

Measuring Desertification in continuum: Normalized Difference Vegetation Index-based Study in the Upper East Region, Ghana

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Abstract

This paper builds on current research in desertification and approaches design to assist in the accurate measurement of desertification in both spatial (pixel level) and temporal scales taking cue from two earlier studies by Lampray in 1975 and Prince in 1998. These studies vary both in time and space, hinge on different perceptions which directed the methodological approach and conclusions, their points of divergence and convergence have proven to be the strength of many current desertification studies including this one. The focus of this study was to find an indicator-based based approach, i.e. Using Normalized Difference Vegetation Index (NDVI) which can measure desertification in a continuum over long term. Whereas long-term and continuous analysis is important, this study finds that spatial pattern of land degradation in the UER differ from place to place and from time to time which may be attributed to land use types and intensity. The study therefore concludes that although the general surfaces appearance is important, localized land degradation and short term degradations are likely to be overlooked. Assessing desertification in continuum should reflect both temporal and spatial land degradation degradation trajectories. These trajectories have implications for identifying the cause or causes of degradation and developing targeted approach both at the regional and local levels. In the case of the UER, efforts at combating desertification would more likely be effective at locality level where decisions on land preparation, including the use of fire, the timing and the method of cultivation is likely to be effectively enforced.

Key Words: desertification, continuum, pixel, spatio-temporal

1. Introduction

Desertification, also referred to as dryland degradation, remains a controversial subject since its first scientific use in 1927. Lavauden is credited to have first used the word desertification in a paper. However, Aubreville was the first person to use desertification in the scientific literature (Dregne 1986; Hellden 1991; Thomas 1997; Lambin et al 2001; Geist and Lambin 2004). Aubreville (1949) in his famous and ever-cited book, *Climats, Forêts, et Desertification de l'Afrique Tropicale*, described desertification as the changing of a productive land into a desert as a result of ruination of land by man-induced soil erosion. Aubreville observed the ruination of land in the humid and sub-humid tropics where he worked. He concluded that tree cutting, indiscriminate use of fire, and exposure of soil to erosion by water and wind through certain modes of cultivation were the principal causes of desertification (Aubreville 1949; Dregne 1986).

The enormity of local and national studies focusing on the subject of desertification demonstrates not only its socio-ecological importance, but also the fact that some parts of the desertification puzzle remain unsolved (FAO 1999; Veron et al 2006; Geist and Lambin 2004). Generally, the word desertification lacks an accurate and universally acceptable definition. This disallows scientists the opportunity to assess and measure it in its various forms. Similar definitions of desertification were found in the literature. Expanding on concept of desertification propagate by Kassas, Kates, Johnson, and Dregne define desertification as the impoverishment of arid, semiarid, and some sub-humid ecosystems by the combined impact of man's activities and drought. It is the process of change in these ecosystems that can be measured by reduced productivity of desirable plants, alterations in the biomass and the diversity of the micro and macro fauna and flora, accelerated soil deterioration, and increased hazards for human occupancy (Dregne 1977). In this definition, desertification does not refer only to totally devastated land where nothing grows since there are very few places where man and drought have totally destroyed the vegetative cover and caused virtually permanent land damage. Slight to severe, but not total, land degradation is much more common and much more significant in the vast majority of inhabited arid regions of the world (Dregne 1977).

The most extensively-cited definition in the literature today came from United Nations Commission on Environment and Development (UNCED) which was adopted by United Nations Environmental Program (UNEP). UNEP defined desertification as: "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (UNEP 1994). UNEP limited the

definition of desertification to ‘land degradation ... resulting from diverse human impact’ (Rasmussen et al 2001). Emphasis placed on climatic variations in this definition, compared to the other two definitions above is an indication of the disagreement that existed concerning different causative factors of dryland degradation (Hulme 1993). Even so, this authoritative definition by UNCED appears meaningless and lacks content without further defining what constitutes land degradation. In this study, however, desertification, for the purpose of monitoring and control, should be defined to include how it manifests itself for easy identification and management. According to Prince (2002), common manifestations of desertification, especially those that can be detected from remote sensing are loss of biological productivity, soil erosion, loss of vegetative cover, land cover diversity change, as well as energy and water flux change. However, Prince (2002), further suggests that assessing desertification based on soil is a pathological activity and is counter-productive. Irrespective of how and what causes desertification, the initial observation that will prompt a second look will be progressive surface vegetation change. This proposition is also supported several studies (Prince et al 1998; Prince (2002); Veron et al 2005, 2006); and Reynolds et al 2007) and has become the current paradigm that researchers are looking into.

The United Nations Convention to Combat Desertification (UNCCD) defines land degradation to include reduction of or loss of biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, range, pasture, forest, or woodlands arising from land uses or from processes resulting from human activities and habitation patterns. Williams and Balling, on the other hand, define land degradation as the reduction of biological productivity of dryland ecosystems, including rangeland pastures and rain fed and irrigated croplands. According to the authors, land degradation results from an acceleration of certain natural, physical, chemical, and hydrological processes, including erosion and deposition by wind and water, salt accumulation in soils, groundwater and surface runoff, as well as a reduction in the amount or diversity of natural vegetation, and a decline in the ability of soil to transmit and store water for plant growth. Even with what appears to be a clear definition of land degradation, the initial concern of these scientists is biological productivity, which would be seen as plant and vegetation cover changing over time, (here it is referring to negative change) such that even using NDVI, will manifest as reduction in NDVI. Nevertheless, it must be emphasized that scientists narrowly define land degradation to reflect their discipline and perhaps to generate interest in their studies. It is not uncommon to read geomorphological abstracts with land degradation focusing on erosional processes, while soil scientists focus on physical and chemical properties of the soil. Similarly, ecologists focus on productivity of natural vegetation, but botanists concern themselves with the changes in species’ composition and loss of biodiversity. Thus by definition, what constitutes land degradation in the eyes of an ecologist or botanist would not be counted by the soil scientist and vice versa (Rasmussen et al 2001). From environmental monitoring perspective one looks at land degradation in terms of progressive degradation in vegetation cover; hence, land degradation process and desertification become synonymous and are used interchangeably. It must also be clarified that for progressive land degradation to be considered desertification, it should have been studied in a continuum, for no less than 15 years, by which period the threshold effects of inter-annual and inter-decadal climate fluctuations and desiccation would have been revived.

