MONITORING DEGRADED ARID RANGELANDS WITH GIMMS NDVI3g DATA: A CASE STUDY OF THE WESTERN ALGERIAN STEPPE

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Abstract. While numerous studies have employed AVHRR GIMMS imagery to assess ecosystem dynamics in drylands worldwide, particularly in the Sahel, few have focused on North Africa, and even fewer have been validated with field observations. This study aims to address this gap by testing the hypothesis of concordance between NDVI3g time series and field-based data at a medium scale. Five georeferenced sampling campaigns (1987-2012) were conducted using a standardized protocol combining vegetation plot surveys, based on the aligned-points technique, with pedological surveys, enabling simultaneous assessment of vegetation cover, phytomass, and soil surface characteristics. Contrary to our hypothesis, antagonistic trends were observed, analysis of the NDVI3g data reveals a significant positive trend ($p < 0.0001$) with a low mean value (<0.17) and low temporal variability (coefficient of variation = 12), suggesting a greening dynamic. In contrast, field measurements indicate a decline in phytomass and plant cover, confirming previous studies on the Algerian steppe and attesting to a regressive dynamic. These discrepancies highlight the predominant influence of soil components. In these sparsely vegetated areas, the spectral response appears more strongly correlated with soil moisture and surface roughness than with chlorophyll content. While our findings provide new insights into the interpretation of NDVI3g in North African drylands, the limited number of field samples and the low temporal resolution of the dataset warrant further investigations to confirm these preliminary results.
Keywords: *drylands, dynamic, AVHRR, re-greening, trends*

Introduction

Long-term monitoring is crucial for a better understanding of dynamic ecosystems, especially those in arid zones. Approximately 70% of dryland areas are located in Africa and Asia (Mirzabaev et al., 2019). These ecosystems are prone to desertification, which is a form of land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including climatic variations and human activities (UNCED, 1992). Several studies have used remote sensing tools, primarily the NDVI (Normalized Difference Vegetation Index), to monitor the long-term evolution of ecosystems. The NDVI is a widely recognized vegetation index that provides a measure of canopy greenness and is related to the quantity of phytomass (Andela et al., 2013; Fensholt et al., 2013; Guo et al., 2022; Cao et al., 2023). Various global studies often based on remote-sensing data, particularly GIMMS NDVI have identified a re-greening trend, either at a global scale (Helldén and Tottrup, 2008) or specifically within the Sahel region (Olsson et al., 2005; Fensholt et al., 2013; Ogutu et al., 2021; Yang et al., 2022). However, very few have addressed this phenomenon in North Africa (Hirche et al., 2018).

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In Algeria, the largest country in Africa and one that encompasses a significant portion of the Sahara, arid rangelands are undergoing rapid dynamics, often in a regressive manner (Kadi-Hanifi, 2003; Bensaïd, 2006; Hourizi et al., 2017; Boudjemline and Semar, 2018; Alliouche and Kouba, 2023; Bouzekri et al., 2023; Kadri and Nasrallah, 2023). Their pivotal location makes them emblematic of North Africa as a whole, as these rangelands, found on the High Plateaus, are relatively uniform. To the west, they merge into the eastern Moroccan steppes, and to the east, they extend to the steppes of the Tunisian southern ridge.

Our study area is situated south of Oran and represents the most expansive steppes in Algeria. These steppes adjoin the Moroccan steppes to the west. Our previous research center, known as CRBT (Centre de Recherches sur les Ressources Biologiques et Terrestres), which was dedicated to the inventory and monitoring of natural resources, has been following these rangelands since 1975 (CRBT, 1978). Several field campaigns have been conducted up to the present day to track the evolution of these ecosystems (OSS/ROSELT, 2013; Hirche et al., 2011; Hourizi et al., 2017; Slimani and Aidoud, 2018). However, since the temporal sampling resolution and spatial extent of some campaigns were not fully satisfactory, we sought to compare the field data with remotely sensed data from the AVHRR GIMMS NDVI3g satellite dataset. Unfortunately, the GIMMS $NDVI_{3g}$ V_0 data ends stops in 2013, which constrained us to process only field data from the same period. These satellite data can serve as a proxy for field vegetation assessments, particularly its phytomass. This approach employs remote sensing and is related to vegetation indices, with the normalized difference vegetation index (NDVI) being the most universally applied.

While various satellites equipped with numerous sensors theoretically exist for such studies, in practice, monitoring vegetation via remote sensing can be challenging. This is because images from most satellites require correction for both geometric distortions and radiometric noise. Such issues are a particular challenge in diachronic studies.

