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The Relationship between Spatial Vegetation Indices: A Case Study for the South of Ukraine

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Abstract The paper presents the results of the study devoted to the determination of the interrelationship and interchangeability of five widely used indices of agricultural science and practise, namely NDVI, EVI, EVI2, NDWI and DSWI. The study was carried out for the fixed polygon, located in the cold arid steppe zone of Kherson region of Ukraine, during the period 2019-2022 using the cloud-free satellite imagery from Landsat-8, obtained at AgroMonitoring API. The strength and direction of the interrelationship were determined by a standard correlation analysis procedure for all pairs of vegetation indices. As a result, high discrepancies and inequality in distribution of the values of the vegetation indices studied by the years of the study were established. Analyzing the generalized data for 2019-2022, it was established that the strongest relationship and the highest possible interchangeability is attributed to the NDVI, EVI, and EVI2, where Pearson's correlation coefficient averaged to 0.8483-0.9090. The DSWI and EVI indices are moderately correlated (the correlation coefficient is 0.7698), therefore, their interchangeability is questionable. The NDWI index has the weakest correlation with the other indices studied (the correlation coefficient does not exceed 0.6269) and is a unique measure for the determination of water stress in plants. Further studies are required to determine whether the DSWI, NDVI and EVI could be interchangeable in crops monitoring.

Keywords Disease Water Stress Index, Enhanced Vegetation Index, Normalized Difference Vegetation Index, Normalized Difference Water Index

1. Introduction

Remote sensing opens new opportunities for the research and management of environment, especially, in the monitoring of vegetation cover. Spatial imagery, obtained using different sensors and represented by different bands, is used to calculate various vegetation indices, which are of great importance for the assessment of the vegetation cover conditions by various aspects, e.g., density, stress levels, growth cycles, biomass, resilience, and susceptibility to adverse climatic and anthropogenic factors, general land cover dynamics and characteristics, etc. [1, 2]. Remote sensing data are a huge source of the information on qualitative and quantitative parameters of vegetation, and they are a powerful scientific instrument when combined with modern geoinformation systems (GIS) technologies. It is difficult to imagine current environmental and agricultural science in isolation from remote sensing [3].

Different vegetation indices are applied for different purposes. For example, the normalised difference vegetation index (NDVI) is commonly used to analyse and characterise general conditions of the plants, grown or cultivated in certain area. Its calculation is quite simple (1), requiring data on near infra-red (NIR) and red (Red) spectral bands, and most agricultural data farming and environmental monitoring online platforms offer NDVI screens and/or NDVI figures for the recent years or even decades [4]. Sometimes, this information is additionally accompanied by time-curve analysis. It is worth noting that different platforms provide NDVI obtained from different initial sources, e.g., Sentinel-2, Landsat-8. This is true not only for NDVI, but for other vegetation indices, too, and it is important to know the source of the vegetation index derivation because it is dangerous to compare vegetation indices received from different satellites, or apply monitoring patterns or mathematical analytical models, developed for certain satellite, to others. The latter may result in errors and fail in environmental modelling. However, atmospheric correction techniques could be handy to diminish the difference between NDVI data from different sources [5].

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

Another valuable and popular vegetation index is the enhanced vegetation index (EVI). The index was developed to minimise atmospheric distortions connected with the evaluation of vegetation cover using NDVI, as the latter is greatly affected by atmospheric noise, as well as canopy structure. The first to mention the new computation methodology were Liu & Huete [6], and the equation of the EVI calculation generally looks as (2), introducing the blue spectral band (Blue). It is better at characterising the structure of the vegetation canopy [4], less susceptible to atmospheric phenomena and aerosol concentration, as well as to the albedo of the soil cover. However, EVI is less spread in practice, and is mainly used in scientific purposes.

$$EVI=2.5*(NIR-Red)/(NIR+6Red-7.5Blue) \quad (2)$$

The enhanced vegetation index 2 (EVI2) was developed by Jiang et al. [7]. This vegetation index is a modified version of regular EVI, and the main distinctive feature is that it is based on the use of the Moderate Resolution Imaging Spectroradiometers (MODIS) imagery obtained with Terra and Aqua satellites. As a result, it utilises only the NIR and Red bands for the calculation (3), as NDVI does.

$$EVI2=2.5(NIR-Red)/(NIR+2.4Red+1) \quad (3)$$

EVI2 was mainly directed at the phenological monitoring, quantity, and general conditions of vegetation, as well as NDVI and EVI. It has been proven that EVI2 performs somewhat better than NDVI because it is less susceptible to soil albedo and generally is quite close to EVI [8, 9].