Various researchers have attempted to measure desertification through a variety of approaches. In measuring desertification, one of the controversial issues has been the nature of the phenomenon. While one school argues that it is a state, another school contends that it is a process. Others even maintain that reversibility, or lack thereof, must be the most crucial element for measuring desertification. While delineating the phenomenon, terms such as “state,” “process,” and “reversibility or irreversibility”; are useful for measurement purposes, they also have implications for policymaking and management. Thus, in deciding on an approach to use for detecting and measuring desertification, one needs to consider a few questions.

First, is desertification a state or a process? If desertification is considered a state, then we can take a snapshot approach with a single satellite image to detect how it looks. In reality however, desertification is not static; it is a process and changes over time. This was the cardinal shortcoming of the first approach by Lamprey (1975) when he compared the southward boundary of the Saharan desert at two different time periods in southern Sudan. He used a vegetation map from 1958 and compared that with an aerial photograph of 1975 and field surveys to conclude that desertification advanced 90-100 km in 17 years. In Sahel Africa, the presence of vegetative cover is often subjected to inter-annual and inter-decadal variations due to rainfall anomalies. This means that in periods of rainfall anomaly, vegetation declines and recovers sharply when rain returns. Plant seeds, especially in dryland areas, have the capacity to remain dormant for as long as 10 years during periods of drought and desiccation but are revived when conditions improve. Thus using two dates to map desertification is an over-simplification of the problem because it says nothing about the vegetation status during intervening years. Moreover, it does not take into account inter-annual and inter-decadal rainfall anomalies which can

coincide with these two periods of analysis. It is against this background that Prince (2002) argued that desertification needs to be studied as a continuous process for no less than 15 years for any meaningful conclusion.

Secondly, is desertification reversible or irreversible? In this case, if desertification is seen as irreversible; then desertification would be conceived as desert-like conditions associated with bare surface and severe soil degradation, including gullies. . Global Assessment of Soil Degradation GLASOD used the extent of soil degradation and the expert opinions of 250 people to assess and quantify desertification. By combining qualitative and quantitative variables of soil and vegetation, they concluded that 70% of all drylands are affected by desertification. In reality, desertification has phases, beginning with degradation of surface cover (vegetation) before reaching the soil (Collado et al 2002; Lu et al 2004). The desertification process can be reversed, but when it gets to the soil, it is in the advanced stage. Desertification, therefore, has to be assessed in a continuum from the onset to the hyper state. Initially it is reversible and action must be taken before it reaches the irreversible state. It is against this background that GLASOD's approach to analyzing and monitoring desertification was criticized as autopsy or postmortem by Veron et al (2006) and Prince (2002).

The Rain Use Efficiency (RUE) approach has also been used to measure desertification. Le Houerou (1984) suggests and applies it to the Sahel region of Africa, and Prince (2002) revisits it. What this approach sought to do was to approach desertification in terms of early warning by identifying early signs that can be detected before it reaches the autopsy state; that is, methodology based on early indicators. RUE is the ratio between annual above ground primary production (defined as the rate of aerial biomass accumulation by plants, ANPP) and annual precipitation (Prince et al 1998; Prince 2000, 2002; Veron et al 2006). The physical principle behind this approach is that desertification decreases the proportion of precipitation that is diverted to infiltration and transpiration largely due to increased runoff or evaporation. RUE adopts both statistical and remote sensing approach, including surface moisture detection and thermal to detect moisture and evaporation. In another sense, RUE is assessed in terms of NDVI and soil moisture. RUE is, however, criticized on the grounds that desertification does not always reduce Annual Net Primary Production (ANPP). The Jornada Experimental Range at the Chihuahuan Desert of New Mexico shows that desertification did not substantially change ANPP (Huenneke et al 2002).

1.1 Theoretical Consideration

Concepts relating to desertification are often confused with the desertification process itself. These are what Thomas (1997) describes as the 5Ds; which include Drylands, Drought, Desiccation, Desertification and Desertization. There is the need to distinguish between these terms, as they are closely linked and often confused with one another. Similarly, differentiating between them would not only enhance the meaning of desertification, but also its identification as a process that has a beginning and an ending. Distinguishing between these terminologies and/or processes is necessary because they have different causes and impacts and thus require different policy interventions for ameliorating and controlling their impacts. In assessing desertification in continuum, it is important to clarify some of these concepts since they are key to the definition of desertification and how it is studied.

The first concept of interest is the concept of drylands, where desertification normally occurs. The nature and parts drylands that can be included in desertification studies are important. Drylands refer to regions of water scarcity, which manifest in the form of poor primary production and nutrient cycling (Safriel et al, 2005). In dryland regions, precipitation is counterbalanced by loss of moisture through the combined effect of evaporation from surfaces and transpiration by plants, commonly referred to as evapotranspiration. Drylands are therefore measured by the difference between precipitation (moisture supply) and potential evapotranspiration (moisture loss), also known as the aridity index. Aridity index values lower than 1 indicates an annual moisture deficit (Safriel et al 2005). The World Atlas of desertification defines drylands as areas with Aridity Index (AI) of 0.65, that is, areas in which annual mean potential evapotranspiration is at least 1.5 greater than annual mean precipitation (Safriel et al 2005). Drylands differ by the degree of aridity, using AI (Precipitation – potential evapotranspiration). In the World Atlas of desertification, UNEP has identified 4 subtypes of drylands with increasing degrees of aridity, namely dry subhumid, semiarid, arid, and hyper-arid. One, however, needs to point out that desertification does not occur in hyperarid regions because these regions are already existing deserts, which by definition, cannot be included in the desertification process.

