Technical Report

Climate Change Parameters, Diarrhoeal Diseases and Malaria in the Health Districts of Nara and Commune VI of Bamako District, Mali, 2000-2010: A Retrospective Study

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Technical Report

Climate Change Parameters, Diarrhoeal Diseases and Malaria in the Health Districts of Nara and Commune VI of Bamako District, Mali, 2000-2010: A Retrospective Study

Submitted by the:

REPUBLIC OF MALI

One People – One Goal – One Faith

Ministry of Health

National Health Department

Ministry of Equipment and Transport

National Meteorology Department

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This study is the result of fruitful collaboration between the World Health Organization (WHO) Centre for Health Development (WHO Kobe Centre/WKC) in Kobe, Japan, the WHO Regional Office for Africa (AFRO), the WHO Intercountry Team for Central Africa, the WHO Country Office in Mali and the Ministry of Health. It was carried out thanks to the work of the National Technical Working Group (NTWG) set up within the framework of the Libreville Declaration.

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Throughout the study, the research team received technical support from Dr Lucien Manga (PHE/AFRO), Mrs Hawa Senkoro (PHE/IST/CA) and Mr Maïga Fatoumata Sokona (PHE/WCO/Mali).

PROJECT SUMMARY

About the Project

This technical report was the final product of a research project funded by the World Health Organization (WHO). This was a joint collaboration between the WHO Centre for Health Development (WHO Kobe Centre - WKC) and the WHO Regional Office for Africa (WHO AFRO).

The research project was carried out officially through the work of the National Technical Working Group (NTWG), Mali, set up within the framework of the Libreville Declaration, which implemented the research project.

The research project provided a case study to address the knowledge gap on the impact of climate change on the occurrence of diarrhoeal diseases and vector-borne diseases (specifically malaria) in Mali, using data from two settings: Nara (rural) and Commune VI (urban). It was based on a generic research protocol entitled "Assessing the relationship between climatic factors and diarrhoeal and vector-borne diseases – a retrospective study generic research protocol" that was developed and published by the WHO Regional Office for South-East Asia (WHO SEARO) in 2010.

Project Objectives

The overall objective of the project was to assess the impact of climate change on diarrhoeal diseases and malaria in Mali from 2000 to 2010. The specific objectives were to: (1) establish the link between climate parameters (rainfall, temperature and relative humidity) and diarrhoeal diseases;(2) establish the link between climate parameters (rainfall, temperature and relative humidity) and malaria; and (3) identify the non-climate parameters capable of impacting the transmission of these two climate-sensitive diseases - in the health districts of Nara and Commune VI of Bamako District, Mali.

Project Team Members (National Technical Working Group/NTWG, Mali)

Mr Boubacar Abida Maïga, Sanitary Engineer, Head of the Public Hygiene and Sanitation Division of the National Health Department, Mali
Professor Sékou N'Faly Sissoko, Atmospheric Physics Specialist, Atmospheric Environment Research and Training Officer, National Meteorology Department,
Mr Sory Ibrahima Bouaré, Sanitary Engineer, Environmental Toxicology Specialist in the Public Hygiene and Sanitation Division, Mali
Mr Oumar Guindo, Computer Expert, Administrator of the health information system database
Dr Didier Doumtabé, Researcher, Malaria Research and Training Center (MRTC), Faculty of Medicine, Pharmacy and Odontostomatology, Mali

Project Team Members (WHO)

Dr Lucien Manga, Regional Adviser, Protection of the Human Environment, WHO Regional Office for Africa (WHO AFRO)
Mrs Hawa Senkoro, Technical Officer, Protection of the Human Environment, WHO AFRO
Mr Maïga Fatoumata Sokona, National Professional Officer, Protection of the Human Environment, WHO Country Office, Mali
Dr Jostacio M. Lapitan, Technical Officer, Urban Health Emergency Management, WHO Centre for Health Development (WHO Kobe Centre)

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LIST OF ABBREVIATIONS AND ACRONYMS

AFRO	WHO Regional Office for Africa
CDM	Clean Development Mechanism
CSCOM	Community Health Centre
CSRef	Referral Health Centre
IPCC	Intergovernmental Panel on Climate Change
MDG	Millennium Development Goal
MRTC	Malaria Research and Training Center
NDA	National Designated Authority
NTWG	National Technical Working Group
PANA	National Programme of Action for Adaptation to Climate Change
SANA	Situation Analysis and Needs Assessment
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization
WKC	WHO Kobe Centre

EXECUTIVE SUMMARY

Introduction. The Intergovernmental Panel on Climate Change (IPCC) and the UN Framework Convention on Climate Change (UNFCCC) have established that climate change and its impacts are irrefutable and constitute real threats to the environment and human health. The current world scientific information indicates that a reasonable amount of adverse consequences on the prime requirements of life such as water, air, food and human habitat can be attributed to certain aspects of climate change and global warming, increasing risks to human health. Mindful of the responsibilities and tasks inherent in acknowledging climate change, Mali has done what it could to be able to respond to the challenges brought about by climate change. In 2010, as part of the implementation of the Libreville Declaration, Mali prepared the health and environment situation analysis and needs assessment (SANA) paper; and in 2011, prepared a health sector climate change adaptation plan.

Objectives. The overall objective of this study was to assess the impact of climate change on diarrhoeal diseases and malaria in Mali from 2000 to 2010. The specific objectives were to:1) establish the link between climate parameters (rainfall, temperature and relative humidity) and diarrhoeal diseases in the health districts of Nara (Koulikoro Region) and Commune VI of Bamako District; 2) establish the link between climate parameters (rainfall, temperature and relative humidity) and malaria in the health districts of Nara (Koulikoro Region) and Commune VI of Bamako District; and 3) identify the non-climate parameters capable of impacting the transmission of these two climate-sensitive diseases.

Methodology. Data were collected by two groups of trained investigators, assisted by the reseach team. Health Information System (HIS) Officers and the Climatology Division of the National Meteorology Department, Mali actively participated in data collection by providing documents (i.e., quarterly progress reports of the various entities, quarterly weather reports, etc). Data were entered directly using EXCEL software. Climate parameter data were collected over a 20-year period (1990 to 2010). Disease data were collected through HIS officers of Nara District and Commune VI of Bamako District over the years 2000 to 2010. The study was conducted and completed within a year from 2011 to 2012.

Discussion. The meteorologic data used were related to three climate parameters: 1) temperature (recorded under shelter in degree Celsius); 2) rainfall (cumulative rainfall amounts per month); and 3) relative humidity (recorded at 8.30 am and at 5.30 pm). Monthly and annual temperature, rainfall and relative humidity averages were used to describe the various change trends of each climate parameter from 1990 to 2010. These data were later cross analyzed with that of diseases to determine a correlation using the Spearman test. For disease data, the incidence rate was adopted and calculated for diarrhoea cases diagnosed and treated, as well as for fever cases presumed to be malaria cases diagnosed and treated as such in the health districts of Nara and Commune VI of Bamako District.

During the years 2000 to 2010, the project team observed an upward trend in the incidence of diarrhoeal diseases, irrespective of the study site. Temperature seemed to have no infuence on diaarhoeal incidence in Nara while rainfall and relative humidity seemed to influence the incidence of diarrhoeal diseases. As for malaria, during the study period, there was an upward trend in the incidence of simple and severe malaria in Nara, while in Commune VI, there was a slight downward trend. The differences between rural and urban areas could be explained by several non-climate factors, including population. The correlation between malaria incidence and climate parameters, namely rainfall and maximum and minimum relative humidity was significant in both sites. However, the correlation was higher in Commune VI than in the Nara health district.

Conclusions. In the two study sites (Nara and Commune VI of Bamako District, Mali), results highlighted an upward trend in climate parameters, namely maximum temperature, rainfall and relative humidity, for the 2000 to 2010 period. This increasing trend may reflect climate change in both sites and may have had a direct or indirect impact on the health of the populations of Nara and Commune VI. Data, however, did not permit to demonstate the direct impact of indicative climate change on diarrhoeal disease and malaria incidence. However, this work showed some linkage between the variability of climate parameters, namely rainfall, temperature and relative humidity, and their impact on diarrhoeal disease and malaria incidence that were statiscially significant. This study provided a basis to pursue similar study and analysis in the future, hopefully, using a longer timeframe (at least 30 years or more).

Study Limitations. While it was easy to obtain data on meteorological parameters collected over a 20-year period, it was not the case with data on diseases. Lack of reliable data over a period of more than 10 years compelled the project team to limit the study to an 11-year period (2000 to 2010). This work was unable to establish simple and severe malaria incidence rates because such classification of the disease was effective only from 2007. Incidence distribution by age bracket could not be done both for diarrhoea and malaria. Mortality related to the two diseases could not be analyzed owing to lack of data.

Keywords: climate change, climate variability, diarrhoeal diseases, vector-borne diseases, retrospective study

1. INTRODUCTION

1.1 Context

For sometime now, the Intergovernmental Panel on Climate Change (IPCC) and the scientific body of the United Nations Framework Convention on Climate Change (UNFCCC) have established that climate change and global warming are irrefutable and constitute real threats to the environment and health [1]. The 2007 report states that world temperature will continue to rise by 0.1ºC every decade, for dozens of years, if greenhouse gas emissions remain at their 2000 levels [2]. If current emission levels persist, average temperatures are expected to rise by about 4 ºC during the 21st century [3]. Climate scenarii foresee a very probable median temperature rise of 3 to 4 °C in 2080-2099, compared to the 1980-1999 average, for most African countries. The land areas of the Sahara and the semi-arid regions of southern Africa could experience a 1.6ºC rise in temperature, while equatorial countries like Cameroon, Uganda and Kenya could experience a 1.4 ºC temperature rise. However, the interior of the continent is likely to get warmer faster than coastal regions [4].

Environmentally, climate change manifests itself, among other things, in:

- temperature rise;
- increase in the severity and frequency of extreme weather conditions (e.g., droughts, floods, storms, cyclones, heatwaves and cold spells);
- decrease in water resources; rise in ocean levels;
- increase in climate variability and rivers’ flow regime.

World scientific information confirms that certain aspects of climate change and global warming are already having adverse consequences on the prime necessities of life: water, air, food and human habitat, engendering threats to health.

Concerning human health, most climate change related problems are not caused by this phenomenon; they are rather aggravated or intensified by changing weather conditions. In such a situation, it is necessary to assess the vulnerability of health to climate change and study the capacity of health systems to cope with this additional threat from climate change. Health consequences include:

- the proliferation of disease vectors;
- high incidence of diarrhoeal diseases;
- heat stress ;
- increase in respiratory diseases due to air quality;
- increase in cases of injury due to extreme weather conditions;
- recrudescence of malnutrition.

The direct and indirect health consequences constitute a health hazard, particularly in developing countries and among the most vulnerable populations: elderly persons, persons with chronic diseases, children and women [2]. These consequences have a considerable potential in terms of impact on the community and heavy burden on health systems, the end result being an increase in health care costs and reduction in economic productivity [2].

In Mali, the climate is characterized by a great year-to-year and intra-season rainfall variability. The rainfall regime is greatly influenced by climate variability and change.

The particularities of such climate are prolonged drought and pronounced extreme weather events, such as high precipitation, blustery winds and heatwaves. This explains why since the 1970s, there has been: a nearly 20% drop in annual average rainfall resulting in a southward isohyet movement of about 200 km (the 1200 mm isohyet no longer exists on the map of Mali) [5], a reduction in the average duration of the rainy season, a disturbance in temporal and spacial distribution of rainfall, an increase in the frequency of heatwaves and downpours of exceptional intensity, leading to floods.

The health and environment Situation Analysis and Needs Assessment (SANA) shows that the consequences of climate change on health in Mali could be:

- proliferation of disease vectors;
- high incidence of diarrhoeal diseases;
- heat stress;
- increase in respiratory diseases due to air quality;
- increase in the number of cases of injury due to extreme weather conditions; and
- recrudescence of malnutrition.

1.2 Mali’s Response to Climate Change

Aware of the problems inherent in climate change, Mali has signed and ratified the United Nations Framework Convention on Climate Change, as well as the Kyoto Protocol. It has also set up a National Designated Authority (NDA) of the Clean Development Mechanism (CDM). In response to UNFCCC obligations, Mali presented its Initial Communication on Climate Change in September 2000 and is currently preparing the second. In July 2007, Mali produced a report on the National Programme of Action for Adaptation to Climate Change (PANA). The Programme identified 12 climate risk sectors, including health. The PANA sensitivty matrix ranked the agriculture and health sectors first in terms of vulnerability to climate change.

In 2008, Mali’s Ministry of the Environment and Sanitation produced the "elements of the national policy on adaptation to climate change ".

In 2008 and 2009, Mali respectively prepared reports on the assessment of climate change impacts on development programmes and a survey on the mapping of climate change adaptation initiatives.

In 2010, as part of the implementation of the Libreville Declaration, Mali prepared the « health and environment Situation Analysis and Needs Assessment (SANA)» paper. According to the analysis, climate change is one of the most significant effects of ecosystems degradation in Mali and its consequences include floods, proliferation of disease vectors and air and water pollution. SANA helped to highlight these harmful effects of climate change on health.

In 2011, Mali prepared a health sector climate change adaptation plan [7] ; its objective is to minimize the negative impacts of climate change on health, and more specifically to:

- improve knowledge about impacts of climate change on health;
- create awareness of climate change-related health risks among the population and decision-makers; and
- build national capacity to adapt to the negative effects of climate change on health.

To achieve these objectives, 6 (six) intervention strategies are required, namely:

- risks and national capacity assessment;
- integrated surveillance of climate change impacts on health;
- research;
- capacity building;
- response to climate-sensitive diseases exacerbated by climate change;
- resource mobilization.

As part of the implementation of the Libreville Declaration and following the Luanda Recommendations, it was imperative to make an inventory of the most plausible medium- and short-term health consequences of such a climate change. It is necessary to identify all the aspects of climate change likely to impact the spread of infectious diseases. It is consequently for this purpose that WHO took the initiative to prepare a standard protocol for the conduct of a pilot study on climate change and its impact on diarrhoeal and vector-borne diseases with a view to identifying strategies and actions that will help to meet these challenges.

2. OBJECTIVES

2.1 Overall Objective

Assess the impact of climate change on diarrhoeal diseases and malaria in Mali from 2000 to 2010.

2.2 Specific Objectives

- Establish the link between climate parameters (rainfall, temperature and relative humidity) and diarrhoeal diseases in the health districts of Nara (Koulikoro Region) and Commune VI of Bamako District;
- Establish the link between climate parameters (rainfall, temperature and relative humidity) and malaria in the health districts of Nara (Koulikoro Region) and Commune VI of Bamako District.
- Identify the non-climate parameters capable of impacting the transmission of these two climate-sensitive diseases.

2.3 Expected Outcomes

- The impact of temperature (maximum and minimum), rainfall and relative humidity on diarrhoeal diseases and malaria transmission dynamics is established;
- The impact of climate change on disease transmission dynamics is assessed using climate determinants.
- Appropriate environmental indicators for an early warning system are identified.

2.4 Snapshot of Mali

Mali is a vast continental country located in the heart of the Sahel and West Africa between longitude 10° and 25° North and 4°East and 12° West. The country covers a surface area of 1 241 238 km^2,that is approximately 4.2% of the total surface area of the African continent. Located in the Sahel, Mali has a dry climate and close to 65% of its territory is found in semi-desert and desert zones.

Mali's climate is characterized by high year-to-year and intra-season rainfall variability, as well as high variability within each of the climatic zones. Owing to its high altitude, Mali enjoys a tropical climate. It suffers the influence of the hot and dry harmattan and the humid rain-bearing monsoon winds.

Mali has three seasons:

- The hot and dry season (March–June) is the period of intense heat (37 to 40ºC) ;
- The rainy season (from June to October) is the period of farming activities; rivers are navigable and it is green everywhere; temperatures are bearable (25ºC in August) ;
- The cold season (November –February). There is a relative freshness all over the country.

3. METHODOLOGY

3.1 Study Type

It is a retrospective study to assess the impact of climate parameters, temperature, rainfall and relative humidity on diarrhoeal diseases, cholera and malaria in the health districts of Nara and Commune VI of Bamako District, Mali from 2000 to 2010.

3.2 Study Sites

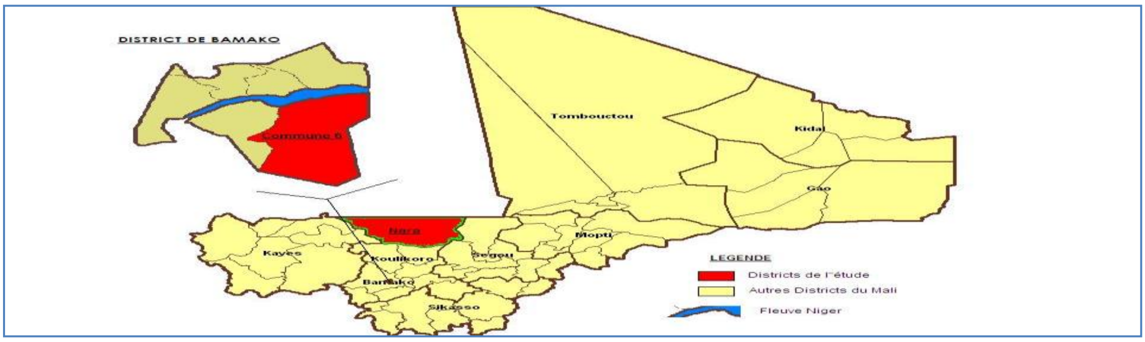

Figure 1 : Location of Study Sites

3.2.1 Nara Health District

Located at the far-north of Koulikoro Region, the Nara health district covers a surface area of 30 000 km², that is 1/3 of the Region's surface area. It is bounded:

- on the north by the Islamic Republic of Mauritania;
- on the south by the Banamba and Kolokani Circles;
- on the west by the Nioro, Sahel and Diéma Circles (Kayes Region); and
- on the east by the Niono Circle (Ségou Region).

