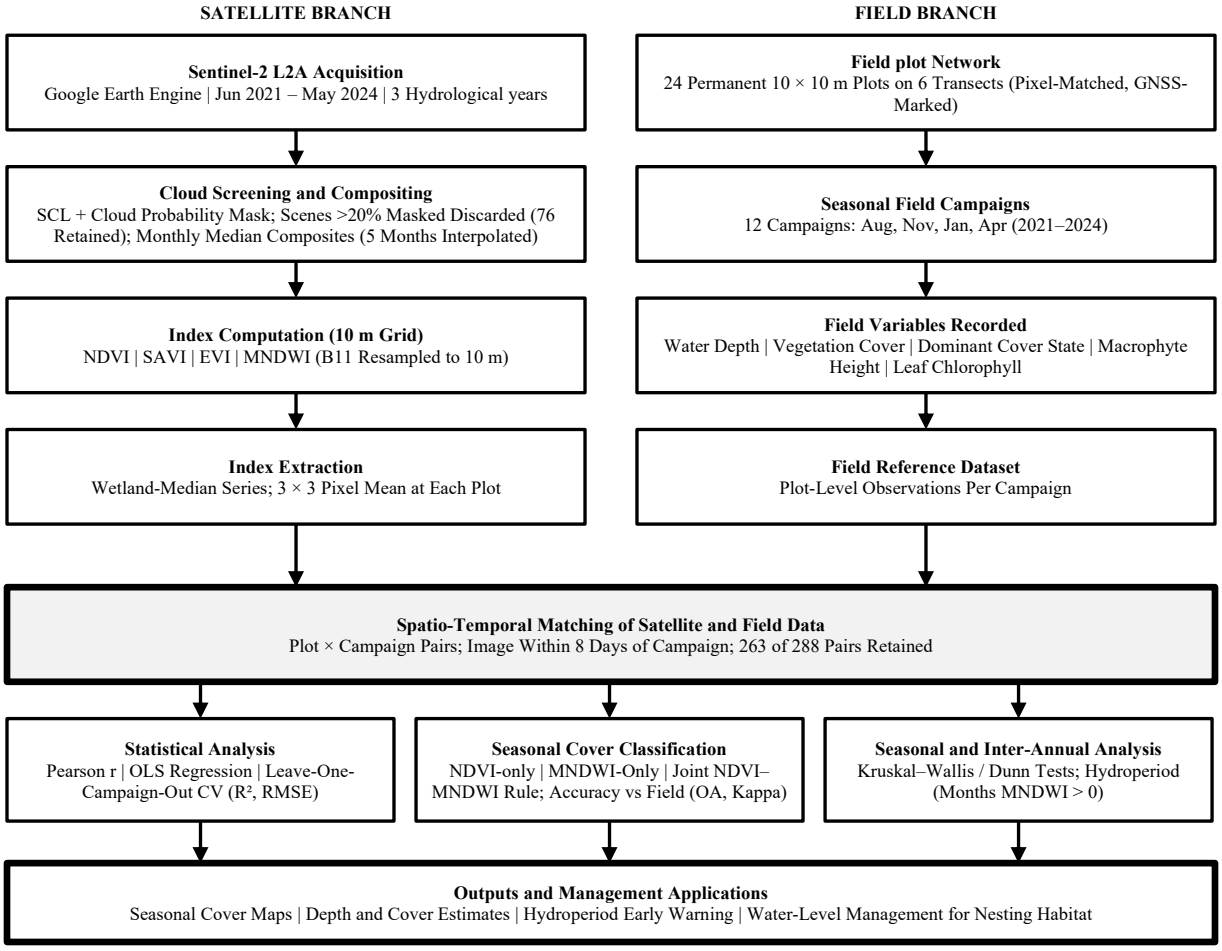


Figure 1: Workflow for Integrating Sentinel-2 Vegetation and Water Indices with Field Observations to Monitor Seasonal Change in the Vedanthangal Tank Wetland

As shown in figure 1, the Sentinel-2 imagery (cloud-masked, monthly composites; NDVI, SAVI, EVI, and MNDWI) and field measurements collected from the 24 permanent plots are matched to individual pixels and used for regression, cover classification, and accuracy assessment. This provides seasonal cover maps and hydroperiod estimates for water-level management.

