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Spatiotemporal Response of Vegetation to Rainfall and Temperature fluctuations in the Sahel. Case study in the Forest Reserve of Fina, Mali

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Abstract: Forests constitute a key component of the Earth system but the sustainability of the forest reserves in the semi-arid zone is a real concern since its vegetation is very sensitive to the climate fluctuation. The understanding of the mechanisms for the interaction vegetation-climate is poorly studied in the context of African Sahel. In this study, the characteristics of the vegetation response to the fluctuations of precipitation and temperature is determined for the forest reserve of Fina. Rainfall estimates, air temperature and NDVI are used to establish the lag correlations between fluctuations of vegetation and climate variables at both seasonal and interannual bases. Results shows increasing tendency of NDVI started from the 1990s coinciding the recovery of the rainfall from the 1980s drought and the obtained correlation(r=0.66) is statistically significant (pvalue<0.01). The strongest responses of vegetation to rainfall and temperature fluctuations were found after 30 and 15 days, respectively. Moreover, at shorter time lag (e.g. 15 days) more pronounced vegetation responses to both rainfall and temperature were found in agricultural dominated land while at longer time lag (e.g. 30 days) stronger response was observed in Bare dominated land. The vegetation response to the climate fluctuation is modulated by the land use/cover dynamics.

Keywords: NDVI, Rainfall, Air temperature, vegetation response, Fina Forest Reserve, Mali.

1. Introduction

The Sahel is a sub-region of sub-Saharan Africa stretching between about 12° and 18° latitude north and characterized by the transition from the arid conditions of the Sahara desert and the humid climate from the Guinea coast. The sub-region is undergoing serious impacts of climate variability with high fluctuations in the vegetation [1]. The interaction vegetation-climate is very strong in semi-arid zone as the Sahel. Since 1950 the population in Africa had quadrupled and is projected to quadruple again until the end of the twenty-first century [2]. Enormous population growth and urbanization contribute as factors to alter the ecosystems specially forest [3]. The understanding of the mechanisms of the interaction vegetation-climate remain a challenge and it is poorly studied in the context of African Sahel.

Climate change constitutes a shift in meteorological condition that last for a long period of time usually centuries while climate variability is a short-term fluctuation happening year to year [4]. The United Nations Intergovernmental Panel on Climate Change [5] defines Climate variability as 'any change in climate over time, whether due to natural variability or as a result of human activity'. In sub-Saharan Africa subsistence agriculture, which is the backbone of economic activity for the majority of the people, is threatened by impacts of long- and short-term climate variability. Existing forest reserves act as buffer zones to reduce the negative impact of climate variability on community livelihoods through regulating the overall ecosystem functionality. Hence it is crucial to understand the impact of climate variability on existing forest vegetation reserves in order to implement mitigation measures and adaptation strategies for communities to improve their resilience and livelihood conditions. Existing forest reserves are essential in regulating ecosystem functionality through the reduction in CO2 emissions as a result of deforestation. Since forests are altered by both natural and human pressure, it become more complex to evaluate the response of vegetation change from the climate fluctuations. Indeed, the forest reserve of Fina is one of the natural reserves in Mali with limited human activities [3]. Thus, this reserve constitutes a good case for quantifying the extent that vegetation responses to the climate fluctuation.

Forest vegetation is very sensitive to climatic fluctuations and has strong control over the flow of water, carbon and energy between land and atmosphere [6]. It is expected that this flow would alter with the changing climate and rainfed agriculture that is prevalent in Mali. In recent decades, there has been an increased interest to study the effects of climatic change, mainly rainfall and temperature, on existing forest vegetation distribution and ecosystem functions. It is generally agreed that most eco-systems on earth have been modified to various degrees by human disturbance and climate change [3].

Prolonged drought is the greatest threat to livelihoods and ecosystems in forest reserves of Mali, and is a leading driver to desertification when combined with in-creasing human pressure on land resources. Mali is among the fastest growing countries in sub-Saharan Africa with an annual population growth rate of nearly 3% [7] resulting in the conversion of an estimated 100,000 hectare of land each year to cope with the rising food needs Convention on Biological Diversity [8]. The study area, Fina forest reserve of the 'Boucle de Baoulé' was very rich in biodiversity thirty years ago, and is declining towards degradation in recent years. Studies highlighted that the alteration of the vegetation in Fina forest reserve [1] resulted from a climate deterioration effect (which is drought) and high pressure associated with agricultural and pastoral activities. The vegetation in the Fina forest reserve suffered from effects of the 1980s drought [1], and partially recovered since then due to the presence of good rain (mean annual rainfall 1100 mm). However, the impact of that partial recovery in the rainfall [9] on the trend of the vegetation cover in Fina reserve is not well established. Thus, there is need to study the relationship of rainfall and climate variability on the vegetation index of the forest reserve in order to provide informed and targeted guidance to decision makers for forest reserve protection.

Many authors [10, 11, 12] used NDVI to study the response of vegetation dynamics to climate variability. This relation is evaluated at every scale from local to global scales and the results showed strong relationship between rainfall and vegetation index. Furthermore, various studies obtained positive correlation between vegetation and rainfall for 10 days, month, seasonal and interannual data across the worldwide [12]. Hence, the interaction between vegetation dynamics with climate variability is una-voidable in global change studies according to [13, 14].

Previous study [15] indicated that the water balance is directly influenced by the fluctuation of precipitation and temperature causing changes in soil moisture regime which, in turn, in-fluences plant growth. It is established that in the semi-arid region, the correlation be-tween NDVI and precipitation is highest for a multi-month average and NDVI is con-trolled by soil moisture in the concurrent month [16]. Also, temperature has a negative influence on vegetation growth [10]. Many studies have reported on the relationship between rainfall and NDVI and few touched the lag correlation between them. Similar to rainfall, air temperature effect on NDVI was assessed by many authors but there was few or no study on the lag correlation between climate factors and vegetation. It was also observed that interannual relationship was assessed while studies omitted the re-covered period of vegetation from natural events as drought.