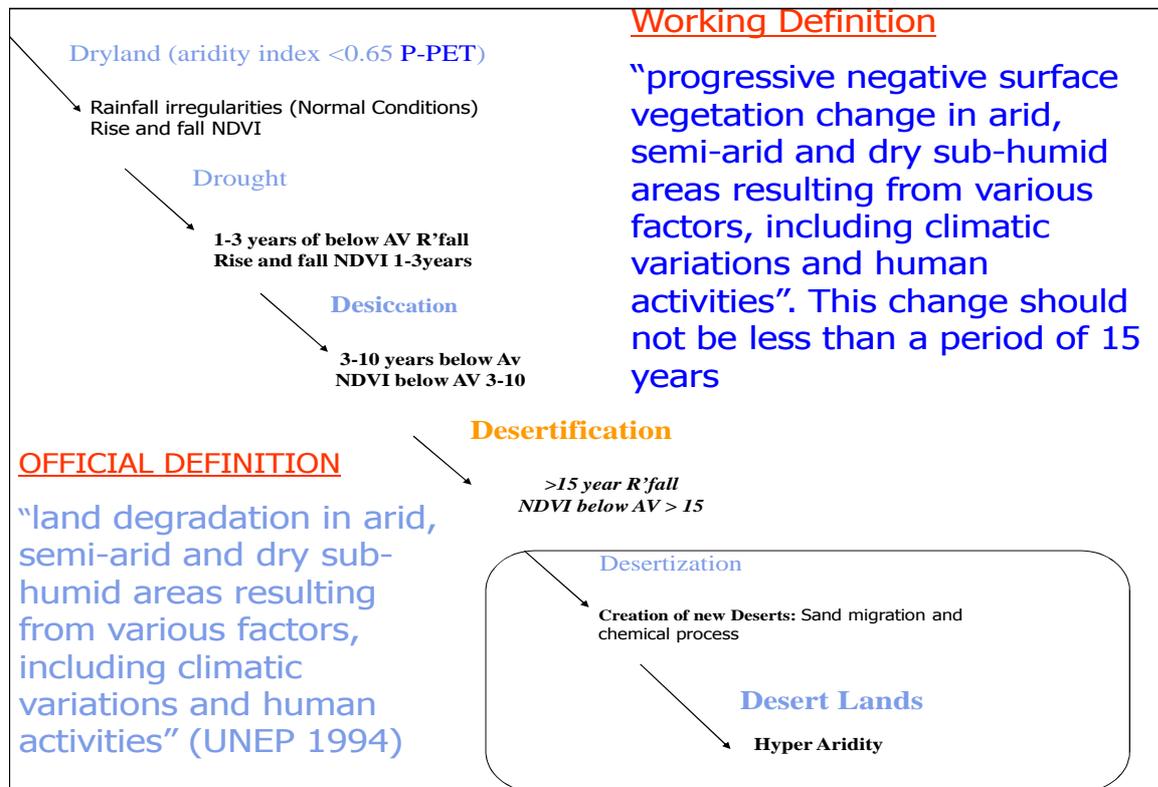


Figure 1: Desertification in continuum

In dryland regions, potential evapotranspiration exceeds precipitation and as such, are classified as regions of potential water deficit. This potential water deficit affects the ecosystem types and functionality, such as vegetation cover type, crop production, forage, drainage systems, animal life, and ability to meet human needs. It is equally common to classify dryland subtypes based on land use; a classification based on ecosystem types. Safriel et al (2005) classify drylands based on land use types as rangelands, croplands, and urban lands. Rangelands and croplands constitute about 90% of global dryland area and form the base of agropastoral livelihood (Safriel et al 2005). The latitudinal limit of global drylands extends between latitude 65° N and latitude 55° S, and they occur on all continents and encompass nearly half of the global landmass. The remaining land area is made up of polar, forest, and woodlands.

The next concept of interest is drought. Drought can be described as a behavioral pattern of an element of climate; rainfall, over a period of not more than 3 years. Specifically we refer to drought over a period of one or two years with rainfall below average such that water scarcity becomes evident. Drought occurs naturally and lasts over a short-term (1 ± 2 years) period when precipitation is significantly below normal recorded levels. Generally, vegetation wither during periods of drought but recover rapidly after the rain returns (Darkoh 1998; Toulmin 1994; Agnew and Warren 1996). When expecting drought, there is the need for an early warning system coupled with a well-functioning rapid response system to deal with food and fodder shortage, emergency employment schemes, crop insurance, and programs for post-drought rehabilitation.

Thirdly, desiccation on the other hand is referred to as a period of extended drought, lasting for a decade (Darkoh 1998). That is a period of well below-average rainfall which lasts for at least one decade. It should be emphasized that drought and desiccation are differentiated by their temporal extent. In terms of their impact, one would agree that longevity of occurrence would determine the severity of impact, all things being equal; however, some droughts tend to be very severe. Desiccation, on the other hand, is measured in the longer-term (decadal order) deficits in rainfall which can seriously disrupt ecological and social patterns and require national

and global response. Recovery after desiccation is much slower, for trees may have died and vegetation may then take years to recover. Responses include management of population movements and the development of alternative livelihood systems (Agnew and Warren 1996). Desiccation preparedness would also involve measures to ensure adaptation in farming and livestock systems to withstand much drier and more variable rainfall.

Dryland degradation is considered a persistent decrease in the biological potential of soils and vegetation due to human use and/or climate variability. Dryland degradation is synonymous to desertification and is therefore used interchangeably in this study. Dryland degradation may be caused by either climate and/or human activities and requires interventions mainly in the areas of policy directed to regional and national levels. Some of the common areas of policy reform include land-tenure system, pricing policy for crop and livestock products and farm-level technological adaptation, education and other infrastructural support meant to ensure ecological recovery, stable incomes and land investment, and promotion of livelihood for the affected population (Darkoh 1998; Toulmin 1994; Agnew and Warren 1996).

Desertization, on the other hand, is defined as the irreversible extension of desert land forms and landscapes to areas where they did not occur. Desertization can be considered the tail end of desertification. Whereas desertification is reversible, desertization is technically irreversible. Some analysts, including Thomas (1997), have argued that the irreversibility stems from cost, time and other resource constraints.