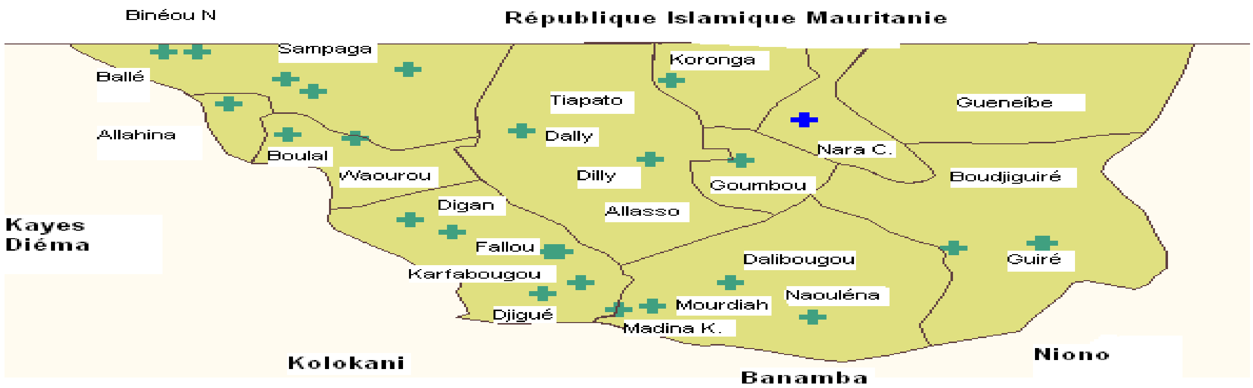

Figure 2 : Nara Health District

In 2011, the Nara health district had 260 801 inhabitants, that is an average population density of about 9 inhabitants per km² with a 3.6% growth rate. It has a Sahelian-type climate. Temperatures vary between 18° and 40°. Annual average sunshine duration is 8.2 hours per day.

The district has two main seasons:
- the dry season: it is cold from October to February and hot from March to June;
- the rainy season, which runs from July to September.

The average number of days of rainfall in 2011 was 39 days and the average annual cumulative rainfall for the same period was 365.9 millimetres (mm). It is the district with the lowest rainfall in Koulikoro Region. Vegetation is made up mostly of tree steppe characterized by thorny shrubs of the acacia, commiphora and combretaceae type. Stunted species are mostly found in the northern part.This zone is characterized by fragile and extremely vulnerable ecosystems.

Rainfall varies from 300 to 600 mm annually. Temperatures reach 46 °C in the hot season.
The central/Sahelian region of Mali is the most sensitive region to changes in rainfall patterns, as most households generate more than 70% of their income from the agricultural and/or livestock sectors. It is therefore a zone that is more vulnerable to climate change. The health district has 26 health areas, 19 of them functional.

Proportion of the population located 0 to 5 km, 5 to 15km and more from a health centre [8].

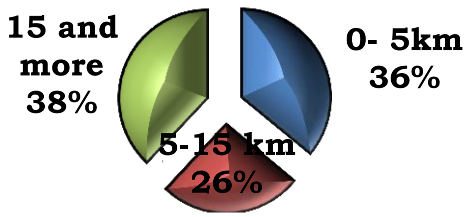

Figure 3 : Population Distribution According to Distance to a Health Centre

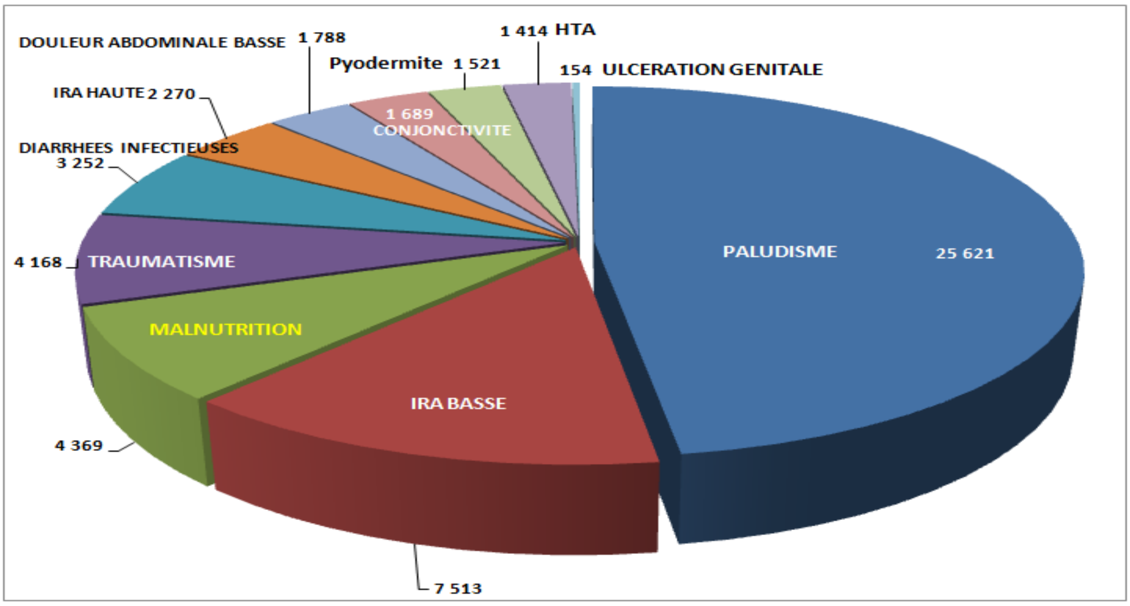

Figure 4 : Disease Distribution in Nara

3.2.2 Commune VI of Bamako District

Commune VI of Bamako District is located on the right bank of the Niger River, within the capital of Mali. It is bounded on the east and on the south by the Kati Circle, on the west by Commune V, and on the north by the Niger River. It is the largest council of the Bamako District. It covers an area of 94 km2, with an estimated population of 620 360 in 2009, and a 9.4% population growth rate. Its population is made up of 50.6% men and 49.4% women. The council has experienced rapid growth given the availability of land and the construction of social housing.

Commune VI has a rugged landform dominated to the east of Banankabougou by Outa-Koulouni rising to a height of 405 metres, to the west of the Yirimadio crossroads by Taman Koulouno with a height of 386 metres, to the east of Dianeguela- Sokorodji by Kandoura Koulou, Magnambougou Koulou and Moussokor Kountji Fara, the entire range rising to an altitude of 420 metres and to the east by Dougou Koulou. The climate of Commune VI is of the Sahelian type and varies from year to year with a dry season from February to June, a rainy season from June to September and a cold season from November to January. Its vegetation has been degraded by chaotic timber exploitation and long years of drought. It is of the Sudano-Sahelian type with tall trees like cedrar, shea and mango tree.

Commune VI has a referral centre set up in 1981 as a maternity, then, raised to a referral health centre (CSRef) in 1999. The centre is one of the oldest of the 6 (six) referral centres of Bamako District. However, the referral system only started in June 2004. The Commune VI CSRef is easily accessible as it is located along the wide Bamako avenue (Avenue de l'OUA). It is linked to 10 Community Health Centres (CSCOMs) namely: ANIASCO in Niamakoro II, ASACOBAFA in Banankabougoufaladiè, ASACOCY in the Yirimadio "Cité des 1008 logements sociaux", ASACOFA in Faladié, ASACOMA in Magnabougou, ASACOMIS in Missabougou, ASACONIA in Niamakoro I, ASACOSE in Sénou, ASACOSO in Sogoniko, ASACOSODIA in Sokorodji – Dianéguéla and ASACOYIR in Yirimadio .

3.3 Study Duration

The study lasted for one year.

3.4 Data Variables and Processing

Data was collected by two groups of trained investigators, assisted by the reseach team. HIS Officers and the Climatology Division of the National Meteorology Department actively participated in data collection by providing documents (quarterly progress reports of the various entities, quarterly weather reports, etc.). Data was entered directly using EXCEL software. Climate parameter data was collected over a 20-year period (1990 to 2010) and concerned:

- Maximum and minimum temperature (recorded under shelter and in degree Celsius)
- Rainfall (cumulative rainfall amounts per month)
- Relative humidity (percentage of mass of water vapour contained in the air over the maximum mass of water vapour that the air may contain at that temperature, recorded at 8. 30 am and 5.30 pm).

Disease data was collected thanks to the Health Information Systems (HIS) of Nara District and Commune VI of Bamako District over the years 2000 to 2010 and concerned:

- The incidence of diarrhoeal diseases;
- The incidence of cholera; and
- The incidence of malaria in all its forms (simple and severe).

3.5 Method of Analysis

To allow for comparison between variables of a different nature, we standardized the various variables: each variable was centred around the average, then reduced (X-X(average)/σ). We estimated the coefficients of correlation between standardized temperature, rainfall and relative humidity values and those of diarrhoea, cholera and malaria incidence. The correlation was measured on a monthly basis between each of the three climate parameters from January 2000 to December 2010, and diarrhoea, cholera and malaria incidences.

We also considered the cross-trends of each meteorological parameter and the annual disease incidence, and tested the statistical significance set at 5%. The Spearman correlation test is used to determine the relation between monthly climate variables and malaria incidence. If the value of r (coefficient of correlation) is > 0.5, the correlation is positive. For 0.7< r >1, or for r = or close to 1, there is a strong correlation between the two variables.

The cross correlation cefficients were measured between each of the three meteorological parameters and the month-by-month incidence of diarrhoea and malaria. (A 0 gap corresponded to coupling a meteorological variation of a given month with the disease incidence recorded during the same month; a gap of +1 corresponded to coupling a meteorological variable of a given month with the incidence recorded the following month; a gap of +2 corresponded to coupling a meteorological variable of a given month with the incidence recorded two months after, etc.). This data was analyzed as a continuous series (10 years x 12 months = 120 monthly incidence values) [8] .

4. RESULTS

4.1 Descriptive Analysis of Meteorological Parameters

4.1.1 Temperature

4.1.1.1 Maximum Temperature

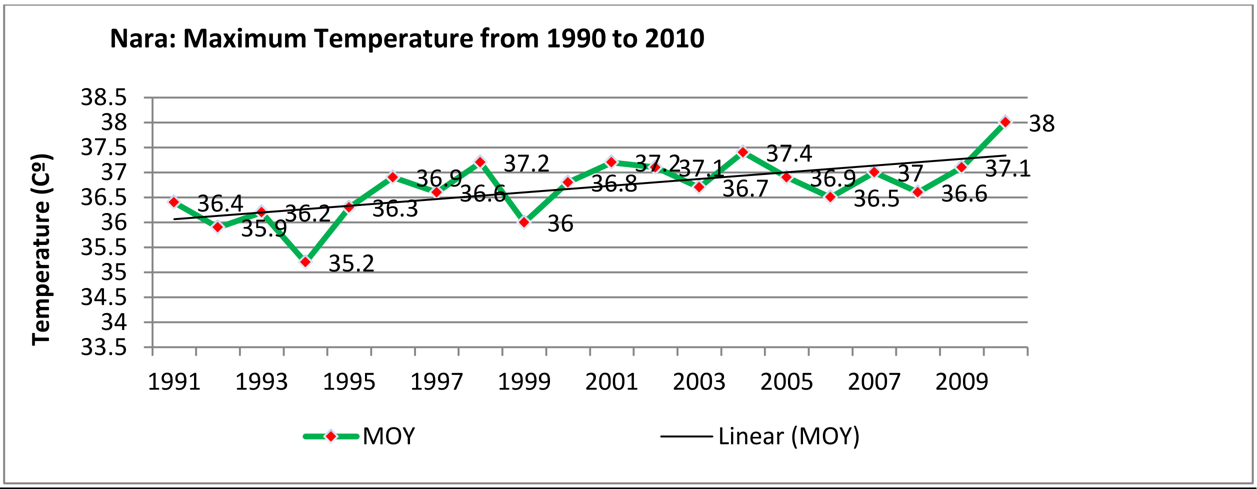

Figure 5 : Year-to-Year Maximum Temperature Average Variability

We notice a high year-to-year maximum temperature average variability from 1990 to 2010. Extreme temperatures were recorded as follows: 35.2º C in 1994 and 38º C in 2010. Generally, there is an upward trend in the average of maximum temperatures.

Table I : Inter-monthly Maximum and Minimum Temperature Average Variation in Nara

AvTº/Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec.**
Maxi Av Tº	31.4	35.2	38.2	41.3	42.0	40.2	35.8	33.4	35.6	38.2	36.3	32.9
Mini Av Tº	15.0	17.9	21.4	25.3	27.7	27.6	25.2	23.8	23.9	23.0	19.4	15.9
Av Tº	23.2	26.6	29.8	33.3	34.9	33.9	30.5	28.6	29.7	30.6	27.8	24.4

January appears to be the mildest month with an average temperature of 23.2ºC compared to May, the hottest month with 34.9º C, followed closely by June with a temperature of 33.9º C.

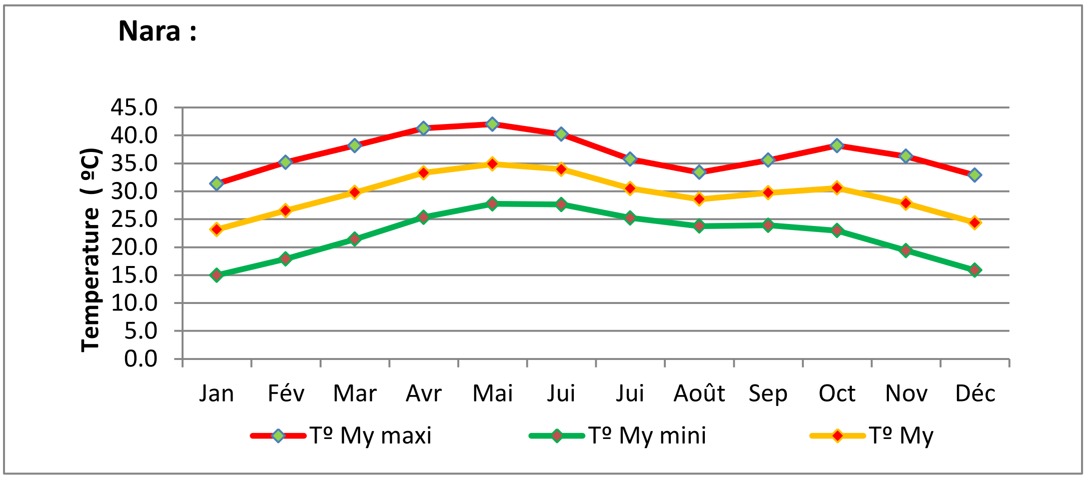

Figure 6 : Inter-monthly Maximum and Minimum Temperature Average Variability in Nara

Figure 6 shows that maximum and minimum temperatures and their averages have the same trend. The highest maximum temperature (42.0º C) was recorded in May and the lowest temperature (31.4º C) in January.

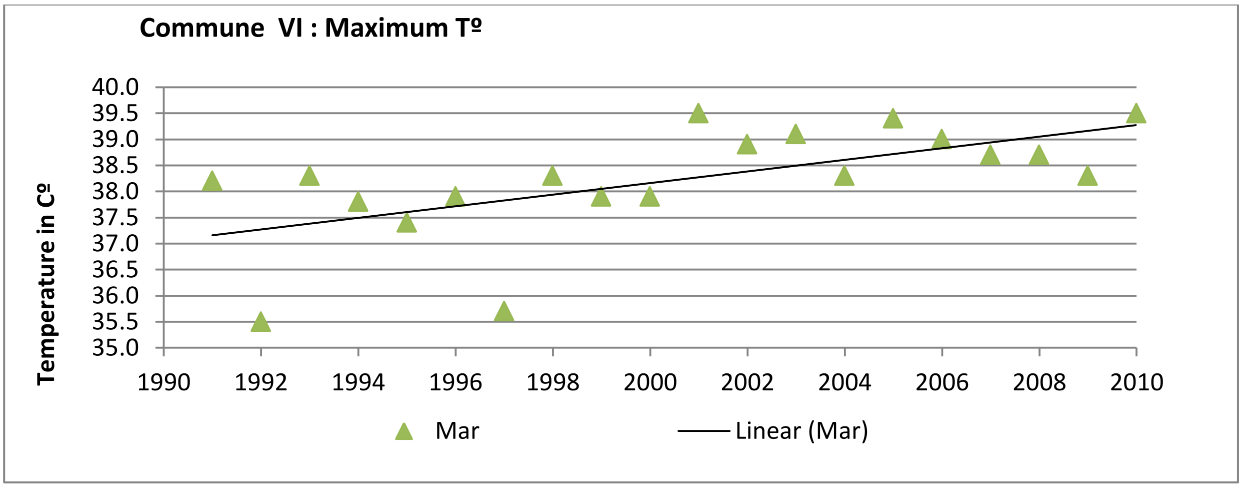

Figure 7 : Maximum Temperature Trends in March

Figure 7 represents the maximum temperature average for all the months of March from 1990 to 2010. It shows an upward maximum temperature trend for the months of March. The same trend was observed for the months of February, April and May which correspond to the period of intense heat. However, it should be noted that maximum temperature averages for the months of September show a downward trend.

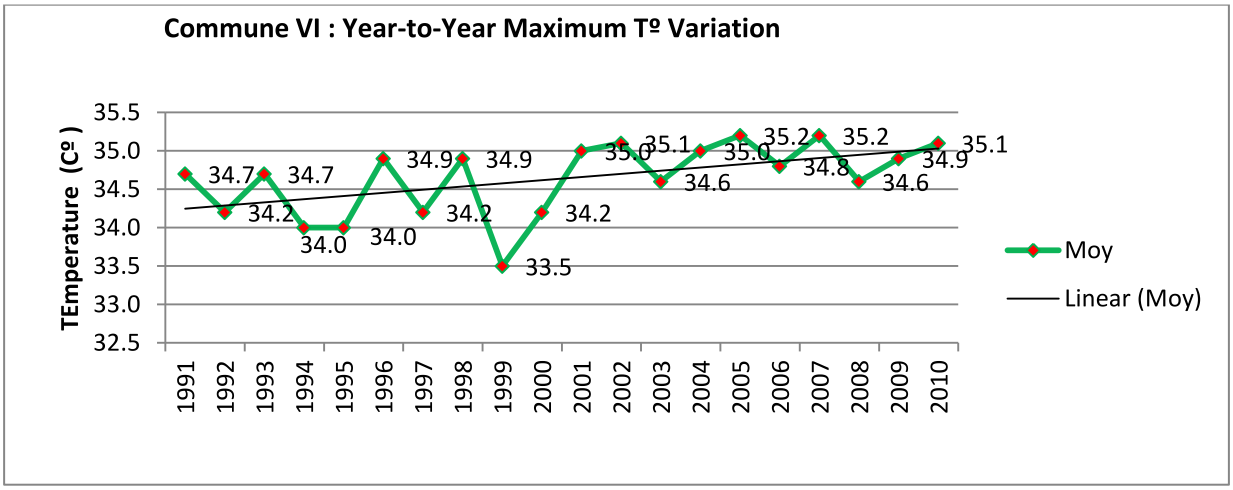

Figure 8 : Year-to-Year Maximum Temperature Average

The table shows a high year-to-year maximum temperature average variability from 1991 to 2010 in Commune VI. Extreme temperatures were recorded as follows: 35.5º C in 1999 and 33.5º C in 2005 and 2008. However, maximum temperature averages show an upward trend.