Satellite Data and Pre-Processing

The surface reflectance images of Sentinel-2 L2A products from 1st June 2021 to 31st May 2024 were processed in Google Earth Engine. Three hydrological years of images were analyzed, covering the period of three complete years, which started in June and ended in May of the following year to ensure that one complete cycle of northeast monsoon inundation occurred in each year. Image selection was based on scene classification and the cloud probability product; all cloudy pixels including clouds, cloud shadows, cirrus

and saturated pixels were masked, and scenes having more than 20% of the wetland polygon masked out were discarded. Finally, 76 selected images were obtained, which were not evenly spread across the year due to the occurrence of cloudiness in both monsoons. In order to get a regular time series, monthly median composite of images was created, and five months of out of thirty-six months of the time series were interpolated.

The 20m SWIR channel (B11) was re-sampled to 10m by nearest neighbour re-sampling in order to allow all indices to be calculated using a common 10m grid. Wetland perimeter was digitised using the extent of maximum water spread seen in the series as well as the bund and channel positions and then a 20m buffer was added around the perimeter to reduce edge effects around the bund road.

Vegetation and Water Indices

Four indices have been generated per scene and shown in equations (1) to (4). For vegetation greenness, NDVI and SAVI have been used, for EVI to provide an index with reduced sensitivity to saturation in the dense canopy, and MNDWI for surface water. The indices are defined below, with the following notation for bands in Sentinel-2:

$$NDVI = (NIR - Red) / (NIR + Red) \quad (1)$$

$$SAVI = [(NIR - Red) / (NIR + Red + L)] \times (1 + L), with\ L = 0.5 \quad (2)$$

$$EVI = 2.5 \times (NIR - Red) / (NIR + 6 \times Red - 7.5 \times Blue + 1) \quad (3)$$

$$MNDWI = (Green - SWIR) / (Green + SWIR) \quad (4)$$

The green–near infrared NDWI was also derived as part of exploratory analysis. Since it performed poorly in distinguishing between shallow turbid water and wet soil in the margins of the tank compared to MNDWI and since the two indices were highly correlated, only the MNDWI was used for the main analysis. Values of the index were computed for the entire wetland as the median of all valid pixels, while for each plot, index values were computed as the mean of a 3×3-pixel window within the plot boundary.

Field Observations

Twenty-four permanent plots were set up in July 2021 on six transects from the bund to the inflow side of the tank, thus covering the depth variation from deep water to shallow water at the edges of the tank. The size of each plot was 10 m × 10 m which is equivalent to one Sentinel-2 pixel with the center of the plot determined using GNSS with an accuracy of ± 3m.

Field surveys were carried out on four occasions per year in August (southwest monsoon period), November (start of the northeast monsoon period), January (high water following the monsoon period) and April (pre-monsoon drawdown), resulting in twelve surveys from August 2021 to April 2024. The field work was carried out within a period of three days and whenever possible within five days of a cloud-free or nearly cloud-free Sentinel-2 acquisition. In each plot, the following data were collected: (i) water depth at five points in the plot using a graduated pole, which was averaged to the plot value; (ii) total cover by vegetation, assessed visually as the percent cover of the plot by living plant material in four 5 m × 5 m sub-plots; (iii) dominant cover type, determined as open water, vegetation floating on water, emergent vegetation on water, vegetation growing on saturated or dry ground, or bare substratum; (iv) mean height of emergent macrophytes, measured on ten randomly selected shoots; and (v) leaf chlorophyll content, measured on ten mature leaves of the dominant macrophyte using a handheld chlorophyll meter. Plot that could not be accessed safely during high water were observed from a small boat.

Integration and Statistical Analysis

Data from satellites and fields were paired by campaign and plot, resulting in up to 288 paired samples. The elimination of pairs for which either the pixel associated with the plot was masked or the nearest acceptable satellite image was acquired more than eight days away from the campaign resulted in 263 paired

samples. Correlation coefficients were computed between all indices and all field parameters, while ordinary least squares were employed to estimate the relationships between vegetation indices and vegetation coverage and MNDWI and water depth. Model performance was estimated through the coefficient of determination (R^2) and root mean square error (RMSE) based on leave-one-campaign-out cross-validation, where one campaign at a time was held out from model fitting and predicted using a model estimated from the remaining eleven campaigns.