As has been shown, the 5Ds are related when placed in a continuum and a separated by time and reversibility difficulty by vegetation. In addition they occur on drylands which is explained by the AI, which means the severity of moisture deficiency as one move along the continuum and this is illustrated by figure 2.

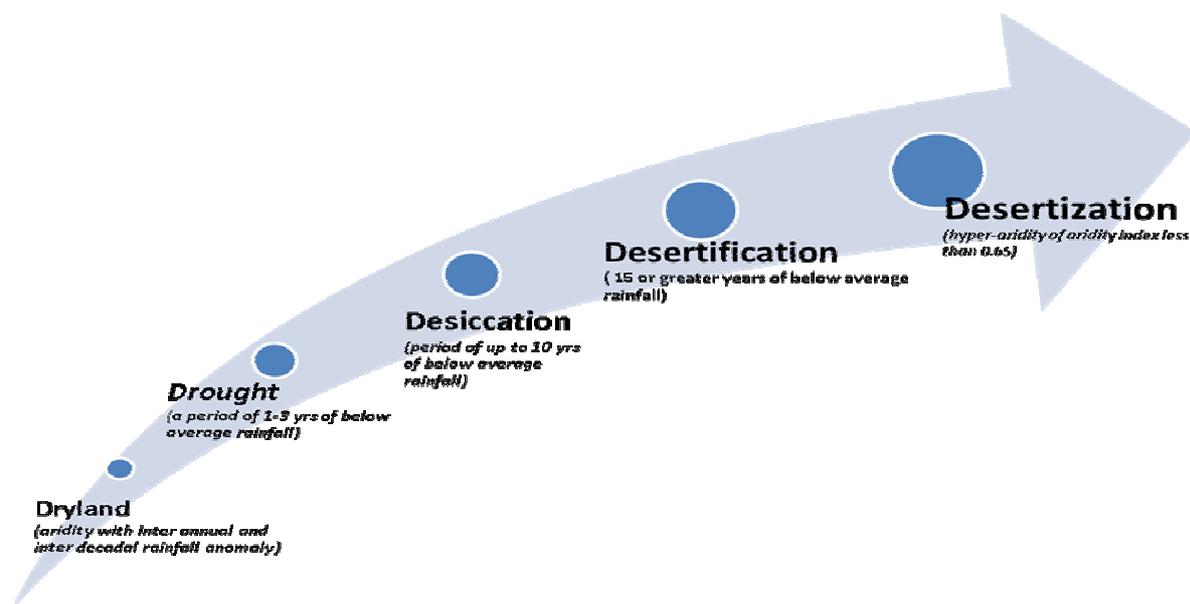


Figure 2: Desertification in continuum (space and time)

2. Materials and Methods

This study was part of a broader study that assessed the extent of land degradation in the UER Ghana, using a low resolution GIMMS (Global Inventory Modeling and Mapping Studies) NDVI, also known as NDVIg from AVHRR satellite images from 1982-2007. The study also analyzed seven (7) single date Landsat Thematic Mapper five (TM5) images of the same area. The Landsat TM5 images were selected to be close to near anniversary period for the avoidance of seasonal NDVI changes in responds to rainfall, burning and farming periods. The satellite data was supplemented by an extensive field data collection using Global Positioning Systems (GPS) and digital camera. In addition 60 local farmers regarded as key informants were interviewed for accounts of rich local history ranging from ecological change, farm practices, and land ownerships to other

cultural practices. Lastly crop production data for the area from 1984-2007 was also analyzed in search for convergence of evidence. For this paper, the study presents the assessment of desertification in a continuum using NDVIg data. The discussion at this point focuses on the methodology applied in the analysis of the NDVIg data and the conclusions drawn from the NDVIg analysis.

The use of NDVI for the study of desertification has been criticized in many ways, yet it remains the most widely used and perhaps the most relevant indicator of the desertification process compared to other Vegetation Indices (VIs). The phenomenon desertification, by definition and indicators used, is progressive negative surface vegetation change. Using NDVI to assess desertification helps the study to focus on process indicators and avoid assessing desertification after the fact (Lamprey (1975), while avoiding assessment with expert opinions (GLADSOD 1990). NDVI as process indicator serves as early warning and can be detected using remote sensing technology, a perspective commonly shared by pundits such as Prince et al (1998), Prince (2002), Veron et al (2005, 2006), and Reynolds et al (2007). Also NDVI is used to avoid confusion with rock and soil reflectance, and above all, to avoid under and over estimation of vegetation presence and health, an essential indicator of desertification. The spectral signature is defined as the characteristic set of reflectance by a target over the electromagnetic spectrum. Different targets reflect different amounts of energy at different wavelengths. A multispectral satellite sensor is designed to sense earth targets at multiple bands designed to distinguish different types of ground cover at different conditions such as vegetation, water, rocks, etc. In studying vegetation, healthy vegetation looks different from harvested land, and both are different from open water (Campbell 2008; See figure 3). VI's are used to measure vegetation health based on inclined vegetation reflectance in the red and Near Infrared (NIR) bands called the red edge.

The formula for calculating NDVI is:

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

The general formula for VI is:

$$\text{VI} = \text{NIR} - \text{Red} \quad (2)$$

Using the example from figure 3, the VI measure of healthy and unhealthy green vegetation would be calculated as follows - equation (2):

$$\text{Healthy Vegetation: } 0.50 - 0.08 = 0.42 \quad (2a)$$

$$\text{Unhealthy Vegetation: } 0.40 - 0.30 = 0.10 \quad (2b)$$

VI values range from -1.0 to +1.0. VI in the positive value range indicates green or vegetated surfaces (reflectance in NIR > RED) and higher positive values indicate increases in green vegetation.