The disease water stress index (DSWI) is commonly applied to characterise the stress of water shortage in plants, as well as their damage due to the lack of moisture and other factors [4]. It is calculated as follows in the (4) and requires water sensitive shortwave infra-red spectral band (SWIR1) band to be assessed, as well as green (Green) spectral band [10].

$$DSWI=(NIR-Green)/(SWIR1+Red) \quad (4)$$

The normalized difference water index (NDWI) was primarily developed to assess the water status of vegetation cover and identify non-urban surface water associated with wetlands; it is calculated using Green band as follows in the (5) [11, 12].

$$NDWI=(Green-NIR)/(Green+NIR) \quad (5)$$

In more detail, this vegetation index was designed to maximise the reflectance of water through the use of the Green band; minimise the low reflectance of the NIR by water; use the high reflectance of the NIR by vegetation and soil cover. Therefore, a higher water presence is characterised by high positive NDWI values, while vegetation and soil cover generally have lower (about zero) values of the index [11].

Notwithstanding the fact that every vegetation index is unique and serves best for concrete purposes, it could not be neglected that they possess some common characteristics when analysing the formula for their computation [13]. For example, NIR band is used in all the vegetation indices mentioned above. Therefore, it could be presumed that the vegetation indices can have some optical preconditions for mutual inter-relation. This hypothesis has been recently scientifically proved for some of the vegetation indices, including EVI, EVI2, and difference vegetation index (DVI) [14]. On the other hand, different vegetation indices were claimed to be better under specific environmental conditions and to reach specific goals, therefore questioning the possibility of their mutual interchangeability [15]. However, there were no objections to the substantiation of one vegetation index with another, kindred one, imperatively expressed in scientific publications.

The fact is that there are a few scientific studies devoted to the investigation of mutual inter-relation and interchangeability of the vegetation indices, mentioned above. However, this subject is of great importance as it can provide a solution for a more universal application of the vegetation indices in agricultural science and practise, especially when some of the vegetation indices required in specific situations are not available. For example, it is important to know whether one can use NDVI instead of NDWI or DSWI to estimate water stress, if the specific indices are not accessible for certain fields or plots. Therefore, the goal of current study was to determine the strength and direction of the relationship between the NDVI, EVI, EVI2, DSWI, and NDWI, and suggest whether some of these vegetation indices could be interchangeable in some cases.

2. Materials and Methods

The study on the relationship between NDVI, EVI,

EVI2, DSWI, and NDWI was carried out for the period 2019-2022 for the cultivated lands of the Institute of Climate-Smart Agriculture (former Institute of Irrigated Agriculture) of the National Academy of Agrarian Sciences of Ukraine. The cultivated land is located in the south of Ukraine, Kherson region, located within the polygon, built up by geographical points with the following coordinates: 46°44'1.3"N, 32°41'31.0"E; 46°45'53.2"N, 32°41'11.8"E; 46°45'58.7"N, 32°43'58.1"E; 46°43'54.2"N, 32°43'51.4"E. The allocation of the polygon relative to the regional centre of Kherson city is demonstrated in Figure 1.

The area is characterized with cold steppe zone climate (BSk, or semi-arid cold climate) and dark-chestnut soil cover. The zone belongs to the areas of risky agriculture with high dependency and requirements for irrigation [16, 17].

Topographically, the area is a part of the East European Plain and is characterized by plain macro and micro relief with very little areas of hollows. The elevation of the studied area above the Black Sea level is 41 m. The vegetation cover of the studied area is purely represented by cultivated plants, among which the greatest share belongs to winter cereals (wheat and barley), maize, sorghum, oil rapeseed, soybeans, and sunflower. Almost no natural vegetation is present in the polygon, apart from small forest shelter belts, located by the perimeter of the fields.