Seasonal contrasts were conducted by classifying monthly compositions and campaign measurements into four seasons: pre-monsoon (March-May), southwest monsoon (June-September), northeast monsoon (October-December) and post-monsoon (January-February). Seasonal contrasts between index values were examined using Kruskal-Wallis test and then pairwise comparisons using Dunn's multiple comparison test with Bonferroni correction. Inundation period for each hydrological year was quantified as the number of months during which the median value of the wetland MNDWI was higher than zero.

Seasonal Cover Classification and Accuracy Assessment

Each composite per month was labeled based on four cover classes corresponding to the field cover classes: open water, vegetation over water, vegetation on land, and bare substrate. Three methods were evaluated in terms of their performance: NDVI threshold classification method, MNDWI threshold classification method, and a combined classification method using thresholds of both NDVI and MNDWI. For the combined threshold classification method, the criteria were: if MNDWI was greater than 0.20 and NDVI was less than 0.20 then the pixel was assigned to open water; if MNDWI was greater than -0.05 and NDVI was 0.20 or higher then the pixel was assigned to vegetation over water; if MNDWI was less than -0.05 and NDVI was 0.25 or higher then the pixel was assigned to vegetation on land, and to bare substrate otherwise. The thresholds of the combined method were determined based on the distributions of the two index values in the plots in the first hydrological year and used unaltered in the other two hydrological years.

III. Results

Seasonal Trajectories of Vegetation and Water Indices

All indices indicated a robust and reliable seasonality pattern that is clearly related to the filling and drawdown of the water tank (Figure 2). The MNDWI experienced a sharp increase in November due to northeast monsoon runoff and the filling of the basin, peaked in December/January, and decreased consistently from February as the basin was drawn down and the water was gradually lost through evaporation. The NDVI index experienced an opposite trend during the wet period; namely, the value reached its minimum when the basin was flooded due to open water being present in most pixels and then rapidly increased as floating and emergent macrophytes colonised the area of drawdown. Greenness was highest in April, at the end of the drawdown period, but then decreased in May when the dry bed became exposed and herbaceous vegetation senesced.

Seasonal means of the indices and field variables are given in table 1. Seasonal differences were significant for all four indices (Kruskal-Wallis, $p < 0.001$). NDVI, SAVI, and EVI showed maximum values during pre-monsoon and minimum during post-monsoon, while MNDWI showed maximum value during post-monsoon and minimum during southwest monsoon. The largest seasonal variability of MNDWI and open water was observed during northeast monsoon, due to the inter-annual difference in the timing of tank filling. Seasonal trajectories of field variables were similar to those of satellite indices. Water level was above 85 cm in January; vegetation cover was minimum when the tank was full and maximum during the April drawdown period; and during southwest monsoon campaigns, the tank bed was almost dry with moderate vegetation cover of terrestrial grasses and herbs.

Table 1: Seasonal Mean (± Standard Deviation) Values of Satellite-Derived Indices, Open-Water Extent and Field Variables at the Vedanthangal Tank Wetland, June 2021 – May 2024

Season	Scenes (n)	NDVI	EVI	SAVI	MNDWI	Open water (ha)	Vegetation cover (%)	Water depth (cm)
Southwest monsoon (Jun–Sep)	18	0.34 ± 0.03	0.22 ± 0.03	0.25 ± 0.03	−0.34 ± 0.05	0.6 ± 0.5	37.5 ± 8.2	2.0 ± 2.6
Northeast monsoon (Oct–Dec)	12	0.26 ± 0.08	0.16 ± 0.05	0.19 ± 0.06	0.11 ± 0.24	15.8 ± 8.7	29.4 ± 10.1	58.7 ± 24.3
Post-monsoon (Jan–Feb)	15	0.22 ± 0.07	0.14 ± 0.05	0.17 ± 0.05	0.35 ± 0.08	24.1 ± 3.8	23.6 ± 6.9	89.7 ± 15.2
Pre-monsoon (Mar–May)	31	0.49 ± 0.07	0.33 ± 0.05	0.37 ± 0.06	−0.12 ± 0.14	4.2 ± 3.1	64.8 ± 9.6	21.3 ± 12.4