However, AVHRR GIMMS data are among the most ancient images that circumvent these challenges, as they come with geometric and radiometric pre-processing. The $NDVI_{3g}$ GIMMS images represent a long-term NDVI time series, derived from Advanced Very High-Resolution Radiometer (AVHRR) instruments aboard various satellites operated by the National Oceanic and Atmospheric Administration (NOAA). Although they offer a coarse spatial resolution, their high temporal resolution makes them especially suitable for monitoring arid vegetation, which tends to be relatively uniform over vast areas, such as in the Sahel and in North African steppes. Numerous studies utilizing GIMMS NDVI images have been conducted worldwide (Helldén and Tottrup, 2008; Ibrahim et al., 2015; Burrell et al., 2020; Li et al., 2021). However, only a few have focused on Algeria (Hirche, 2018). This paper builds upon research on the evolution of NDVI using AVHRR GIMMS, particularly in the Sahel, and adopts methodologies similar to those employed by the DeSurvey project, where some authors conducted reference studies about desertification at global scale (Hellden and Tottrup, 2008). This methodology was detailed by Tottrup and Hellden (2007) in the DeSurvey project (A Surveillance System for Assessing and Monitoring Desertification), in which we were involved. According to these authors, the overall objective was to develop a simple, yet robust, standardized method for identifying areas where vegetation productivity or cover is consistently declining, which could indicate desertification, or conversely, increasing, indicating re-greening.

In this context, the primary objective of this study is to assess vegetation dynamics in the Algerian steppe between 1982 and 2013 by comparing NDVI3g time series with

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long-term field observations collected since 1975. More specifically, we address three research questions: (i) do NDVI3g trends reflect actual changes in phytomass and vegetation cover measured in the field? (ii) what discrepancies exist between remotely sensed indicators and field data? and (iii) which environmental or methodological factors help explain these discrepancies? By answering these questions, we aim to evaluate the reliability and limitations of NDVI3g as a proxy for vegetation monitoring in North African drylands.

Materials and methods

Study area

The study area is situated in the southern part of Oran, within the south-western High Plateaus of Algeria. This area consists of open rangelands and is located between 32° 30’ - 34° 50’ N latitude and 1° 44’ W - 2° 00’ E longitude (*Fig. 1*). The average altitude is around 1000 m a.s.l. The main landforms correspond to Quaternary polygenic glacis (Kadi-Hanifi, 2003).

Vegetation

The Algerian steppes belong to the Maghreb steppe floristic domain (Meddour, 2012). They were dominated by graminean grass steppes as alfa (*Stipa tenacissima L.*) and sparte (*Lygeum spartum L.*) which constitute mediocre pastoral value and very palatable chamaephytic steppes like white wormwood (*Artemisia herba-alba Asso.*) (CRBT, 1978; Nedjraoui and Bedrani, 2008; Slimani and Aidoud, 2018). Further south, there is dominance of the Remt steppes (*Hammada scoparia (Pomel) Iljin*) ensuring the transition with the Saharan vegetation (*Fig. 1*). Azonal formations are represented by psammophyts and halophyts with different forage values (Nedjraoui and Bedrani, 2008).

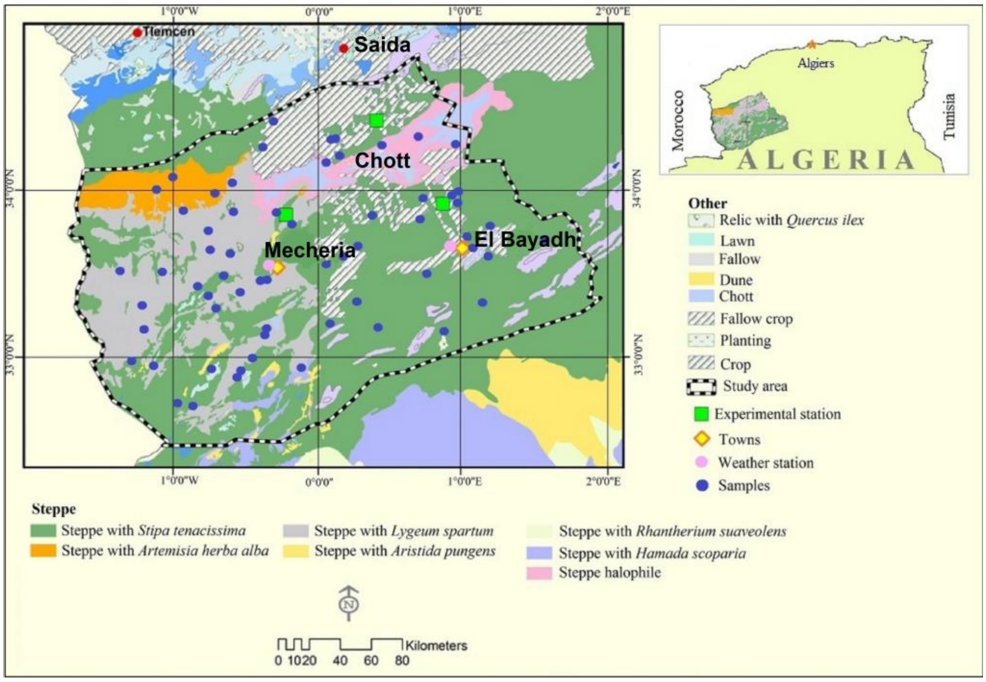

Figure 1. *General locating and landcover of the survey zone [1978]. Source: CRBT (1975), layout Salamani and Ait Hammouda (2024)*