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Focusing in Fina forest reserve, the objective of this paper is to determine how NDVI is correlated to rainfall and temperature with the view to understand the response of vegetation to the fluctuation of these climate variables. This study addresses three key questions: first, how vegetation responds to annual rainfall variability? Secondly, at which lag time vegetations give maximum response to the intra-seasonal fluctuations of precipitation and temperature? Thirdly, are the vegetation response to climate strongly modulated by the land-use/cover dynamics?

2. Materials and Methods

2.1. Study Area

2.1.1. Location and site characteristics

The forest reserve of Fina is located in Kita local administration [17], between 13°10′ - 13°40′ north latitude and 9°30′ - 9°50′ west longitude (Figure 1). Fina forest re-serve cover an area of 136,000 hectare. Rainy season occurs from Mai to October with a maximum rainfall in August. The forest reserve is located between isohyets 800 to 900 mm with an annual mean temperature of 35° C. The hydrographic in the reserve are an affluent of the Senegal River, Baoulé and its effluent Kénié (Figure 1(b)). The soils fertility is relatively weaker and silty texture, which leads to compaction and erosion in the aquifer [18].

2.1.2. Land use Map

The study area is classified into seven classes of land uses and covers [19, 3]: agriculture, water, bare land, steppe, savanna woodland, shrub savanna and forest. This classification is obtained from 2017 Landsat-8 image. As indicated in Figure 1(c) steppe occupied the greatest area among all land use class with 47%. Steppe cover is characterized by grassy formations, comprising a discontinuous herbaceous carpet and mainly of annual species, with sometimes the presence of woody plants. The woody has low density and height lower than ten meters. Mostly, it finds in the driest zones, with the accesses of the deserts of the Sahara. The smallest area is water body (1%) followed by shrub savannah and agriculture with 4 and 6% respectively.

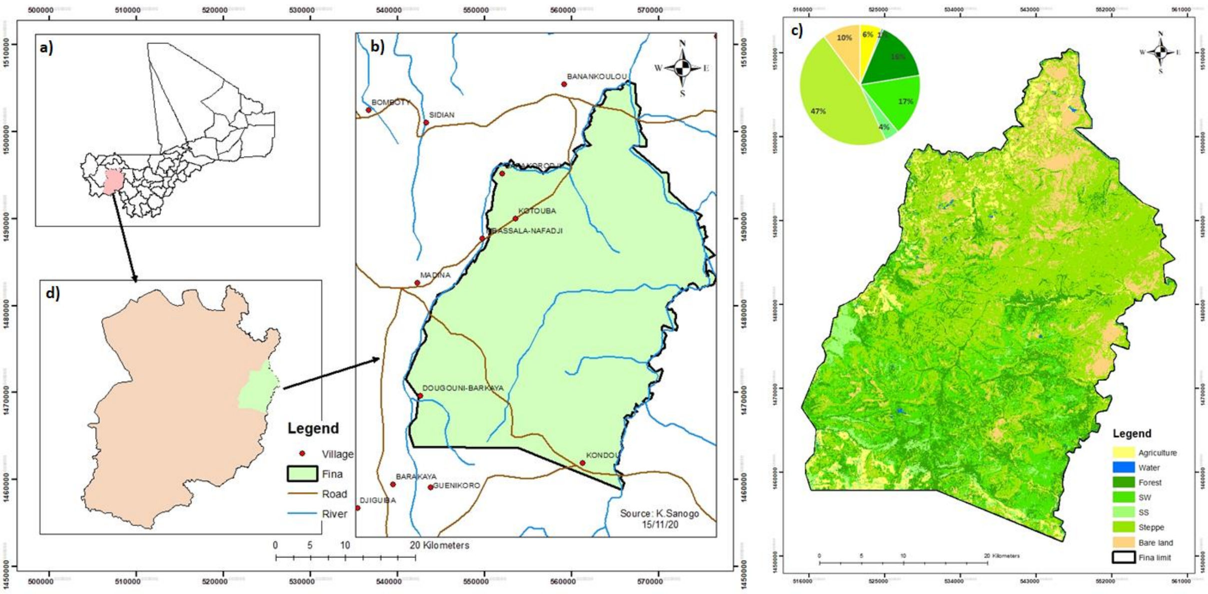

Figure 1: Map of Mali (a) showing the administrative department of Kita with the indication of the forest reserve of Fina (d). Panel (b) refers to the geographical map of reserve and panel (c) refers to land use map with the percentage of land use and land cover classes.

The stone plateau, characterized by shallow soils, and bushfire effect are aggregated to bare land (10%). Savanna woodland and forest have covered area of 17% and 16% of the total area. In Figure 1(c), it is clearly observed that 83% of Fina forest reserve is occupied by vegetation while only 17% of water, agriculture and bare land. Most of the agricultural land are located to the northwest and southwest part of the forest reserve.

2.2. Data Description

2.2.1. Rainfall and Air temperature data:

The African Rainfall Climatoloy version 2 (ARC2) dataset was used for this study and it consists of daily data with a spatial domain of 40°S to 40°N in latitude, and 20°W to 55°E in longitude encompassing the African continent from 1st January, 1983 to the present. The data of ARC2 uses an operational rainfall estimation algorithm [20], and it is updated to Rainfall Estimates Version 2 [21]. The ARC2 rainfall constitutes a good product over African Sahel. Authors [9] used many rain gauges data of west Africa to validate ARC2 rainfall products, significant correlations were found for stations in the Sahel. The land surface temperature from MODIS through its Aqua sensor was used. This data was 1km spatial resolution and 8-days composites available from 2002 to 2017.

2.2.2. Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) uses the red and near-infrared bands of the electromagnetic spectrum for analyses of live green vegetation or not. NDVI is an index which depends on the percentage ground cover of vegetation, ground water, and the amount of biomass. NDVI derived from satellite data is an important indicator that is used to analyze vegetation dynamics and its response to climate variability in worldwide [22]. This index is also used to monitor the spatiotemporal vegetation dynamics and eco-climatological studies. Its value ranges between -1 (water bodies) and 1 (dense vegetation). The conventional formula used to compute is as follows:

$$\boldsymbol{NDVI} = \frac{(\boldsymbol{NIR-RED})}{(\boldsymbol{NIR+RED})} \quad (1)$$

where NIR and RED denote spectral reflectance in the near-infrared (800-1000 nm) and red (620-750 nm) portions of the electromagnetic spectrum, respectively.