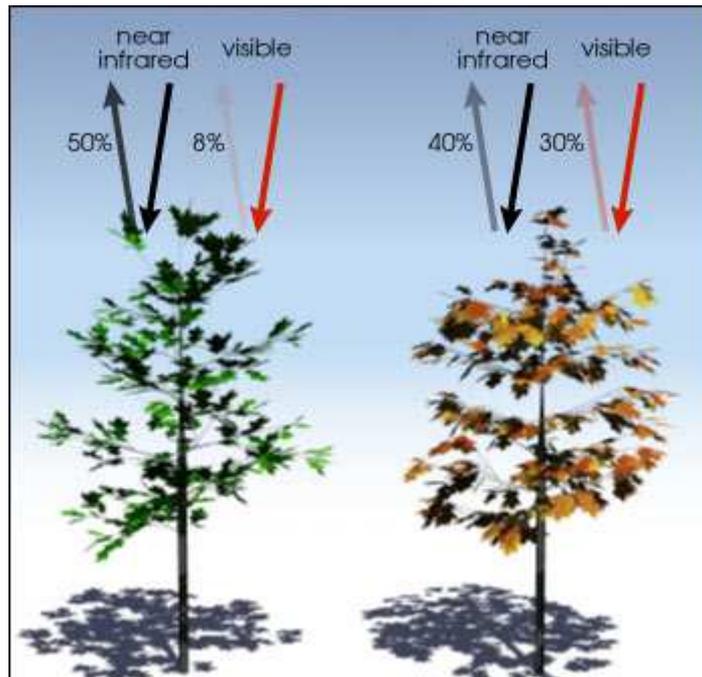


Figure 3: The absorption and reflectance of healthy and unhealthy vegetation in red and NIR bands (Simmon 2009)

According to Campbell (2008), there is one major problem with using VI to measure vegetation. He stated that two identical patches of vegetation could have different VI values if one were in bright sunshine and another under a hazy sky. The bright pixels would have larger reflectance values in the NIR and red reflectance, and therefore a larger absolute difference between the band reflectance values. As a result, a more preferred version of the VI, the NDVI, is normally used. The NDVI is preferred because it helps to compensate for this major problem, simple VI explained above, by focusing on the difference in proportion to total illumination. It does this by using the ratio of the difference to the sum (Campbell 2008).

The formula for calculating NDVI is shown in equation (1) above. We can demonstrate the potency of NDVI using the same figures used for VI in equation (2a) and (2b) by substituting the reflectance figure in NDVI equation (1) above.

$$\text{Healthy Vegetation: } (0.50 - 0.08) / (0.50 + 0.08) = 0.72 \quad (1a)$$

$$\text{Unhealthy Vegetation: } (0.40 - 0.30) / (0.40 + 0.30) = 0.14 \quad (1b)$$

There are many variations of VI and they follow these same principles, but healthy vegetation shows higher values in NDVI as shown by equation (1a) than VI in (2a) and (2b) (Campbell 2008). Similar reflectance characteristics are exhibited by bare soil and rock in their reflectance levels in NIR and red bands. However, on bare soil and rocks, NDVI values are near zero. Clouds, water, and snow, on the other hand, exhibit reflectance behavior opposite of vegetation in NIR and red bands; hence NDVI shows negative values in their presence.

Generally, cloud cover constitutes a major problem for remote sensing by obscuring the vegetation below and this affects NDVI calculation. In an effort to circumvent problems caused by cloud cover, NDVI is typically calculated using multiple composite images of the same area, with the hope that at least one image will be cloud-free. For example, the GIMMS NDVI used for this study was 15 consecutive days of AVHRR data composite to make the NDVI product. This means that for each pixel of each band, the highest of the 15 values is used and the lower remaining is thrown out. Generally, the highest value data area is either cloud-free or represents the least cloudy day. Cloud interference in GIMMS NDVI used for this study could be possible only if the study area was covered continuously for all 15 days.

A remarkable character of NDVI in the African region and Sahel sub-region is the extent of fluctuations linked to the inter-annual and inter-decadal fluctuations associated with drought and desiccation. As defined earlier, drought refers to a period of one to three years of below normal rainfall as established by the local climate. Desiccation, on the other hand, is a period of below normal rainfall, usually lasting 3-10 years. Expectedly, vegetation withers within this period; however, when conditions are revived, vegetation recovers sharply. This means that drought and desiccation can be observed with NDVI trends depicting peaks and troughs of either 3 years or up to 10 year intervals. However, when NDVI trends decline or fall below a certain level (usually set by the base year) continuously or consistently for over 10 years, then we have a process indicator that suggests desertification in action. This framework is also linked to the causative agent of the desertification. Since no drought or desiccation lasts for more than 10 years, if the land degradation trend depicted by NDVI persists for more than 10 years, we talk of desertification. It can then be argued that, there may be two possible causative agents--either climate change or human-induced land degradation. It is against this background that desertification was defined by UNEP (1994) as land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities.

3. Results and Discussions

This study was conducted in the UER of Ghana, which forms part of the Sahel region of West Africa. Geographically the UER is located between latitude 10.40 N and 11.5 N and longitude 1.36 W and 0.09 E. It falls within the dry sub-humid portions of the Sahel with an annual rainfall of about 1100 mm. The seasonal trend of vegetation growth measured by NDVI in a normal year for the UER shows a gradual rise from April, peaks in September and declines gradually from late October and reaches its minimum in February. However, in abnormal years, which would simply be interpreted as drought years, the NDVI trend would look different, corresponding to the timing of the rain in the locality of interest. The seasonal or intra-annual variability may not relate to land degradation however inter annual and decadal variability relates to land degradation and desertification.

This section discusses the results of inter annual NDVI for a period of 26 years, using GIMMS NDVI. Twenty-six years mean NDVI, composed of a 15-day average composite from 1982 to 2007 and plotted to measure desertification in a continuum is presented below (Figure 4). Generally, the temporal NDVI indicates that greenness in the region has increased steadily, after the starting lows of what appears to be drought years of 1982, 1983, and 1984 (figure 4), that is three (3) years of below average NDVI. It also shows the regular cycle of NDVI fluctuations linked to rainfall anomalies, that is a cycle of inter annual rise and fall of vegetation greenness commonly associated with the study area. From the period 1982 to 2007, vegetation greenness rose steadily from an annual mean of about 0.37 in 1982 (the base year) to about 0.45 in 2007, the end year. This indicates a positive mean NDVI change of about 21.6% over a period of 26 years. NDVI peaks occur in 1986, 1990, 1997, 2002 and 2007. Conversely lowest NDVI points were recorded 1984, 1992, 1996, 1998 and 2005.