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With regard to the steppe vegetation dynamics, several phytoecological and phytosociological studies hypothesized that the Algerian steppes were presumably colonized by forests (CRBT, 1978; Hirche et al., 2011; Djebaili, 1978; Slimani and Aidoud, 2018). Their gradual deterioration, led to degraded forests as matorrals then to the colonization of grass vegetation such as *Stipa tenacissima*, *Lygeum spartum* and *Artemisia herba-alba.*

Data and analysis methods

Climate data

To compare climatic variations with the $NDVI_{3g}$ time series, climatic data were collected and provided by the National Meteorological Office covering a period from 1975 to 2013 (ONM, Office National Météorologique, 2018). Note that very few weather stations exist in the current study area, Mecheria and El Bayadh stations.

The rainfall, a prominent parameter is low with averages ranging from 225 mm in Mecheria, the main station, to 266 mm in El Bayadh (a mountainous area surrounding the north-east). Its inter-annual distribution is irregular.

$NDVI_{3g}$ Data

The vegetation dynamic analysis is based on standardized vegetation index among which the oldest and most used is the “NDVI” proposed by Rouse et al. (1974). This index is a simple ratio between the red and near infra-red reflectance bands.

The values of NDVI range from −1.0 to +1.0, increasing positive NDVI values indicate increasing amounts of green vegetation. NDVI values close to zero and decreasing negative values indicate non vegetated features such as barren surfaces (rock and soil) and water, snow, ice and clouds. The formula is (Rouse et al., 1974):

$$NDVI = \frac{NIR-RED}{NIR+RED} \qquad \text{(Eq.1)}$$

where: RED and NIR stand for the spectral reflectance measurements acquired in the visible (red) and near-infrared regions respectively.

In this study, the GIMMS $NDVI_{3g}$ images were used. They are a long-term time series of NDVI, derived from Advanced Very High-Resolution Radiometer « AVHRR » instruments (sensor 7, 9, 11, 14, 16, 17, 18 and 19) from various satellites operated by the National Oceanic and Atmospheric Administration « NOAA ». The GIMMS NDVI3g dataset represents a globally standardized vegetation index, specifically designed for long-term vegetation monitoring. This dataset provides bi-monthly composite values at 8 km spatial resolution, offering one of the most extensive temporal records available for studying vegetation dynamics across multiple decades. The GIMMS $NDVI_{3g}$ images (version $NDVI_{3g}$ V0) were downloaded from Global Land Cover Facility https://ecocast.arc.nasa.gov/data/pub/gimms/3g.v0/ and correspond to NOAA Global Inventory Modeling and Mapping Studies (GIMMS)

The GIMMS images cover a large part of the globe, requiring an initial extraction of a subset corresponding to the study area. $NDVI_{3g}$ statistics were computed for each image across all dates, resulting in a total of 768 bi-weekly images spanning the period from 1982 to 2013. To enable comparison with field data, annual mean NDVI values were standardized as z-scores over the study period, according to the following formulation:

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$$z_i = \frac{NDVI3g_i - NDVI3g_{mean}}{NDVI3g_{std}} \quad \text{(Eq.2)}$$

where $NDVI_{3gi}$ is the mean value obtained for year i, $NDVI_{3gmean}$ and $NDVI_{3gstd}$ are respectively the mean and standard deviation of all the yearly means available for the period.

Vegetation and soil sampling

Ecological field data for this study were extracted from historical records collected since 1975 and were carried out by the former Terrestrial and Biological Resources Research Center [CRBT], which became integrated into our university as Plant Ecology and Environment Laboratory [LEVE/USTHB]. A fundamental feature of these data is that all sampling campaigns were conducted according to the same standardized protocol, which guarantees that the results are directly comparable across different years of observation. This methodological consistency was deliberately maintained to ensure that the trends reflect real ecological changes rather than variations in sampling practices.

Each plot was carefully chosen not only for its ecological representativity but also for its ease of relocation in the field. Geographical coordinates were established with high precision, and locations were selected so that researchers could consistently identify and revisit them over time. This dual focus—representativity and accessibility—helped ensure the robustness of long-term monitoring. The purpose of georeferencing was to minimize spatial variation in order to take into account only temporal variation.

This irregularity was due mainly to logistical and financial constraints. Nevertheless, all the campaigns included in this study applied exactly the same protocols, making them methodologically homogeneous. only datasets meeting these strict conditions were retained for analysis. On this basis, five complete campaigns with 75 plots assessing phytomass by direct method were used in this study. The inventories were established in 1987–1988, 1994–1995, 2001–2002, 2006–2007 and 2010–2011. Although the temporal spacing between campaigns represents a limitation, the long observation provides a valuable dataset for identifying medium-term ecological dynamics.