Figure 1. Location of the studied polygon (marked with figure 1) in Kherson region, Ukraine

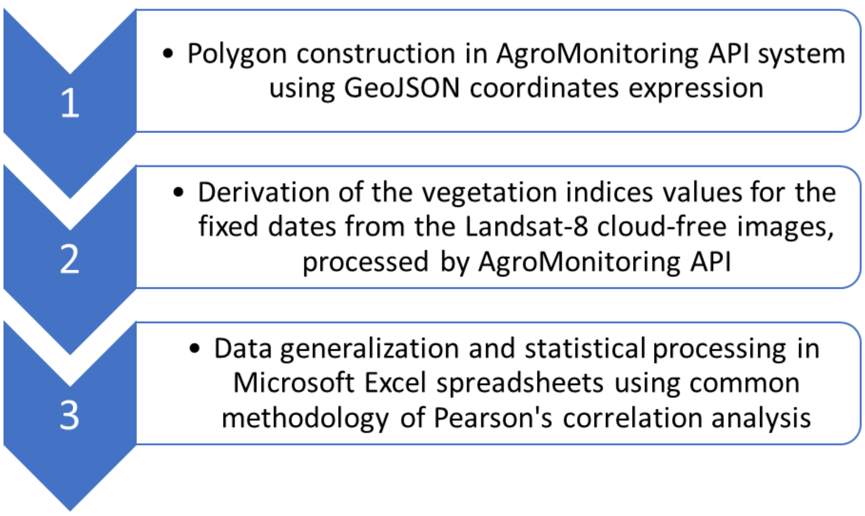

Figure 2. Methodology flow chart

Vegetation indices were obtained from the AgroMonitoring Application Programming Interface (API) platform. Landsat-8 cloud-free terrain images with a spatial resolution of 30 metres (obtained using visible, NIR, SWIR and thermal infrared spectral bands) were used to derive the values of the vegetation indices time series for the period April-November of each year of the study. The value of the vegetation index was derived for the fixed dates. Furthermore, the values of the vegetation indices were analysed using the standard procedure of Pearson's correlation and determination coefficients calculation to determine the strength and direction of their relationship. The calculations were performed in Microsoft Excel 365 spreadsheets using the built-in statistical algorithm for correlation analysis, and the total number of data inputs included 68 "NDVI-EVI-EVI2-DSWI-NDWI" samples [18]. General methodological flow is expressed in the Figure 2.

The study was conducted both for each year of the period, and the period 2019-2022 overall, with a focus on the general time span and internal differences in the vegetation indices relationship by the years of the study.

3. Results

As a result, a dramatic difference in the relationship between the vegetation indices studied by the years of study was determined (Table 1, Figure 3), as well as a generally high discrepancy in the distribution. It is also evident that 2022 was the year of the most specific vegetation conditions with distinctly different patterns for some vegetation indices (NDVI-NDWI, NDWI-EVI, NDWI-EVI2, NDWI-DSWI), which could be put upon the affection of the cultivated lands by military activities. In general, in all studied periods, a strong direct relationship is recorded for the pairs NDVI-EVI, NDVI-EVI2 and EVI-EVI2, with the strongest direct connection between NDVI and EVI2 (Pearson's correlation coefficient value falls within the range 0.9090-0.9790).

Table 1. Correlation relationship between the vegetation indices (NDVI, EVI, EVI2, NDWI, and DSWI) by the years of the study during 2019-2022

Pair of the indices	Pearson's correlation coefficient				
	2019	2020	2021	2022	2019-2022
NDVI-NDWI	0.9007	0.8226	0.6468	-0.2490	-0.4786
NDVI-EVI	0.9316	0.8357	0.9803	0.9338	0.8483
NDVI-EVI2	0.9790	0.9564	0.9242	0.9310	0.9090
NDVI-DSWI	0.9294	0.8069	0.9590	0.2969	-0.0687
NDWI-EVI	0.9531	0.7967	0.4844	-0.2400	0.3614
NDWI-EVI2	0.8228	0.3461	0.3062	-0.3594	0.1171
NDWI-DSWI	0.9669	0.9510	0.6618	0.0158	0.6269
DSWI-EVI	0.9528	0.8820	0.8683	0.4779	0.7698
DSWI-EVI2	0.8609	0.5094	0.7132	0.3457	0.5593
EVI-EVI2	0.9378	0.7999	0.8766	0.9072	0.8818