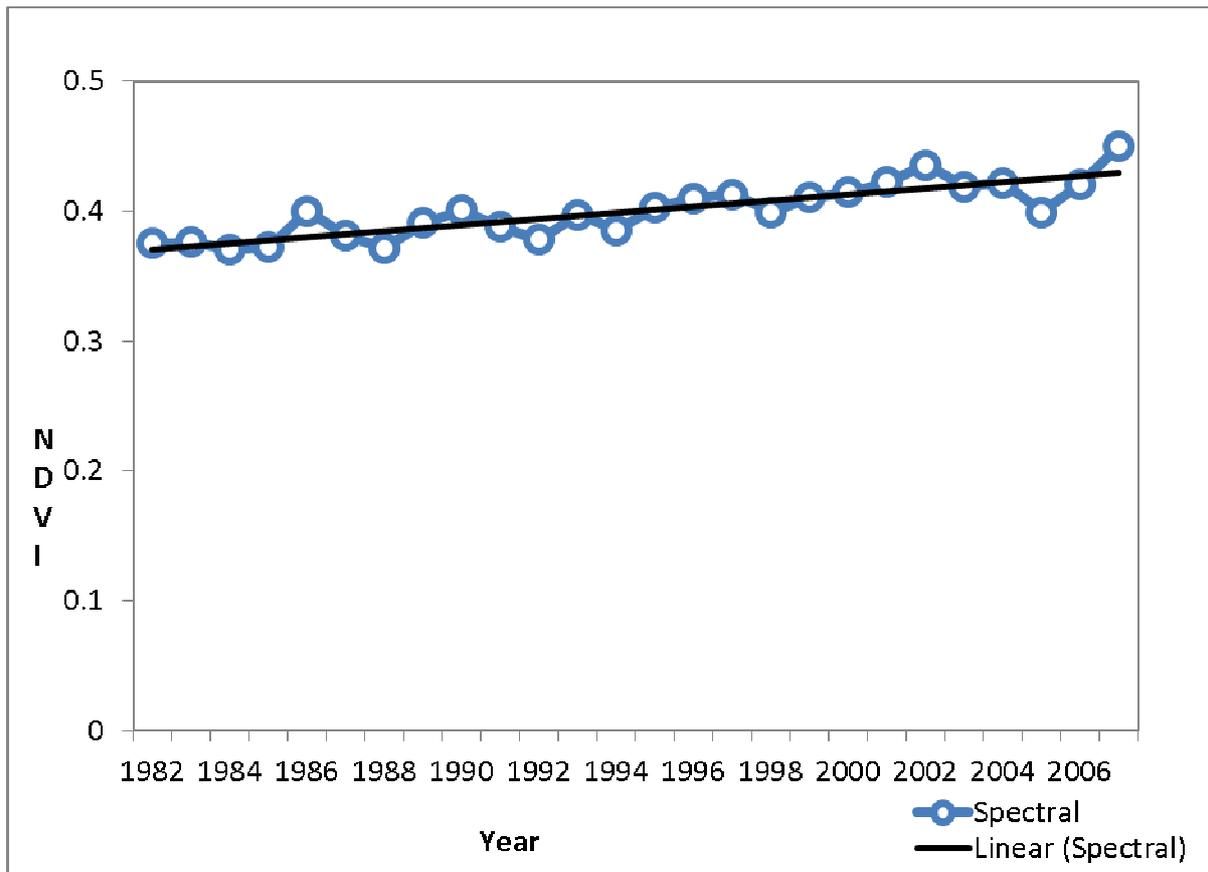


Figure 4: Mean NDVI for the UER 1982-2007

The spatial dynamics of NDVI in the study area is also presented on figure 5. The analysis focused on how NDVI has changed spatially based on NDVI per pixel. The analysis focused on pixels-based NDVI losers and gainers, i.e. pixels that lost surface greenness and those that saw an increase in surface greenness over the reference period. From 1982 to 1990, an average of 41 pixels of 8km^2 each, which translate into 328 km^2 lost greenness measured in terms of NDVI in the UER. Conversely, land area of approximately 2064 km^2 gained or showed increase in surface greenness. The period 1990 to 1999 saw 102 pixels (816 km^2) losing its surface greenness, while 197 pixels of 8km^2 (1576 km^2) gained greenness. However, more land area lost surface greenness from 1990-1999 than the period 1982-1990. Areas that lost vegetation were concentrated around the south-west, and south-central portions of the study area. Compared to 1982-1990 and 1990-1999, the period 1999 to 2007 lost less vegetation. An average of 19 pixels (8km^2) equals 152 km^2 lost vegetation, while 280 pixels, equivalent to 2240 km^2 , gained vegetation. Whereas 1999-2007 had the lowest number of pixels losing greenness, the period 1982-1990 had the highest gain in greenness. On the other hand, the period 1990-1999 had both the highest number of pixels losing greenness, and at the same time, the minimum gains in vegetation greenness. There is no single pixel which lost vegetation for more than four (4) continuous years. Figure 5) shows four (4) sample pixels of the highest and lowest gainers and losers of greenness over the study period.