Table II: Inter-monthly Mmaximum and Minimum Temperature Average Variation in C.VI

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max Tmp Av M	32.5	35.9	38.2	39.4	38.0	34.8	31.5	30.5	31.9	34.3	35.3	33.5
Min Tmp Av	17.6	20.4	23.3	25.2	25.3	23.3	21.9	21.6	21.3	21.4	18.5	17.1
Av	25.1	28.1	30.8	32.3	31.6	29.1	26.7	26.1	26.6	27.8	26.9	25.3

Table II shows maximum temperature variation between 30.5 ºC (August) and 39.5ºC (April) concerning maximum temperature averages, while minimum temperature averages vary between 17.1ºC (December) and 25.3ºC (May). The highest maximum temperatures were recorded in the months of February, March, April and May.

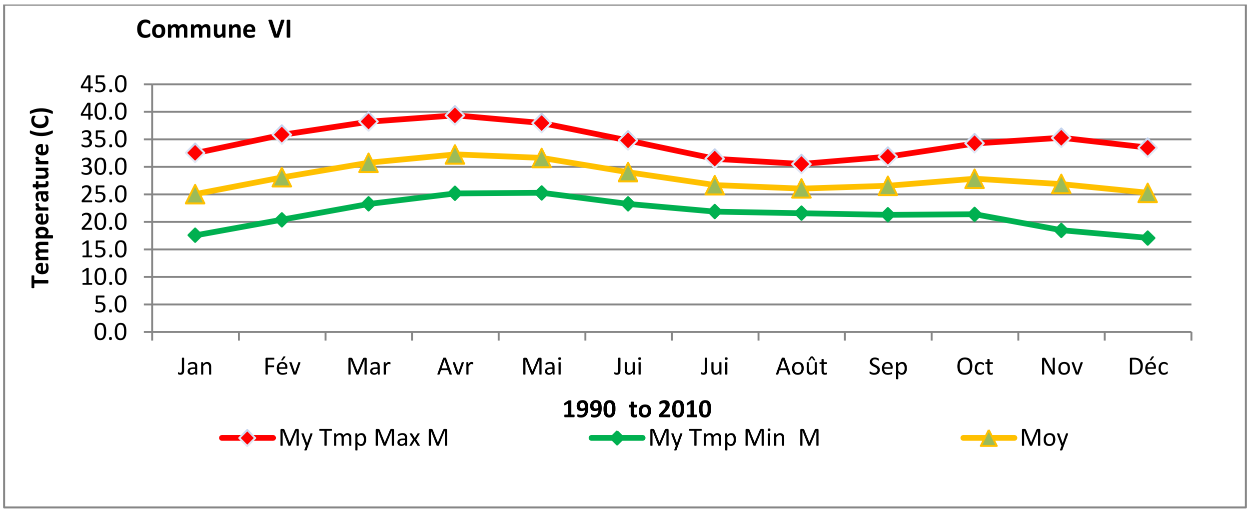

Figure 9 : Monthly Maximum and Minimum Temperature Average Variation in C.VI

Figure 9 shows that maximum and minimum temperatures and their averages present the same trend.

4.1.1.2 Minimum Temperature

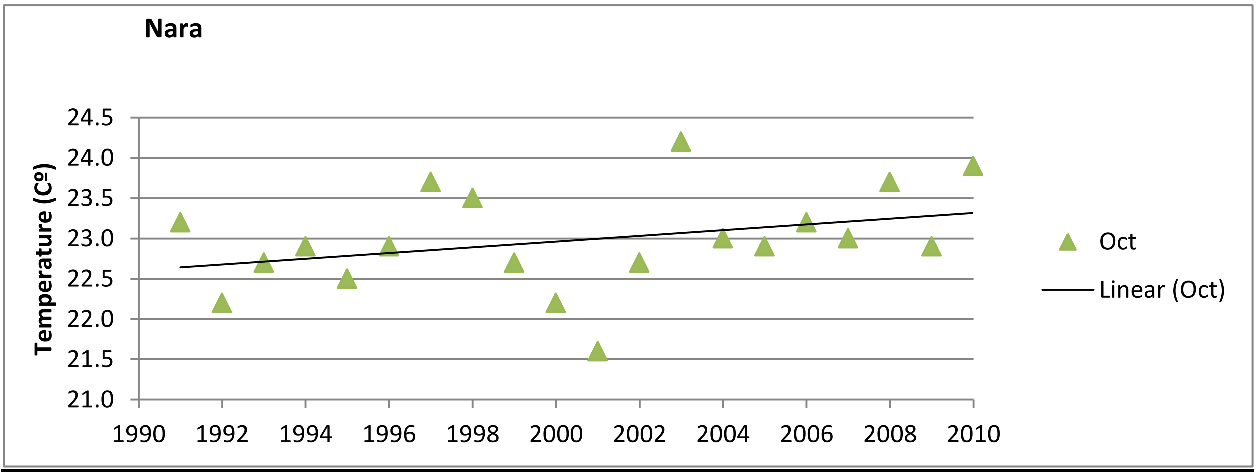

Figure 10 : Minimum Temperature Trends in the Month of October from 1990 to 2010

The minimum temperature average observed in the month of October from 1990 to 2010 shows an upward trend. On the contrary, the months of January, June, July, August and September show a downward trend.

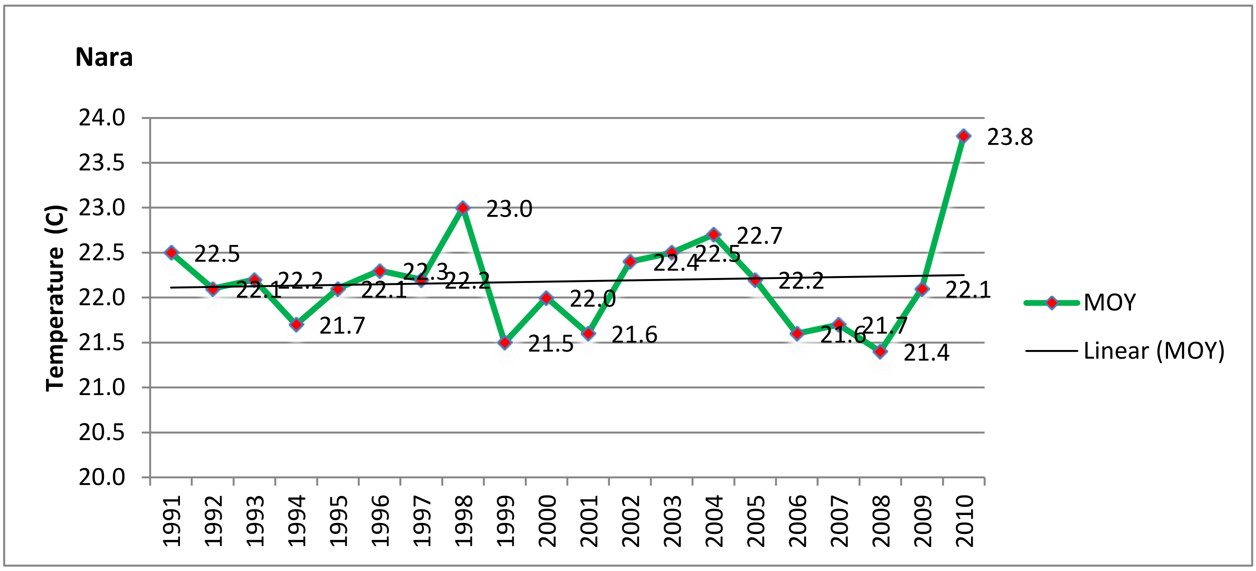

Figure 11 : Year-to-Year Minimum Temperature Average Variation Trend

Minimum temperature averages show a significant year-to-year variability; they however show an upward trend (Figure 11).

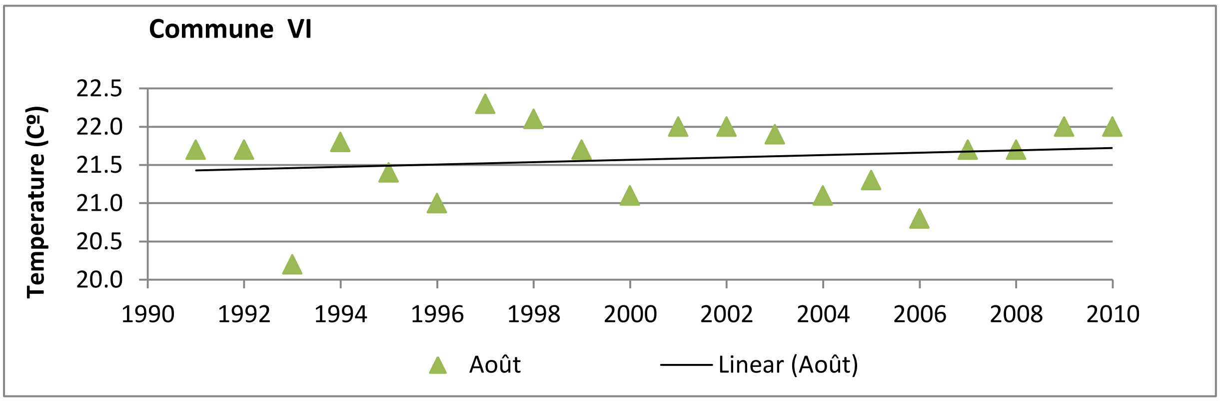

Figure 12 : Minimum Temperature Trends in the Month of August from 1990 to 2010

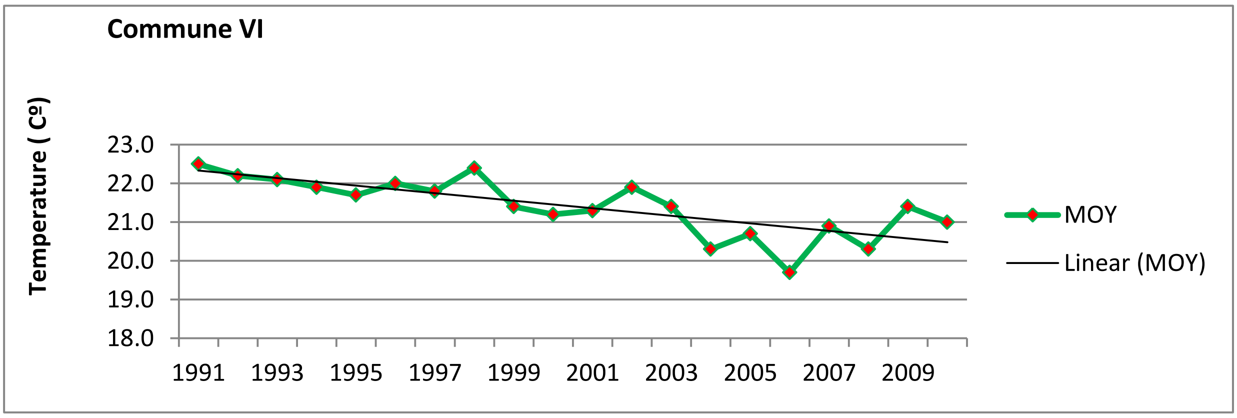

Figure 13: Year-to-Year Minimum Temperature Average Variation

Figure 13 shows the year-to-year minimum temperature average variability from 1990 to 2010. We notice a downward trend confirmed by monthly temperatures, with the exception of those of August and September where there is an upward trend.

4.1.2 Rainfall

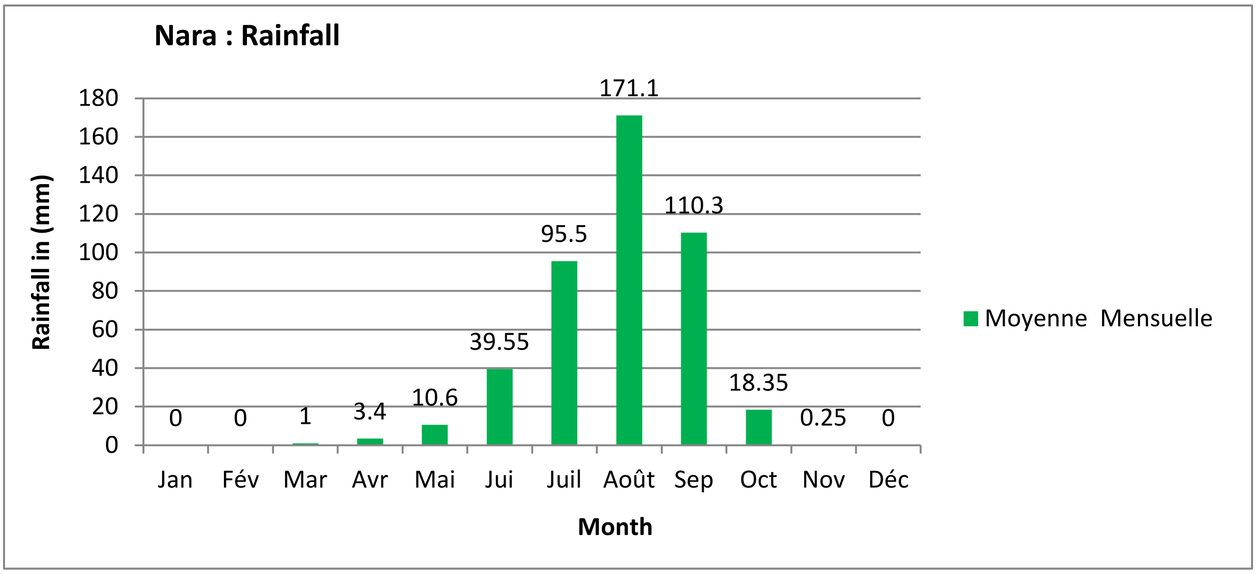

Figure 14 : Monthly Rainfall Average Distribution in Nara

Monthly or decade-based temporal rainfall distribution is unimodal. In other words, there is only one rainy season with a peak (171.1 mm) in the month of August. The months of December, January and February are dry, but there are a few traces of exceptional rainfall in April.

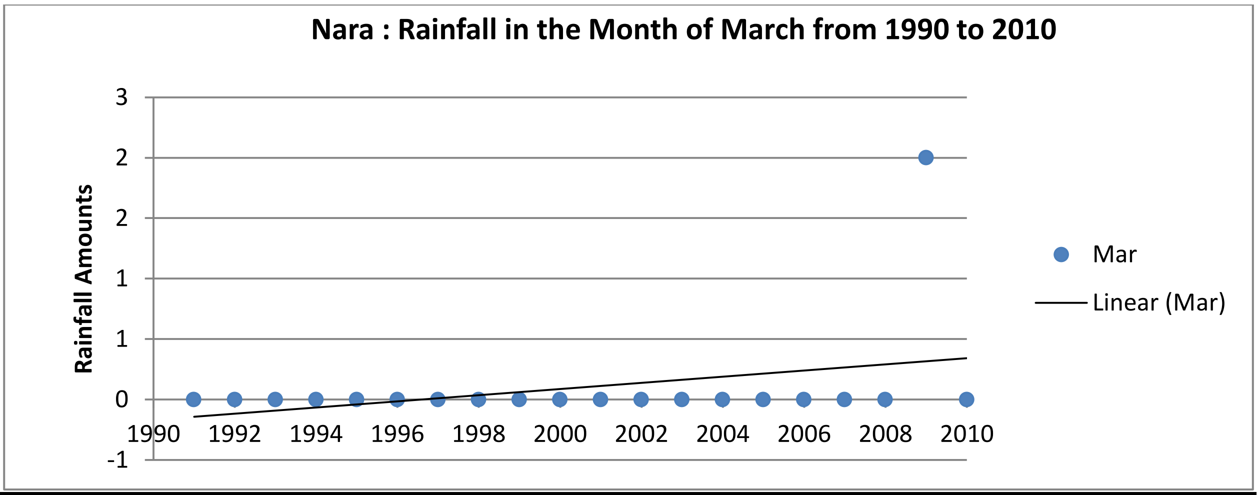

Figure 15 : Rainfall Trends in March

The rainfall average trend in the month of March from 1990 to 2010 is on the rise; the reverse is observed in January. Generally, however, year-to-year rainfall (1990 to 2010) shows an upward trend.

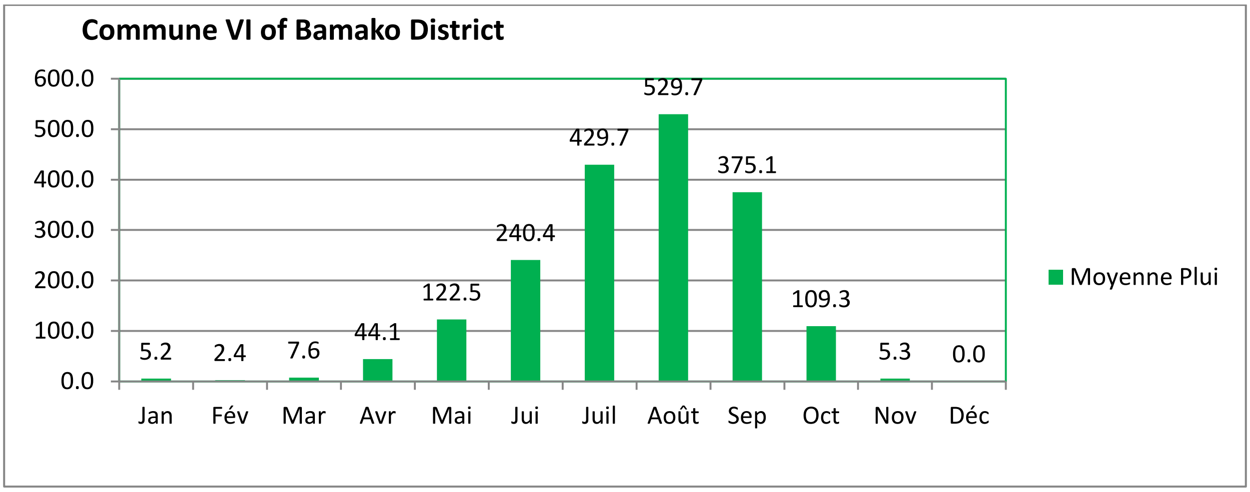

Figure 16 : Monthly Rainfall Average Distribution in C. VI of Bamako District

Monthly or decade-based temporal rainfall distribution is unimodal. In other words, there is only one rainy season with a peak (529.7 mm) in August. No rainfall was recorded in December, while a few traces of exceptional rains were observed in January, February and March.