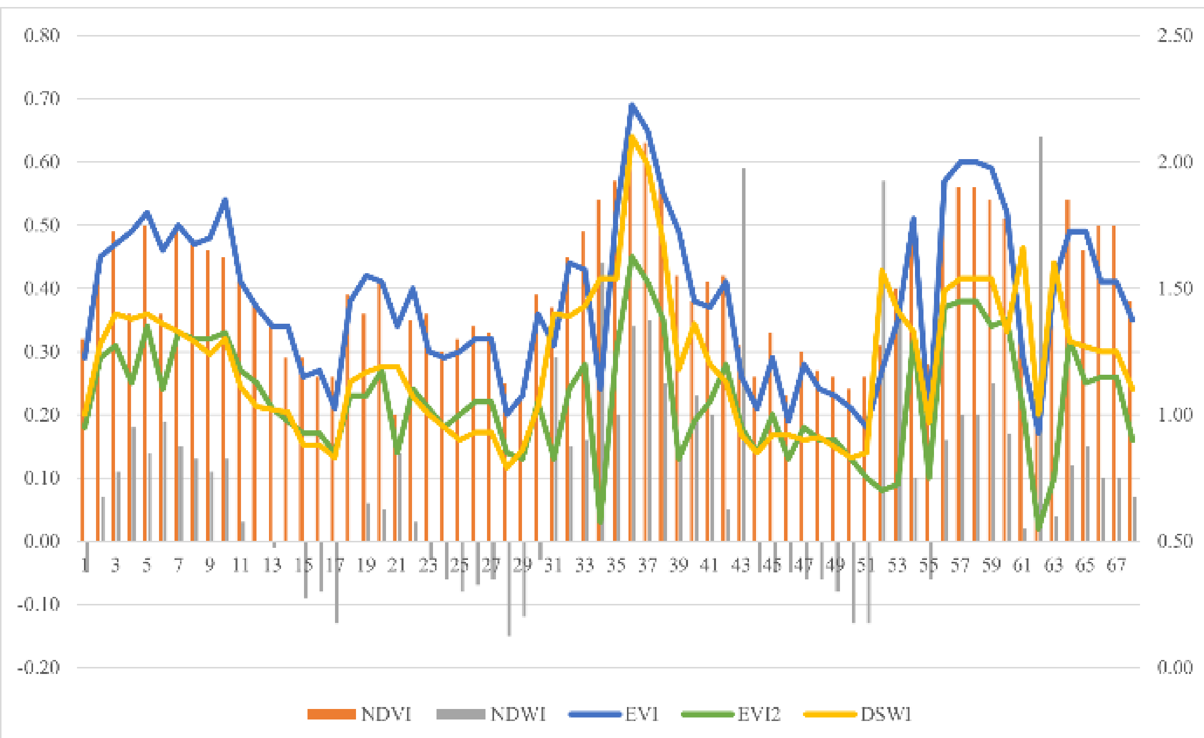

Figure 3. The distribution of the values of the vegetation indices (NDVI, EVI, EVI2, NDWI, and DSWI) for the whole period 2019-2022

At the same time, the weakest relationship was established for NDWI-EVI2. Contradictory results were obtained for NDVI-DSWI (strong relationship for 2019, 2020, 2021, and weak for 2022), NDWI-EVI (strong relationship for 2019, moderate – for 2020, moderate to slight – for 2021, and weak indirect – for 2022), NDWI-EVI2 (strong relationship for 2019, weak – for 2020 and 2021, and weak indirect – for 2022), NDWI-DSWI (Strong for 2019 and 2020, moderate for 2021, and weak for 2022), DSWI-EVI (strong for 2019, 2020, 2021, and moderate for 2022), DSWI-EVI2 (strong for 2019, moderate for 2020. 2021, and weak for 2022). Such fluctuations by the years of the study allow concluding that the relationship and interchangeability of the studied vegetation indices is strongly dependent on some specific features of the observation periods, for example, climatic conditions, cultivation practises, and crop allocation on the cultivated lands.

The values of the coefficients of determination for the studied pairs of the vegetation indices are presented in Table 2. They represent the same patterns of the relationship strength but provide no details on its direction. Usually, it is recommended to analyse the whole period of the study, not separate years. From this point of view, generally, the strongest relationship and interchangeability is detected for NDVI, EVI, and EVI2, while a moderate relationship and, as a result, somewhat uncertain interchangeability is recorded for DSWI and EVI. In summary, NDWI was found to be the most specific and irreplaceable vegetation index, followed by DSWI, EVI, EVI2, and NDVI.

