Diachronic analysis of the evolution of climatic parameters and land use in Kintignan - Siguiri (Republic of Guinea)

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ABSTRACT

This study is part of a logical continuation of several studies carried out in the Republic of Guinea on environmental challenges; climatic conditions coupled with the anthropogenic activities carried out by the Guinean populations on the natural heritage. This study area, located in the sub-prefecture of Kintignan, Prefecture of Siguiri, constitutes an economic lever with regard to economic activities, in particular the exploitation of gold practiced by more than 90% of the local population as well as others from the four regions of Guinea and neighboring countries. The approach consisted of an analysis of monthly data averaged for an accumulation period of one day on a special resolution 0.25°X0.25 or 25km X 25km of the climatic parameters (temperature and precipitation) from the Siguiri meteorological stations of on the one hand and high resolution European reanalysis data of the 5th generation (ERA5) from the European Center for Medium-Range Weather Forecasts (ECMWF) on the other hand. Satellite data (Sentinel2 and Landsat) from the years 2000 and 2019, 10-meter resolution as well as data from field visits were used in this present work for the analysis of changes. Precipitation and temperature status maps were produced using ERAS data with results displayed graphically over the period from 1980 to 2020. These results were calculated using annual precipitation totals and the annual averages of the mean air temperature at 2m were also calculated on each grid point from E1 and E2 respectively. Added to this are the simple anomalies (AS) for the annual averages of the mean temperature. Standardized Precipitation Index (SPI) to quantify precipitation deficit.

Keywords: *Climatic, Diachronic, analysis, parameters, Kintignan*

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1. Introduction

The Republic of Guinea is facing enormous difficulties related to a high spatio-temporal variability of climatic parameters. The poor distribution of rainfall coupled with temperature rises at different scales of the country and the degradation of natural resources (water, soil, vegetation) constitute real scourges which precarious the way of life of the populations. These, to meet their basic needs, engage in agro-pastoral activities and artisanal mining which accentuate the ecological imbalance and further compromise their survival.

The prefecture of Siguiri located in the northern part of Guinea has huge gold deposits. It is particularly sensitive to climate change due to a relatively fragile ecosystem and a way of life of the populations based on artisanal gold mining. Added to this is the low rainfall, a permanent characteristic of arid climates. The rural commune of Kintignan, our study area, is located between 11°36'N, 9°23'W and faces demographic and environmental problems due to unprecedented artisanal gold mining.

According to estimates by the United Nations Economic Commission for Africa, more than one million people are involved in this sector throughout the country (CEANU, 2011). In the special zone of Kintignan, for example, 75,000 people are involved in the process according to estimates by EGIS (2016: 216). These figures, even if they are approximations for the moment, highlight the commitment of operators to work in the gold sector, despite the serious health consequences, even fatal, that can occur. Almost all of these operators came from other regions of Guinea and certain neighboring countries such as Mali, Côte d'Ivoire and Burkina Faso.

In view of this environmental and social context, the diachronic analysis of the evolution of climatic parameters and land use in Kintignan is a privileged entry into the evaluation of interactions between man and his environment. Thus, the information that will come from the analysis of satellite images, in particular Landsat, will always remain one of the useful methods in identifying appropriate strategies for better managing land use. Several methods have been invented and applied for this purpose, with varying levels of effectiveness (Mas, 2000; Lu et al, 2004). Among these, the diachronic and multi-date analysis of land cover is one of the most used, because it is a method that also takes into account the spatial distribution of changes (Franklin et al, 2002 Griffith et al, 2003). This is an approach commonly applied by several authors (Ramankutty & Foley, 1999; Braimoh & Vlek 2005; Liu et al. 2005; N' Guessan et al, 2006; Tidjani et al, 2009; Kouassi, 2014; Soro et al, 2014).

With the objective of diachronic analysis of the evolution of climatic parameters and land use in Kintignan between 1982 and 2020 in order to assess the different trends in the evolution undergone by the natural landscape during this period, this analysis will allow with sure cost to determine the degree of degradation of the vegetable cover, and the water resources due to the anthropic activities. The result of this study will make it possible to produce essential decision-making support tools for development planning and land use planning.

