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Environmental change in the Sahel: reconciling contrasting evidence and interpretations

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Abstract The Sahel has been the object of intensive international research since the drought of the early 1970s. A considerable part of the research has focused on environmental change in general and land degradation, land cover change and climate change in particular. Rich and diverse insights from many different scientific disciplines about these three domains have been put forward. One intriguing feature is that an agreement on the overall trends of environmental change does not appear to emerge: questions such as whether the Sahel is greening, cropland is encroaching on rangelands, drought persists remain contested in the scientific literature, and arguments are supported by contrasting empirical evidence. The paper explores the generic reasons behind this situation in a systematic manner. We distinguish between divergences in interpretations emerging from (1) conceptualizations, definitions and choice of indicators, (2) biases, for example, related to selection of study sites, methodological choices, measurement accuracy, perceptions among interlocutors, and selection of temporal and spatial scales of analysis. The analysis of the root causes for different interpretations suggests that differences in findings could often be considered as complementary insights rather than mutually exclusive. This will have implications for the ways in which scientific results can be expected to support regional environmental policies and contribute to knowledge production.

Keywords Scientific controversies · Land degradation · Land use · Climate change · Scale · Bias

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Introduction

In the wake of the drought in the early 1970s in the Sahel region, the UN spurred an intensive interest in the issue of dryland degradation/desertification, most prominently marked by the UN Conference on Desertification in 1977, followed by the UN Convention to Combat Desertification (emerging from the Rio-conference in 1992). This fuelled a significant increase in the scientific efforts to provide an empirically supported understanding of both climatic and anthropogenic factors involved, as well as a surge of, often alarmist, popular accounts of desertification.

The Sahel region (here understood as the zone with between 150 and 700 mm of mean annual rainfall) was

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early portrayed as an example of complex human–environment interactions (e.g. Picardi 1974). On the one hand, the environmental constraints, such as highly erratic rainfall and poor soil quality, limit the potential for agricultural and pastoral production, which has been and still is an important backbone in the local livelihood portfolio. On the other hand, land use practices have been tuned to cope with and adapt to the environmental constraints. The linkages between the biophysical and human subsystems sometimes take the form of positive feedbacks: soil degradation due to 'overcultivation' may be expected to trigger expansion of cropland in order to compensate for low yields, which in turn will cause accelerated soil degradation in the newly included marginal land (Greenland et al. 1994). Such unsustainable trajectories have been proposed to represent the archetype of a 'Sahel syndrome' (Schellnhuber et al. 1997; Lüdeke et al. 2004). Although these narratives have been challenged by several scholars (e.g. Mortimore and Turner 2005; Niemeyer and Mazzucato 2002), the narrative of a vicious cycle of land degradation has remained dominant and mostly unchallenged in the environmental policy documents for decades (Speirs and Marcussen 1999; Reenberg 2013).

Despite decades of intensive research on human–environmental systems in the Sahel, we find a range of conflicting observations and interpretations of the environmental conditions in the region and the direction of changes. The disputes have evolved around especially the three themes 'land degradation/desertification', 'land use and land cover change' and 'climate change and variation'.

The issue of land degradation has received a lot of attention since 70s. Research was in many cases mono-disciplinary, in other cases interdisciplinary. Meta-studies were carried out to synthesize existing knowledge (e.g. Geist 2005; Geist and Lambin 2004), while a specific class of studies relied on Earth observation (EO), in particular time series of satellite data. These aimed to detect changes in primary productivity and whether or not the Sahel had been 'greening' (Anyamba and Tucker 2005; Eklundh and Olsson 2003; Fensholt et al. 2012; Herrmann et al. 2005; Heumann et al. 2007; Olsson et al. 2005). The findings on the greening of the Sahel often appear to be in sharp contrast to other studies of land degradation.

As concerns 'land use and land cover change', the claim that crop production was expanding into marginal land was early considered an established truth and has played a key role in the above-mentioned idea of a 'Sahel syndrome'. It is supported by the assumption of a necessary link between cropland expansion and population growth (e.g. Bilsborrow and Ogendo 1992). Such a correlation has been demonstrated in empirical case studies, not least in the less dry parts of the Sahel (e.g. Hansen and Reenberg 1998). Recent material, however, strongly indicates that cropland development is far from being related in a simple manner to population pressure (e.g. Rasmussen and Reenberg 2012; Reenberg 2009), and meta-studies reveal the diversity of causes put forward to explain cropland changes in Sahelian environments (van Vliet et al. 2013; D'haen et al. 2013).

