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CROP CONDITION MONITORING USING VEGETATION INDICES DERIVED FROM SATELLITE REMOTE SENSING DATA

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Abstract

Timely monitoring of crop conditions is essential for improving agricultural productivity, optimizing irrigation, and supporting sustainable land management. Traditional field-based monitoring provides valuable information but may require considerable time and labor, particularly when agricultural areas are extensive. Satellite remote sensing offers an efficient complementary approach by enabling repeated observation of crop development over large territories. This thesis examines the scientific and methodological foundations of crop condition monitoring using vegetation indices derived from satellite imagery. Particular attention is given to the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), and Normalized Difference Water Index (NDWI), as well as data obtained from the Sentinel-2 and Landsat satellite missions. The study follows a literature-based analytical approach and considers the interpretation, practical applications, and limitations of vegetation indices in agricultural monitoring. It emphasizes that vegetation indices should be interpreted in relation to crop type, growth stage, soil background, atmospheric conditions, and field observations. The findings synthesized from the literature indicate that satellite-derived vegetation indices can support crop vigor assessment, identification of spatial variability, and early detection of potential agricultural stress. However, reliable interpretation requires appropriate image preprocessing, temporal analysis, and validation using field-based information.

Keywords: crop monitoring, vegetation indices, NDVI, EVI, NDWI, Sentinel-2, Landsat, remote sensing, precision agriculture, GIS.

1. Introduction

Agricultural production is increasingly affected by water scarcity, changing climatic conditions, soil degradation, and the need to use natural resources more efficiently. Under these circumstances, timely and spatially detailed information about crop development is important for agricultural planning and decision-making. Conventional crop monitoring generally depends on field inspections, measurements, and expert observations. Although these methods remain essential, they may not adequately represent spatial differences across large or heterogeneous agricultural areas.

Satellite remote sensing provides an additional means of observing vegetation across extensive territories and at repeated intervals. Optical satellite sensors record reflected electromagnetic radiation in different spectral bands. Because healthy and stressed vegetation exhibit different spectral responses, satellite observations can be transformed into vegetation indices that help characterize crop conditions.

The Normalized Difference Vegetation Index (NDVI) is among the most widely used indicators of vegetation greenness and photosynthetic activity. Other indices, including the Enhanced Vegetation Index (EVI) and the Normalized Difference Water Index (NDWI), provide complementary information about vegetation structure and water-related conditions. Their combined use can improve the interpretation of crop development, although no single index can independently identify every type of agricultural stress [1–4].

The availability of Sentinel-2 and Landsat imagery has expanded the opportunities for monitoring crop conditions at field and regional scales. These datasets can be integrated into geographic information systems (GIS) to produce vegetation maps, compare fields, and examine

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seasonal changes. Nevertheless, reliable agricultural assessment requires careful image processing, knowledge of crop phenology, and validation against field observations.

2. Aim and Research Objectives

The aim of this study is to examine the methodological potential of satellite-derived vegetation indices for monitoring crop conditions and identifying spatial and temporal variability in agricultural vegetation.

The objectives are:

1. To explain the scientific principles underlying vegetation indices used in crop monitoring.
2. To examine the characteristics and agricultural applications of NDVI, EVI, and NDWI.
3. To assess the potential of Sentinel-2 and Landsat imagery for monitoring crop development.
4. To identify methodological limitations affecting the interpretation of vegetation indices.
5. To propose an integrated workflow combining satellite imagery, GIS analysis, and field validation.

3. Materials and Methods

This thesis employs a literature-based analytical approach rather than reporting a newly conducted field experiment. It synthesizes established remote-sensing methods and published research on vegetation indices, satellite observations, and agricultural monitoring.

The methodological framework consists of four stages:

- Satellite data selection: identifying appropriate Sentinel-2 or Landsat imagery for the study area and crop-growth period.
- Image preprocessing: applying relevant atmospheric correction, cloud and shadow masking, and image quality control.
- Vegetation-index calculation: deriving NDVI, EVI, and NDWI from the appropriate spectral bands.
- Spatial and temporal interpretation: comparing index values across fields and growth stages, then evaluating the results using field observations where available.