Two distinct datasets of NDVI were acquired from Global Inventory Modelling and Mapping Studies (GIMMS) for the period of 1983-2005 and from Moderate Resolution Imaging Spectroradiometer (MODIS) for the period of 2006-2017 (Table 1).

Table 1: Description of climate variables, vegetation index and land images used

Data	Source	Period used	Time interval	Spatial Resolution	Product Availability
Rainfall	ARC2[1]	1983-2017	Daily	0.1 degree	1983 to present
Temperature	MODIS[2]	2006-2017	8 Days	1 km	2006 to present
Landsat 8 Image	GLCF	2017	-	30m	2013 to present
NDVI	GIMMS[3]	1983-2005	16 Days	8 km	1983-2005
	MODIS[4]	2006-2017	15 Days	1 km	2006 to present

[1]*ftp://ftp.cpc.ncep.noaa.gov/fews/fewsdata/africa/arc2/bin*

[2]*http://iridl.ldeo.columbia.edu/SOURCaaES/.USGS/.LandDAAC/.MOD232IS/.1km/.8day/version005*

[3]*http://iridl.ldeo.columbia.edu/SOURCES/.UMD/.GLCF/.IMMS/.NDVIg/.global/.ndvi*

[4]*http://iridl.ldeo.columbia.edu/expert/ SOURCES/USGS/LandDAAC/MODIS/version_005/WAF/.*

2.3. Methods of analysis

2.3.1. Data preprocessing

Climatic parameters were downloaded from NOAA website in NetCDF format then processed using R software. The ARC2 product was used to calculate 15 day, monthly, and annually mean rainfall. 15-day and monthly mean temperature are calculated form the data derived from MODIS. The land cover map was produced from Landsat 8 data using maximum likelihood classification. The two products of NDVI being at different resolutions, the MODIS NDVI had been transformed and regridded to the resolution of GIMMS data. The two data were normalized with respect to their respective mean before concatenate them for time series analysis.

2.3.2.Standardized and Normalized Anomaly

In order to properly compare variables with different scales and units, all data had been standardized with respect to their respective long term mean and standardized deviation. The method used for calculation of the Standardized Precipitation Index (SPI) and standardized NDVI (sNDVI) is described in [24]. The formulation of the standardization is given by:

$$\boldsymbol{Z} = (\boldsymbol{x} - \boldsymbol{\mu})/\boldsymbol{\sigma} \quad (2)$$

Where:

x: data series

σ: standard deviation of the whole data series

μ: mean value of the whole data series

Z: standardized value of a year.

The normalized anomaly (X) for a given variable is computed with the following formulation:

$$\boldsymbol{X} = (\boldsymbol{x_i} - \boldsymbol{x_{min}})/(\boldsymbol{x_{max}} - \boldsymbol{x_{min}}) \quad (3)$$

Where:

x_i: data series at time i; x_{min}: minimum value of the data series; x_{max}: maximum value of the data series and X: normalized series between 0 and 1

2.3.3.Lag-Correlation Analysis

Lag correlation refers to the correlation between two time series shifted in time relative of one to another. Lagged correlation is important in studying the relationship between rain fall, temperature and vegetation for two reasons. Firstly, one series may have a delayed response to the other series, or perhaps a delayed response to a common stimulus that affects both series. Secondly, the response of one series to the other series or an outside stimulus may be "smeared" in time, such that a stimulus restricted to one observation elicits a response at multiple observations. The simple correlation coefficient between the two series properly aligned in time is inadequate to characterize the relationship in such situations. In the present study the lag correlation is established between vegetation index and climate variation at lag0, lag1, lag2 and lag3, vegetation being leaded by precipitation and temperature.

3. Results

3.1. Spatial distribution of Rainfall, Temperature and NDVI

Figure 2 shows the spatial variation of the long-term mean of the annual value of rainfall, temperature and vegetation in Fina reserve. Rainfall show strong spatial variation decreasing from south to north. This observed rainfall gradient is typically the characteristic of West African monsoon which carried moisture from the Gulf of Atlantic Ocean to the subregion and decrease in intensity northward. The spatial variation of NDVI showed higher vegetation cover in southern part of the map. The northwest and central part of the forest reserve exhibit lower vegetation index as result of the pressure induced by agricultural activities, charcoal exploitation and the shallow soils characteristics in some areas. Bare land areas showed a very limited canopy and it appeared on hill area over the northeast part of the reserve. NDVI index depends to reflectance of different vegetation types and steppe class showed lower vegetation index. Temperature is varying from 28°C to 43°C with an average of 35°C. Higher temperature is observed in the northern area while the lower value is recorded in the southern part of the forest reserve. The variation of vegetation and temperature are in opposite direction as high temperature make rise the evapotranspiration inducing lost in the water available for plant. In sum, the observed distribution of NDVI (maximal in the south and minima in north) is significantly explained by the rainfall precipitation pat-tern which is abundant in the south and weak in the north. However, the south-north gradient of the NDVI is in negative agreement with the temperature distribution which is higher northward.