2. Methodology

2.1 Presentation of the study area

Located between 10.8° and 12.5° North latitude and 8.74 and 10.2 West longitude, the prefecture of Siguiri is one of the areas most exposed to climate and environmental change due to its geographical position and the importance of mining activities (gold). Its climate is a humid tropical climate of the southern Sudanese (Sudano-Guinean) type, characterized by the alternation of two (2) seasons: a dry season from November to May and a rainy season from June to October (Mara, Bayo and Traore 2012) . In the dry season, the Harmattan blows from the East and North-East, a dry wind laden with dust. During the winter, the monsoon blows from the West and South-West, bringing humidity and abundant rainfall. (MEEF 2013) . The vegetation is dominated by wooded savannah. The Niger River crosses the area and the hydrography there is very dense, which further exposes the area to recurrent flooding (MEEF 2014) .

Since 2000, the largest gold company in the country has been established in this area. This has favored the massive influx of foreign populations, the proliferation of artisanal gold mining as well as increased pressure on the environment and natural resources in the area.

2.2 Climate data

The prefecture of Siguiri has a synoptic type meteorological observation station, whose observations of certain parameters predate 1970. But the increased interruption and irregularity of the observations of certain data, in particular precipitation and temperature, has led us use reanalysis data. The data used in this study are European high resolution 5th generation reanalysis data (ERA5) from the European Center for Medium-Range Weather Forecasts (ECMWF) (Hersbach, et al. 2020) .

ERA5 is the replacement for ERA-Interim reanalysis. It is based on the version of ECMWF IFS (Cy41r2) which was operational until 2016. It is one of the most used data in climate studies today (Sabater, et al. 2021). ERA5 data is accessible through the website https://cds.climate.copernicus.eu/ .

In this study, monthly data averaged for an accumulation period of one day on a special resolution 0.25°X0.25 or 25km X 25Km were used. Thus, a total number of 23 grid points are found in the prefecture of Siguiri, two of which are in our study area: sub-prefecture of Kintinian.

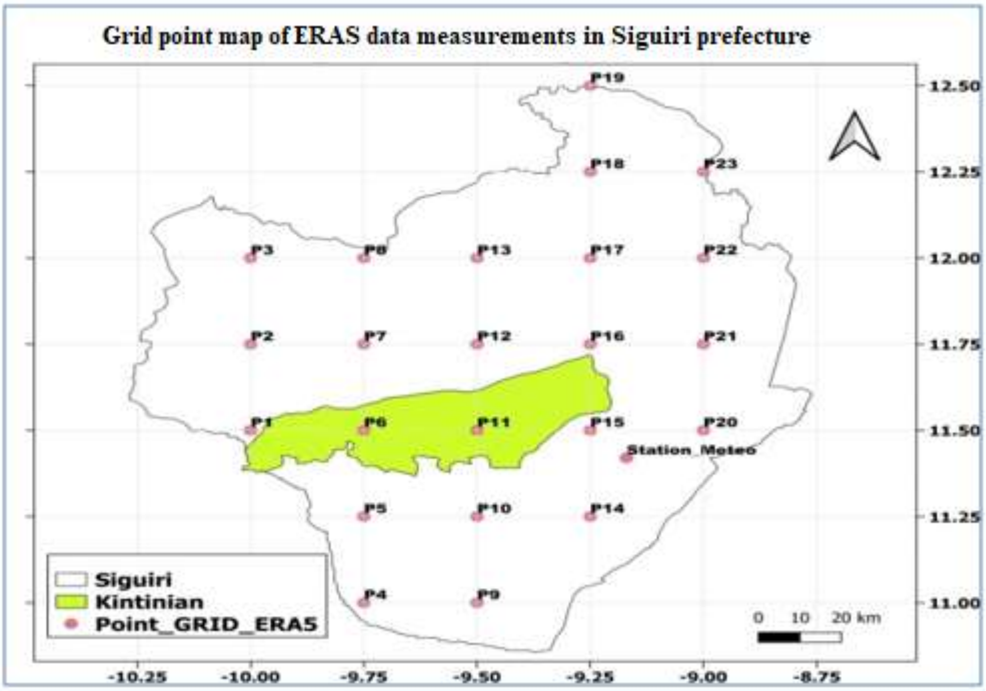


Figure 1: Grid point map of ERA5 data measurements in Siguiri prefecture

2.3 Environmental and cartographic data

Satellite data (Sentinel2 and LandSat) from the years 2000 and 2019, 10-meter resolution as well as data from field visits were used in this present work for the analysis of changes **. High resolution** Google earth pro imagery was also used for adjustment and validation of sentinel2 and Landsat imagery.

2.4 Data analysis and processing methods

2.4.1 Production of reference maps - Pivot 2018

This phase consisted in the production of the reference land cover database (BDOS) for the year 2018 based on recent high-resolution satellite image coverage (Sentinel2 type of 10 meters resolution). Several classification tests were carried out until a good classification was obtained before continuing with a visual interpretation. These tests also aimed to define the relevant thresholds, in particular the smallest mappable unit (MMU).