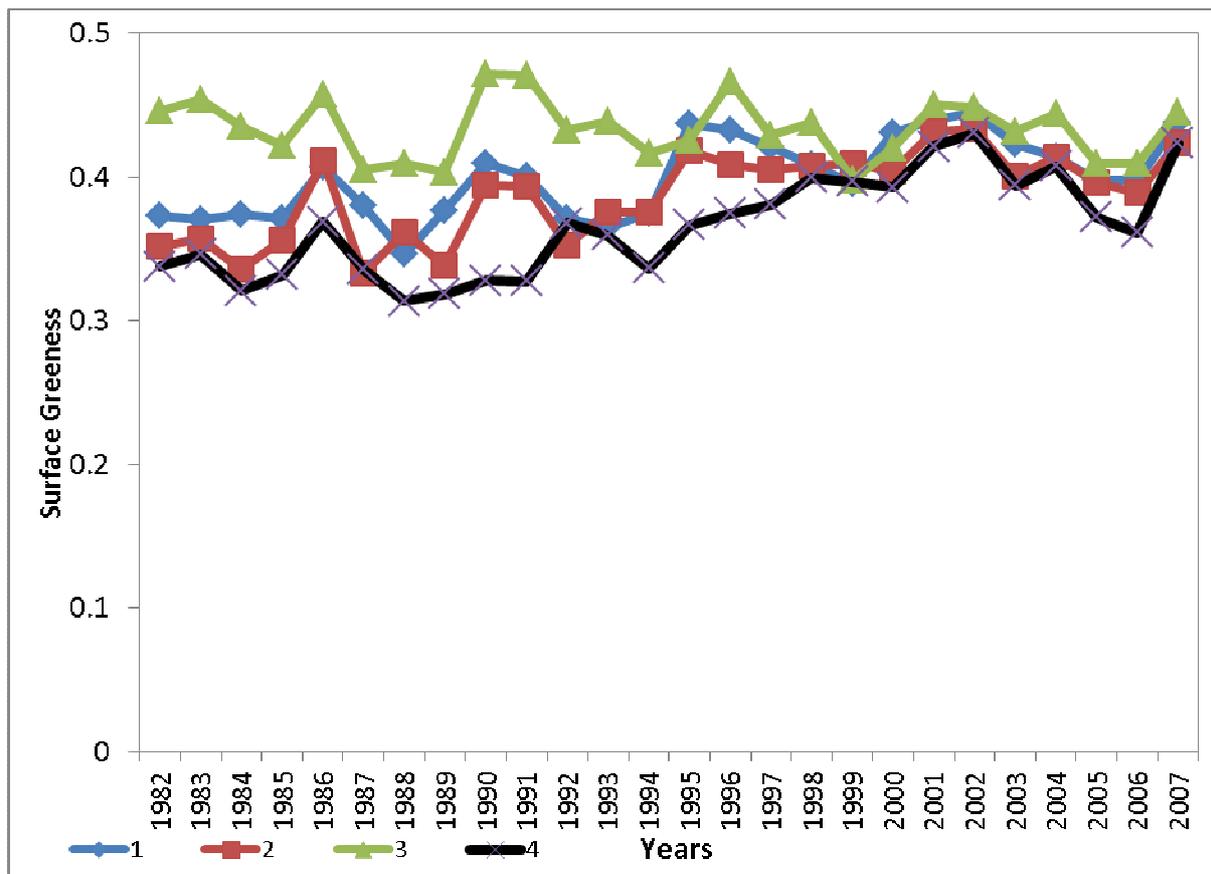


Figure 5: Four (4) sample pixels of spatial gainers and losers NDVI

From figure five (5) pixel four (4) has the lowest NDVI value from 1982 and it showed rise and fall in early years and subsequently recorded lowest in 1988 and 1994. The four years of low NDVI in pixel four (4) is not supported by NDVI values in the surrounding areas which were rising instead. Although pixel one (1) also recorded the lowest value in 1998, the NDVI values rose in the following year. This suggest that the four years of low NDVI may not necessarily be due to rainfall pattern of the area, but could well be explained in terms of land use.

Figure 6 is the spatial representation of pixels that gained, remain the same and pixels that lost vegetation over the 26 years of spatial analysis.