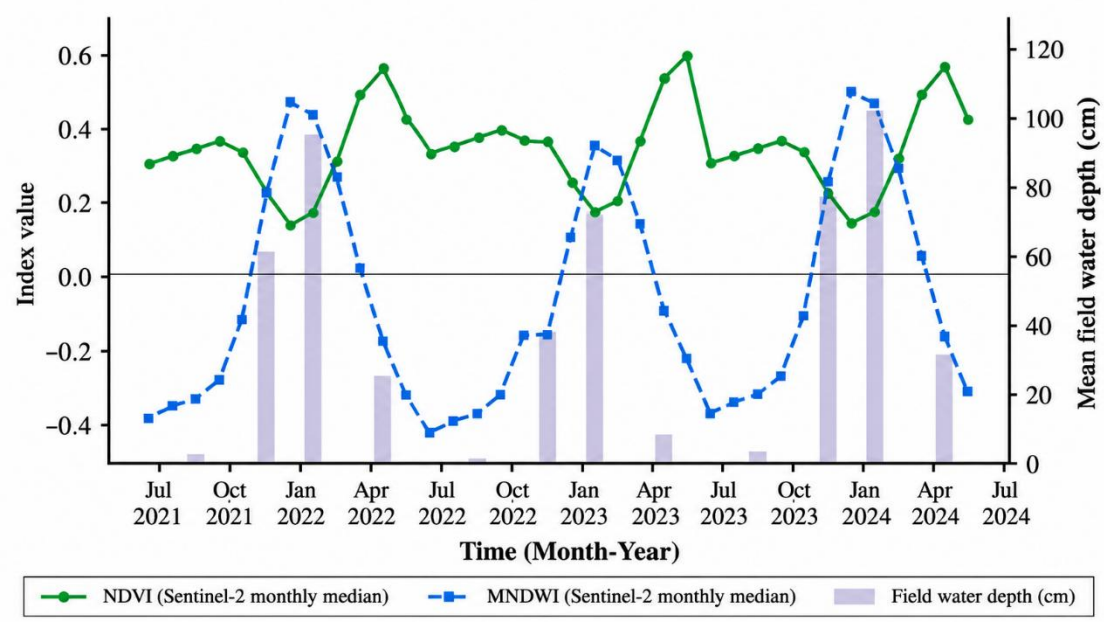


Figure 2: Monthly Sentinel-2 NDVI and MNDWI (Wetland-Median Values) and Mean Water Depth Recorded at the 24 Permanent Field Plots During the Twelve Field Campaigns, Vedanthangal Tank Wetland, June 2021 – May 2024

Relationships Between Satellite Indices and Field Variables

Indices derived from satellites proved highly correlated with field variables that were supposed to correspond to them. MNDWI was significantly correlated with water depth ($r = 0.89$, $n = 263$, $p < 0.001$). The correlation appeared nearly linear for depths ranging from approximately 10 cm to 120 cm. However, MNDWI poorly correlated with water depth for depths less than 10 cm, due to the contribution made by wet soil and emerging plant stems to the pixel value. Water depth was estimated from MNDWI with an R^2 of 0.79 and RMSE of 13.6 cm.

Of the vegetation indices examined, NDVI exhibited the most significant correlation with vegetation cover estimated from the ground measurements ($R^2 = 0.78$; cross-validated RMSE = 9.8%), followed by SAVI ($R^2 = 0.76$; RMSE = 10.3%) and EVI ($R^2 = 0.74$; RMSE = 10.9%). Residuals of the NDVI regression contained two distinct systematic patterns. First, in the case of plots with floating vegetation above shallow waters, NDVI was biased downward due to reduced reflectance in near-infrared wavelengths as a result of presence of water under and in-between leaves – the average residual for such plots equaled

−11.2 percentage points. Second, NDVI became saturated for dense mats of Ipomoea occupying more than 80% of the area of a plot, and changes in vegetation cover did not result in a significant change in the index. EVI was less prone to saturation and had a higher correlation with macrophyte height (r = 0.71) than NDVI (r = 0.63). Chlorophyll index of leaves showed significant correlation with both NDVI (r = 0.58) and EVI (r = 0.61); the highest chlorophyll index was measured during the April surveys when macrophytes actively grew on nutrient-rich and newly exposed sediments.