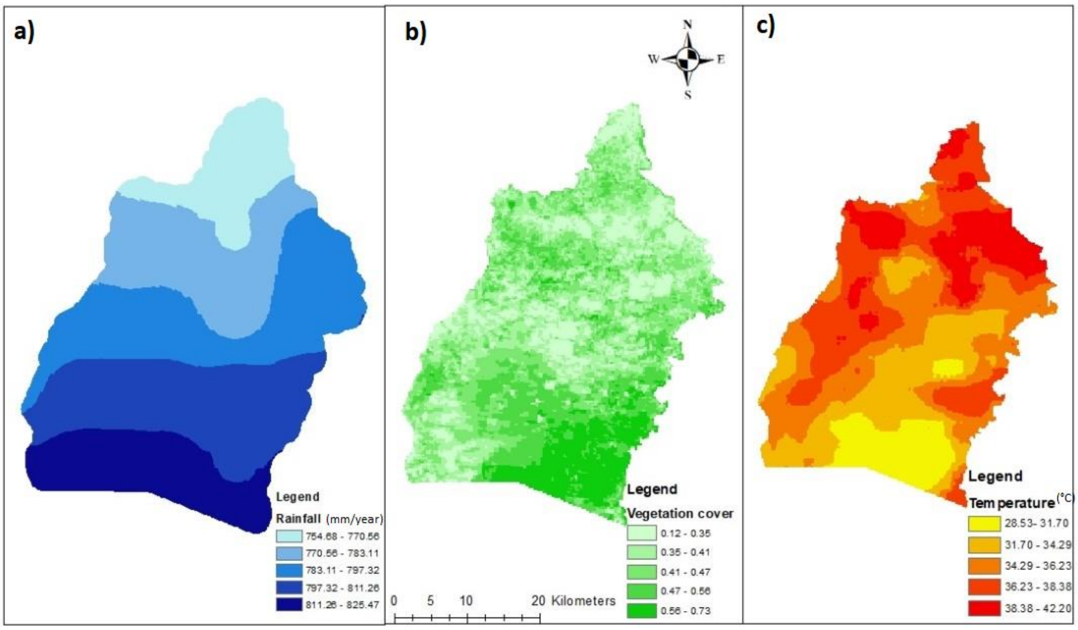

Figure 2: Maps showing the spatial distribution of rainfall (a), NDVI (b) and temperature (c) over Fina reserve.

3.2. Vegetation year-to-year response to rainfall variability

The annual rainfall exhibits strong inter-annual variability and the years of the entire 1980s and half of 1990s recorded lower than the normal rainfall. This period is known as the Sahel drought which has affected the entire ecosystem across the whole sub-region. During this dry period, vegetation had seriously declined by the negative water budget resulted by low rainfall and high evapotranspiration. After this period, some partial recovery is observed in the rainfall amount which started around 1998. The 2000s decade recorded higher than normal rainfall except for the years 2006 and 2007 which recorded rainfall amount below normal.

Figure 3 depicts also the time series of vegetation index variation which showed a weaker vegetation cover on the years 80s and 90s. The NDVI was below normal during the period from 1983 to 2000. It appeared that the vegetation had recovered three year later after the starting of the rainfall recovery. This period corresponded to the re-greening of the vegetation over the entire Sahel.

The time series of vegetation and rainfall standardized index (Figure 3) high-lighted the strong the dependence of vegetation to the rainfall fluctuation. It reveals the weaker resilience capacity of vegetation to drought conditions which is caused by the excessive evapotranspiration under the dry and warm climate conditions of the Sahel. However, after the prolonged period of drought, three years (1998-2000) were sufficient to regenerate the vegetation growth. A positive 3-year lag relationship existed between annual rainfall variability and vegetation growth in the study area, which is remarkably important to consider for any conservation strategies that enhance biodiversity in Fina forest reserve.

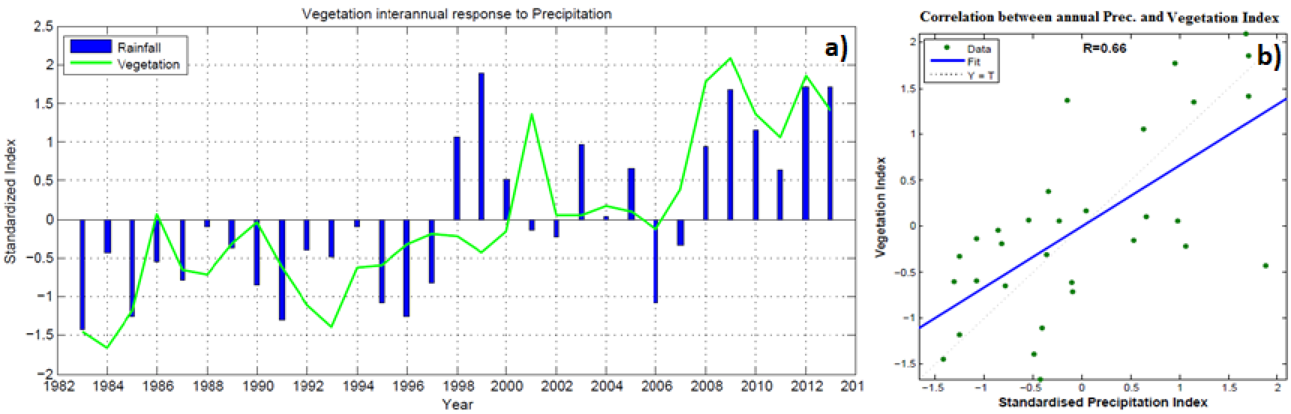

Figure 3: Time series (a) and linear regression (b) of NDVI and standardized precipitation index from 1983 to 2013 over the Fine forest reserve.

The variability of annual rainfall has a major contribution to the interannual dynamics of vegetation in Fina reserve. The linear correlation is evaluated to r=0.66 and exceeds 99% level of significance. In the semi-arid region under the high temperature and high evapotranspiration, the amount of water available to the plant is strongly influenced by the input rainfall. The variability of annual rainfall constitutes of the primer factor of the annual vegetation dynamics in Fina forest reserve.

3.3. Seasonal response of vegetation to rainfall and air temperature fluctuations

The seasonal variability of the biweekly mean value of rainfall and NDVI for the period of 2006-2013 is indicated in Figure 4. The rainfall amount is very low from November to April and the NDVI shows very weak pattern during this dry season ac-companied by an excessive high temperature. High vegetation cover appears during the rainy season with the occurrence of rainfall from May to October. The maximum value of rainfall occurred in early August coinciding with the minimum of the temperature while the vegetation index showed a maximum value in one month later in September. The lag-correlation analyses involved lag 0 (for the covariation), lag 1 (SPI is two weeks ahead on sNDVI), lag 2 (SPI being four weeks ahead on sNDVI), lag 3 (SPI being six weeks ahead on sNDVI).