As concerns the issue of climate change/variability, much writing seems to be based on the assumption that drought is an inescapable fate of the Sahel, and that climate change is a major challenge to livelihoods, food security and agricultural production. In contrast to this, other studies see climate change as only one among many constraining conditions for agriculture in the Sahel (Nielsen and Reenberg 2010), and/or point to the possibility that rainfall may actually increase, at least in the central parts, allowing (and requiring) quite different adaptation strategies (Mertz et al. 2011). In relation to this, there has been a long-standing and still continuing debate on the 'Charney-hypothesis' (Charney 1975), attributing the Sahel drought to a biogeophysical feedback, in which overgrazing may play an important role.

Thus, with respect to all three broad themes, conflicting evidence and interpretations are presented in the literature, which obviously raises the question: Why is it so difficult for the scientific community to agree on the environmental changes taking place in the Sahel? This paper explores such conflicting evidence and interpretations of Sahelian environmental change by

1. Providing a general overview of possible generic sources of contrasting evidence
2. Discussing whether the apparent contradictions are 'real' or if the contrasting evidence may be considered complementary and gives a better understanding of environmental change in the Sahel.

Sources of apparently diverging findings

Inconsistencies of concepts

Key concepts in the literature on environmental change in the Sahel are not always defined and used in a consistent manner. Disagreements may in some cases be traced back to inconsistencies of this sort.

Land degradation

Contrasting evidence has indeed been visible within the theme of land degradation. The massive number of studies showing or assuming that land degradation is ongoing in the Sahel, summarized in meta-studies and summaries, such as (Geist 2005; Geist and Lambin 2004), stands out in sharp contrast to a substantial, yet still much smaller, number of studies, demonstrating that since 1981, the Sahel has been characterized by a 'greening' trend (Anyamba and Tucker 2005; Eklundh and Olsson 2003; Fensholt et al. 2012; Fensholt et al. 2013; Herrmann et al. 2005; Heumann et al. 2007; Olsson et al. 2005). Both categories of studies go further from observing land degradation to explaining them, by reference to a long range of explanatory variables and models. The question to be discussed here is whether the contrasting evidence finds some of its explanation at the conceptual level: Are there conceptual incongruences between these two categories of studies that result in the different findings? We argue that this is the case, and that the confusion lies in the definitions of land degradation used, and in the widely different interpretations of these definitions found in the individual studies. This can be illustrated by the choice of 'indicators' of land degradation selected in each study.

Many different definitions of desertification/land degradation have been proposed and used. The closest we get to a common standard is the current definition suggested by the United Nations Convention to Combat Desertification (UNCCD, (www.unccd.int)) in which desertification is equated with land degradation in drylands:

> Desertification means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities.
> Land degradation means reduction or loss, in arid, semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands…

For operational use, the definition must be translated into a 'measurement protocol', assuring that research produces results that allow comparison. The definition cited points to several indicators, e.g. biological productivity, economic productivity and ecosystem complexity. This is not necessarily problematic, but some of these are difficult to measure in ways assuring comparability. The conceptually simplest one, biological productivity, is actually very difficult to estimate in situ for any sizeable area, while EO does offer such possibilities. Economic productivity, on the other hand, may be easier to estimate in situ, whereas EO techniques are of limited use. Finally, ecosystem complexity may be difficult to define and measure, and indicators may vary greatly between studies. Indicators representing these three components of land degradation are not necessarily correlated: there are numerous cases where an increase in biological productivity is accompanied with decreases in economic productivity and/or ecosystem complexity (Herrmann and Tappan 2013). One example is conversion of semi-natural savannah grasslands into cultivated land. This will probably increase economic productivity yet decrease ecosystem complexity, while effects on biological productivity may be positive or negative. For these reasons, it is not surprising that studies of land degradation, whether based on in situ observations or satellite image analysis, show incomparable and/or inconsistent results.