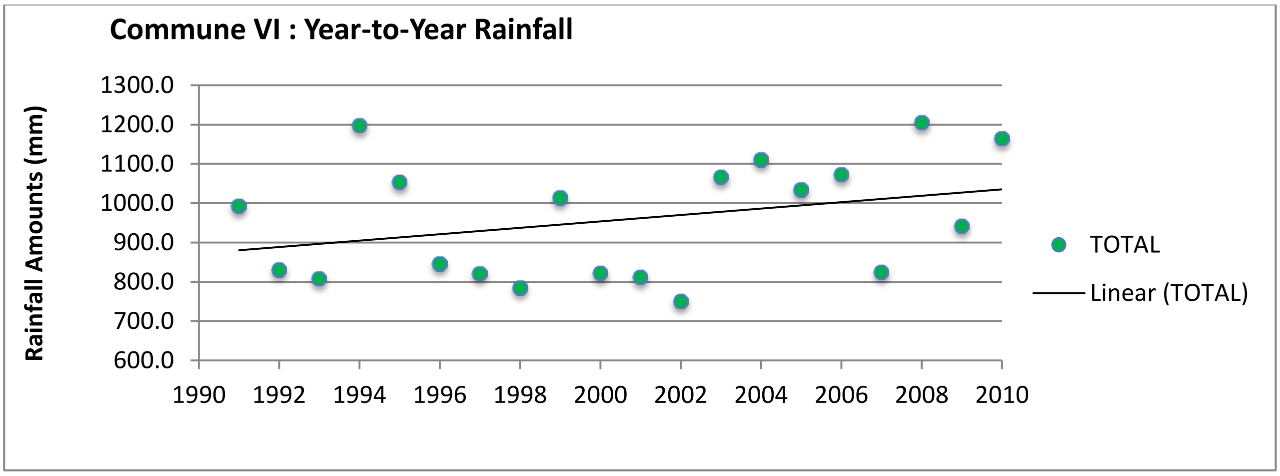

Figure 17 : Year-to-Year Trend in Rainfall Amounts

We observe a high year-to-year cumulative rainfall variability in Commune VI of Bamako District. We however notice an upward trend during the last 20 years whereas it is the reverse for rainfall in June.

4.1.3 Relative Humidity

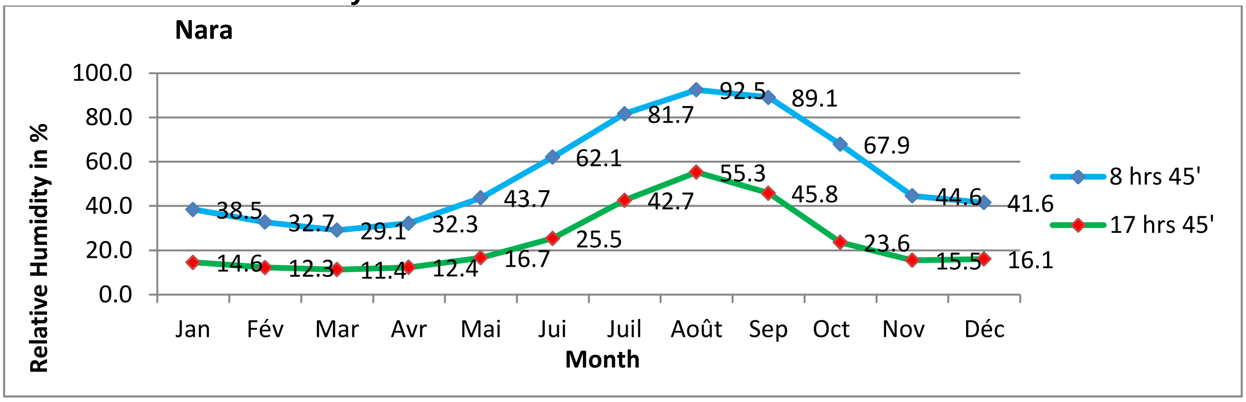

Figure 18 : Monthly Maximum and Minimum Relative Humidity Average Variation in Nara

Inter-monthly maximum and minimum relative humidity average variation shows a unimodal distribution. Maximum and minimum relative humidity of 92% and 55.3% respectively was recorded in August. The lowest rates of 38.5% (maximum) and 14.6% (minimum) are observed in January.

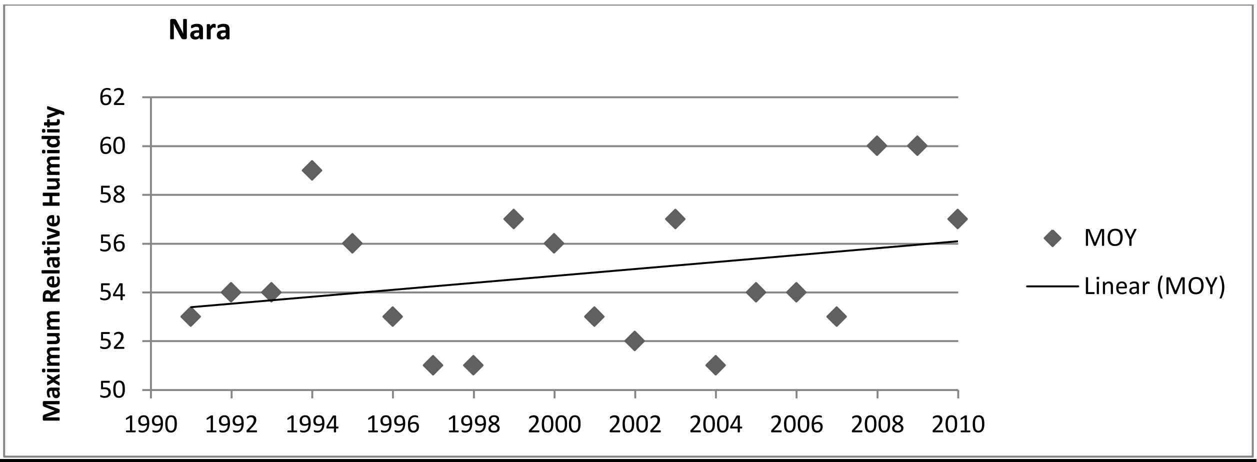

Figure 19 : Year-to-Year Maximum Relative Humidity Average Trend in Nara from 1990 to 2010

Year-to-year maximum relative humidity variability is high, with an upward trend from 1990 to 2010. The same trend is observed in inter-monthly averages.

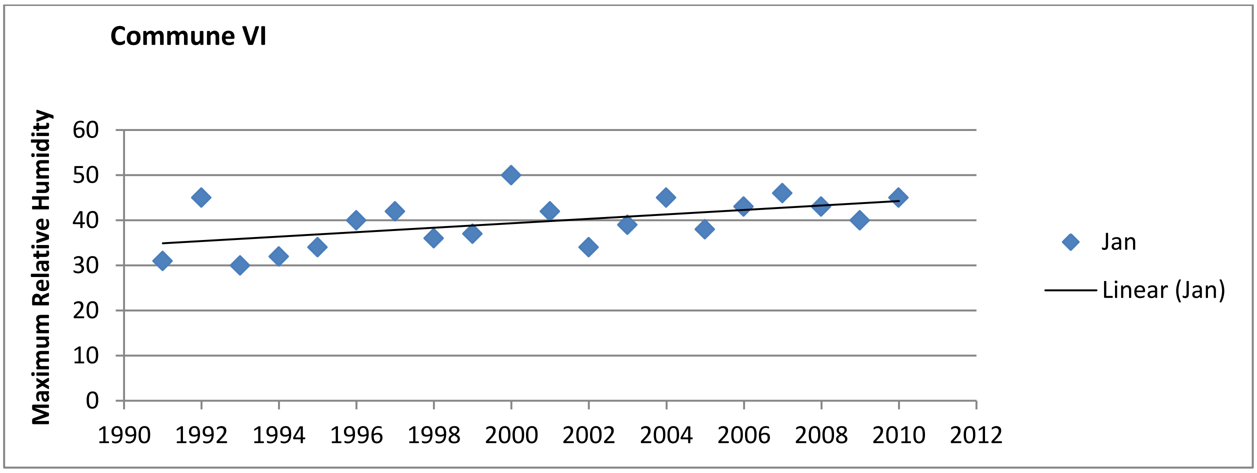

Figure 20 : Maximum Relative Humidity Trend in January in C.VI of Bamako District

There is an uptrend in maximum relative humidity for all the months from 1990 to 2010, save for June where it is the reverse. However, the uptrend was also observed in annual averages.

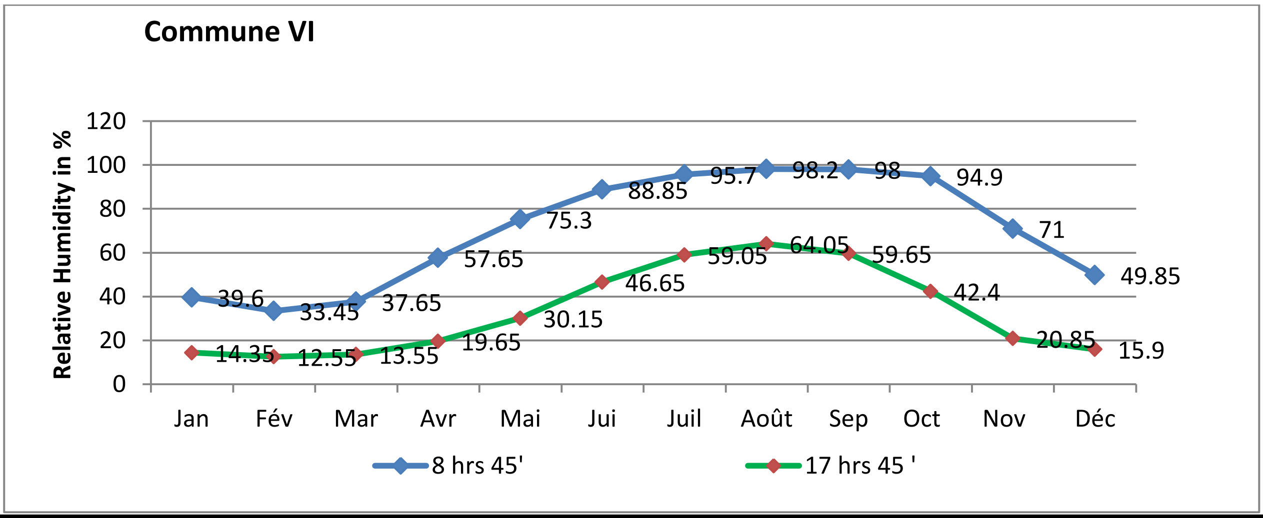

Figure 21: Monthly Maximum and Minimum Relative Humidity Average Variation

Maximum and minimum relative humidity does not vary much and shows the same trend, that is a unimodal distribution. The highest rates, 98.2% (maximum) and 64% (minimum), were recorded in August. In contrast, the lowest were recorded in February, with 33.45% (maximum) and 12.55% (minimum).Minimum relative humidity shows the same trend. We notice an upward trend in year-to-year minimum relative humidity average.

4.2 Descriptive Analysis of Disease Data

4.2.1 Diarrhoea

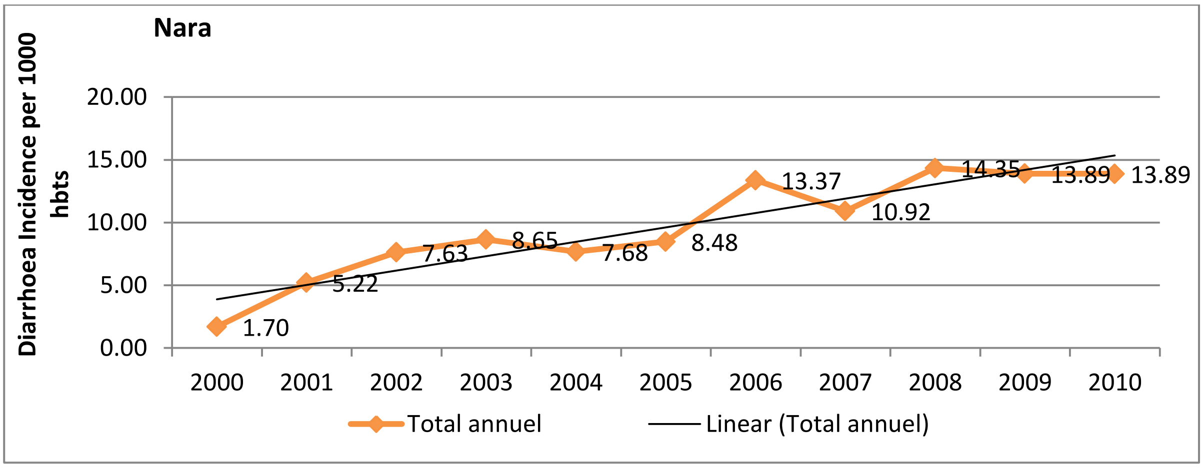

Figure 22 : Year-to-Year Diarrhoea Incidence Variation in Nara

Diarrhoea incidence distribution was on the increase from 2000 to 2010. The highest rates were recorded in 2003 with 8.65% ; in 2006 with 13.37%; and in 2008 with 14.35%.

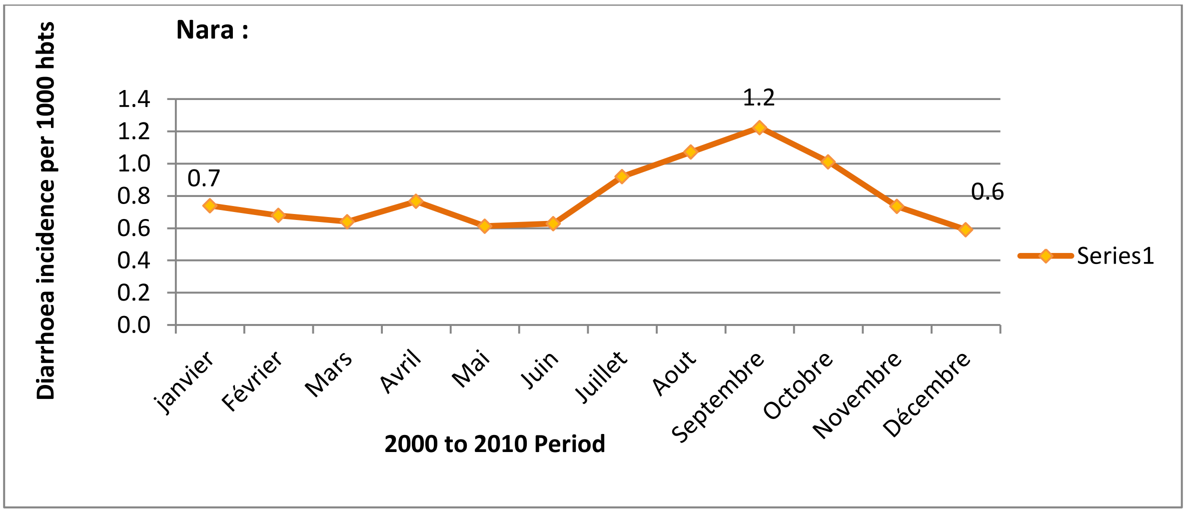

Figure 23: Monthly Diarrhoea Incidence Variation in Nara

Inter-monthly diarrhoea incidence distribution is unimodal, with a renewed outbreak observed from June, reaching a peak in September.

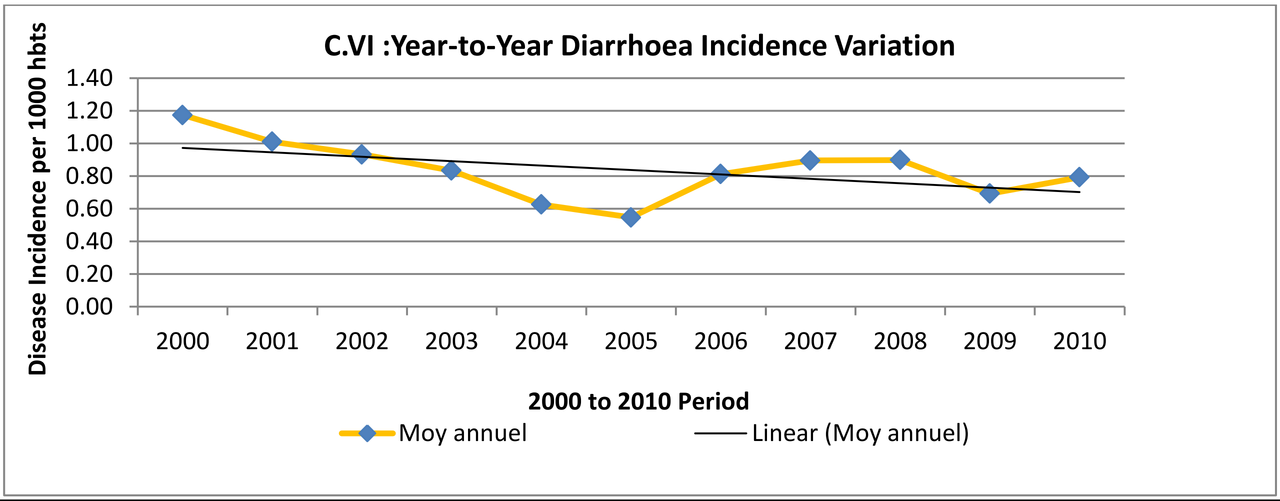

Figure 24 : Year-to-Year Diarrhoea Incidence Rate Variation Trend in C.VI of BamakoDistrict

The year-to-year diarrhoea incidence variation in Commune VI dropped considerably from 2000 to 2005, and then increased progressively up to 2008. Generally, however, diarrhoea incidence is on a downward trend.

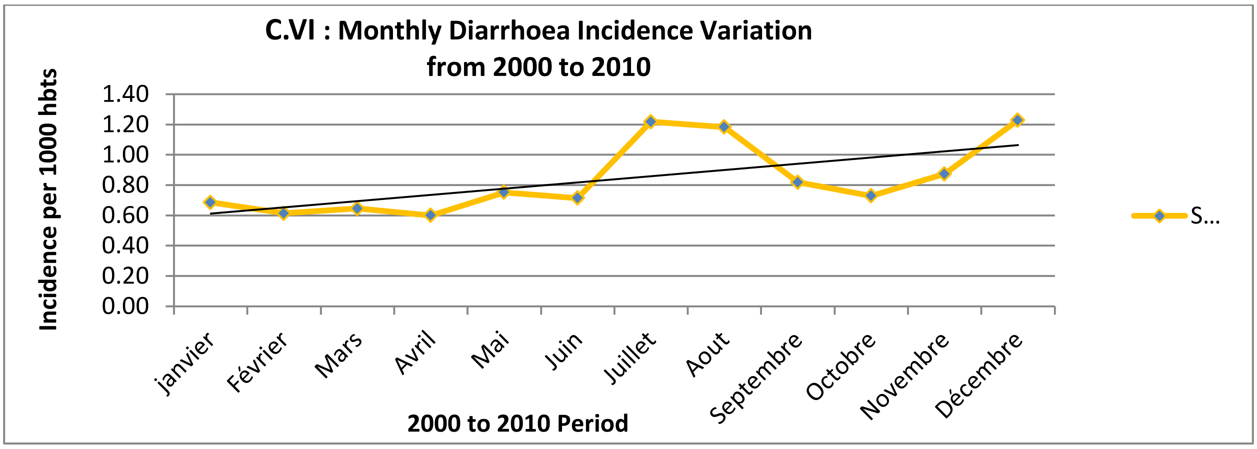

Figure 25 : Monthly Diarrhoea Incidence Distribution in C.VI of Bamako District

The inter-monthly diarrhorea incidence variation did not change much from January to June, then there was a renewed outbreak after June and a peak in July. But generally, there is an upward trend in diarrhoea incidence.