3.3.1. Relationship between Rainfall and Vegetation at seasonal

Vegetation and rainfall exhibit similar seasonal pattern (Figure 4) in terms of climatological mean, but for one year to another, the two seasonal patterns may present some discordance. This was observed in 2012 (Figure 4) where the weaker amount of rain in July was not reported in the variation of NDVI.

Also, in 2007 the peak of rainfall has occurred early in July consequently the vegetation index reached its maximum in August. The analysis presented in Figure 4 indicates a lag of two bi-weeks (one month) between the peak of rainfall and vegetation, as the peak of vegetation occurs one month later to the peak of rainfall. Vegetation growth increases progressively and then became stable around August-September as it reaches its peak then, it starts decreasing in response to the retreat of rains.

The spatial lag correlation between the seasonal vegetation index and rainfall are seen in maps of Figure 5. Correlation coefficients are evaluated between the standardized values SPI and sNDVI from 1983 to 2017. The coefficients from lag-correlation varied from 0.61 to 0.81 for lag0 and 0.88 to 0.91; 0.64 to 0.82 and 0.23 to 0.50 for lag1, lag2, and lag3 respectively. Lag 2 showed the highest correlation between rainfall and vegetation index.

For lag 0 and 1, the spatial distribution of the correlation coefficients indicates high correlation in Eastern part of the reserve, which decreases Westward however the opposite is observed for lag2 and 3.

Scatter-plots in Figure 5 depict the regression line and the correlation coefficients between sNDVI and standardized precipitation index from 1983 to 2017. A high relationship is found between vegetation index and SPI at seasonal scale as vegetation growth is driven by rainfall amount with respect of the seasonal rainy season.

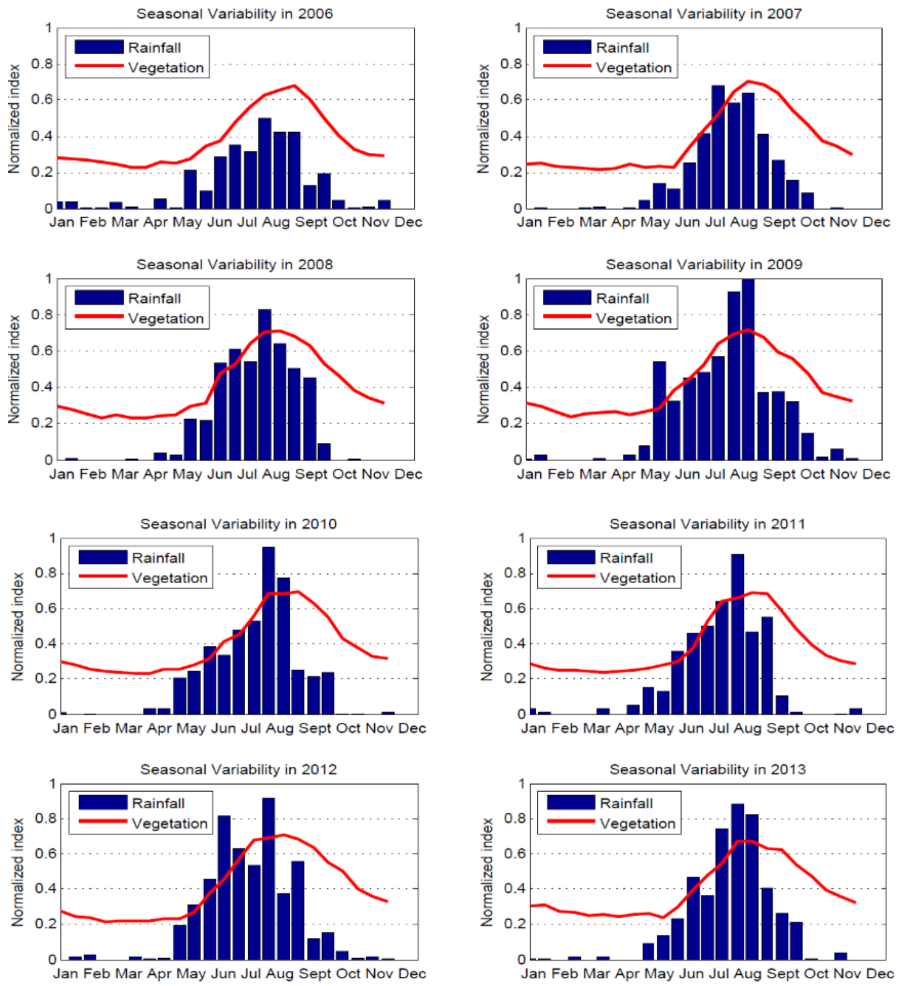

Figure 4: Seasonal variation of monthly rainfall (histogram) and vegetation index (red line) for individual years from 2006 to 2013

The highest correlation is observed at lag 2 (one-month lag). These results revealed that the maximum response of vegetation to rainfall occurred with two bi-weeks (one month) accumulation of rain. The finding is consistent with the one-month delay observed between the peak of the rainfall (early August) and the peak of Vegetation index (in September). The inspection of the lag2 correlation map (Figure 5) revealed stronger response of vegetation to rainfall over the western part of the re-serve where forest constitute the dominant land cover category. At lag1, the correlation coefficients are stronger in Eastern part of the reserve dominated by agricultural land.