The plot sampling method was related to the “mixed sampling” developed by Gounot (Gounot, 1969) which uses all sources of information:

- Vegetation cover was measured using the aligned points technique (points-intercept method), itself an adaptation of the quadrat point method (Gounot, 1969). A graduated line of at least 20 m in length with a 10 cm mesh was deployed, and point recording continued until 100 vegetation contacts had been documented. To frame the observation area, a cord was used to delimit a rectangular plot with the quadrat line at its center.
- Plant biomass (phytomass) was quantified on areas corresponding to the minimum sampling unit, which varied depending on the degree of land degradation. In relatively dense vegetation, an area of 32 m^2 was sufficient, while in more degraded rangelands the sampled surface was extended to 128 m^2 (OSS/ROSELT, 2013; CRBT, 1978). Perennial and annual species were harvested separately in order to distinguish between functional groups.
- Soil characteristics were also documented for each plot. Surface features such as the percentage of sand cover were recorded systematically. Soil moisture was estimated using the gravimetric method, which consists of collecting samples with an auger at two depth intervals (0–20 cm and 20–40 cm) along a vertical profile.

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With respect to soil properties, texture was considered the key parameter. Following Pouget (1980), texture was defined as the combined percentage of clay and fine silt (A + LF %). Along with organic matter content, this factor determines the soil's water retention capacity and wilting point, and thus conditions the soil water profile. These measurements were consistently integrated with vegetation data, thereby providing a holistic view of the ecological dynamics of the monitored rangelands.

Statistical analysis

Linear regression using the least squares method

This analysis examines potential relationship between two variables; with one ($NDVI_{3g}$) as the dependent variable and the other independent (phytomass, rainfall…). The method is based on parametric statistics and the regression is established using the least squares method.

However, this method being parametric, it notably requires adjustment to a normal distribution and verification of homoscedasticity. It also suffers from the problem of outliers and autocorrelation. Its interest is above all to compare the results of the slopes obtained by the two methods (least squares and S_{en} slope).

Mann Kendall Test

The non-parametric Mann-Kendall test (Mann, 1945; Kendall, 1975) was applied to detect monotonic trends in time series data. This widely used method offers the advantage of not requiring normality assumptions for the data and being robust against outliers. The calculation of the S statistic and its variance enables assessment of significant trends under the null hypothesis of no trend (Kendall, 1975). In parallel, Sen's method (1968) was applied to estimate trend magnitude through median slope calculation, thus providing a robust alternative to least squares estimators (Sen, 1968).

Results

$NDVI_{3g}$ trend

The statistics of each $NDVI_{3g}$ image, pixel averages, show that the NDVI values are globally very low (*Table 1*), as well probably as vegetation cover.

Table 1. *Descriptive statistics of the NDVI3g dataset*

Setting	Value
Average	0.13896651
Standard deviation	0.01686501
Coefficient of variation	12.1360246
Number of scenes	768
Number of pixels	1260

Moreover, the coefficient of variation is also low (12%) underlying a weak dynamic between images.

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The Mann Kendall Test (*Table 2*) highlights the existence of a trend (*p*-value is less than 0.0001) and H_0 is rejected. The S_{en} slope shows a positive trend. Note that seasonality (Bimonthly data, Period = 24) and the possible autocorrelation were taken into account.

Table 2. *Statistical results of Mann Kendall Test*

Test	Kendall Tau	*p*-value	S_{en} slope	S	Var S
$NDVI_{3g}$	0.263	< 0.0001	0.00046	3129.000	536855.333

Continuity correction has been applied

Given that the calculated *p*-value is lower than the significance level alpha=0.05, we must reject the null hypothesis, and retain the alternative hypothesis H_a. These results underline the existence of positive trend in the $NDVI_{3g}$. This trend is very significative as the *p*-value is very low and the value of the statistic S is high (3129).

Evolution of $NDVI_{3g}$ by linear regression

Time series of $NDVI_{3g}$ for selected area over the period from 1982 to 2013 is presented in *Figure 2*. The $NDVI_{3g}$ evolution computed for each year shows a clear increasing trend for the study area in general, values ranging from more 0.12 to 0.16.