Seasonal Cover Classification

The combination decision rule using NDVI and MNDWI yielded the best classification results. In comparison with the field reference data of the second and third year independently, it gave 88.6% of total accuracy and 0.84 value of kappa. The pure MNDWI decision rule resulted in 81.2% (0.74 of kappa) and pure NDVI – 79.4% (0.71 of kappa). All the improvements in combination of these indices were due to vegetation over water class where producer's accuracy changed from 64.3% (for pure NDVI) to 86.1% (for combined decision rule). Many plots of vegetation over water were classified incorrectly as bare substrate or open water with pure NDVI and open water with pure MNDWI. Open water was mapped with highest accuracy by any method at the post-monsoon maximum (producer's accuracy more than 95%) and the only possible mistake was due to vegetation on land and bare substrate at the end of dry period with low vegetation greenness.

The classification results demonstrated a definite sequence of changes in the spatial dimension. First, open water formed in the deep areas in the central and bundside sections of the tank, from where it extended to the inflow side. Vegetation over water first appeared in the shallow water areas close to the inflow as well as the Barringtonia trees during the drawdown period, expanding gradually inwards with the receding water level. Open water was most persistent in the central pool in close proximity to the bund that had shallow water for at least two out of three years until April, and constituted the primary breeding and feeding site for waterbirds.

Inter-Annual Variability

However, the seasonality was seen in all three years, but the onset and magnitude differed. In 2021-22 and 2023-24, filling took place in November, with a peak MNDWI value of 0.46 in December for 2021-22 and 0.49 in December for 2023-24, while the median wetland surface stayed inundated for five continuous months, namely from November to March. For 2022-23, the onset of filling was in December, with a smaller MNDWI peak value of 0.34 in January, and inundation duration was four months. From field observations, the drier year was evident from the mean water depth in January of 2023 that had a depth of 72 cm, whereas in January of 2022 and 2024, it was 95 and 102 cm, respectively.

There were changes to the plant growth cycle as well, due to the shortened wet period. In 2022-23, there were higher values of NDVI for November since the tank bed was mostly dry and vegetated, the post-monsoon minima of NDVI was not so deep, and the maximum value of green vegetation was reached not in April but in May. On land, the vegetation grew earlier and covered a larger part of the tank bed during the pre-monsoon period, while vegetation over water was about 33% smaller compared to the other two years.

IV. Discussion

Performance and Complementarity of Vegetation and Water Indices

The findings prove that remote sensing indices can represent the key seasonal trends of the monsoon wetland if calculated at 10m resolution and formed into a dense time series. The inverse correlation of NDVI and MNDWI during the wet period, as well as their simultaneous reduction in the late dry period, is associated with the alternation of open water, water vegetation, and substrate which is typical of seasonal tank wetlands. The pattern is consistent with the current knowledge regarding the response of NDVI to

green vegetation and reduction by water presence, while MNDWI highlights open water due to the contrast between the green and low shortwave infrared reflectance of water.

It was found that out of all the vegetation indices NDVI was the one that predicted the total vegetation cover the best while EVI was better related to the height of the macrophytes and not saturated by dense floating mats. This was consistent with the purpose of developing EVI as a vegetation index that would still be sensitive at high-biomass canopies and that would minimize background and atmospheric influences. The performance of SAVI was close to NDVI which indicated that the soil adjustment factor did not make a big contribution to this wetland because it had a dark moist clay as an exposed substrate most of the time during the drawdown process rather than bright dry soil for which the index was developed.

The most significant methodological result obtained was that none of the indexes were able to describe the vegetation-over-water condition that is prevalent in the seasonal wetlands during the period of drawdown. The presence of water underneath the plants diminishes the near infrared reflectance and decreases the value of NDVI, whereas the canopy of the vegetation attenuates the open water signal in MNDWI. Consequently, the rules that relied on a single index were not able to correctly classify these pixels, often identifying them as bare substrate or open water. Combining the indexes into a simple classification rule improved the producer's accuracy for this category by over 20 percentage points, while increasing the total accuracy by seven to nine percentage points.

Value of Integrating Field Observations

Field observations served three purposes in this research project. Firstly, they served to calibrate the indices with respect to variables of managerial importance, thus enabling MNDWI to be interpreted as an indicator of water depth and NDVI as an indicator of vegetation cover. Secondly, they served as an independent means of assessment of the classification accuracy, since it is impossible by mere visual interpretation of imagery to distinguish between floating vegetation on water and vegetation on saturated soil. Finally, they helped to explain the residuals of the regression equations and understand the influence of sub-canopy water presence and canopy saturation that would otherwise be considered as noise. Leave-one-campaign-out validation confirmed that the dependencies were season-independent and year-independent, which is quite a promising sign since a model that was calibrated during a certain period can be used for interpretation of images from other periods at the same site.