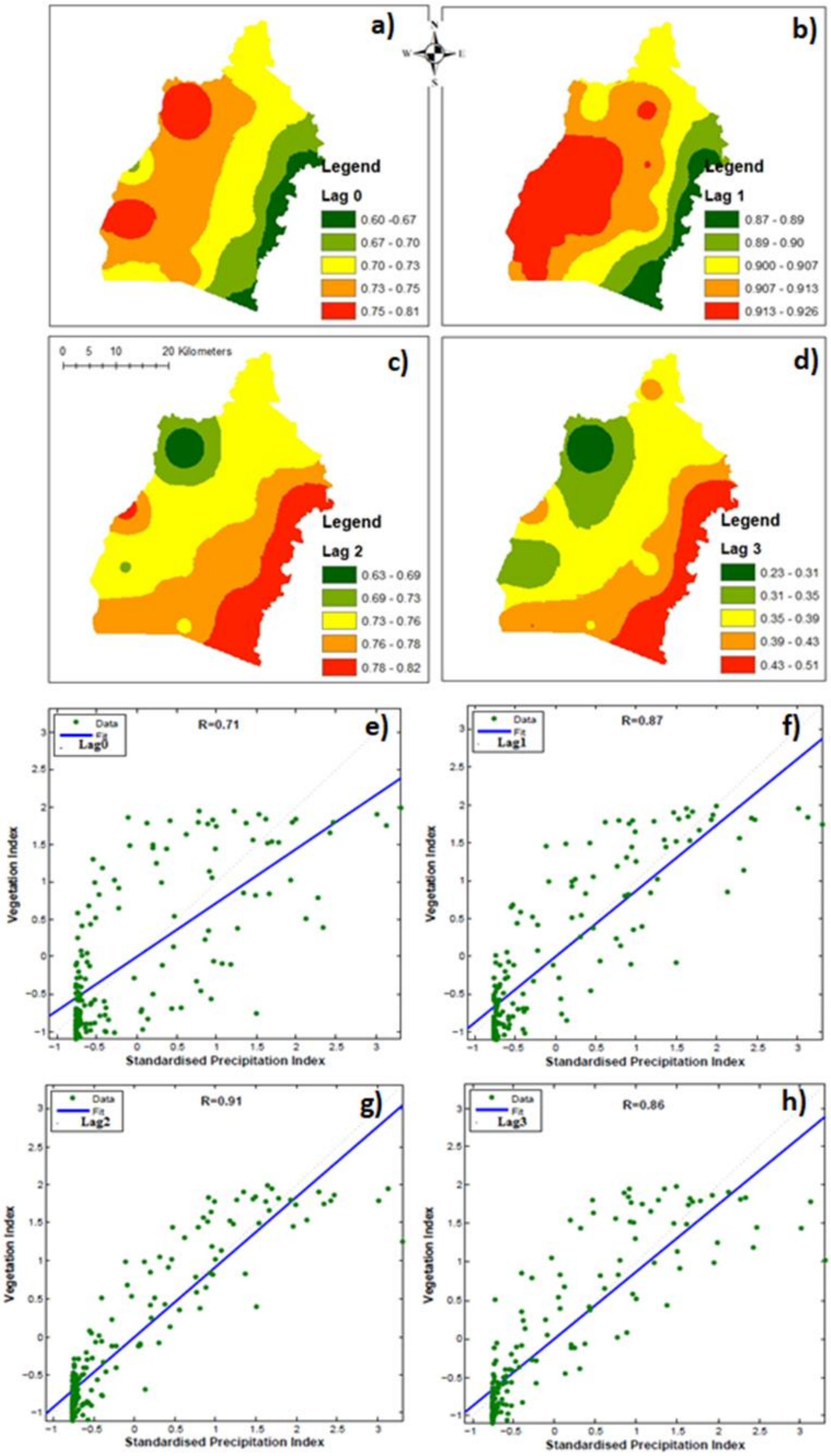

Figure 5: Maps are spatial lag-correlation and scatter-plots are temporal lag-correlation between rainfall and NDVI.

The southeastern border of Fina reserve is limited by a river where low correlation is observed at lag 0 and 1. Indeed, the relationship between vegetation growth and rainfall is a function of soil characteristics. Reserve area with stone and shallow soil as well cultivated soils exhibit a fast response of rainfall (lag0 and 1) and the response de-crease as the lag increases. This observation suggests that these land categories have limited capacity of water retention compared to forest. Furthermore, in forest area, vegetation shows higher correlation with rainfall at longer lag due to the capacity of soils to accumulate moisture.

3.3.2. Relationship between Vegetation and Temperature

The analysis in Figure 6 represents the seasonal cycle of maximum temperature and NDVI. In the study area the maximum air temperature ranges from 32°C to 38°C. The analysis shows that the highest value of maximum temperature is observed from March to mid-April while the lowest value of maximum temperature was recorded in August. Furthermore, high value of temperature steadily rises from September to October and declines from November to February coinciding with the harmattan period in Mali. The seasonal relationship between NDVI and temperature is represented for individual year from 2006 to 2013. Negative relationship exists between air temperature and vegetation index at seasonal time scale. The lowest temperature is recorded in August coinciding to the well greening state of the vegetation. The highest temperature is observed in April and the vegetation index presents the lowest value. The temperature during the period from March to May is very high with less moisture in the atmosphere. At this period the vegetation is strongly degraded whereas during the rainy season the atmosphere is very moist as a result the air temperature drop down and the vegetation grow remarkably with lower stress from higher temperature and reduced soil evaporation which in turn results in higher soil moisture storage. Therefore, there is a negative correlation between vegetation and temperature (i.e. scatterplots of Figure 7). Furthermore, the analysis indicated that temperature is a major impacting factor for plant growth with negative effect during the rainy season. The seasonal variation of temperature contributes strongly to NDVI change only at specific times of the growing season.