It is, however, not fair to claim that most inconsistencies are caused by the ambiguities of the UNCCD definition on land degradation. Many empirical studies of land degradation go beyond this to develop radically different operational definitions. In the meta-study of 132 case studies by Geist (2005), the choices of land degradation indicators (most of which are in situ studies) are summarized. This useful exercise demonstrates that the land degradation indicators used include many that do not conform to the UNCCD definition. As concerns the EO-based studies, those aiming at identifying long-term trends on the basis of time series of coarse resolution data can be divided into two main groups: one uses indicators of biological productivity, such as the 'normalized difference vegetation index' (NDVI), while the other associates land degradation with changes in 'rain use efficiency' (RUE) (see e.g. Fensholt and Rasmussen 2011; Prince et al. 2007). The latter group attempts to eliminate the effect of rainfall change (by a 'normalization' procedure) on biological productivity in order to isolate the impact of non-rainfall-related changes, e.g. human impacts. The results of these two groups are not easily comparable. Confusion obviously arises, when studies of NDVI trends explain these trends by rainfall change (Fensholt et al. 2012), while studies of RUE trends for the same area and period and based on the same EO data by definition point to non-rainfall explanations. This contradiction is only a product of the indicators used, not a real case of contrasting evidence.

The concepts of land cover and land use

The literature on land cover and land use change in the Sahel displays numerous examples of contrasting evidence. Most evident are the contrasting trends in the cultivated area, ranging from claims that the cultivated area expands in parallel with rapid population growth (see e.g. Gray 1999; Leblanc et al. 2008; Paré et al. 2008) to reports of stable (Tappan and McGahuey 2007; Mazzucato and Niemeijer 2002), and in some cases, even declining cultivated areas (Rasmussen and Reenberg 2012). Despite these contrasting stories of cropland change, only the claim of a rapidly expanding cultivated area caused by the increasing food demands of a growing population has found its way into the generic descriptions of 'Sahel syndromes' of land degradation and environmental change provided by e.g. Geist (2005), Schellnhuber et al. (1997) and Lüdeke et al. (2004).

One reason for these different stories of land use and land cover change may be that the conceptual meanings of the terms land use and land cover adopted in the studies differ. The studies build on various sources of information including in situ measurements at village level, as well as high (IKONOS, QuickBird etc.), medium (Landsat, SPOT, ASTER) and coarse (NOAA AVHRR, SPOT Vegetation, MODIS etc.) resolution satellite images and combinations of these.

The term land cover has most widely been used and defined as the surface cover on the ground, such as millet fields or forest. The remote sensing research community has played a key role in land cover change detection. On the contrary, land use has traditionally been a concern primarily of social scientists, such as economists, human geographers, anthropologists and planners as land use refers to the activities undertaken on the land and the purpose the land serves. Although the two terms denote areas of study that have historically been separate, a tendency to use the two terms interchangeably is observed (Turner and Meyer 1994). Land cover change detection carried out by remote sensing specialists have, for example, been confused with land use despite the fact that land use and land use change mapping assessments through remote sensing techniques still remain a major challenge (Martinez and Mollicone 2012). The confusion can be illustrated by comparing the studies of Paré et al. (2008) and Rasmussen and Reenberg (2012) which both analyse changes in cropland area. While Paré et al. (2008) refer to their analysis as a land use change analysis, Rasmussen and Reenberg (2012) refer to their study as a land cover analysis even though the two studies are based on the same sources of information (satellite images and aerial photos). Possibly as a consequence of using land use instead of land cover, Paré et al. (2008) include both fallow areas and currently cultivated areas in their definition of cropland, and they then arrive at an increasing cropland area. In contrast, Rasmussen and Reenberg (2012) do not include fallow areas in the land cover class of croplands, and they observe a decreasing trend. This insight points to the fact that the two studies are actually not directly comparable and they should therefore not be perceived as conflicting. Further, it becomes clear how different conceptual meanings have given rise to contradicting observations on land use and land cover change.

Disciplinary bias

In his meta-study of land degradation, Geist (2005) relates the causal complexes, identified in each case study, to the disciplinary background of the researchers involved. Natural scientists tend to find biophysical causes, while scientists with a social science background tend to find human causes of land degradation. This may be attributed to either that scientists find what they are trained to look for or that scientists select study sites in a biased manner. Similarly, Rasmussen (1999) discusses disciplinary biases in land degradation research, often associated with the specific definitions and sets of indicators they chose to use: soil scientists tend to interpret land degradation as soil degradation, and geomorphologists tend to focus on erosion as the key indicator of land degradation, while botanists tend to interpret it as loss of ecosystem complexity, vegetation impoverishment or reduction in diversity. Anthropologists, on the other hand, focus on human perceptions of degradation, rather than on biophysical indicators, while economists are interested in the economic productivity of land. Interestingly, all will have some basis for claiming that the UNCCD definition of land degradation, cited above, justifies their particular focus.