The classification was carried out using qgis software with integrated OTB tools. This made it possible to produce models and a kappa index of the classification. After the classification a visual interpretation of the vectorized data was carried out in order to clean and correct any errors that the classification could not take into account. During the visual interpretation high resolution google images (30 cm) were used.

2.4.2 Production of change maps - Pivot 1990

Once the 2018 baseline database was considered acceptable, land cover changes that occurred between 2018 and the 1990 pivot were identified and mapped. This step was only performed once the BDOS 2018 produced was validated. The proposed methodology for the assessment of changes was not automatic and was based on visual interpretation and comparison of images from 2018 and 1990.

2.4.3 Analysis and processing of climate data

After acquiring the climatic data, several processing operations were carried out before the analyses. Temperatures in degrees Kelvin were converted into degrees Celsius and precipitation in m were converted into mm (1m=1000mm). Since the precipitation data is monthly data averaged over an accumulation period of one day, it was multiplied by 30 (30 days) to estimate the monthly precipitation amounts. The grid points of the study area (Siguiri) were extracted and mapped. The annual accumulations of precipitation and the annual averages of the mean air temperature at 2m were also calculated on each grid point from E1 and E2 respectively (Tillé 2010) .

$$P_{recip_{totAN}} \sum_{i=1}^{n} P_i \quad ; \quad T_{emp_{MoyAN}} = \frac{\sum_{i=1}^{n} T_i}{N} \qquad \text{(E1) and (E2)}$$

Where $P_{reciptotAn}$ is the annual accumulation of precipitation, $T_{empMoyAn}$ is the Annual average of the average air temperature, Pi is the amount of precipitation of month i, Ti is the average temperature of the area of month i, N is the number of months in the year. As for the analyses, they focused on the trend and the interannual variability of the annual accumulations of precipitation and the annual averages of the average air temperature at the various points of the Grid. To characterize the trends, the linear regression coefficients (a) were calculated over the period 1981-2020 for each grid point and spatialized over the entire prefecture of Siguiri. Concerning the variability, we calculated and represented graphically for each grid point, the simple anomalies (AS) for the annual averages of the mean temperature.

Standardized Precipitation Index (SPI) to quantify precipitation deficit (McKee, Doesken and Kleist 1993) . To calculate the SPI index, it is ideally necessary to have monthly readings spread over at least 20 to 30 years, but preferably over 50 to 60 years, or even more, which constitutes the optimal period (Guttman 1994) . a probability distribution to this long series of readings, then it is transformed into a normal distribution so that the average SPI index, of the place considered and for the period of time studied, is equal to zero (Edwards and McKee 1997) . Positive SPI values indicate precipitation above the median and negative values indicate precipitation below the median. Since the index is normalized, it is possible to represent humid climates and arid climates in the same way; thus it is also possible, thanks to the SPI index, to monitor wet periods (WMO 2012) . The reference period for this study is 1991-2020.

Last name	Formula	Equation (E)
Linear regression coefficient (a)	$a = \frac{Cov(X,Y)}{(\sigma x)^2}$	E3
Simple Anomaly (AS)	$AS = X_{ti} - X_{tm}$	E4
Standardized Precipitation Index (SPI)	$SPI = \frac{Pi - Pm}{\sigma}$	E5

Or in - E3: Cov = covariance, Y= climatic variable series (Precipitation or temperature), X = years (observation period; E4: X_{ti} = Average temperature of year i, X_{tm} = Average temperature of the reference period; E5 : Pi= cumulative annual precipitation for year i, Pm = mean annual cumulative precipitation for the reference period.

3. Results and Discussions

3.1 Evolution of climatic parameters

3.1.1 Precipitation variability and trend

It emerges from the analysis of figures 2 and 3, not only a strong inter-annual variability of rainfall accumulations but also a downward trend in annual rainfall accumulations on all 23 grid points (Stations) (Loua, et al. 2017, Diallo, et al. 2019).

From the point of variability, the analysis of the standardized precipitation index makes it possible to distinguish four distinct periods:

- The 1981 -1995 period, a wet period with annual rainfall totals above the 1991-2020 reference average. It is a period when the rains have been abundant. The years 1994 and 1989 were the wettest during this period;
- The period 1997 – 2003: an unstable period, characterized by the alternation of wet and dry years.
- The 2004-2015 period, a dry period where the annual rainfall totals were lower than the 1991-2020 reference average. The driest years were 2004, 2006 and 2014 respectively.
- The 2016-2020 period, a wet period with annual rainfall totals above the 1991-2020 reference average. This denotes a resumption of abundant rainfall in the area.