4.2.2 Cholera

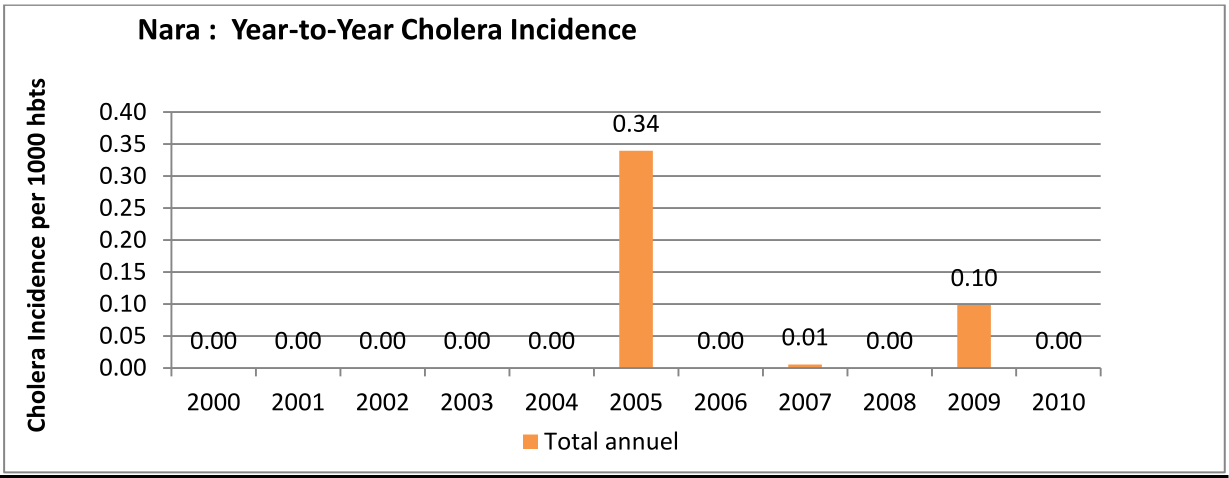

Figure 26: Year-to-Year Cholera Incidence in Nara

The Nara health district suffered 3 cholera epidemics between 2000 and 2010. The 2005 epidemic was the most severe compared to those of 2007 and 2009.

4.2.3 Malaria in all its Forms (Simple and Severe)

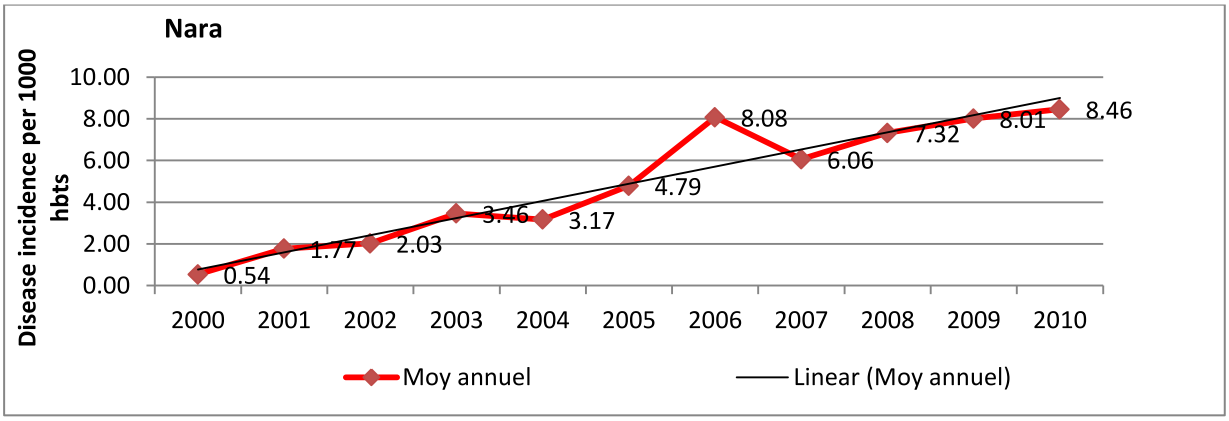

Figure 27 : Year-to-Year Simple and Severe Malaria Incidence Variation in Nara

The year-to-year malaria incidence remained on an upward trend between 2000 and 2010. It peaked in 2010 at 8.08‰ against 0.54‰ in 2000.

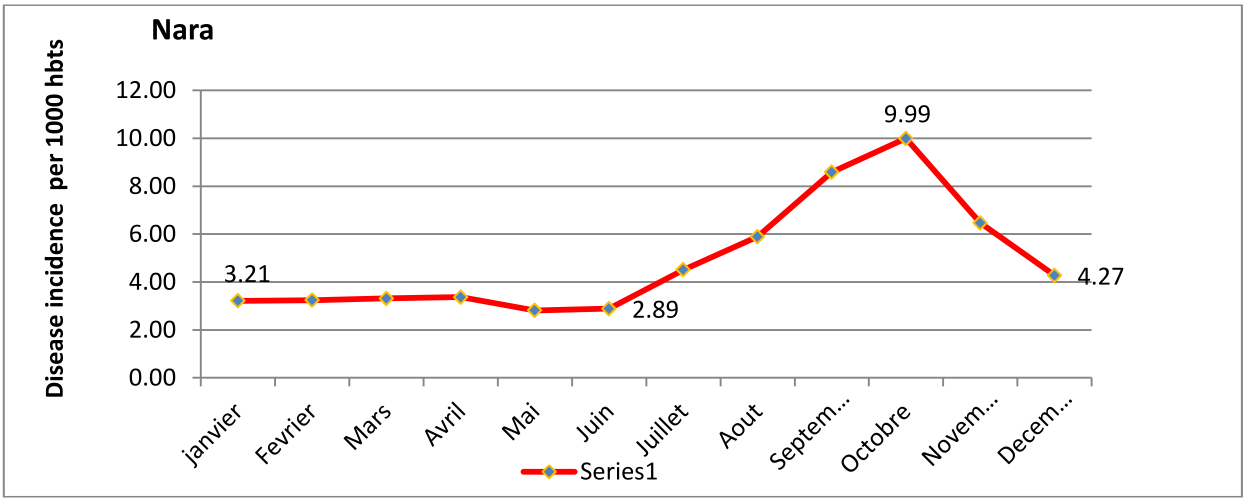

Figure 28 : Monthly Simple and Severe Malaria Incidence Variation

Malaria incidence hardly varies between December and June, then there is a recrudescence which peaks in October at 9.99%.

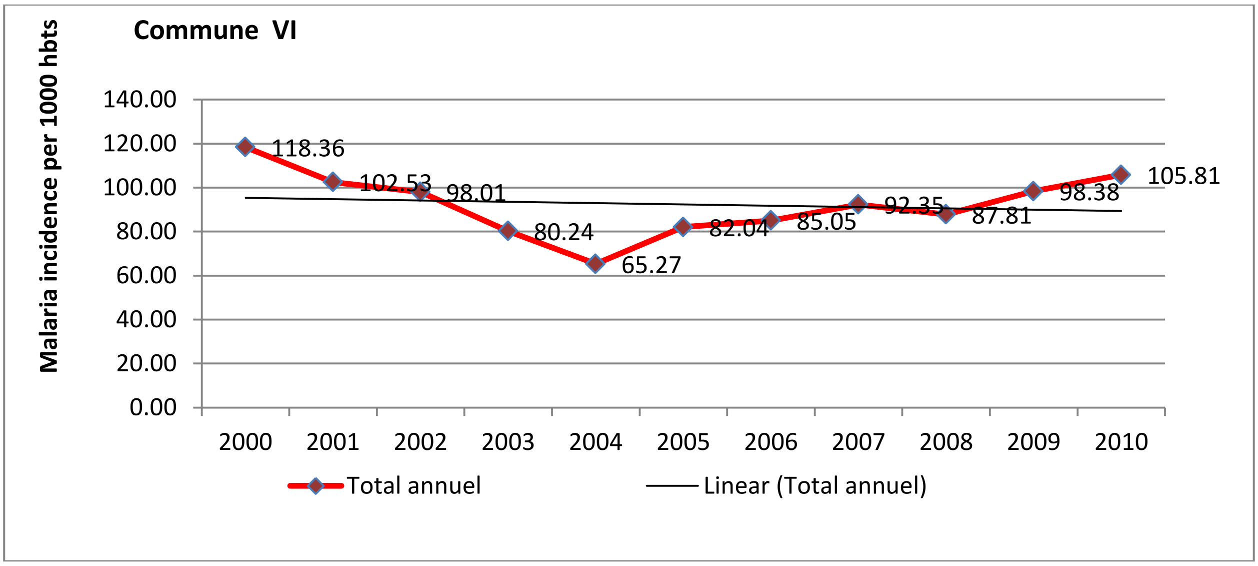

Figure 29 : Year-to-Year Simple and Severe Malaria Incidence Variation in C.VI of Bamako District

Malaria incidence recorded a marked drop between 2000 and 2004 with 118.36% and 65.27% respectively. But there was a gradual rise from 2004 up to 2010. However, the year-to-year malaria incidence rate average is slightly on a downward trend.

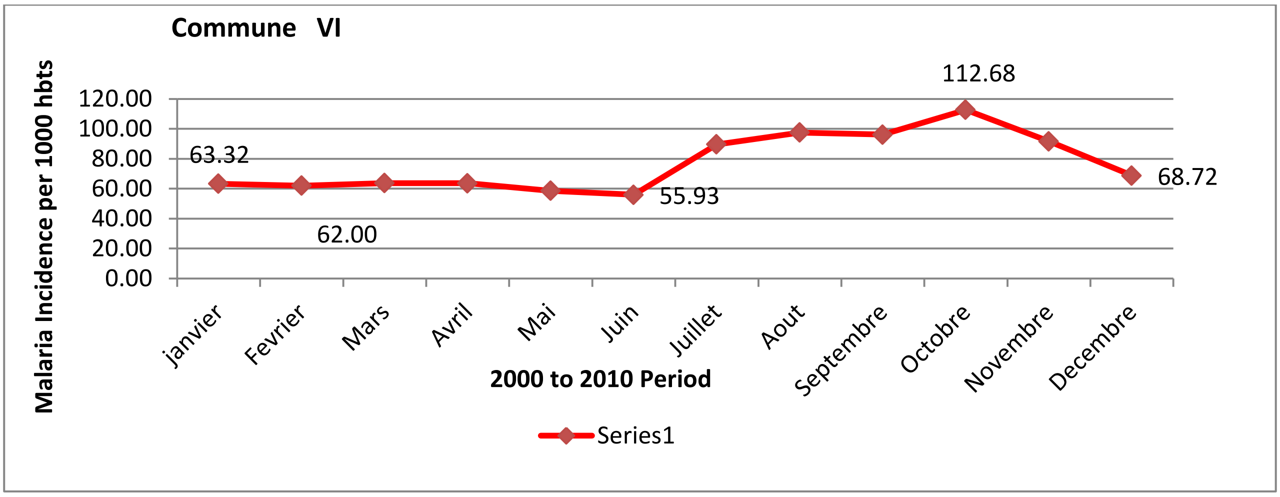

Figure 30 : Monthly Simple and Severe Malaria Incidence Variation in C.VI of BamakoDistrict

Monthly malaria incidence distribution varies very little between December and June. However, it increases steadily from June and peaks in October at 112.68%. The lowest rate of 55.93‰ was recorded in June.

4.3 Cross Analysis of Climate Parameters with Disease Data

4.3.1 Link Between Diarrhoea Incidence and Temperature

4.3.1.1 Diarrhoea and Maximum Temperature

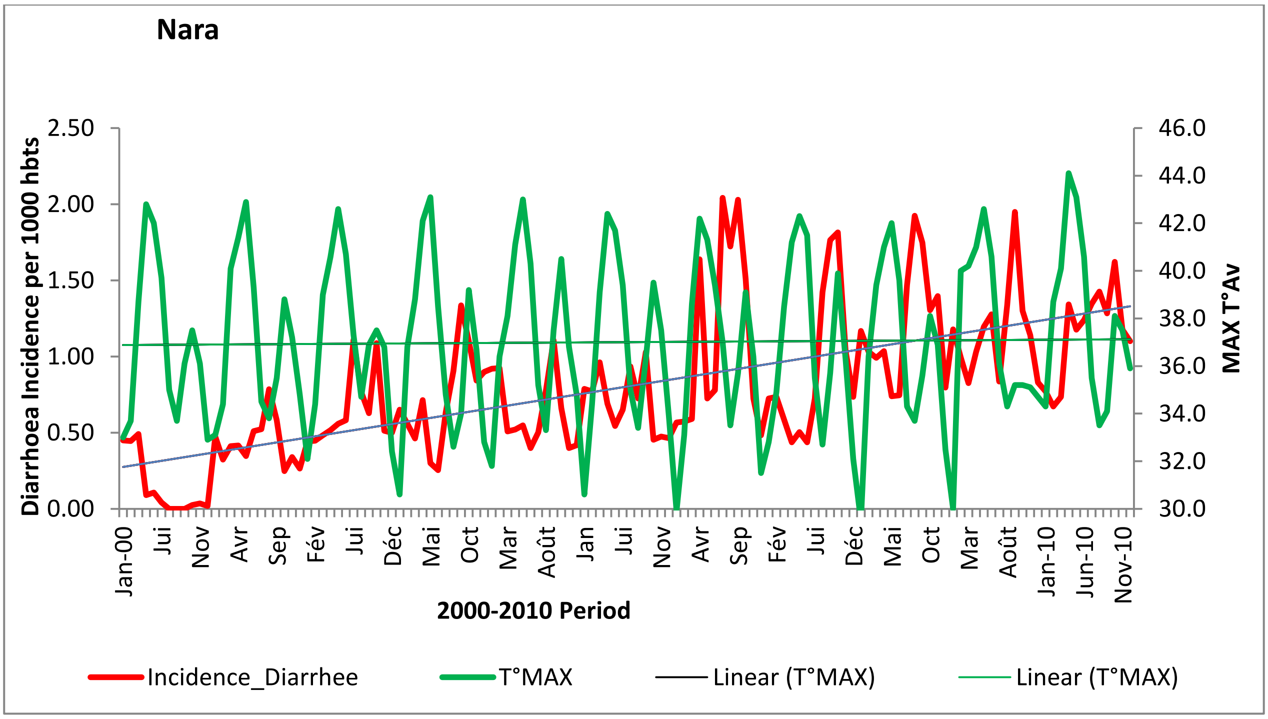

Figure 31: *DiarrhoeaIncidenceAccordingtoMaximumTemperatureinNara*

Temperature variation during the study period seems to be very low, while diarrhoea incidence shows a marked upward trend.

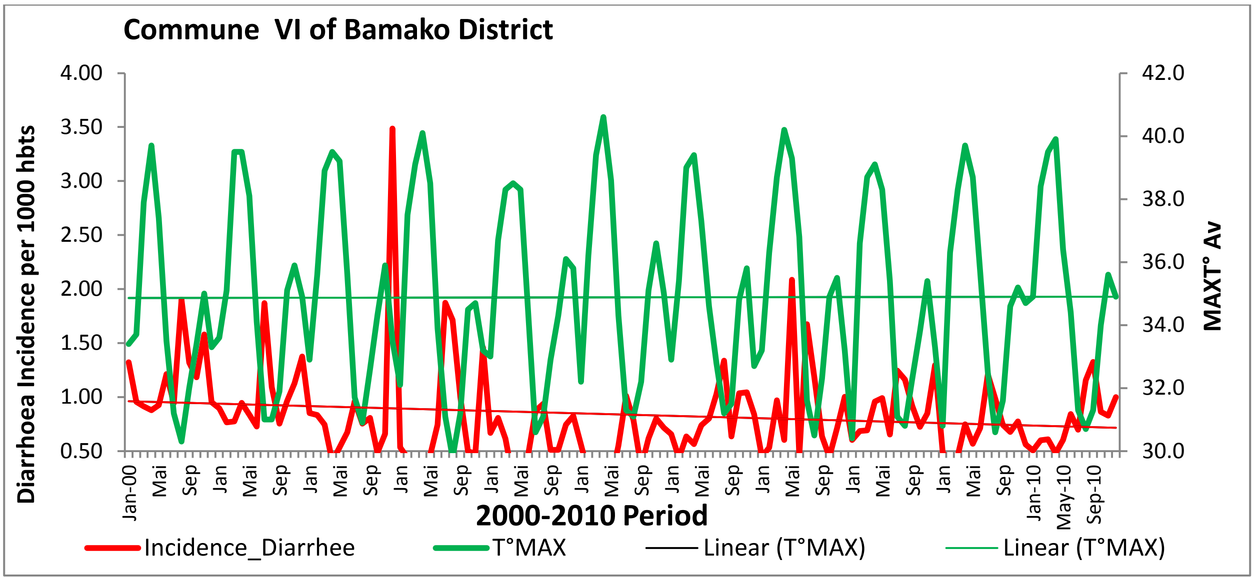

Figure 32: Diarrhoea Incidence According to Maximum Temperature in C.VI of Bamako District

Maximum temperature seems to be on a slight upward trend while the reverse is true for diarrhoea incidence.