Strategic bias

Another reason behind conflicting evidence may have to do with strategic answers by interviewees. Discourses related to development agendas and priorities make it to most villages in the region (Nielsen et al. 2012). High dependency on foreign aid, stories of need, poverty, land degradation, desertification, and in recent years, climate change vulnerability is often communicated by villagers to researchers (Olwig 2013; Nielsen et al. 2012). Such stories are tightly entangled with a hope that some benefits such as development projects can be obtained by communicating vulnerability. In Burkina Faso, projects have become one of the most prominent sources of income (Nielsen et al. 2012).

Methodological biases

Diverging or conflicting results may also originate from differences in methodological choices and strategies adopted by the researchers.

As mentioned earlier, several studies based on coarse resolution Earth observation data have reported an increase in vegetation productivity, referred to as the greening of the Sahel. But this narrative is not necessarily confirmed by the other types of analysis (Horion et al. 2014), including high-resolution satellite-based studies (Gonzalez et al. 2012; Herrmann and Tappan 2013). Three major methodological choices may lead to such differences: (1) choice of temporal and spatial scale and resolution; (2) choice of the dataset (/data provider); and (3) choice of the biophysical variable(s).

Choice of temporal and spatial scale and resolution Spatial and/or temporal aggregation of data to coarser entities such as geographical or administrative regions is commonly used in environmental research to enable comparison with official statistics available for administrative entities. Several studies have shown that spatially and/or temporally aggregated data give precious information on past, present and future states of the environment (Pettorelli et al. 2005; Nemani et al. 2003). However, aggregated data must be used with caution to study natural processes. De Jong and de Bruin (2012) have shown that differences in vegetation trends may be due to the use of different aggregation periods (10 days, growing season or calendar year), with the largest variations in detected changes found when aggregating over periods that mismatched the vegetation cycle. This relates to the concept of ecological fallacy, implying that conclusions inferred from a population at a given level of spatial or temporal aggregation may not be valid at a different (higher or lower) scale (de Jong and de Bruin 2012; Zaninetti 2005; Gotway and Young 2002).

Environmental change studies in Sahel have used EO data since 70s (Landsat) and 80s (AVHRR), implying that the start of the time series coincides with the drought. It is therefore inevitable that most analyses find an increase in greenness/vegetation productivity. Qualitative studies based on discontinuous measurements are typically comparing a limited number of observations in time, and these studies are also heavily dependent on the exact timing of the data collection. Forward/backward extrapolation in time from a limited number of 'time slices' should be done with caution.

Environmental change is not only associated with the temporal domain but should also be considered in the context of comparisons conducted in the spatial dimension. Studies, based on field data or high-resolution remotely sensed information, will typically be sample based, in contrast to studies using a wall-to-wall coverage of moderate to coarse spatial resolution satellite imagery. Hence, it is imperative that the sampling design assures an unbiased sample. This has not necessarily been the case within desertification/land degradation research where sampling often has been governed by the expectations of finding land degradation. However, the qualities of local scale studies should certainly not be overlooked. As shown in a recent EO-based case study from northern Burkina Faso (Rasmussen et al. 2014), use of time series of moderate resolution (MODIS, 250 m resolution) data, instead of coarse resolution (AVHRR GIMMS, 1/12° (approx. 9 km) resolution) data, allows for identification of spatial patterns of trends pointing towards local, anthropogenic effects on vegetation productivity, while the regional pattern of trends, resulting from the analysis of GIMMS data, may be explained by rainfall change.

Choice of dataset (data provider) Remote sensing studies based on different EO systems (e.g. AVHRR, VEGETATION, MODIS) suggest different trends of environmental change. Data pre-processing strategies and time series continuity problems may be responsible for this. Studies based on the AVHRR records spanning almost 30 years are challenged by including data from many different sensors that need to be co-calibrated due to changes in sensor characteristics and orbital drift (van Leeuwen et al. 2006). Similar issues were raised for EO time series based on the VEGETATION 1 and 2 sensors, where reflectance discrepancies between the two sensors may have created a positive bias in greenness trends in the Sahel as compared to other sensors such as MODIS (Fensholt et al. 2009; Horion et al. 2014). When using long-term EO time series derived from multiple instruments, it is crucial to ensure that temporal variation in the recorded signal reflect changes in land surface conditions, not technical issues related to design and calibration of sensors (de Beurs and Henebry 2005) nor changes in atmospheric aerosols or water content.