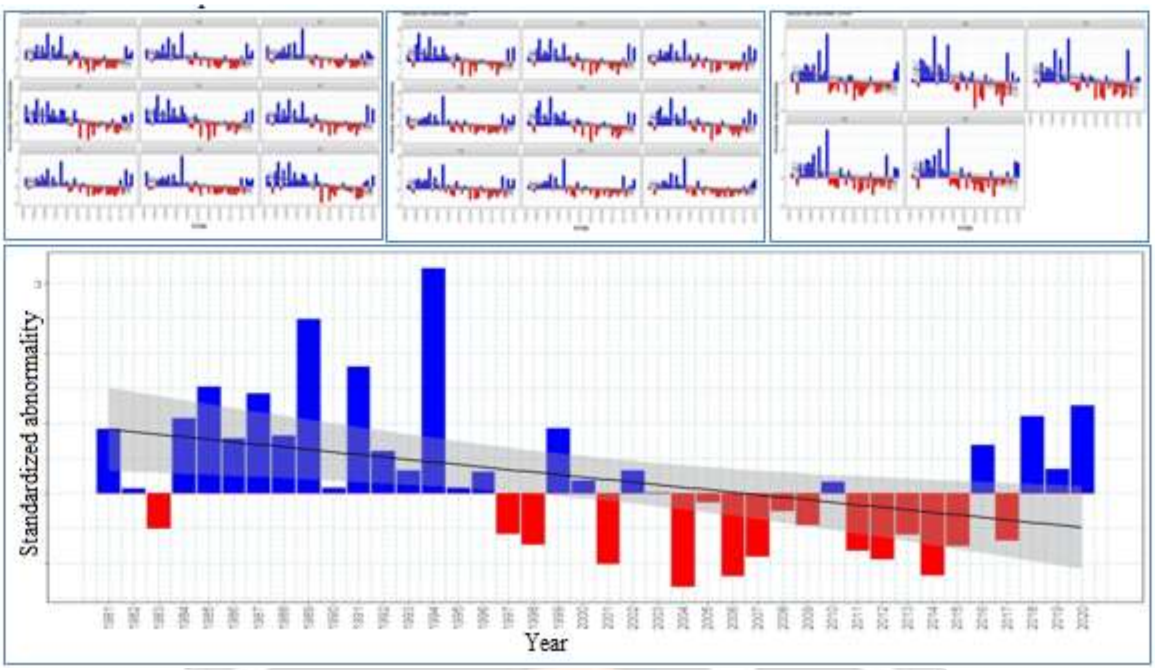


Figure 2: Standardized precipitation index compared to the 1991-2020 reference. Data source: ERA5

From the trend point, the values of the regression coefficient are all negative. This situation indicates a downward trend in rainfall over the entire prefecture of Siguiri, including the sub-prefecture of Kintinian. (Béavogui 2012, Diallo, et al. 2019). The value of the coefficient varies between -12 and -21, which means a decrease varying between 12 and 21 mm of rain per decade. This drop is also greater in the South, West and North-West of the Siguiri prefecture and lower in the central part of the study area (Figure 3).