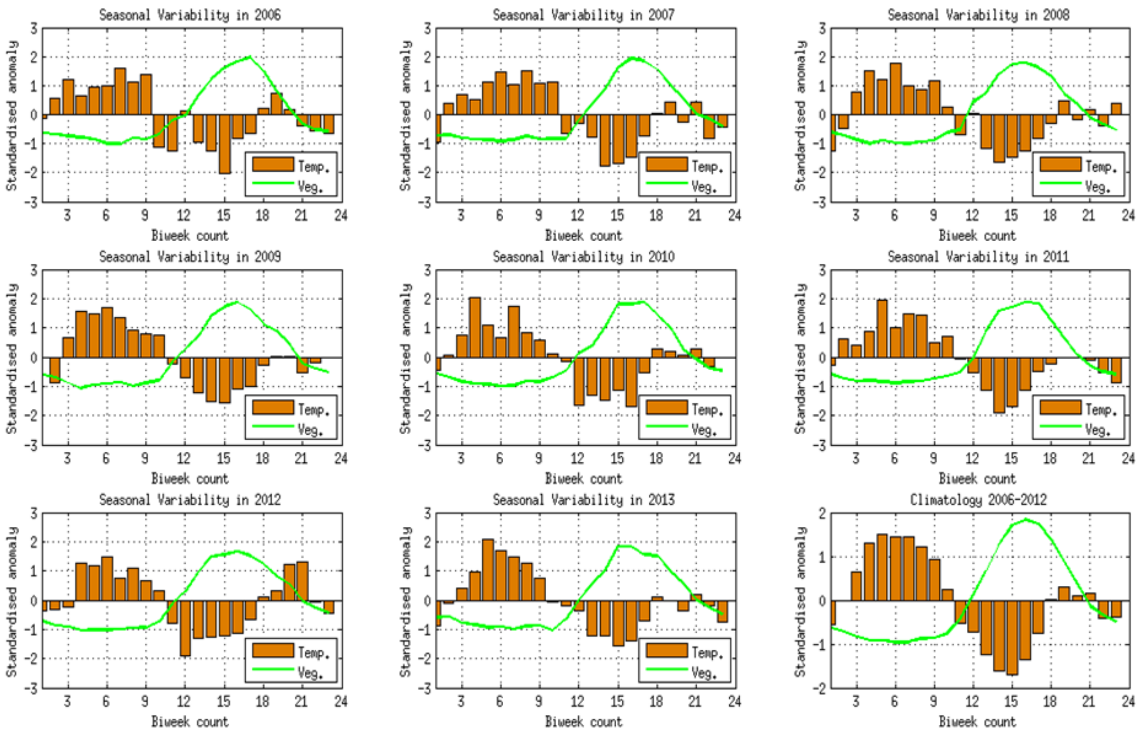

Figure 6: Seasonal variation of biweekly maximum temperature (histogram) and vegetation index (green line) for individual years from 2006 to 2013.

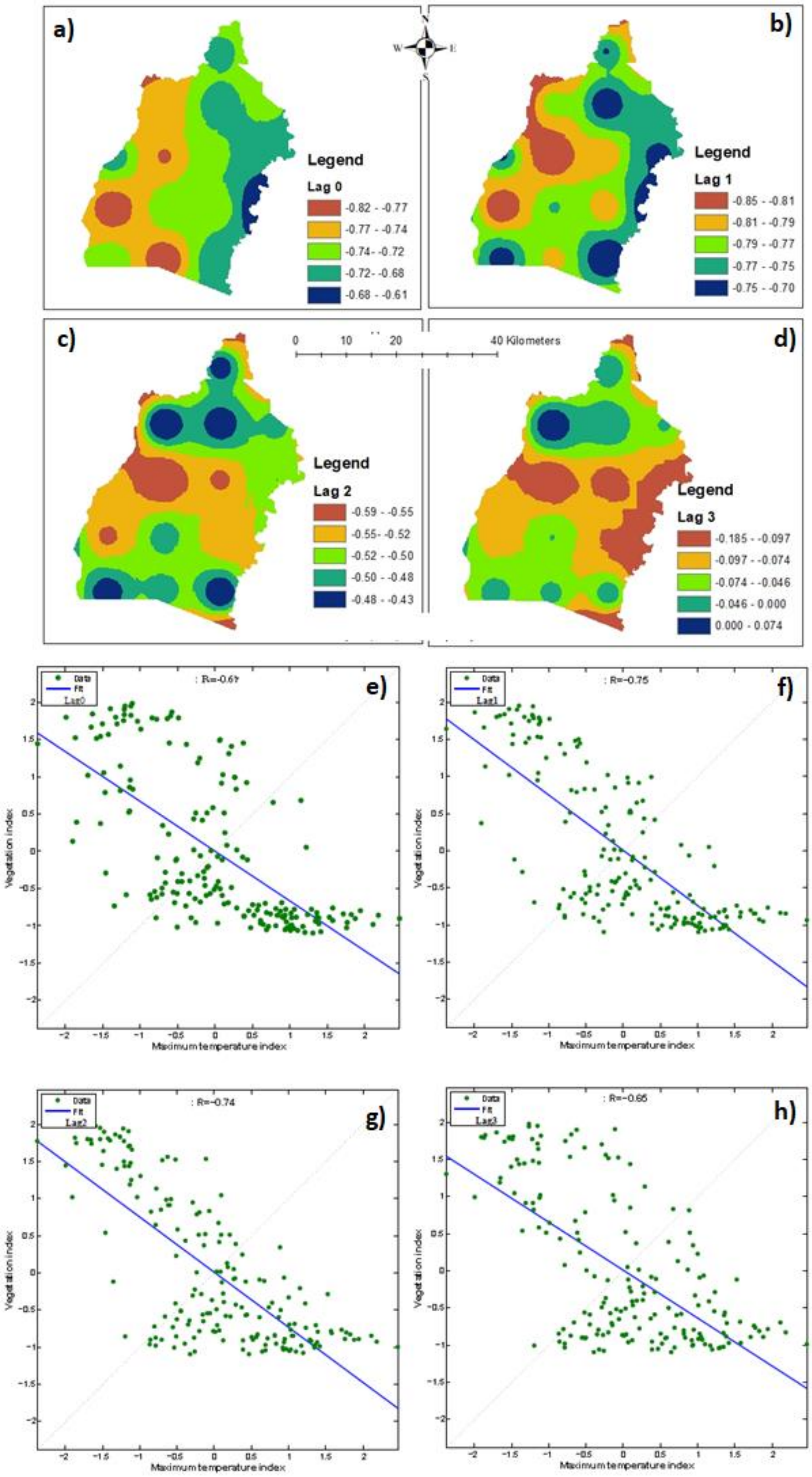

Figure 7: Maps are spatial lag-correlation and scatter-plots are temporal lag-correlation between maximum temperature and NDVI.

The scatter-plots (Figure 7) show strong negative correlation between the season-al variations of vegetation in response to temperature fluctuation. The lag0 correlation gives a coefficient of -0.67 significant at 0.01 level. Lag1, lag2 and lag3 show correlation coeffi-cients of 0.75, 0.74 and 0.65, respectively. All coefficients are statistically significant (pvalue<0.01). The maximum correlation coefficient is observed at lag1. This observation highlighted the presence of high response of vegetation to the variation of maximum temperature after a period of two weeks. Values are expressly higher in are-as surrounding by villages in the western part of the reserve.