Table 2. Determination coefficients for the vegetation indices (NDVI, EVI, EVI2, NDWI, and DSWI) by the years of the study during 2019-2022

Pair of the indices	Coefficient of determination				
	2019	2020	2021	2022	2019-2022
NDVI-NDWI	0.8113	0.6767	0.4184	0.0620	0.2291
NDVI-EVI	0.8679	0.6984	0.9610	0.8720	0.7196
NDVI-EVI2	0.9584	0.9147	0.8541	0.8668	0.8263
NDVI-DSWI	0.8638	0.6511	0.9197	0.0881	0.0047
NDWI-EVI	0.9084	0.6347	0.2346	0.0576	0.1306
NDWI-EVI2	0.6770	0.1198	0.0938	0.1292	0.0137
NDWI-DSWI	0.9349	0.9044	0.4380	0.0002	0.3930
DSWI-EVI	0.9078	0.7779	0.7539	0.2284	0.5926
DSWI-EVI2	0.7411	0.2595	0.5087	0.1195	0.3128
EVI-EVI2	0.8795	0.6398	0.7684	0.8230	0.7776

4. Discussion

The study presented in this manuscript provides unique and novel insights on the interchangeability and relationship between five widespread in agricultural science and practice vegetation indices. However, there are several other studies, which could supplement, support or contradict the results, described in this one. For example, Zoungrana et al. [19] carried out a research on the comparison between NDVI and EVI in terms of their response to rainfall amounts and showed that both vegetation indices have similar regularities in the precipitation-based dynamics with slightly better performance of NDVI. On the other hand, some studies refer to the fact that EVI has a better reaction to rainfall amounts, although the dynamics in changes of both indices is strongly connected [20]. These results agree with ours, as well as those of Peng et al. [21] and Qiu et al. [22], who reported a good agreement between NDVI and EVI in remote phenological monitoring, although EVI should be preferred in areas that are densely covered with vegetation.

As for the relationship between EVI and EVI2, Jiang et al. [7] revealed that there is negligible difference between EVI and EVI2 indices, but EVI2 is preferable if there is a difficulty in obtaining reliable data from the Blue spectral band, for example, under the use of Advanced Very High Resolution Radiometer (AVHRR). Our study also supports the idea of interchangeability between the EVI and EVI2 indices, as they are strongly directly interconnected.

The study by Bochenek et al. [23] found that both NDVI and DSWI are strongly related to the leaf area index (LAI), making both suitable for the evaluation of remote vegetation cover. However, the current study found extremely weak interconnection between the NDVI and DSWI, so it is still debatable whether these two vegetation indices could be interchangeable in crops monitoring.

Researchers from Hungary revealed that there is a moderate to strong relationship between NDVI and NDWI, namely, the coefficients of determination fluctuated between 0.66-0.91 within the growing season, but both indices were applicable for the evaluation of the level of drought [24]. However, our results are in contradiction with this statement, as it was found that there is just a moderate indirect relationship between NDVI and NDWI in the long-term analysis. To support our results, we may provide the outcomes of the study by Szabo et al. [25], who also reported about a weak correlation between NDVI and NDWI. Furthermore, it was reported that NDWI was shown to have a quicker response to changes in humidification conditions compared to NDVI, making NDWI an irreplaceable index for monitoring crop water stress. At the same time, we must admit that in 2019 and 2020 we have revealed a strong direct interconnection between the indices, thus making us draw the final conclusion quite difficult because of contradictory outcomes. It perhaps depends on the weather conditions and cultivation practises.

5. Conclusions

The current study provides evidence for high interchangeability between the vegetation indices NDVI, EVI, and EVI2, used in agricultural science and practise to perform dynamic monitoring of crops and the conditions of the natural vegetation cover. As for the other studied indices, their interchangeability remains questionable, as the strength and direction of their interrelationship are significantly different from year to year. The prospective interchangeability could be determined for the DSWI and EVI indices, but further studies are required to accept or deny this suggestion. The limitations of this study are mainly in the limited area of the study conduction, because in other topography and environmental conditions, the outcomes could be different. Furthermore, the study did not evaluate the vegetation indices for the cover of natural vegetation. Further research work will be conducted to erase the limits of locality, involving more areas located in different environmental zones. As for the applicability of the study results, they could be further utilised in automated decision support systems for agricultural practitioners, and in educational establishments.

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