This approach establishes a reproducible framework for crop monitoring without assuming that new satellite processing, field measurements, or model validation have already been completed.

4. Theoretical Foundations of Vegetation Indices

Vegetation indices are mathematical combinations of spectral reflectance values designed to emphasize particular characteristics of vegetation. Green leaves absorb a substantial proportion of red radiation because of chlorophyll pigments and reflect strongly in the near-infrared (NIR) region because of their internal cellular structure. Differences between these spectral responses provide a basis for assessing vegetation greenness and canopy development [1, 2].

4.1. Normalized Difference Vegetation Index (NDVI)

NDVI is calculated using red and near-infrared reflectance:

$$NDVI=\frac{NIR-Red}{NIR+Red}$$

The index generally ranges from −1 to +1. Positive values are commonly associated with vegetation, while values closer to zero may correspond to bare soil or sparse vegetation. Negative values can occur over water, clouds, and other non-vegetated surfaces.

In agricultural applications, NDVI is used to monitor seasonal vegetation development, compare crop vigor within fields, and identify areas that may require further investigation. However, NDVI may become less sensitive to additional increases in biomass when vegetation cover is dense. Soil background, atmospheric effects, and crop type can also influence its interpretation [1, 2].

4.2. Enhanced Vegetation Index (EVI)

EVI was developed to improve vegetation monitoring by reducing certain atmospheric and soil-background influences and improving sensitivity under conditions of relatively dense vegetation [2].

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$$EVI=2.5\frac{NIR-Red}{NIR+6Red-7.5Blue+1}$$

The blue band contributes to the correction of atmospheric effects. EVI can complement NDVI when assessing crop canopy development, particularly where NDVI becomes less responsive to changes in vegetation density.

Nevertheless, EVI also depends on image quality, sensor characteristics, and appropriate preprocessing. It should therefore be interpreted alongside other indicators rather than treated as a direct measurement of crop yield or plant health.

4.3. Vegetation Water-Related Indices

Water availability is a major factor influencing crop development. Spectral indices that use near-infrared and shortwave-infrared reflectance can provide information related to vegetation water content and moisture conditions.

One commonly used formulation is the Normalized Difference Moisture Index (NDMI):

$$NDMI=\frac{NIR-SWIR}{NIR+SWIR}$$

NDMI can support the identification of spatial differences in vegetation moisture conditions. Gao's foundational study demonstrated the potential of near-infrared and shortwave-infrared observations for assessing vegetation liquid water from space [3].

The terminology requires care: NDWI has been used for more than one index formulation in the remote-sensing literature. Consequently, a study should specify the formula and spectral bands used rather than relying on the index name alone. In crop monitoring, the choice of index should reflect whether the objective is to assess canopy moisture, detect surface water, or examine another vegetation characteristic.

5. Satellite Data and Crop Monitoring

5.1. Sentinel-2 imagery

The Sentinel-2 mission provides multispectral imagery suitable for agricultural monitoring. Its bands include visible, near-infrared, and shortwave-infrared observations, allowing the calculation of NDVI, EVI, and moisture-related indices. Several bands are available at 10 m spatial resolution, while other bands are supplied at 20 m or 60 m, depending on their spectral purpose.

Sentinel-2 is useful for distinguishing spatial variation within agricultural fields and for observing crop development throughout the growing season. Its multispectral characteristics also enable the integration of vegetation greenness and moisture-related information.

5.2. Landsat imagery

The Landsat programme provides a long-term archive of Earth observations that supports the analysis of agricultural and environmental change. Landsat data can be used to calculate vegetation indices and compare crop conditions across different dates and years.

The choice between Sentinel-2 and Landsat depends on the monitoring objective, required spatial detail, temporal coverage, and availability of cloud-free imagery. Combining the datasets may extend temporal analysis, but differences in sensor characteristics, spectral response, and preprocessing must be considered before comparing index values directly.

6. Proposed Workflow for Crop Condition Monitoring

A practical crop-monitoring workflow can be organized into six stages.