4.3.1.2 Diarrhoea and Minimum Temperature

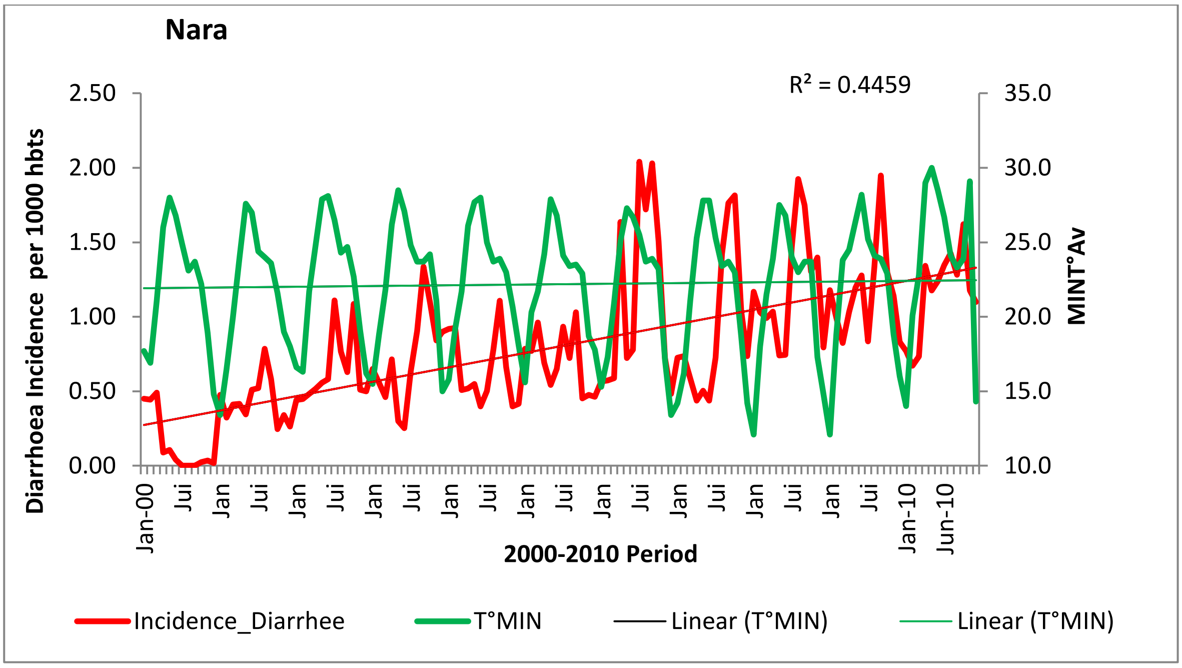

Figure 33: Diarrhoea Incidence According to Average Minimum Temperature in Nara

Minimum temperature varies very little but seems to show an upward trend, just like diarrhoea incidence which, moreover, is more marked.

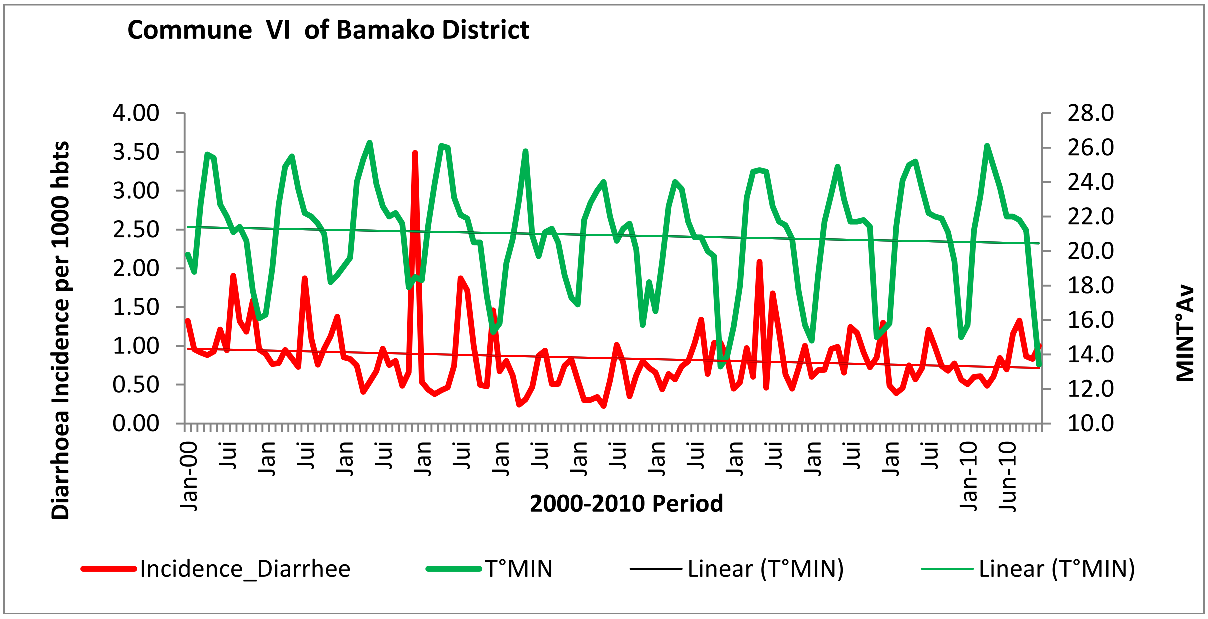

Figure 34: Diarrhoea Incidence According to Minimum Temperature in C.VI of Bamako District

Minimum temperature varies very little but shows a downward trend, just like diarrhoea incidence.

4.3.2 Link Between Diarrhoea Incidence and Rainfall

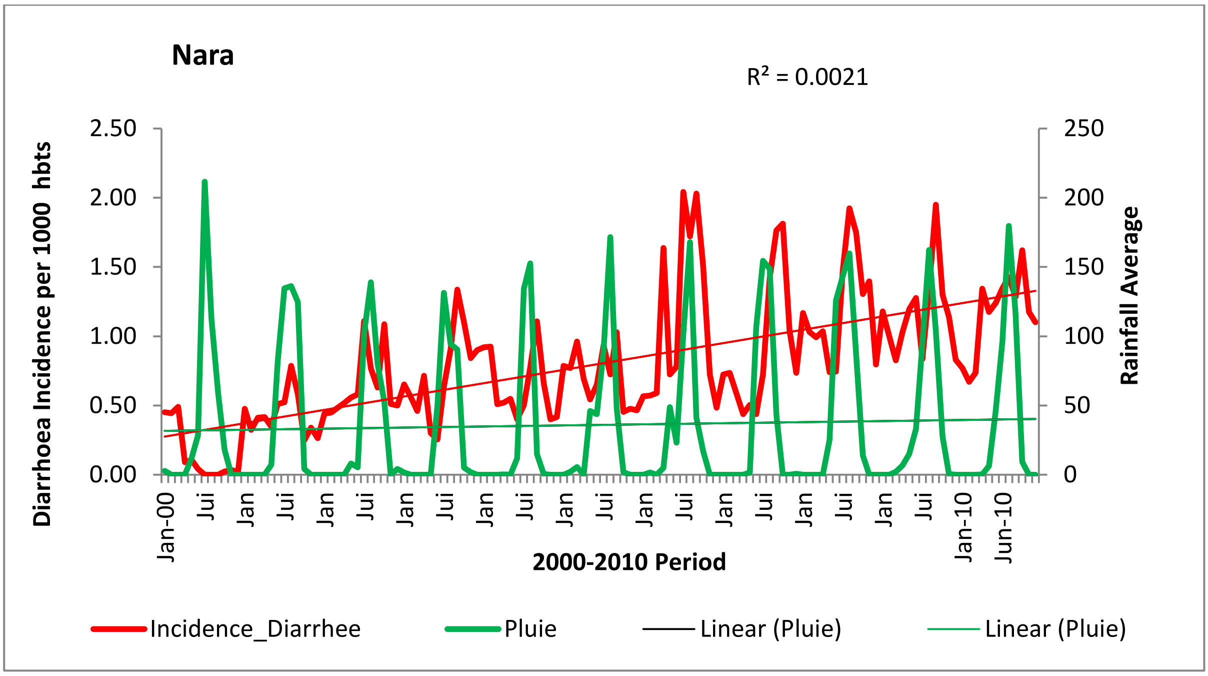

Figure 35 Diarrhoea Incidence According to Rainfall in Nara

There is an upward trend in diarrhoea incidence according to rainfall. We notice that each rainfall peak seems to provoke diarrhoea peak or peaks, especially around the months of June and July.

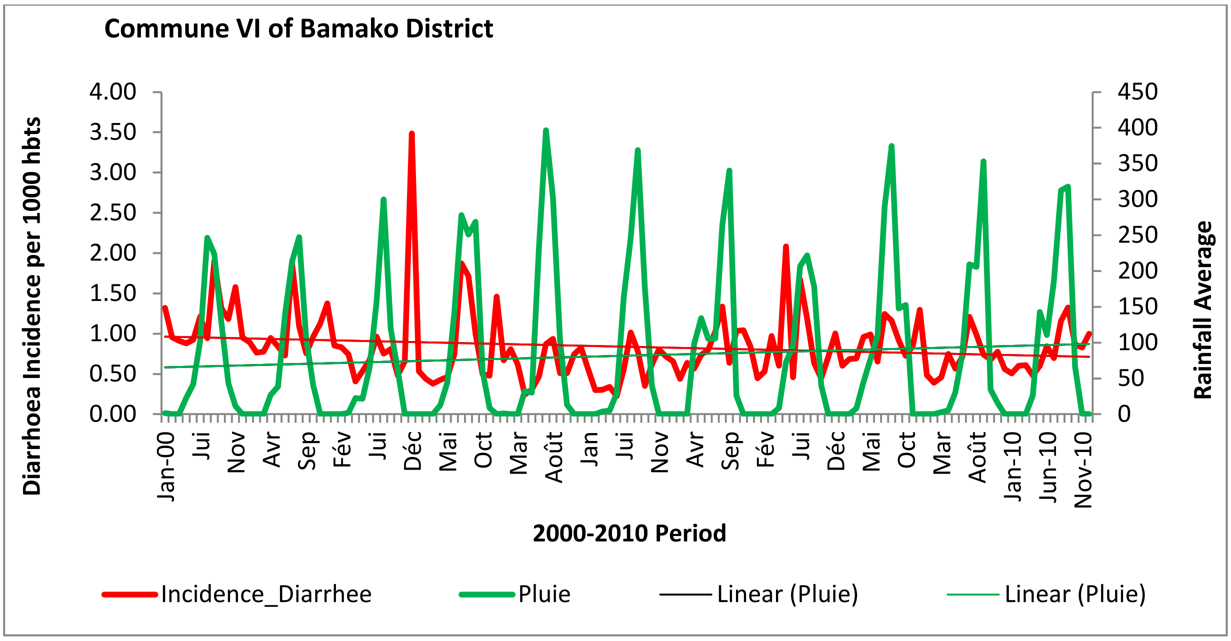

Figure 36: Diarrhoea Incidence According to Rainfall in Commune VIofBamako District

Rainfall is on an upward trend, in contrast to diarrhoea. We notice that each rainfall peak results in diarrhoea incidence variation.

4.3.3 Link Between Diarrhoea Incidence and Relative Humidity
4.3.3.1 Maximum Relative Humidity

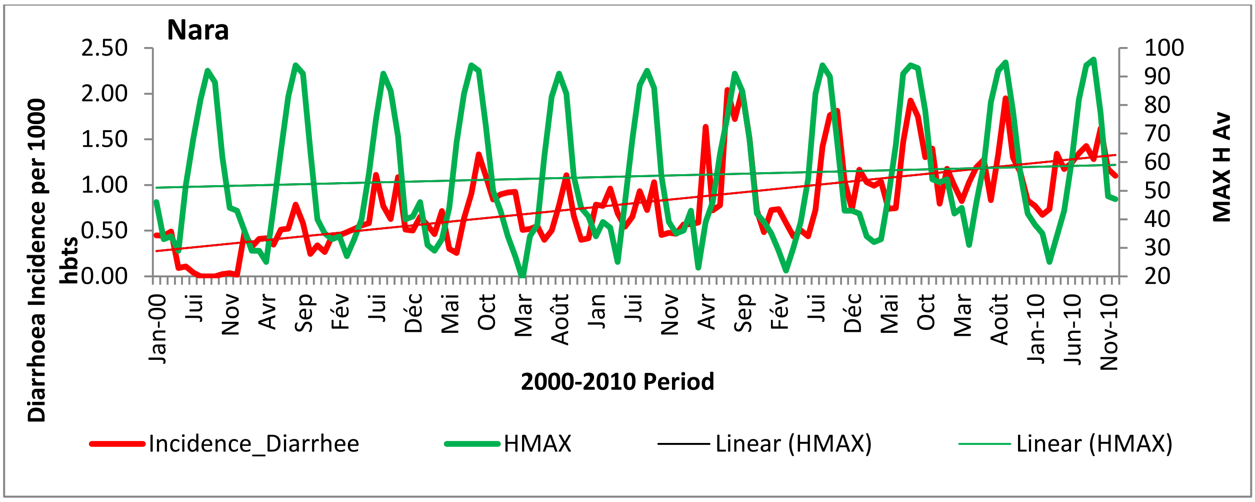

Figure 37 : Diarrhoea Incidence According to Maximum Relative Humidity in Nara

Maximum relative humidity varies very little, but shows an upward trend, just like diarrhoea incidence which, moreover, is more marked.

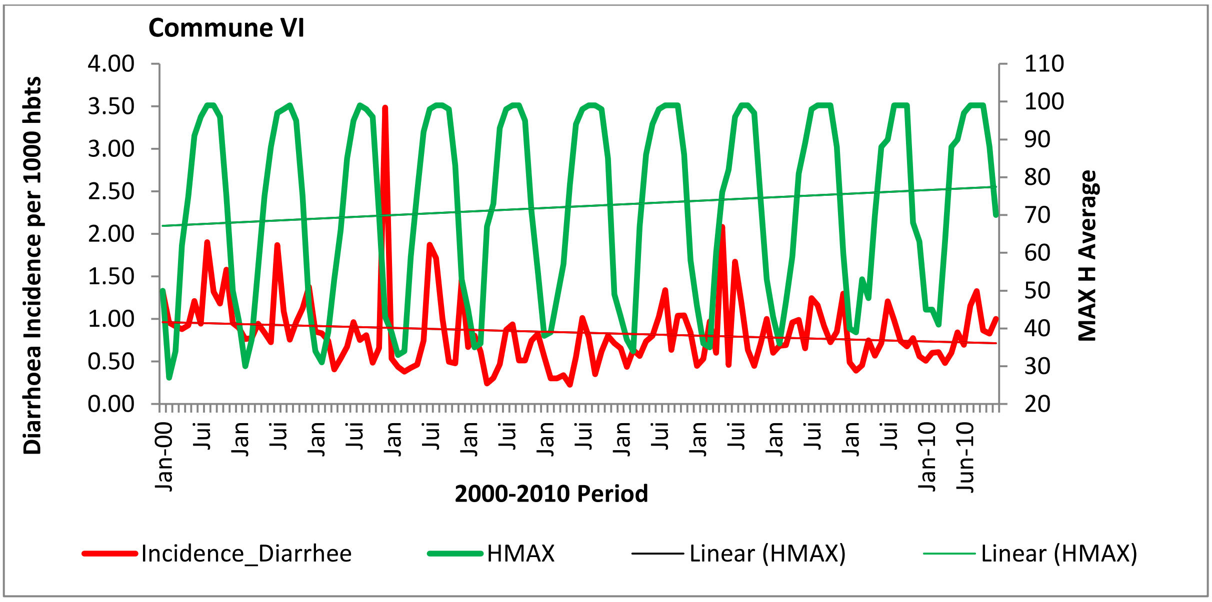

Figure 38: Diarrhoea Incidence According to Maximum Relative Humidity in C.VI of Bamako District

We notice that the minimum relative humidity shows an upward trend, in contrast to diarrhoea incidence.

4.3.2.2 Minimum Relative Humidity

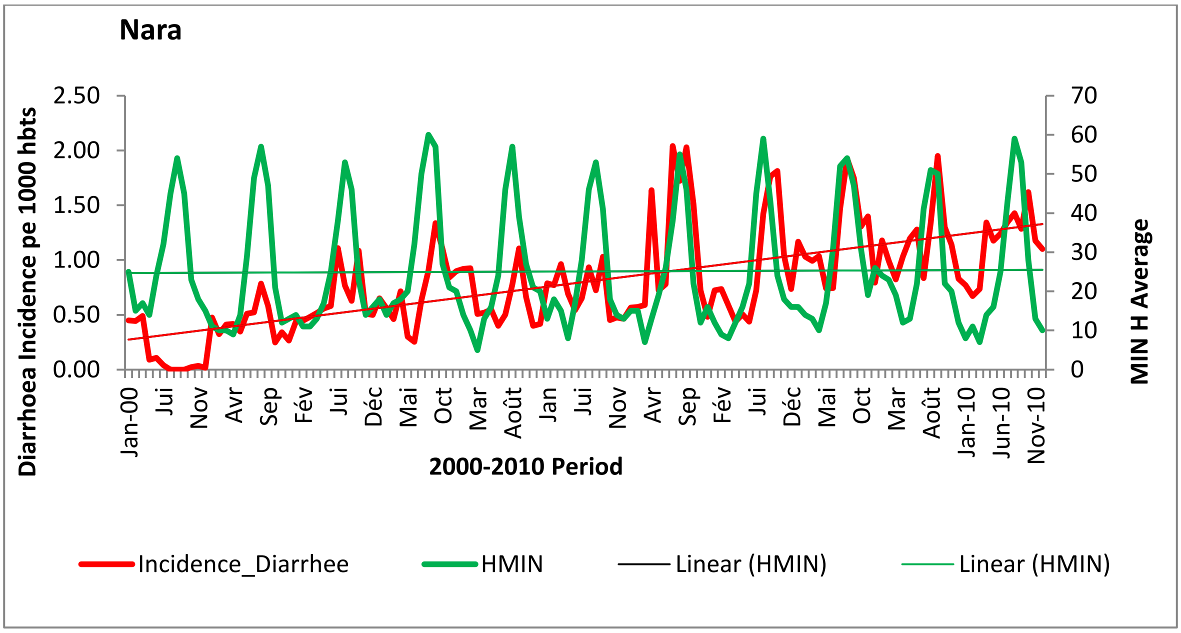

Figure 39: Diarrhoea Incidence According to Minimum Relative Humidity in Nara

We notice that the minimum relative humidity is on a downward trend, in contrast to diarrhoea incidence which shows an uptrend.