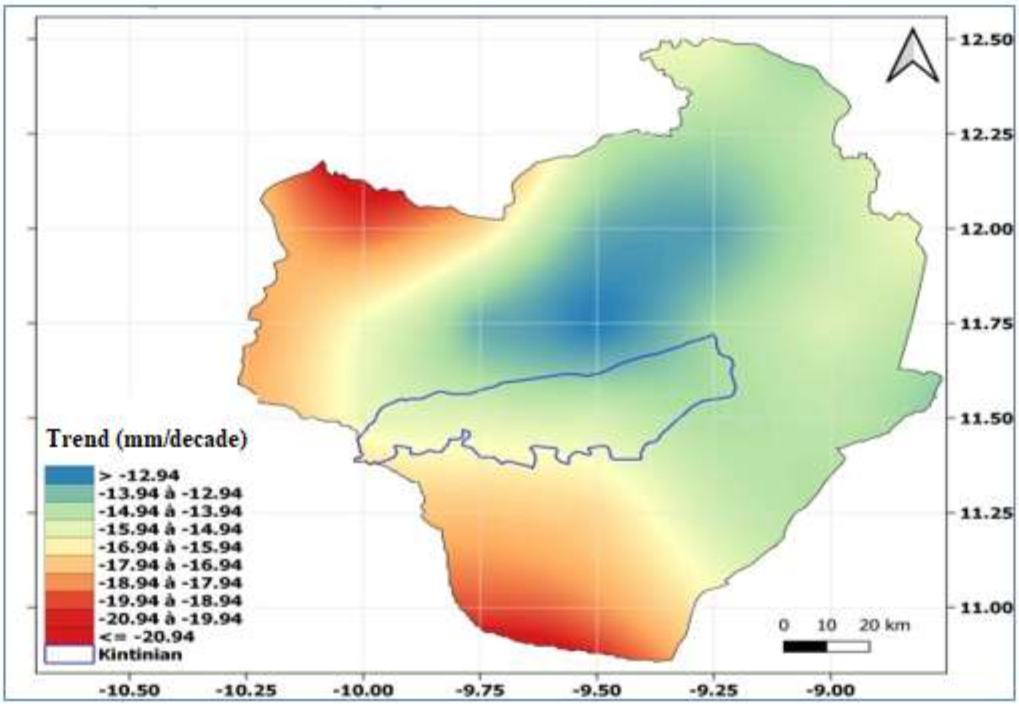


Figure 3: Trend of annual rainfall accumulations from 1981-2020. Data source: ERA5

3.1.2 Mean Air Temperature Variability and Trend

The inter-annual variability of average temperatures is unquestionably in the prefecture of Siguiri (Béavogui 2012). The analysis of the temperature anomalies compared to the period 1991-2020, indicates a strong interannual variability of the average temperatures at the level of all the points of Grid during the chronicle 1981-2020. The 1981-2001 period is a cold period (cool), characterized by the succession of negative temperature anomalies compared to the 1991-2020 average. The 2002-2020 period is a warm period, marked by a succession of positive anomalies in annual average temperatures. The years 2017, 2018, 2019 and 2020 are among the 7 warmest years observed in the study area since 1981. In the 1981-2020 chronicle, the years 1982 and 1986 are the coldest and the years 2005 and 2018 are hot ones (Figure 4).

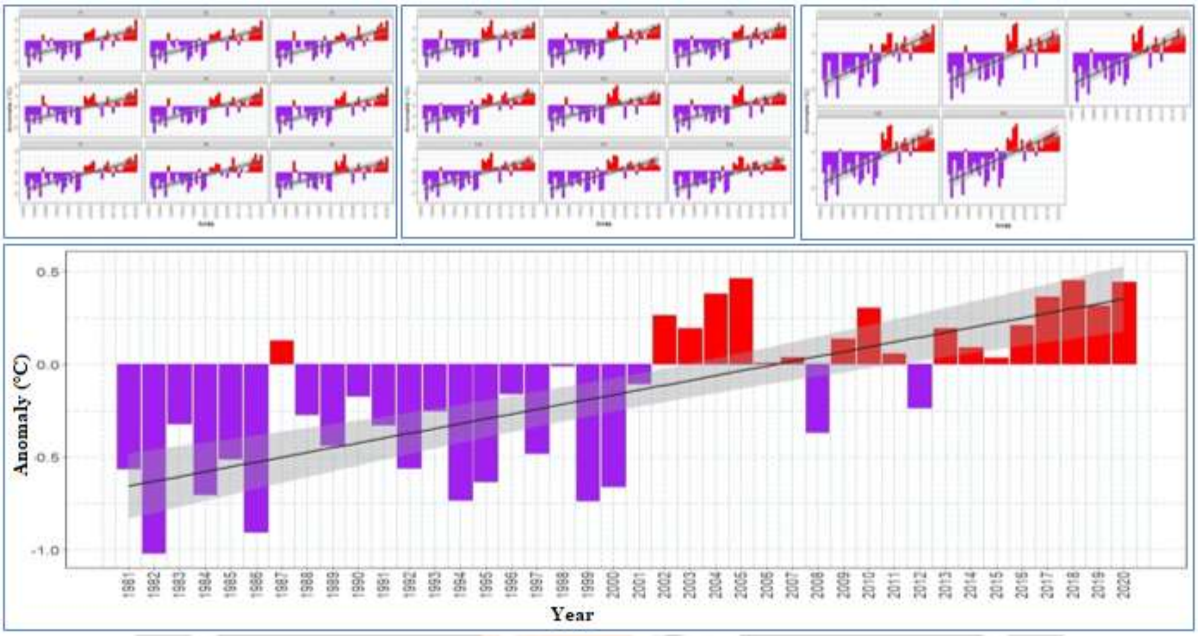


Figure 4: Average temperature anomaly relative to the 1991-2020 baseline. Data source: ERA5