The field design was purposely scaled down: 24 plots surveyed four times a year. It is possible to conduct such an experiment in many protected areas' administrations and community monitoring organizations. It is essential to make sure that the field plots are the same size as the Sentinel-2 pixel and that the field plots are permanently marked, since it helps establish correlations due to the reduction of spatial and scale mismatch typical in comparison of field and satellite observations. The findings confirm the hypothesis that the most valuable wetlands monitoring program would be the one with regular satellite monitoring of few carefully chosen field plots.

Ecological and Management Implications

As demonstrated by the inter-annual analysis, seasonal wetlands are very sensitive to the timing of water availability. In 2022-23, which is a drier year, the delay in filling by about a month led to shorter inundation time and lesser vegetation cover of the water surface as well as terrestrial vegetation cover extending sooner on the bed of the tank. It is important from an ecological point of view as such a wetland depends on colonial waterbirds for its conservation significance. The nesting areas need standing water under the nesting trees as a protective measure against ground predators and foraging areas nearby, and if the central pool dries up earlier, there could be low breeding success and abandonment of nests.

There are several management applications that immediately spring from the outcomes achieved. Using the relationship between MNDWI and depth, managers can assess the water depth and area covered by water using freely available satellite imagery between the field surveys and thereby check the water retention capacity of the central pond in proximity to the nesting trees in critical breeding months. If the

depth of the pond is found to be lower than the depth required for nesting purposes, then managers can think of collaborating with the local water user associations in terms of irrigation releases or timing of desilting. The trends observed in the case of NDVI and EVI can be utilized to keep track of the invasion by floating macrophytes like Ipomoea carnea, which tend to invade the open water areas when the wet season is short. More generally, the classified time series can serve as a benchmark for observing the impact of any change in land use in the catchment, channel modification or monsoon pattern on the ecology of the pond.

Limitations and Future Work

There are some limitations that need to be pointed out. For instance, clouds occurring during both monsoon seasons have limited the amount of optical images and hence, the filling stage, which is ecologically significant, has received less attention compared to the dry season, where there are five months of composite images that use interpolation. Synthetic aperture radar, which is capable of capturing surface water and vegetation structures despite clouds, could help in depicting wet seasons better. The shortwave-infrared band of 20 meters reduces the spatial resolution of MNDWI while mixed pixels are inevitable. The field plots, although appropriately aligned with the satellite grid, did not sample the entire wetland, and even visual estimates of vegetation cover have an element of human error despite protocol standardization. Finally, the study was conducted for three hydrological years and one particular wetland. Testing the transferability of this methodology to a group of wetlands with varying tank sizes, catchment conditions, and management systems, in addition to studying for a longer period, would enable the effects of climatic variability on the functioning of seasonal wetlands to be studied further. Future studies could involve relating the indices of condition to biological criteria like macroinvertebrate communities, fish reproduction, and waterbird breeding.

V. Conclusion

This research shows that using satellite vegetation and water indices alongside structured field observation is an efficient method of monitoring seasonal dynamics of small wetlands in monsoonal conditions. The three-year time series of Sentinel-2 images covered the entire hydrological cycle of the wetland Vedanthangal tank, including monsoonal refilling and flooding, vegetation growth during drawdown and dry-up in the pre-monsoon period. MNDWI showed close correlation with the measured water level, while NDVI, SAVI and EVI accounted for almost all variations in vegetation cover and EVI better described the development of dense macrophyte canopies. There was no one index that would be sufficient to describe the vegetation growth over shallow water – the stage when wetlands are mostly flooded, however, combining NDVI and MNDWI indices solved this problem. When compared year by year, it was revealed that slight delays in filling shortened the wet period, minimized the growth of aquatic vegetation, and promoted the growth of terrestrial vegetation, which is significant for the breeding colonies of waterbirds in the wetland. Repeated and pixel-matched field plots were necessary for calibration of the indices, validation of the maps, and understanding of the errors left, and the effort required for such studies was not beyond the capacity of most wetland management groups. The model was transparent, cheap, based on open data, and transferable to any other seasonal wetland. The addition of radar measurements, use of long-time records, and correlation of the index condition with biological criteria will further increase the importance of the framework as an early warning tool.

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