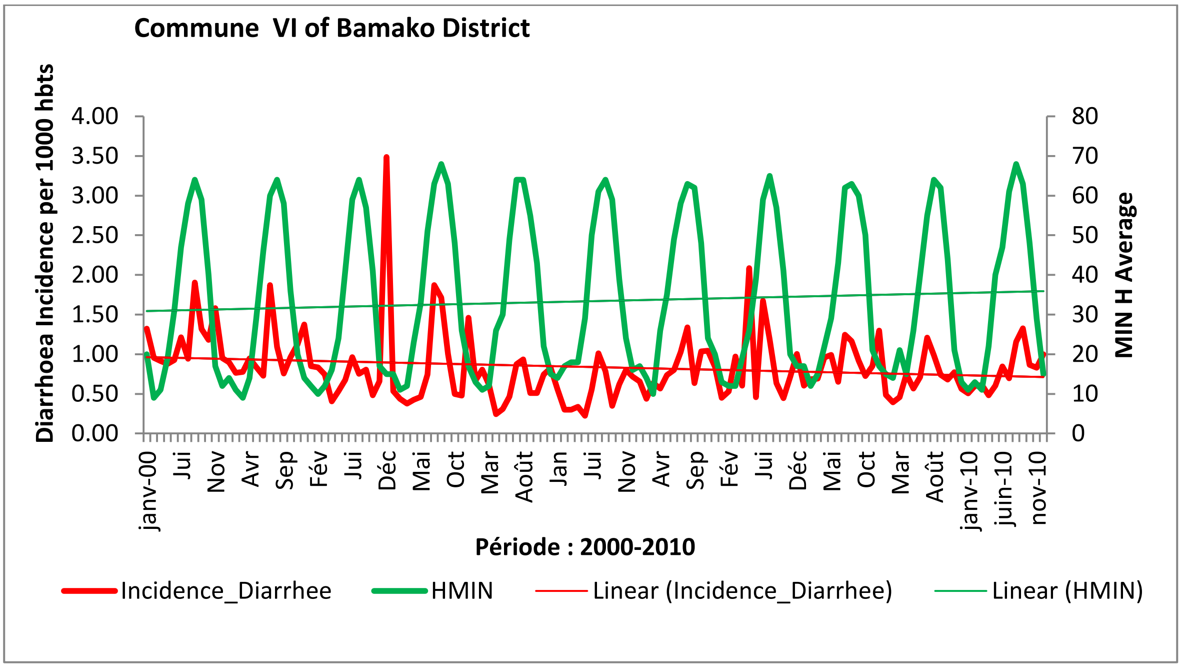

Figure 40 : Diarrhoea Incidence According to Minimum Relative Humidity in C.VI of Bamako

We notice that the minimum relative humidity trend is on the rise, contrary to diarrhoea incidence.

4.3.4 Link Between Simple and Severe Malaria Incidence According to Temperature

4.3.4.1 Malaria and Maximum Temperature

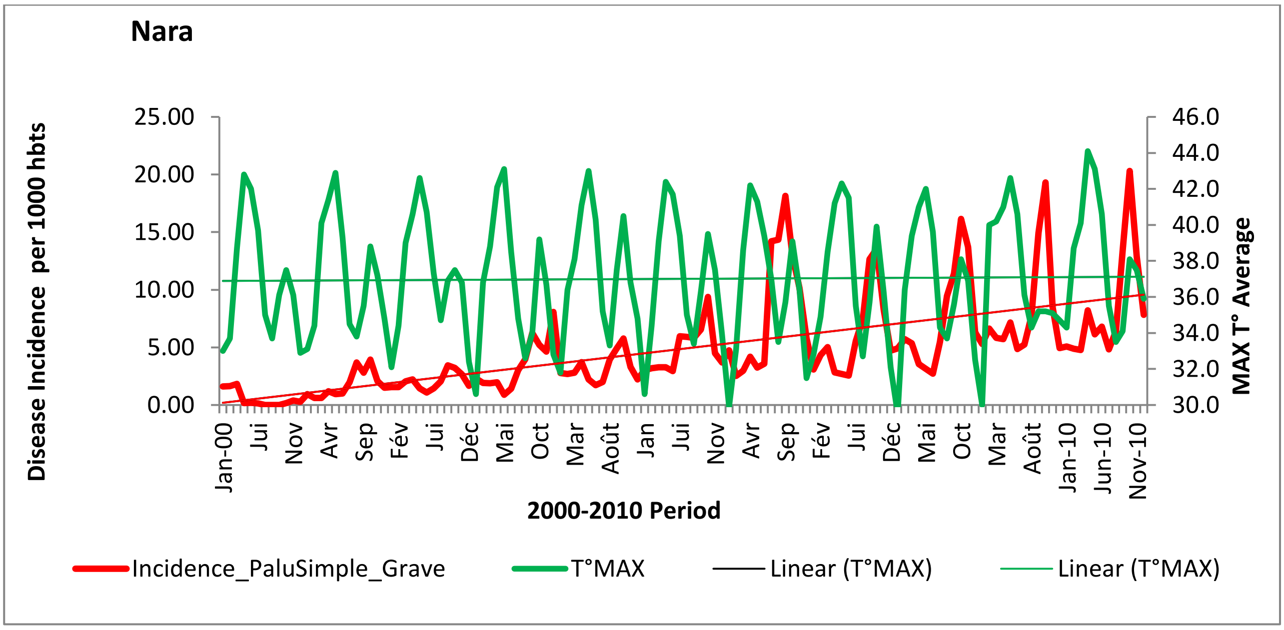

Figure 41: Malaria Incidence According to Maximum Temperature in Nara

We notice low temperature variation, whereas malaria incidence is on an upward trend.

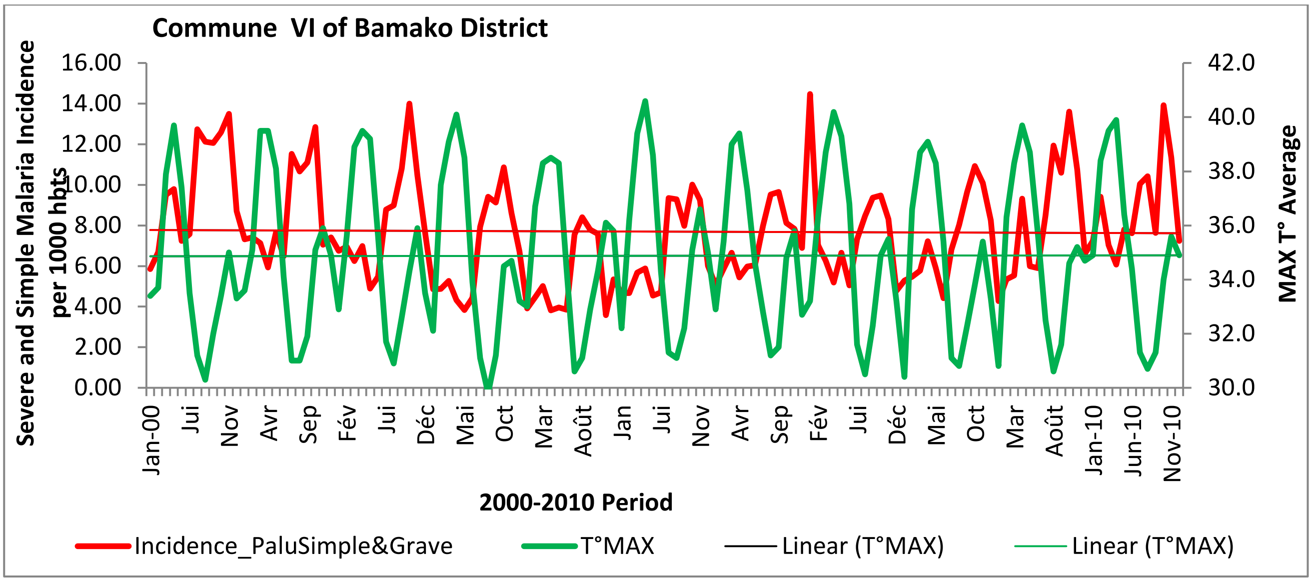

Figure 42 : Malaria Incidence According to Maximum Temperature in C.VI of Bamako District

Maximum temperature does not seem to influence malaria incidence.

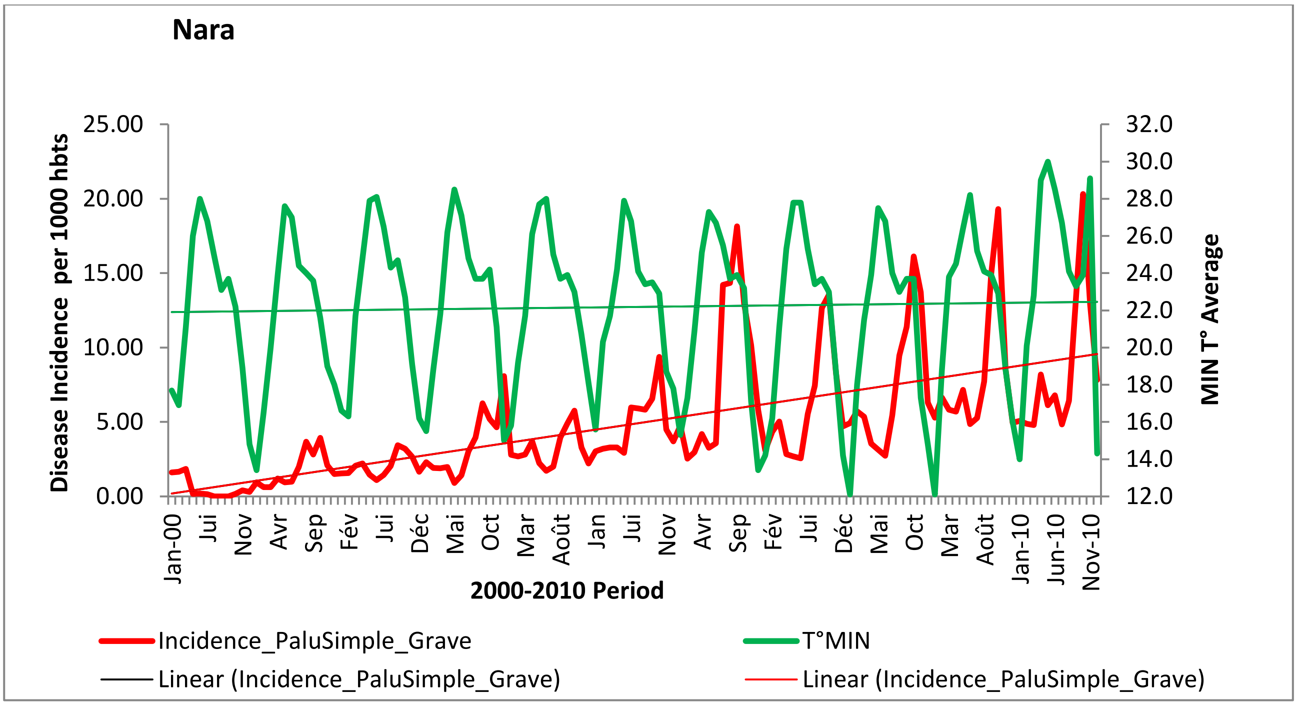

Figure 43: Malaria Incidence According to Minimum Temperature in Nara

Minimum temperature varies very little, but shows an upward trend, just like malaria incidence whose trend is more marked.

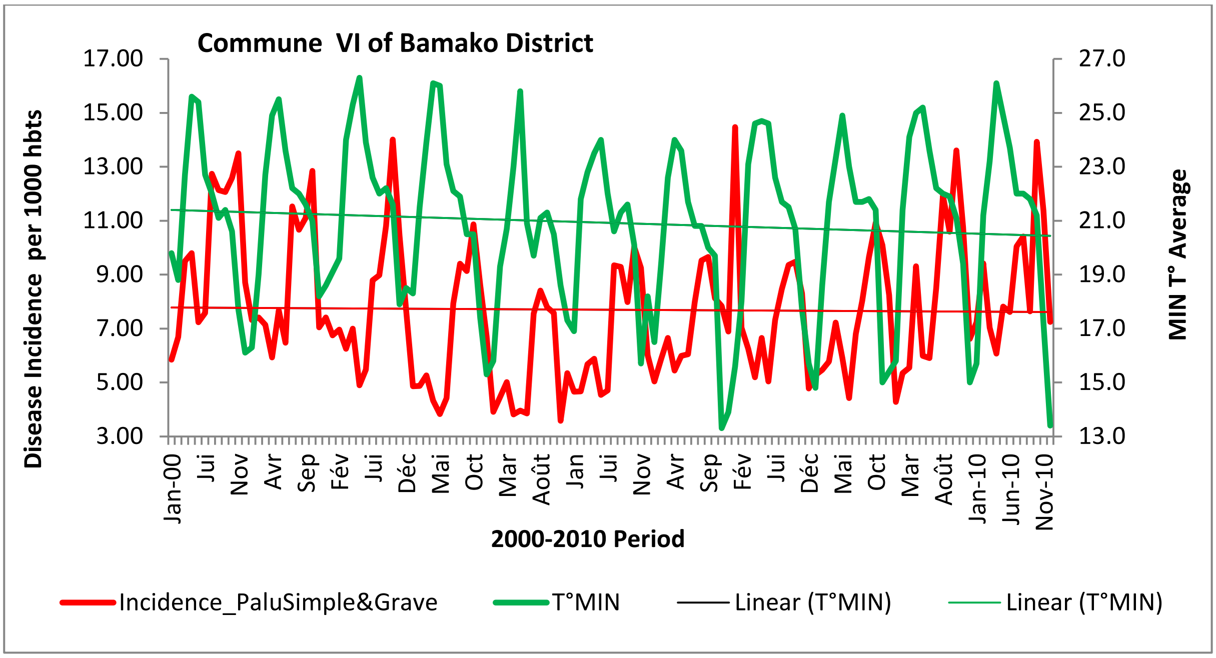

Figure 44 : Malaria Incidence According to Minimum Temperature in C.VI of BamakoDistrict

Minimum temperature is on a downward trend, just like malaria incidence.

4.3.5 Link Between Rainfall and (Simple and Severe) Malaria Incidence

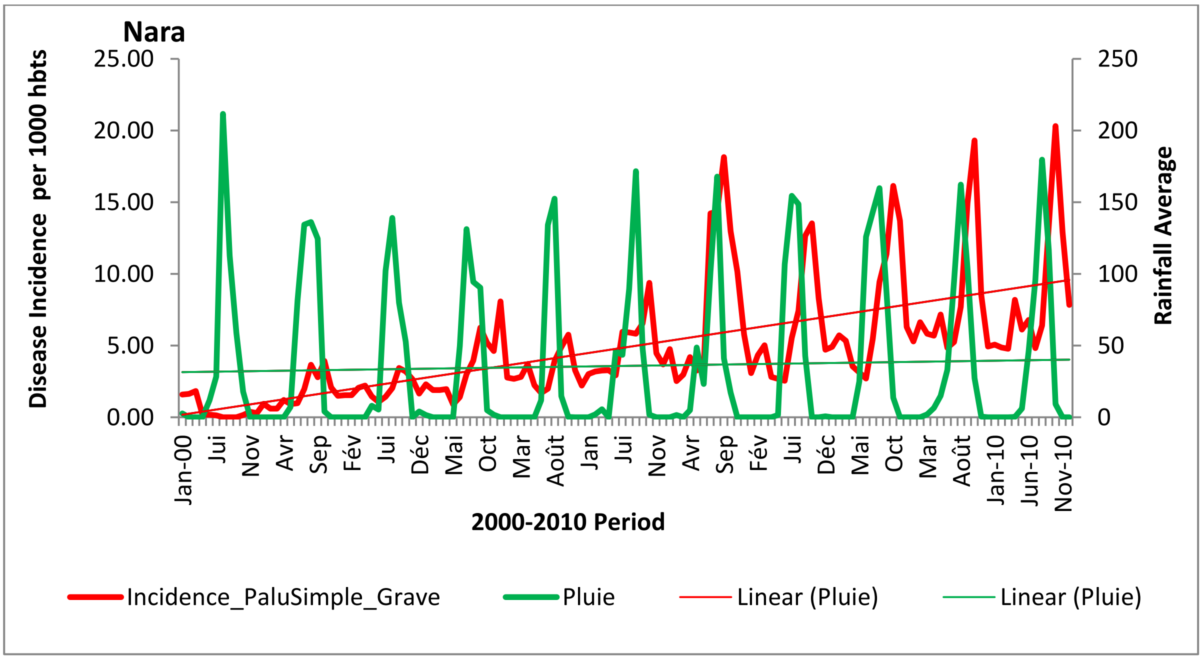

Figure 45: Malaria Incidence As a Function of Rainfall in Nara

We notice an upward trend in malaria incidence as a function of rainfall. Even though there is little variation in rainfall amounts over the years, malaria incidence increases each season.

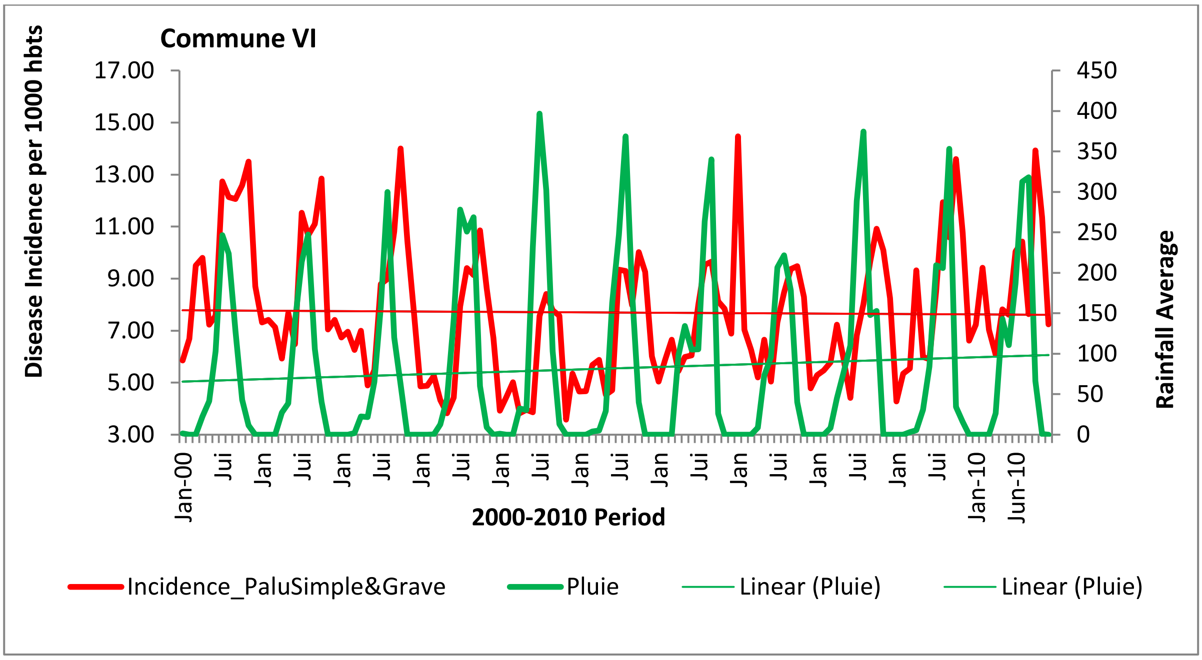

Figure 46 : Malaria Incidence According to Rainfall in C.VI of Bamako District

Rainfall is on an upward trend and each rainfall peakleadsto a delayed malaria incidence peak. This phenomenon seems to point to a link between rainfall and malaria incidence, though malaria incidence seems to be on a downward trend.