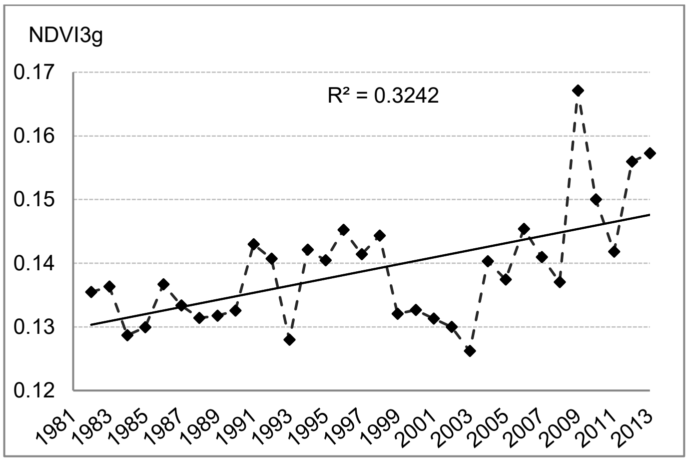

Figure 2. *Annual NDVI3g evolution in study area since 1982*

The regression line equation is:

$$NDVI_{3g} = 0.00056 \text{ years} - 0.97342$$

The coefficient of determination equal to: $R^2 = 0.324$ (*Fig. 2*); The NDVI variability is probably caused by other variables that also changes through time (e.g. precipitation, soil moisture) (*Table 3*).

In conclusion, while statistical analysis confirmed a robust positive trend in the NDVI3g time series ($p < 0.0001$), its limited magnitude (Sen's slope = 0.00046) and moderate explanatory power ($R^2 = 0.324$) underscore that other environmental factors significantly contribute to the spectral response of $NDVI_{3g}$.

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Table 3. *Statistical results of the regression line*

Source	DF	Sum of squares	Mean squares	F	Pr> F
Model	1	0.001	0.001	14.394	0.001
Error	30	0.002	0.000		
Corrected	31	0.003			

NDVI$_{3g}$ drivers

Phytomass and vegetation cover vs NDVI$_{3g}$

The comparison between the evolution of NDVI$_{3g}$ and phytomass (plant biomass) expressed in standard values shows (*Fig. 3*), an overall accordance between NDVI$_{3g}$ and phytomass in the first period, characterized by quite important vegetation cover and phytomass. After 1995, it appears a regular decrease in values, until the 2000s.

After the beginning of the 2000's, considered as a very dry period we note a rain recovery. The NDVI$_{3g}$ is increasing, clearly, but more slowly between the years 2007 and 2011. This increase is largely due to an exceptional rainfall in 2008. But surprisingly, since 2011, there is a separate dynamic between phytomass the NDVI$_{3g}$. Even after a favorable rainy period, the phytomass stabilizes more or less, with a very slight increase since the NDVI$_{3g}$ increases very clearly. The vegetation was so degraded that even after a rain recovery, it cannot grow (recover) quickly. We are probably close to a threshold of vegetation detection.

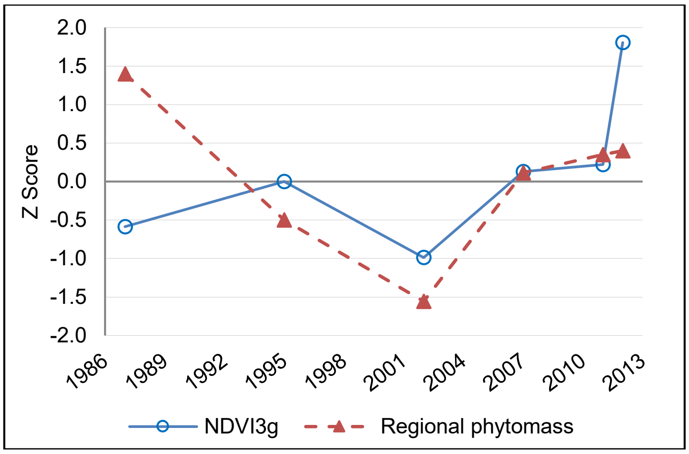

Figure 3. *Evolution of the NDVI3g and the phytomass*

The regression line equation is:

$$y = -0.1207x - 0.8094$$

$r^2 = 0.1521$ (r threshold = 0.34).

The regression line also shows that there's weak relationship between NDVI$_{3g}$ and Phytomass. Overall, the vegetation dynamic is going towards degradation trend, even if following the important rainfall of 2008, we observe an apparently slow recovery which would be discussed, while the NDVI$_{3g}$ shows a clear global positive trend (*Fig. 2*).

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Comparative curves of $NDVI_{3g}$ and vegetation cover generally do not show good agreement (*Table 4*). In 1987, despite average vegetation cover, NDVI was low. Conversely, in 2011, vegetation cover remained low while NDVI showed a significant increase.

Table 4. *Vegetation cover and phytomass measurements in the study area*

Year	Vegetation cover %	Phytomass dry matter per hectare (kg DM ha^{-1})
1987	28.7±11.7	600± 305
1995	21.9.2±7.4	421± 282
2002	10.5±3.4	327± 227
2007	11.8±3.6	391± 275
2011	16.1±5.3	503± 199

Both of these factors have a strong effect on the spectral response (Girard and Girard, 2010). So, for examining the validity of the hypothesis, it is necessary to study the rainfall and the sand evolution in the next sections.