Concerning the temperature trend, the coefficient of the regression line of the 1981-2020 series of average temperatures is positive on all the grid points. This situation indicates a warming trend for the entire prefecture of Siguiri including the sub-prefecture of Kintinian (Mara, 2010). Figure 5 indicates a warming trend varying between 0.21°C to 0.31°C per decade, i.e. a warming of 2.1°C to 3.1°C per century (Figure 5).
Moreover, it is the northern part, precisely the northeast of the Siguiri area, which records the strongest warming trends, i.e. more than 0.25°C per decade. Weak warming trends are recorded in the southern and southwestern areas of the Siguiri prefecture.

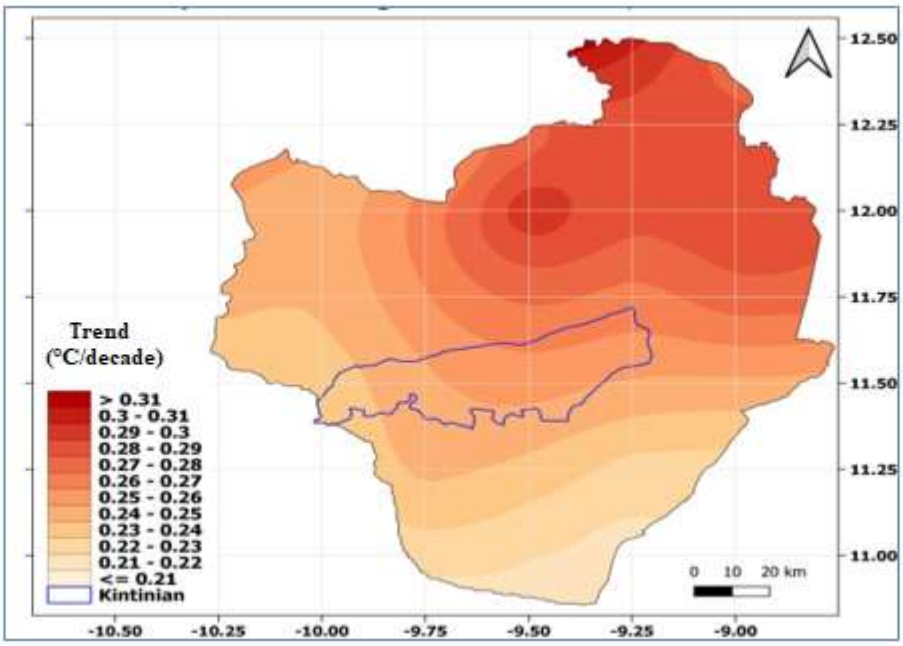


Figure 5: Trend of the average annual chronic temperature 1981-2020. Data source: ERA5

3.1.3 Comparison of standardized rainfall indices for the years 2000 and 2019

Analysis of standardized precipitation indices (SPI) for the year 2000 indicates moderate humidity in the south and southwest, low humidity in the center and low drought in the north. On the other hand, in 2019, moderate humidity was observed in the north, low humidity in the Center-North, and low drought in the Center-South and moderate drought in the south. In 2000, Kintinian observed moderate excess rainfall in the west and low over the parts. In 2019, rainfall was low deficit south of Kintinian and low excess in other parts.

