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Use of the Normalized Difference Vegetation Index (NDVI) to Assess Land Degradation at Multiple Scales

Current Status, Future Trends,
and Practical Considerations

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Preface

This report examines the scientific basis for the use of remotely sensed data, particularly the normalized difference vegetation index (NDVI), for the assessment of land degradation at different scales and for a range of applications, including resilience of agroecosystems. Evidence is drawn from a wide range of investigations, primarily from the scientific peer-reviewed literature but also non-journal sources. The literature review has been corroborated by interviews with leading specialists in the field (Chap. 7).

The use of continuous time series of global NDVI data, based on the NOAA AVHRR sensor, developed rapidly in the early 1990s. Since then, data processing and techniques for analyses of the data have improved significantly. Developments in data quality screening, geometric correction, calibration between sensors, atmospheric and solar zenith corrections, cloud screening, and data mosaicking have enabled the production of several databases of global NDVI data of high quality that are freely accessible over the Internet. The spatial resolution of these datasets ranges from coarse (8–1 km) to medium (250 m).

Even if there is no alternative to remotely sensed data for global- and continental-scale monitoring of vegetation dynamics, the technique is not without weaknesses. The report reviews the use of NDVI for a range of themes related to land degradation. Land-cover change, including deforestation, has been detected quantitatively even though the drivers are elusive (Sect. 3.1). Drought monitoring and early warning systems use NDVI data and have developed fully operational systems for data dissemination and analysis (Sect. 3.2). Desertification processes at the global, continental, and subcontinental scale have been studied intensively in the last two decades; a key finding is that most of the world's drylands show a trend of increasing NDVI. Interpretation of the causes and implications of that greening trend is still a matter of discussion (Sect. 3.3). Soil erosion has been studied at national and sub-national level, primarily using NDVI derived from data of medium to high spatial resolution, such as MODIS at 250 m and Landsat at 30 m resolution (Sect. 3.4). Salinization of soils has been studied using a wide range of remotely sensed data; however, its detection and monitoring is more experimental than for other forms of land degradation (Sect. 3.5). Monitoring of vegetation burning is a field

where NDVI has been widely used for three purposes: to assess the risk of fire in terms of fire-fuel load, detection and monitoring of fire, and mapping burned areas, as well as monitoring vegetation recovery after fire (Sect. 3.6). Soil carbon is an important indicator of land productivity that has been studied by means of NDVI (Sect. 3.7), both as a stand-alone measure and as input to ecosystem models. Studies have shown a high agreement between NDVI-based and ground-based estimates. NDVI has been used to facilitate mapping and monitoring of biodiversity loss, even though species composition cannot be assessed (Sect. 3.8).

Part of the Terms of Reference of the report was to assess the potential of NDVI for monitoring of agroecosystem resilience. Resilience is a concept with a broad range of definitions. In its original form, the ability to recover from disturbance or stress, ecosystem resilience can be assessed to a certain degree by combining NDVI with ancillary data, such as rainfall, often described as a hysteresis curve (Sect. 3.9).

Even if NDVI is by far the most commonly used vegetation index, other indices have been proposed and used for global-scale studies, such as two types of the Enhanced Vegetation Index (EVI). These indices are reviewed and compared with NDVI. The 3-band EVI is subject to certain technical problems, and the 2-band EVI is highly correlated with NDVI. Our conclusion that NDVI is the preferred index for operational monitoring is thus strengthened by the comparison (Sect. 2.3).

Interpretation of trends and patterns of NDVI data cannot automatically be interpreted in terms of land degradation and improvement. The report highlights a number of issues that must be considered for operational use of NDVI for land degradation monitoring (Chap. 4).

It is sometimes asserted that NDVI becomes saturated for dense vegetation (leaf area index >1). This is incorrect. The reason for the asymptotic relationship between NDVI and LAI is because all visible photons are absorbed at high LAI. In fact this confirms that NDVI represents photosynthetic capacity and primary production rather than LAI (Chap. 4).

Distinction between land degradation/improvement and the effects of climate variation is an important and contentious issue. There is no simple and straightforward way to disentangle these two effects. Rain-use efficiency (RUE), calculated by dividing NDVI by rainfall, is sometimes used to separate human action from natural variation. Even if theoretically sound, there are both technical and scientific problems with this approach. The technical problems are related to the mismatch of scale between climate data (most often point based) and NDVI (spatially continuous). Spatial interpolation of point observations is highly problematic, at least for short time periods. The scientific problems are concerned with the contextual relationship between vegetation and rainfall. The following rule of thumb may be applied: where vegetation dynamics are strongly driven by rainfall, i.e., in drylands, declining RUE is correlated with land degradation. In humid areas, where vegetation is not as strongly driven by variations in rainfall, NDVI in itself is strongly correlated with

vegetation dynamics and may be taken as a proxy for land degradation and improvement provided that potential false alarms are accounted for (Chap. 4, Sect. 5.2).