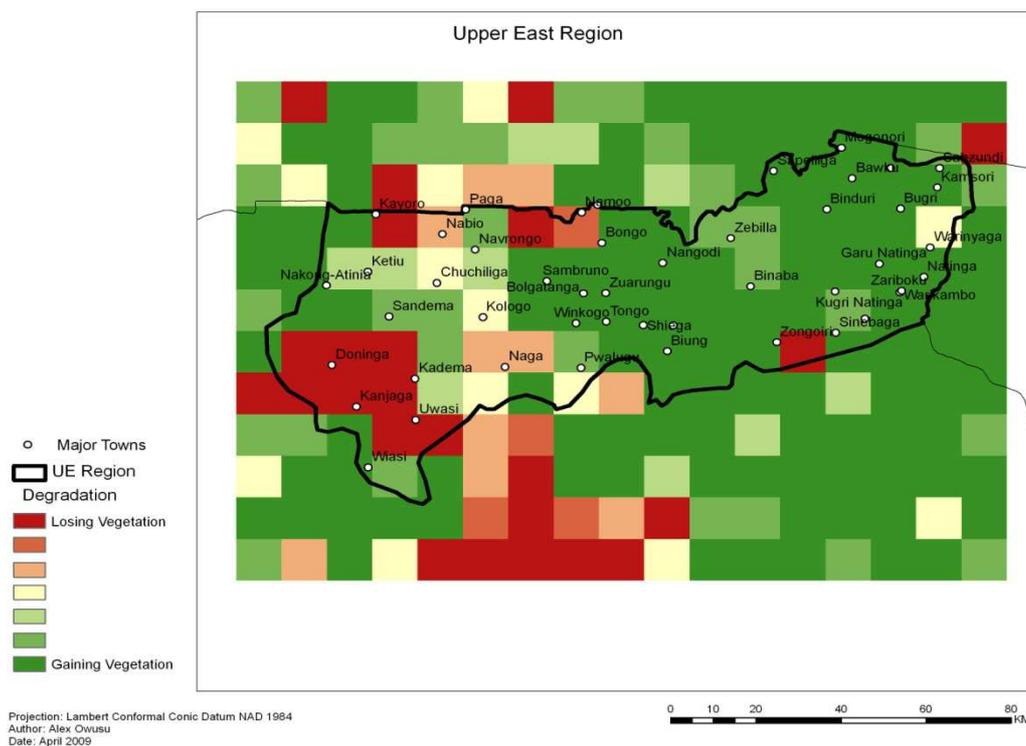


Figure 6: Mean Spatial Pattern of Land cover change

The spatial pattern of gainers and losers show that more pixels in the eastern and central portions of the study area gained vegetation, while south western portions of the study area lost more vegetation from 1999-2007 (figure 5). The overall mean gains and losses show that land degradation is not uniform in the UER, nor does it occur at the same rate. It is against this background that the study concludes that land degradation is more likely to be a function of land use, in terms of frequency and intensity than climate, although climate impact cannot be wholly exonerated. This is because a location of 8km² is not likely to experience different climatic conditions from its neighbors over time. What is certain from the study area is that farmers use fire in clearing land for cultivation and in the process, they are likely to generate wildfire that expands over few to tenths of kilometers.

5. Conclusion

'To date, although a great deal of data on land resources are available, it has not been possible to get a clear picture of the status of desertification at regional or national levels' (UNCCD 2000). This study provides an exploratory study of the status of desertification in the UER, taking inspirations from other studies including Lamprey (1975) and Prince et al (1998). Given that desertification is a matter of life and death to many residents of the UER and dryland regions of Africa, whose survival are tied to dryland vitality, it is imperative that scientists build consensus and collaborate to provide accurate information and credible methodology for its assessment. Since Stebbing's pioneering work on desertification in 1935, several other works, providing different estimates using different methodologies have surfaced and have been critiqued in the literature. Notwithstanding the unfavorable reviews by some scholars in the field, these works have shaped and improved the direction of the discourse and contributed to the methodological development over the years. Two prominent of these studies that have received much attention and reviews in the literature and have also contributed tremendously to the current debate on desertification are the study by Lamprey (1975) and Prince et al (1998) in the Sahel region of Africa. These studies vary both in time and space, hinge on different perceptions which directed the methodological approach and conclusions, their points of divergence and convergence have proven to be the strength of many current desertification studies including this one.

Lamprey's study was an attempt to quantify the rate of advancement of the Sahara desert by comparing the location of the southern margins of the Sahara desert at two different times; that is the 1958 margins according to a vegetation map produced by Harrison and Jackson in 1958; and the 1975 margins according to aerial

photograph and terrestrial surveys conducted by Lamprey (1975). He concluded that there was 90–100 km displacement of the margins of the Sahara desert in 17 years, meaning desert edges were encroaching at the rate of 5.5km per year. Although Lamprey's approximation was criticized, it represented the then ruling paradigm of desertification, which was regarded as an extension of existing deserts. This paradigm was said to be based on observations of foresters like Stebbing (1935) and Aubreville (1949). Aubreville wrote 'these are real deserts that are being born today, under our eyes, in the regions where the annual rainfall is from 700 to 1500 mm'. From their perspective, desertification was regarded as human creation. It was seen as an irreversible state of land characterized by sand dunes, scarce open thorny vegetation (Veron et al 2006). One major flaw of this paradigm and for that matter Lamprey's conclusion was that his approach ignored the fundamental role of climate variability. Later scholars, including Hellden (1991) and Tucker et al (1991) using fieldwork and satellite remote sensing datasets have shown that desert boundaries are very dynamic and fluctuate year after year in direct relationship with annual and perennial rainfall regimes. They have argued that desertification is a dynamic process which can be reversed over time.

Taking cues from criticisms against Lamprey 1975 and the overall call for practical, objective methodology based on indicators, Prince et al (1998) assessed the desertification status of the Sahel region by means of the rain use efficiency (RUE) and concluded that evidence from rain-use efficiencies does not indicate extensive Sahelian desertification. RUE was calculated as the ratio between annual aboveground primary production (the rate of aerial biomass accumulation by plants, ANPP) and annual precipitation. The main assumption of RUE, according to Veron et al (2006) was that "different plant traits, favored by natural selection, and community structure (e.g. soil cover, plant biomass), account for the spatial variation in soils or climate leading to a convergence in the limiting resource use efficiency and that the departures from the average RUE would, thus, constitute the result of human management". Although the application of RUE in Australia (Holm et al 2003), South Africa (O'Connor et al 2001), and Senegal (Diouf and Lambin 2001) have yielded similar results, Hein and de Ridder (2006) stated that incorrect understanding of the relationship between RUE and rainfall has led to a misinterpretation of the satellite record of desertification in the African Sahel. Also the Jornada Experimental Range at the Chihuahuan desert of New Mexico, USA has shown that desertification may not necessarily imply a reduction in ANPP, suggesting that RUE is a poor indicator.

On the basis of these studies and their numerous critics, this study was framed to advance knowledge on contentious issues relating to desertification such as static vs. dynamic, reversibility vs. irreversibility, spatial and temporal scales and more importantly the need for long term analysis, which is in a continuum. Some critical observations in going forward with this study was that Lamprey followed the then prevailing static view, while Prince et al (1998) might have used only 9 years of data, although other scientist including Prince (2002), Nsiah-Gyabaah (1994), Veron et al (2006) have underscored the importance of long-term ecological data in desertification studies.

Whereas long-term and continuous analysis is important, this study finds that spatial pattern of degradation differ from place to place and from time to time which may be attributed to land use types and intensity. The study therefore concludes that although the general surfaces appearance is important, localized degradation and short term degradations are likely to be overlooked. Assessing desertification in continuum should reflect both temporal and spatial degradation trajectories. These trajectories have implications for identifying the cause or causes of degradation and developing targeted approach both at the regional and local levels. In the case of the UER, efforts at combating desertification would more likely be effective at locality level where decisions on land preparation, including the use of fire, the timing and the method of cultivation is likely to be effectively enforced. Similarly the agricultural system of the area, which is based on small-holder farming system where average farm size is about 3 hectares make it important to understand small area and shorted land degradation trajectories since the cumulative effects leads to extensive degradation over long period of time commonly known as desertification.

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