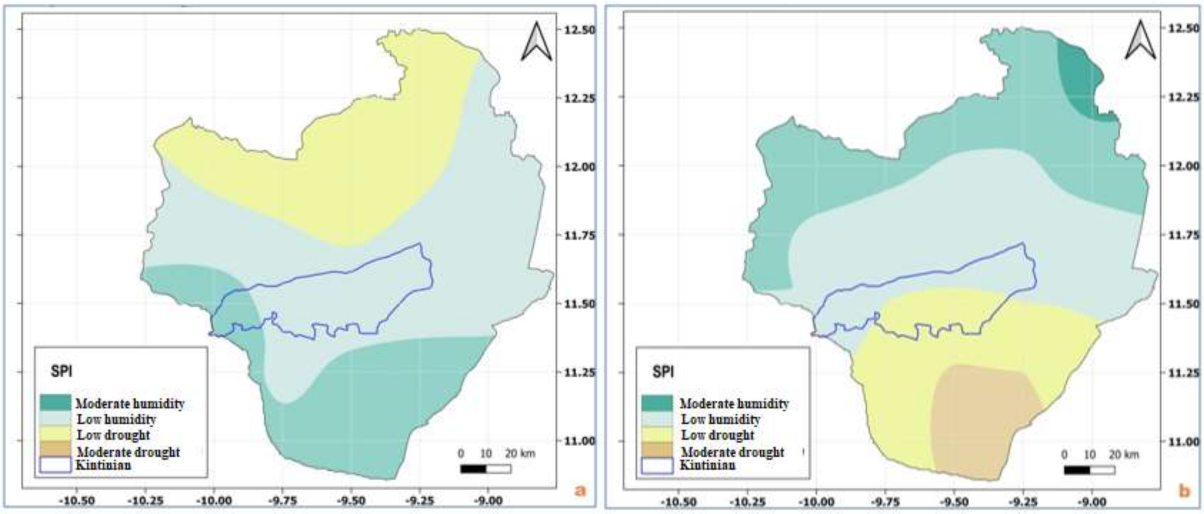
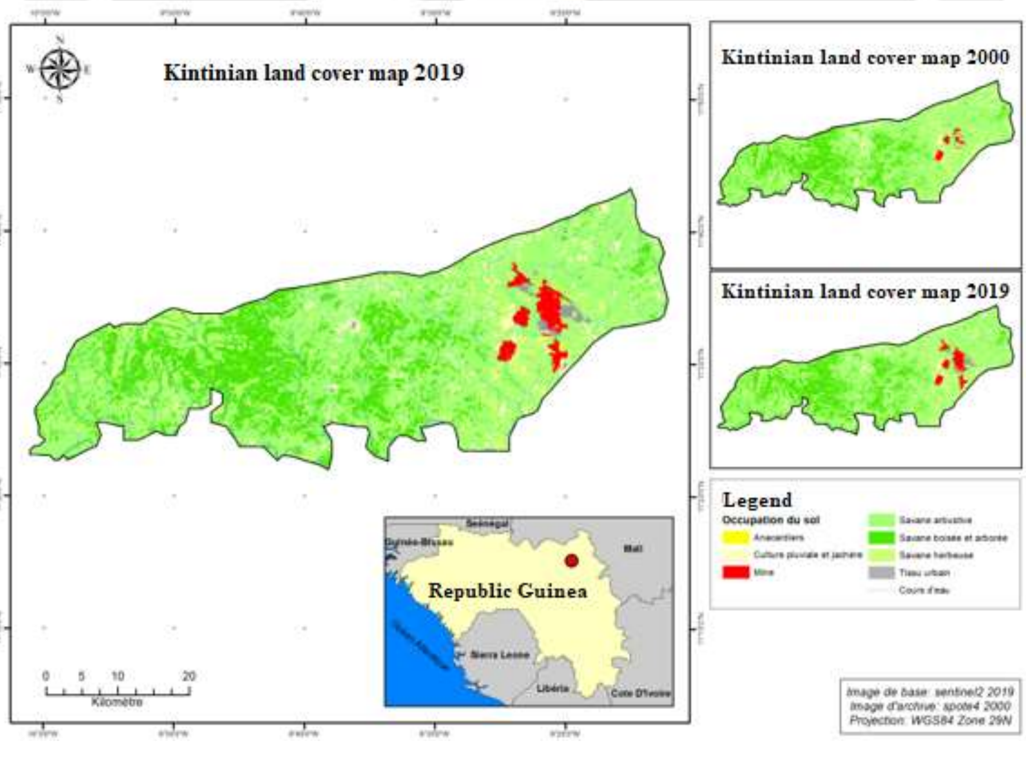


Figure 6: Standardized Rainfall Index (SPI) for 2000 (a) and 2019 (b) compared to the period 1991-2020 in the prefecture of Siguiri. Data source: ERA5

3.2 Evolution of land use

3.2.1 Land cover of the years 2000 and 2019 in Kintinian



Picture 7 : Diachronic observation of the occupations of the ground of Kintignan

In this comparative analysis of land cover maps between the years 2000 and 2019, the focus has been on mining and its related activities, among which little has been mentioned: traditional subsistence agriculture using bush fires as means of clearing, makeshift habitats using wood and payroll, commercial exploitation of firewood, excessive production of charcoal (Millimono et al. 2017) The analysis of land use maps shows that if this exploitation was weakly remarkable from these beginnings until 2000, the interval 2000 and 2019 experienced real changes in the Kintinian area (figure 7). A study of changes in land use between 2000 and 2019 (Figure 7) made it possible to make essential statistics in terms of losses in area of land use units.