The accessibility and reliability of datasets is crucial for operational monitoring. The report reviews 14 of the most important datasets of NDVI and six climate databases that potentially can be used in combination with NDVI data. The most widely used, and also the most rigorously tested dataset is the GIMMS (Global Inventory for Mapping and Modeling Studies) and its most recent version the GIMMS3g. It comprises continuous data coverage from August 1981 to the present at 15-day intervals. It is the only dataset that is continuously updated with new data. The GIMMS3g is accessible free of charge over the Internet. Since 2000, NDVI data are available from both AVHRR (at 8-km resolution) and MODIS (1000–250-m resolution). Normally they are highly correlated, but we recommend the use of MODIS data as the benchmark (Chap. 8).

For monitoring at national, subnational, and project levels, the report recommends the use of nested approaches in which coarse-resolution data, such as AVHRR NDVI at 8-km resolution, are combined with other remotely sensed data that offer higher spatial resolution ranging from 0.5 to 250 m and better spectral and radiometric resolution. These data, calibrated against the long-term but coarse-resolution AVHRR database, can be used to elucidate reasons for changes in the coarse-resolution NDVI signal (such as forest destruction or other land-use change, habitat fragmentation, or soil erosion) and for national, subnational reporting, and project monitoring (Chap. 9).

A combined approach—analyzing spatial patterns and temporal trends in the coarse-resolution imagery, zooming in for greater detail using fine-resolution NDVI supplemented by systematic information on climate, terrain and land cover, and spot checks with very high-resolution commercial satellite imagery—can contribute to the assessment of agroecosystem resilience. Targeted research is needed to establish exact procedures for such applications (Chap. 9).

Although NDVI data are easily accessible and free of charge, successful monitoring of land degradation requires adequate technical, institutional, and skilled human resources. Such capacity, however, can probably be built effectively at existing regional and/or national centers (Chap. 10). With such capacity, NDVI can be used for cost-effective and reliable national reporting on several of the UNCCD core indicators (Sect. 11.1) and potentially also as input to a revised GEF resource allocation method, at least after some further testing on real data (Sect. 11.2).

To conclude, a substantial body of peer-reviewed research lends unequivocal support for the use of coarse-resolution time series of NDVI data for studying vegetation dynamics at global, continental, and subcontinental levels. There is compelling evidence that these data are highly correlated with biophysically meaningful vegetation characteristics such as photosynthetic capacity and primary production that are closely related to land degradation and to agroecosystem resilience. The

GIMMS3g dataset that now contains continuous data coverage since August 1981 is the most reliable, used, and cited database as well as the only database that is up to date, free of charge, and will be continued for the foreseeable future.

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Acronyms

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High-Resolution Radiometer
CIESIN	Center for International Earth Science Information Network
CRU	Climatic Research Unit, University of East Anglia
EUE	Energy-use efficiency
EVI	Enhanced Vegetation Index
FAO	Food and Agriculture Organization of the United Nations
FASIR	Fourier-Adjusted, Sensor and Solar zenith angle corrected, Interpolated, Reconstructed
GDP	Gross domestic product
GEF	Global Environment Facility
GIMMS	Global Inventory for Mapping and Modeling Studies
GLADA	Global assessment of land degradation and improvement
GOME-2	Global Ozone Monitoring Experiment-2
GOSAT	Greenhouse gases Observing SATellite
HANTS	Harmonic ANalysis of Time Series
IRS	Indian Remote Sensing
LADA	Land Degradation Assessment in Drylands
LAI	Leaf area index
LTD	Long-Term Data Record
LUE	Light-Use Efficiency
LULCC	Land-use and land-cover change
MERIS	MEDium-Resolution Imaging Spectrometer
MODIS	Moderate-Resolution Imaging Spectroradiometer
MVC	Maximum Value Composition
NASA	National Aeronautics and Space Administration
NDVI	Normalized difference vegetation index
NDWI	Normalized difference water index
NOAA	National Oceanic and Atmospheric Administration
NPP	Net primary productivity
PAL	Pathfinder AVHRR land

REDD	Reducing emissions from deforestation and forest degradation
RESTREND	Residual trend
RUE	Rain-use efficiency
RUSLE	Revised Universal Soil Loss Equation
SCIAMACHY	SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY
SLM	Sustainable land management
SOC	Soil organic carbon
SOTER	Soil and Terrain Database
SPOT-VGT	Satellite Pour l'Observation de la Terre—Végétation
STAP	Scientific and Technical Advisory Panel of the Global Environment Facility
STAR	System for Transparent Allocation of Resources
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
VASClmO	Variability Analyses of Surface Climate Observations