Stage 1. Define the study area and crops. Agricultural field boundaries should be identified, and crop type and planting dates should be documented where possible. These details help distinguish expected seasonal changes from unusual vegetation responses.

Stage 2. Acquire and preprocess imagery. Suitable satellite images should be selected for relevant crop-growth stages. Cloud and shadow contamination should be removed, and appropriate surface-reflectance products should be used to reduce atmospheric effects.

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Stage 3. Calculate vegetation indices. NDVI and EVI can be calculated to characterize vegetation greenness and canopy development. NDMI or another clearly defined water-related index can be included when moisture conditions are relevant to the research question.

Stage 4. Generate spatial maps. Index values can be mapped in a GIS environment to identify differences among fields and within individual fields. Consistent spatial boundaries and suitable image resolution are important for meaningful comparisons.

Stage 5. Analyze changes over time. Satellite observations should be compared across several dates representing relevant growth stages. A time series can help identify delayed development, unexpected declines, or areas showing different patterns from comparable crops.

Stage 6. Validate and interpret the results. Satellite-derived patterns should be compared with field observations, crop calendars, irrigation records, or other reliable information where available. This step is necessary to determine whether observed differences are related to water stress, nutrient limitations, pests, disease, soil conditions, or other factors.

7. Discussion

Vegetation indices provide a practical means of monitoring crop conditions over large agricultural areas. Their main advantage is the ability to represent spatial variability and seasonal changes in a consistent format. When integrated with GIS, these indices can support field prioritization, targeted inspections, irrigation assessment, and precision-agriculture planning.

However, vegetation indices do not directly identify the cause of crop stress. A low NDVI value, for example, may be associated with sparse vegetation, a different growth stage, poor soil conditions, water limitation, disease, or image-quality problems. Similarly, a high NDVI value does not necessarily guarantee high crop yield. These distinctions are essential when translating satellite observations into agricultural recommendations [1, 2].

Temporal analysis is therefore more informative than relying on a single satellite image. Comparing observations from similar growth stages can reduce the risk of interpreting normal seasonal variation as an abnormal condition. Where reliable historical data are available, current vegetation patterns may also be compared with the typical development of the same crop or comparable fields.

The combined use of NDVI, EVI, and NDMI may provide a more comprehensive assessment than a single index because the indices emphasize different aspects of vegetation response. Nevertheless, index combinations should be selected according to the crop, environmental conditions, and purpose of the assessment. Field verification remains important for confirming the meaning of unusual spectral patterns.

A further methodological issue concerns spatial resolution. Mixed pixels along field boundaries may contain both crops and non-crop surfaces, potentially distorting index values. Cloud cover can also interrupt the time series, while differences in crop varieties, planting dates, irrigation practices, and soil characteristics may complicate comparisons between fields.

Because this thesis is based on published literature and methodological synthesis, it does not report newly processed satellite imagery, field measurements, or experimentally established accuracy values. These would need to be obtained and validated in a separate empirical study.

8. Conclusion

Satellite-derived vegetation indices offer an effective methodological basis for monitoring crop conditions and identifying spatial and temporal differences in agricultural vegetation. NDVI is useful for assessing vegetation greenness, EVI can provide complementary information under relatively dense canopy conditions, and NDMI can contribute to the assessment of vegetation moisture-related variation.

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Sentinel-2 and Landsat imagery provide complementary opportunities for field-level and long-term agricultural monitoring. Their integration with GIS enables the production of vegetation-index maps, comparison of agricultural fields, and analysis of seasonal crop development.

Reliable monitoring requires suitable image preprocessing, consistent temporal comparisons, knowledge of crop-growth stages, and validation against field-based information. Vegetation indices should be interpreted as indicators of spectral and vegetation conditions rather than direct measurements of crop yield or definitive diagnoses of plant stress.

Future empirical research could apply the proposed workflow to irrigated agricultural areas in Uzbekistan, comparing satellite-derived indices with field observations collected at appropriate crop-growth stages. Such research could establish how effectively these methods support local agricultural monitoring and resource-management decisions.

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