3.2.2 Change in land use between 2000 and 2019 in Kintignan

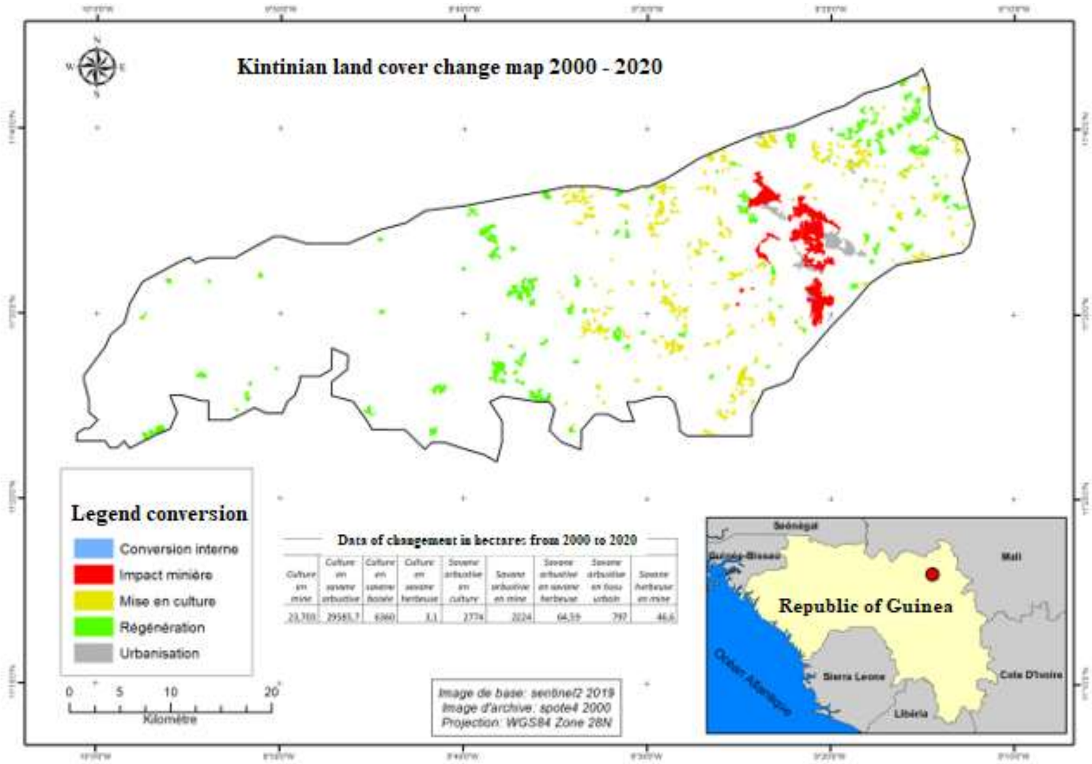


Figure 8 : Change of land use in Kintignan 2000-2019

Internal conversions due to the impacts of mining and unplanned urbanization have led to the loss of nearly 23.7 hectares in plain crop area, 29,585.7 hectares in shrub savanna crop area, 6,360 hectares in wooded savanna, 3.1 hectares in grassy savannah and 2774 hectares in shrubby savannah. This soil degradation coupled with global climate change would accentuate the rainfall deficits observed in the Kintignan area between the years 2000 and 2019.

4. Conclusion

The diachronic analysis of the evolution of climatic parameters and land use in Kintignan has identified problems related to climate change. These problems are the extreme temperatures, the rarity of the precipitations to which is added the demographic pressure. This results in a degradation of the environment which induces a change in land use, in particular the gold rush, both artisanal and industrial, in the sub-prefecture of Kintignan. This rush constitutes a threat to the environment, to which are added social and health problems such as forest resources; sources of water and arable land are threatened with extinction.
The analysis of the results from the data clearly shows a decrease in precipitation (variability of the anomaly rainfall cumulus) for the period from 1980 to 2020 and conversely a rise in temperature during the same period.
These decreases in precipitation and increase in temperature had consequences on agriculture and livestock farming, thus affecting the livelihoods of populations and making them increasingly vulnerable both in terms of food security and their well-being.
Despite all the efforts made by the authorities in terms of environmental and mining legislation, much remains to be done. How to reconcile mining and environmental protection? How to diversify agricultural activities in mining areas? How to restore the sites after exploitations? How can we build resilience for sustainable development? These are all questions to be answered in order to overcome climate change.

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