$NDVI_{3g}$ and rainfall

Among the $NDVI_{3g}$ drivers, one of the most prominent is the rainfall. The $NDVI_{3g}$ values as proxy for plant biomass (phytomass) are compared with annual rainfall ones for the whole area. The results show a very low correlation and coefficient of determination (R^2=0.041) and the *p*-value is > 0.265.

However, if we shift the rainfall by one year, therefore testing $NDVI_{3g}$ against rainfall of the preceding year, the correlation increases very clearly (R^2= 0.40; r =0.63) (*Fig. 4*). It suggests that rainfall impact is delayed for the next year, depending on water reserve.

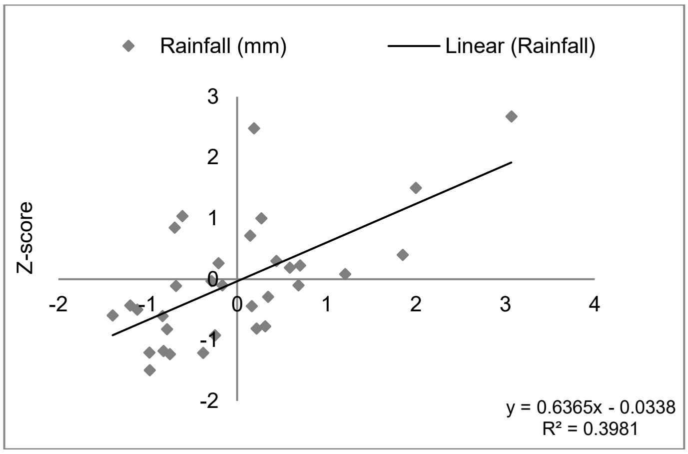

Figure 4. *Correlation between NDVI3g data and rainfall*

The *p*-value is inferior to 0.01. Hence, the null hypothesis is rejected, and it appears that the rainfall quantity influences the $NDVI_{3g}$ amounts. The equation is:

$$NDVI_{3g} = 0,6365\,R - 0,0338$$

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If we study both evolution of $NDVI_{3g}$ and rainfall, we observe an agreement between the two curves (*Fig. 5*), even if their superposition is not perfect, the $NDVI_{3g}$ seems to lag with respect to rainfall as suggested by the above correlation. The huge last NDVI increase was due to an outstanding 2008 rainy year.

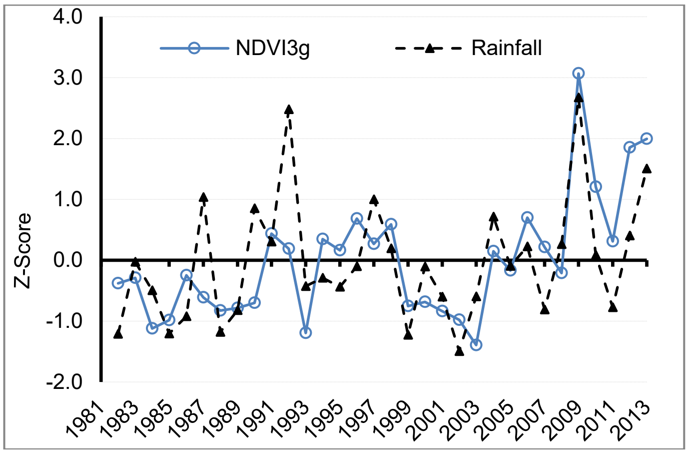

Figure 5. *Compared evolution of $NDVI_{3g}$ and rainfall at station averaged (shifted)*

Sand cover dynamic

The sand cover dynamic illustrates that $NDVI_{3g}$ and sand cover (expressed in %) evolves nearly in opposition of phase. In drought years, the sandy soils of the regions are subjected to deflation and generate autochthonous sands (Grandi et al., 2017) particularly after a succession of drought periods. When sand cover increases, the NDVI decreases (*Fig. 6*). This is clearly apparent at the end of the 1987 and 2000s which corresponds to an intense dry period. The sand rate was already high in 1987, with 38%, while it reached 45% in places in 2002. In 2012, part of the sand migrated or has been consolidated and the sand rate is at its lowest level (21%).

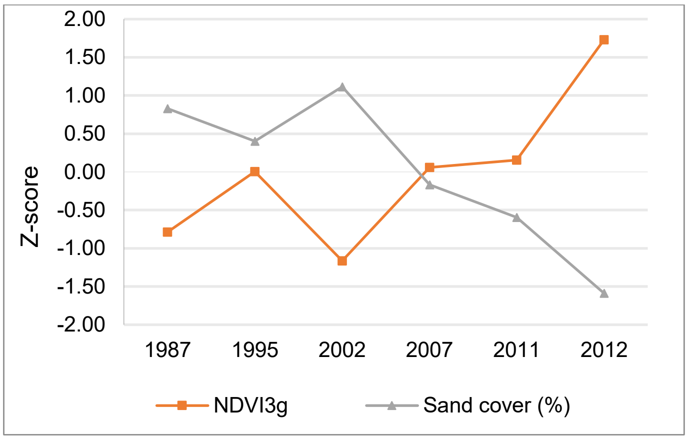

Figure 6. *Dynamic of sand cover (%) and NDVI3g data since 1982*

In a wetted period, it is the contrary. The sand production decreases, the soil is more humid and the $NDVI_{3g}$ spectral response is rising.