The spatial distribution of the correlation coefficient between vegetation and temperature is shown on maps of Figure 7. The scatter-plots showed negative correlation between temperature and vegetation at all lags. The highest correlation observed at lag 1 (two weeks later) suggests that the maximum vegetation gives maximum response to temperature fluctuation after two weeks lag. The inspection of the Lag1-correlation map revealed stronger response of vegetation to temperature over the western part of the reserve where agricultural land constitutes the dominant land use category. The vegetation in central and eastern forest of the reserve shows stronger response to temperature later after one month (lag 2). The western area of reserve, nearby rural area and agriculture land is the most vulnerable to temperature variation.

4. Discussion

The increasing tendencies of the NDVI obtained in the forest reserve of Fina con-firm previous regional-scale findings that revealed increases in vegetation cover in the growing season across most parts of the Sahel in 2000s [1]. The vegetation dynamics and local rainfall are intrinsically linked and vegetation dynamics could provide in-formation about climatic state, such as drought conditions. This can explain the use of NDVI for predictions and impact assessments of disturbances such as drought [25, 26].

Rainfall is the most important constraint to vegetation growth in semi-arid zone. The variability of annual rainfall is a prime factor of the inter-annual vegetation dynamics, the coefficients of correlation obtained is slightly higher than the correlation found by previous studies at regional scale over western [27,28,29]. This difference in the correlation may be interpreted by the scale difference when comparing western Sahel region to the catchment scale of the forest reserve of Fina.

In this study, the maximum correlation between the biweekly values of NDVI and precipitation is found for a lag 2 period (one month) revealing that the vegetation gives maximum response to rainfall fluctuation after one month. This finding is in line with previous study suggesting that NDVI during the growing season is influenced by rainfall not only the concurrent month, but also rainfall accumulated in the preceding months [1]. This aspect is strongly supported by trends in soil moisture variation that indicate an accumulated lag in preceding months. Furthermore, others findings from investigation of Relationship between rainfall and vegetation Index by using NO-AA/AVHRR Satellite Images [30] revealed that the best correlation between NDVI and rainfall is one-month lag-time. However, it has been demonstrated that the response of NDVI to rainfall in the semi-aid region is not linear [31]. The response tends to be stronger within the condition of limited water availability, as more significant correlation between vegetation and rainfall variability from de-noised time series was associated to the Amazon drought [32]. Also, the low capacity of water retention of soils can be explained the significance of the vegetation response to the rainfall fluctuation [33].

The negative correlation between NDVI and maximum temperature could be resulted from the direct inhibition of photosynthesis or the inhibition of plant growth due to water stress or the association of lower temperatures with cloud cover during precipitation events. The present analysis cannot distinguish the causes of the observed negative correlation between vegetation growth and air temperature fluctuation. Results which are in line with several previous studies [11] revealed that the vegetation response to the variation of air temperature is maximal after two weeks period.

This study has contributed to a better understanding of the inter-annual between vegetation and climatic variables in local scale. The relationship between vegetation growth and rainfall is a function of soil characteristics. Reserve area with stone and shallow soil as well cultivated soils exhibit a fast response of rainfall (lag0 and 1) and the

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response decrease as the lag increases. This observation suggests that these land categories have limited capacity of water retention compared to forest. Furthermore, in forest area, vegetation shows higher correlation with rainfall at longer lag due to the capacity of soils to accumulate moisture. Nevertheless, further study incorporating soils data is recommendable since NDVI is found to be controlled by soil moisture of the concurrent month [15, 16].

Previous studies [36, 35] indicated the complexity and the significance of the relationship between the NDVI and various climate variables (rainfall, maximum temperature and minimum temperature etc.). To argue in the same way as others authors [37] more understanding on vegetation response to climate factors is required. We suggest further analysis involving the interactions between temperature, precipitation and other factors (such as evapotranspiration and soil moisture) which are more closely related to the NDVI throughout the season.

5. Summary and Conclusions

It is obvious that forests constitute a key component of the Earth system, however in the context of climate change the sustainability of the forest reserves in the semi-arid zone is a real concern since its vegetation is very sensitive to the climate fluctuation. The understanding of the mechanisms driving vegetation dynamics under climate conditions has great scientific socioeconomic advantage but such complex interactions is poorly studied in the context of African Sahel.

Applying lag-correlation approach between fluctuations of vegetation and climate variables at both seasonal and inter-annual bases, the present study has determined the characteristics of the vegetation response to the fluctuations of precipitation and temperature for the forest reserve of Fina and results are examined in the context of the existing land-use/cover classification of the forest reserve.

The analysis of the long-term time series of NDVI retrieved from GIMMS (1983-2005) and MODIS (2006-2017) reveal increasing tendency of vegetation cover started from the 1990s coinciding the recovery of the rainfall from the 1980s drought [23]. Strong relationship is found between the annual rainfall and NDVI and the obtained correlation(r=0,66) exceed the 99% level of significant (p-value<0,01). Using biweekly data, the precipitation leading correlation with NDVI was the strongest (r=0,91) at lag 2 while the temperature leading correlation with NDVI showed the highest negative correlation (r=-0,75) at lag1. Therefore, it can be established that the strongest responses of forest vegetation to rainfall and temperature fluctuations were found at 30- and 15-days lag, respectively. Moreover, at shorter time lag (15 days) more pronounced vegetation responses to both rainfall and temperature were found in agricultural dominated land while at longer time lag (30 days) stronger response was observed in Bare dominated land. Indeed, human activities within the forest as agriculture and forest exploitation are found as a factor contributing to the vulnerability of the forest vegetation to the fluctuation of rainfall and temperature.

In sum, the modulation of vegetation response to the climate fluctuation by land use/cover categories is obvious in Fina forest reserve, nevertheless the study of such land surface process contributes to the understanding of vegetation-climate interactions which could be used by natural resource planners in the protection of forest reserves.

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