Sampling bias

Attempts to generalize from case studies, each covering only a small area, are sensitive to sampling biases: if the ensemble of case studies is systematically biased by over- or under-representing certain environmental trends or causal factors, this may lead to false generalizations. The way in which case study sites are often selected makes this problem likely to occur. Problems which in a certain period are scientifically fashionable, such as desertification or climate change, attract researchers that will obviously look for case study areas where the problem can be observed. In particular, questionnaire- or interview-based studies take place in sites that have been part of previous (degradation) research efforts over the past 30 years. While this is not necessarily problematic, it may become so if the case studies are used in meta-studies as a basis for measuring the extent of the problem. Land degradation/desertification research provides examples of this: the idea of a 'Sahel syndrome' (Schellnhuber et al. 1997) and the analysis of 'immediate drivers' of desertification in the meta-study of Geist (2005) and Geist and Lambin (2004) both rely on generalizations from case studies, which are likely to constitute a sample heavily biased towards presence of desertification. Such generalizations are likely to conflict with results of analyses not based on spatial sampling, such as EO-based studies. Thus, sampling bias may explain the contrasts between the greening of the Sahel seen from time series of satellite data and the opposite trend seen in in situ-based analyses. It should be noted that the study of Geist (2005) does not claim to produce an unbiased assessment of the extent of desertification. In fact, the case studies included in the meta-analysis were selected on the basis of the mentioning of desertification. Rather, the meta-analysis aims at finding a pattern in the causal explanations given in the case studies. If, however, such analyses are used to argue that desertification dominates the Sahel, sampling bias becomes a problem.

Lessons learnt

We have shown that certain cases of conflicting evidence on environmental change in the Sahel reflect differences in the use of concepts and in the methodological choices. The apparent conflicts may be partly resolved, or at least understood, if the differences are brought to the front. Once this is achieved, the conflicting evidence may sometimes be transformed into complementary perspectives, enriching and nuancing our understanding. A few examples illustrate this.

- Seemingly conflicting evidence on desertification/land degradation from EO-based studies, based on different interpretations of the land degradation concept, utilizing different indicators and leading to contrasting conclusions as concerns whether climatic or human factors are the most important, may be transformed into complementary information by taking the conceptual differences and the various methodological choices into account.
- Claims of land degradation, based on in situ observations of reduced tree cover and disappearance of species, are not necessarily in conflict with claims of the absence of land degradation based on observation of increased vegetation productivity using time series of EO data. Rather, they rely on two different interpretations of the UNCCD definition of land degradation, illustrating the ambiguities of the definition.
- When generalizations about land use and land cover changes in the Sahel, based on small-scale and short-term field studies, appear to be in contrast with the evidence acquired from wall-to-wall analyses using satellite data, it illustrates on the one hand that extrapolation of findings in time and space should be done with caution. On the other hand, it shows that large-scale and long-term trends do not say much about environmental change processes at micro-scale and over shorter periods.

In order to use the conflicting evidence constructively, the causes of the discrepancies must be identified. Hence, the definitions of central concepts, the methodological choices made and the spatial and temporal scales considered must be transparent to the reader, and possible alternatives to the choices made should be outlined. While a number of apparent discrepancies may be resolved by doing so, we do not claim that all scientific controversies about environmental change in the Sahel will disappear. Many scientific questions remain open, such as the question of the effects on greening trends of changes in species composition (Mbow et al. 2013) and the importance of changes in grazing intensity and atmospheric CO_2 concentration in explaining changes in vegetation productivity and composition (Bond and Midgley 2012; Higgins and Scheiter 2012; Scheiter and Higgins 2009).

Conclusions and perspectives

Based on examples, we show that seemingly conflicting findings as regards whether or not desertification/land degradation is a general feature of the Sahel, whether agricultural land use is generally expanding and whether drought is continuing, are commonly found in the literature on Sahel. We trace these conflicting findings to differences and inconsistencies in the definition of concepts and to disciplinary, strategic, methodological and sampling biases. If these differences are taken into account, the results are shown often to be complementary rather than contradictory. It is suggested that in an interdisciplinary field such as this, special attention must be paid to making conceptual and methodological choices explicit, also to scientists from other disciplines with different languages, traditions and norms.

Environmental change in the Sahel is of great policy concern at local, national, regional and global levels, yet many policy documents tend not to be firmly based on research results. Resolving or reducing scientific controversies would place science in a stronger position to inform policies.

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