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Soils and relative humidity

The evolution of the averaged relative humidity in the soil and the NDVI (*Fig. 7*) show a correspondence between them. The humidity has a minimum in 1987 and reaches almost 29% in 2011.

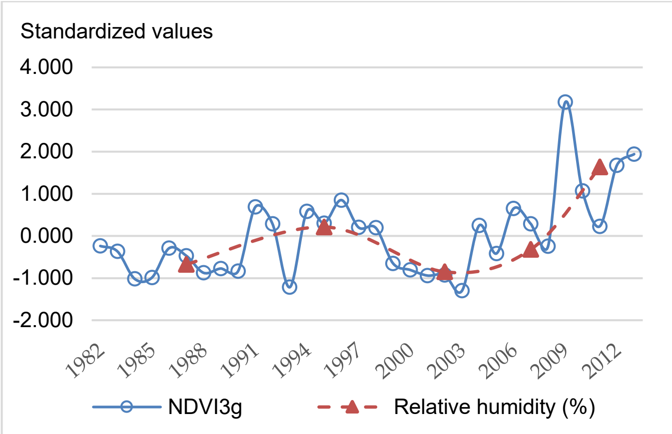

Figure 7. *Evolution of relative humidity and NDVI3g*

Table 5 shows that the sand soils are frequent. They represent 44% for the coarse and very coarse texture, and reach 86% if we add the medium texture that comprises sandy loamy soils.

Table 5. *Distribution of soil texture in the study area*

A+LF % code	Texture	Correspondence	%
<5	Very coarse textured soils	Dune sands	9
5≤X<20	coarse textured soils	Aeolian deposits more or less fixed	35
20≤X<40	Medium texture	Loamy to sandy loam soils	42
40≤X<70	Fine texture	Alluvial Formations	11
≥70	Very fine texture	Vertisols, daya	4

Discussion

Concerning the results of the NDVI trends, they seem to be in accordance with the few works using diachronic studies carried out on a larger scale and using GIMMS NDVI3g images such us those established by Lacaze et al. (2003) which found a positive trend in the whole Mediterranean area. Hirche et al. (2018) compared the NDVI3g trends of courses in North Africa and the Sahel and also found a positive trend. Tottrup and Hellden found a negative trend until 2003, following several drought years. These findings are generally in accordance with several authors who have found a re-greening also in Africa and especially in the Sahel (Fensholt et al., 2013, 2017; Anyamba et al., 2014; Brandt et al., 2014; Dardel et al., 2014; Kusserow, 2017; Tong et al., 2017; Zida et al., 2020; Wu et al., 2022; Jiang et al., 2023).

Unlike the trends shown by NDVI3g, whatever the spatial and temporal scale, several studies have shown a continuous degradation of phytomass, (Oukil et al., 2020; Kadi-Hanifi, 2003; Aïdoud et al., 2006; Nedjraoui and Bedrani, 2008; Slimani et al., 2010;

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Hirche et al., 2013; Amghar et al., 2016; Hourizi et al., 2017; Grandi et al., 2017; Belala et al., 2018). In North Africa, results show overall a trend of degradation (Escadafal et al., 2005). Del Barrio et al. (2016) studying trends in the dry areas of northwestern Maghreb, found its semi-arid areas to be particularly threatened.

About phytomass trend, whatever the spatio-temporal scales and the arid region considered, almost all field studies in Algeria and even in North Africa underpin a clear degradation trend showing phytomass decrease (often linked with sand cover increase), whether in Algeria (Aidoud, 1983; Kadi-Hanifi, 2003; Nedjraoui and Bedrani, 2008; Hirche et al., 2011; Bensenane et al., 2015; Hourizi et al., 2017; Slimani and Aidoud, 2018), in Tunisia (Hanafi and Jauffret, 2008; Gamoun et al., 2010) and in Morocco (Bechchari, 2020). The exceptional rainy years of 2008, have favorable effects on rangelands but this positive result will not be sustainable. The vegetation cover is still low around 16-17% compared to the 28% of 1987, and the phytomass remain at around 500 kg DM ha^{-1} after rainy years when it had only reached 300 kg DM ha^{-1} in dry years. So, why do the values of the spectral data show a clear positive trend? The hypothesis is that rainfall recovery leads to a wet soil that stabilizes soils, particularly the “biological crust” or “biological soil crust» that transform and reduces sandy veil, as has already been underlined by several authors (Floret et Pontanier, 1982; Aidoud-Lounis et al., 1999; Rognon, 2007). This biological crust would ultimately reduce the reflectance. These favorable conditions also imply that the production of sand is reduced which increases correlatively the roughness.

It is interesting to underline that *Figure 3* illustrates that the NDVI is not always linked to the vegetation biomass. In these degraded areas, the sand is not stopped, due to very scattered tufts, and therefore the roughness of the soil is greater. This explains that interpretation is complex because it results from a dynamic balance between the elements tending to reduce the reflectance such as vegetation, roughness and humidity, and others tending to increase it such as the low plant cover, salt efflorescence, increased limescale levels or sand rates. At these low vegetation cover rates, The NDVI3g value seems more related to the soil moisture than vegetation components.

The results reveal that the NDVI and the spectral response of vegetation cover in Algerian’s arid and semi-arid rangelands, seems to be more related to different elements of the soil surface than to the phytomass. Indeed, the low phytomass and vegetation cover linked to an insufficient chlorophyll rate is the first explanation for the inadequate spectral response observed. Several authors already stipulate that below 30-20% of the vegetation cover, the spectral response will not depend mainly on chlorophyll but on soil components such as roughness, organic matter rate, moisture, limestone and gypsum rate. Tucker and Choudhury (1987) found that NDVI was not sensitive below 20% green leaf ground cover in arid areas. Geerken et al. (1998) estimates that a threshold of 30% vegetation cover could be proposed.

The comparison between vegetation cover and vegetation index, at the regional scale, also shows a similar trend. Vegetation cover does not seem to be the main factor because its values have always been low, around or below 30% since 1978 (before 1982!), a putative threshold for detection, and since 1987 it has even been below 20%. It appears that the main component involved in the spectral response is the soil. Thus, vegetation seems to play a role of a soil surface element among others. At low level, it influences the spectral response more by its roughness than by its chlorophyll.

The role of rainfall was also highlighted. The rangelands were particularly green in 2008 and 2012, but this re-greening was mainly due to the exceptional humid conditions,

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to the rise of roughness following the sand diminution, and also to the contribution of annual plants which respond quickly to heavy rainfall. Perennial vegetation has increased its phytomass, but relatively less (OSS/ROSELT, 2013; Hirche et al., 2013; Belala et al., 2018).

The vegetation index and rainfall kinetics show that the curves have more or less the same general shape (*Fig. 5*), That confirms the important role of rainfall in arid areas which seems to influence clearly, but not exclusively the vegetation spectral response (Wessels et al., 2012; De Jong et al., 2013). The rainfall seems to be more correlated with NDVI3g than phytomass. This correlation can be explained by the fact that moist soil strongly absorbs infrared radiation, producing a spectral signal similar to that of vegetation.

However, the temporal resolution of the field data was low, with only five sampling campaigns between 1987 and 2012. This important limitation means that NDVI3g results must be interpreted with caution. While the index is operational and robust in more humid contexts such as the Algerian Tell, it becomes increasingly unreliable in arid environments and even more in Saharan ecosystems. Consequently, these findings should be regarded as preliminary and require confirmation through future studies integrating denser ground observations, alternative vegetation indices, and improved methods for disentangling soil and vegetation signals.

Conclusion

It emerges from this study that the NDVI3g trends show a positive evolution, while most field studies underline a degradation trend. It also appears that there is no strong consistency between the field data and the remote sensing data. The main explanation lies in the very low vegetation cover, and NDVI3g does not always seem suitable to detect vegetation evolution in North African arid zones with sparse plant cover. Monitoring vegetation is possible when cover and phytomass are relatively high, as demonstrated during the first period of observation. As described by several authors, this is also likely the case in other arid regions such as Sahelian zones, where vegetation cover during wet years is much higher. In North Africa, the threshold required to correctly detect vegetation appears to be between 25–30% cover. In such conditions, the main component of the spectral response becomes more related to soil properties than to vegetation. Soil moisture and soil surface texture (sand content, roughness) are directly linked to the reflectance signal, while other parameters such as organic matter and limestone content—although not considered in this study—may also play a role and deserve future investigation.

However, the temporal resolution of the field data was low, with only five sampling campaigns between 1987 and 2012. This low frequency does not adequately match the continuous temporal coverage of satellite observations, making comparisons difficult. Additionally, the number of field samples is limited because of the strict requirement for precise geolocation; only a restricted subset of the collected data fulfilled this criterion, which inevitably reduces the representativeness of the ground observations. Third, the NDVI index itself, although widely used, is known to perform best in regions with relatively dense vegetation. Its use becomes increasingly problematic in arid zones, where vegetation is extremely sparse and soil background effects dominate the spectral response.

For all these reasons, the present work should be regarded as preliminary. The results highlight important discrepancies between NDVI3g trends and field-based evidence of

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degradation, but they need to be consolidated by further studies with higher temporal resolution, a larger number of ground-truthed samples, and complementary spectral indices that may be more robust in arid and desert conditions. Only through such additional efforts can the conclusions drawn here be fully validated and generalized.

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