4.3.6 Link Between Simple and Severe Malaria Incidence and Relative Humidity

4.3.6.1 Malaria Incidence and Maximum Relative Humidity

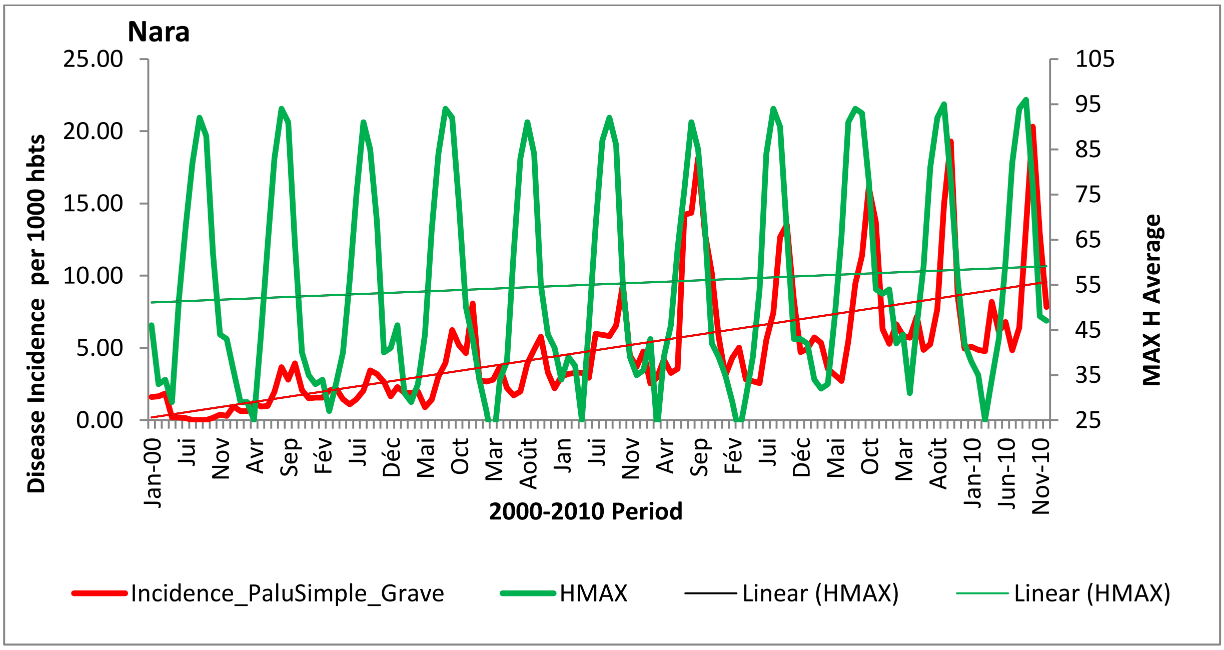

Figure 47 : Malaria Incidence According to Maximum Relative Humidity in Nara

There is an uptrend in maximum relative humidity, just like malaria incidence. The more the maximum relative humidity increases, the more the malaria incidence rises.

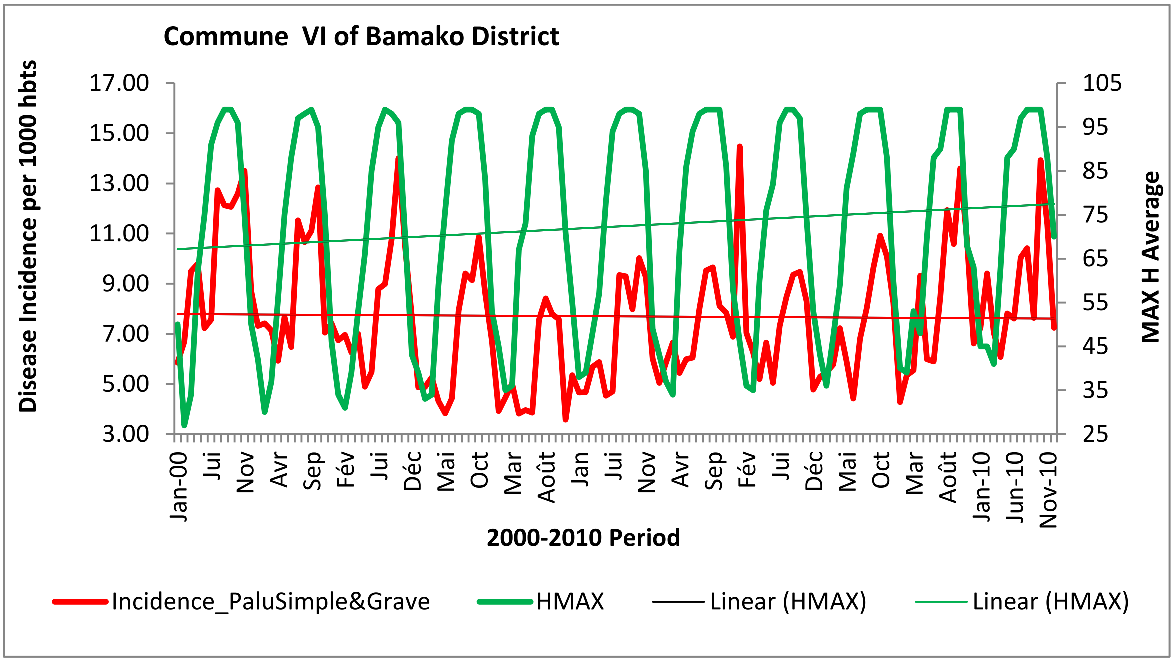

Figure 48: Malaria Incidence As a Function of Maximum Relative Humidity in C.VI of Bamako District. Maximum relative humidity varies very little, but is on an upward trend. It seems to provoke an increase and a variation in malaria incidence peaks, though the trend is slightly on the decline.

4.3.6.2 Malaria Incidence and Minimum Relative Humidity

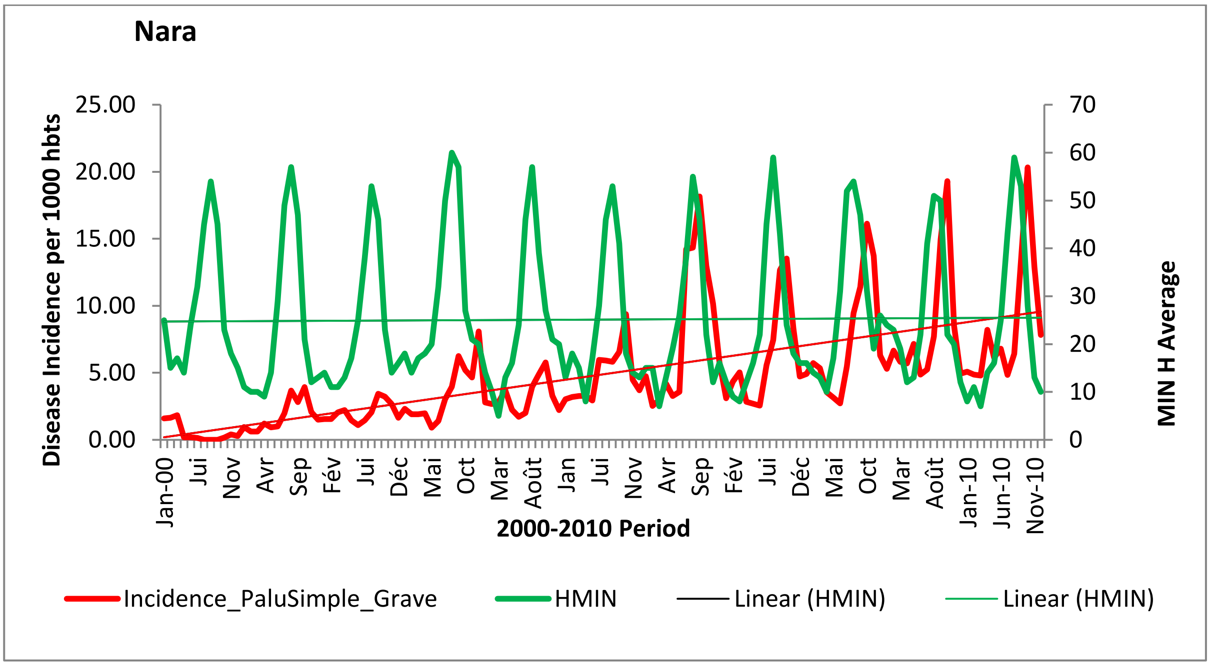

Figure 49: Malaria Incidence as a Function of Minimum Relative Humidity in Nara

Minimum relative humidity hardly varies and is on a downward trend. It however seems to influence malaria incidence. This link is particularly marked from June to November. Malaria incidence increases with minimum relative humidity.

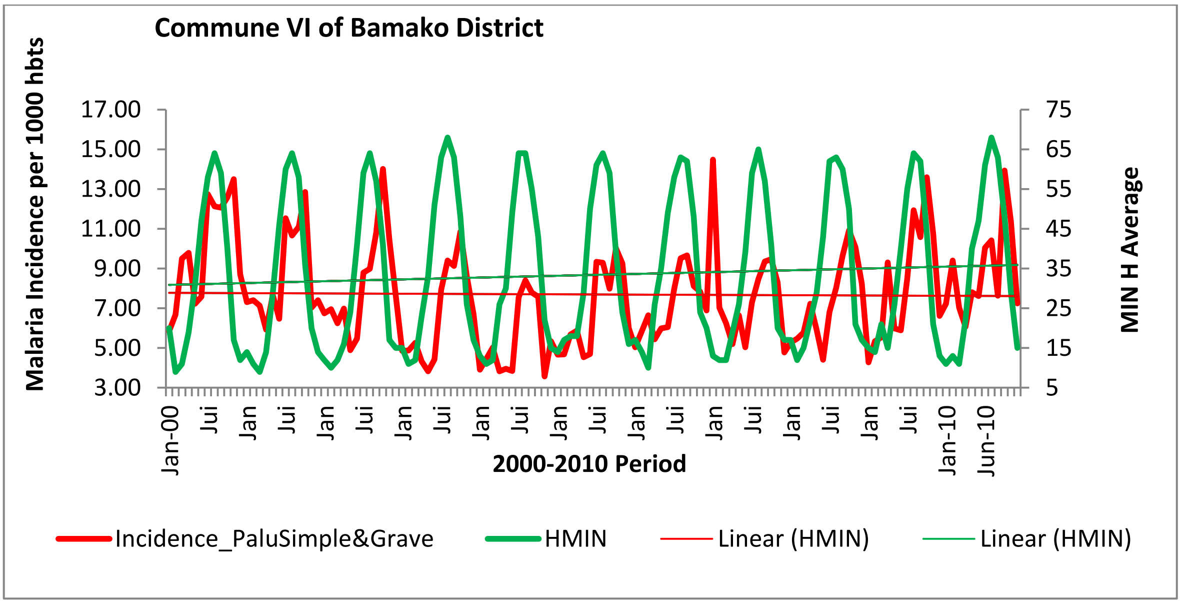

Figure 50 : Malaria Incidence as a Function of Minimum Relative Humidity in C.VI of Bamako District

Minimum relative humidity is on an upward trend, while malaria incidence is on the decline.

4.4 Spearman Correlations (r) Table

4.4.1 Diarrhoea and Climate Parameters in Nara

Table III : Coefficient of Correlation Between Climate Parameters and Diarrhoea Incidence in Nara

	Spearman Coefficient	p-value
Maximum Temperature	-0. 105	0. 231
Minimum Température	- 0. 078	0. 377
Rainfall	0. 290	0. 001
Maximum Relative Humidity	0. 378	0. 000
Minimum Relative Humidity	0. 294	0. 001

There is no correlation between maximum and minimum temperatures and diarrhoea incidence. However, there is a correlation between rainfall and maximum and minimum relative humidity. It is certainly very low, but statistically significant.

4.4.2 Malaria and Climate Parameters in Nara

Table IV: Coefficient of Correlation Between Climate Parameters and Malaria Incidence in Nara

	r (0 month)	p-value	r (1 month)	p-value	r(2 months)	p-value
Maximum Temperature	-0. 104	0. 235	- 0. 144	0. 102	-0. 082	0. 355
Minimum Temperature	-0. 048	0. 586	0. 087	0. 325	0. 230	0. 008
Rainfall	0. 160	0. 067	0. 375	0. 000	0. 451	0. 000
Maximum Relative Humidity	0. 340	0. 000	0. 455	0. 000	0. 469	0. 000
Minimum Relative Humidity	0. 222	0. 011	0. 362	0. 000	0. 404	0. 000

At 0-month gap; at 1-month gap; at 2-months gap

1. At 0-month gap, there is no correlation between maximum and minimum temperatures, nor between minimum relative humidity and malaria incidence. However, there is a statistically significant correlation with maximum relative humidity.
2. At 1-month gap, cross analysis still does not show any correlation between maximum and minimum temperature and malaria incidence. However, not only does correlation appear between rainfall and minimum relative humidity, but also the strength of correlation with maximum relative humidity is on the rise. And these correlations are statistically significant.
3. A cross analysis with a 2 (two)-month gap shows a statistically significant increase in the strength of the correlation between malaria incidence and climate parameters (rainfall, maximum and minimum relative humidity,etc).

4.4.3 Diarrhoea and Climate Parameters in Commune VI

Table V : Coefficient of Correlation Between Climate Parameters and Diarrhoea Incidence in C.VI of Bamako District

	r (0 month)	p-value
Maximum Temperature	-0.442	0.001
Minimum Temperature	-0.159	0.069
Rainfall	0.254	0.003
Maximum Relative Humidity	0.309	0.001
Minimum Relative Humidity	0.302	0.001

There is no correlation between minimum temperature and diarrhoea incidence. However, there is a positive correlation between rainfall and maximum and minimum relative humidity which, though low, is statistically significant. On the other hand, maximum temperature and diarrhoea incidence are inversely correlated. The strength of the correlation is average and statistically significant.

4.4.4 Malaria and Climate Parameters in Commune VI

Table VI : Coefficient of Correlation Between Climate Parameters and Malaria Incidence in C.VI of Bamako District

	r at (0 month)	p-value	r at (1 month)	p-value	r at (2 months)	p-value
MaximumTemperature	- 0.425	0.000	-0.557	0.000	-0.445	0.000
Minimum Temperature	- 0.166	0.057	0.042	0.632	0.298	0.000
Rainfall	0.357	0.000	0.612	0.000	0.647	0.000
Maximum Relative Humidity	0.565	0.000	0.661	0.000	0.560	0.000
Minimum Relative Humidity	0.432	0.000	0.620	0.000	0.618	0.000

At 0-month gap; at 1-month gap; at 2-months gap

1. At 0-month gap, there is no correlation between minimum temperature and malaria incidence. In contrast, there is a statistically significant positive correlation between rainfall and maximum and minimum relative humidity. The strength of the correlation is higher with maximum relative humidity. However, it should be noted that malaria incidence is inversely correlated with maximum temperature, and the correlation is statistically significant.

2. Cross analysis with a 1 (one)-month gap shows an increase in coefficients of correlation between malaria incidence and climate parameters which are rainfall and maximum and minimum relative humility. At a month gap, the strength of the link between climate parameters and malaria incidence is higher. It is the same observation with maximum temperature whose link is still inversely correlated.

3. A 2 (two)-month gap cross analysis shows a more substantial increase in the coefficient of correlation (r = 647) between malaria incidence and rainfall. However, the reverse effect is obtained with maximum and minimum relative humidity, but the correlations are still positive and statistically significant. Lastly, it should be noted that it was through a 2 (two)-month gap cross analysis that it was possible to notice a statistically significant low positive correlation between maximum temperature and malaria incidence.

5. DISCUSSION

5.1 Meteorological Data

The meteorology data used relate to three climate parameters : temperature (recorded under shelter in degree Celsius), rainfall (cumulative rainfall amounts per month) and relative humidity (recorded at 8.30 am and at 5.30 pm). Monthly and annual temperature, rainfall and relative humidity averages were used to describe the various change trends of each climate parameter from 1990 to 2010. This data was later cross analyzed with that of diseases to determine a correlation using the Spearman test.

The descriptive analysis of maximum temperature data showed an upward trend (Fig. 5 and 6), both between years and between months in the two health districts of Nara and Commune VI of Bamako District. Certainly, the same trends were observed during the hottest months (February, March, April and May) in the two sites, but it is in Nara that the highest maximum average temperature (42ºC) was recorded (see Table I). This could be accounted for by the geograhical position of the site. In fact, Nara is located in a western Sahel arid zone further north in relation to Commune VI of Bamako District. However, this maximum temperature upward trend confirms climatic warming both in Nara and Commune VI. Minimum temperature trends are different in the two sites. In Nara, average minimum temperatures show high year-to-year variability and an upward trend, while in Commune VI, they vary little, with a downward trend, on the whole.

The analysis of rainfall data from 1990 to 2010 (Fig. 14 and 16) in the two sites highlighted an upward trend in rainfall amounts. There is a unimodal monthly rainfall distribution in the two sites (Fig.14 and 16). In other words, there is only one rainy season, and monthly rainfall peaks in August. However, monthly cumulative rainfall was higher in Commune VI of Bamako District than in Nara District, with 529.7 mm and 171.1 mm respectively. This difference could be explained by the geographical position of the Nara health district. In fact, in Mali, the monsoon regime is the dominant factor of the rainy season, and annual rainfall decreases from south to north, from more than 1300 mm to less than 100 mm [10]. The first rains appear in May and June, while the last rains fall in October. The results obtained have shown a downward rainfall trend in June in Nara District for the period under study. This could point not only to a shortening of the rainy season, but also to a rainfall deficit in June, and, consequently, an extension of the dry season. This can be explained by the late start of the rainy season observed. However, Commune VI is by far wetter than Nara.

Maximum relative humidity showed an upward trend for all the months from 1990 to 2010, except June. Relative humidity distribution is identical to rainfall distribution, but it is more regular, with an absolute maximum in August. This phenomenon occurs in Commune VI of Bamako District at 98% against 92.5% in Nara. The same trends were recorded regarding minimum relative humidity.

5.2 Disease Data

The incidence rate was adopted and calculated for diarrhoea cases diagnosed and treated, as well as for fever cases presumed to be malaria cases diagnosed and treated as such in the health districts of Nara and Commune VI of Bamako District.

5.2.1 Diarrhoea

During the years 2000 to 2010 covered by the study, we observed an upward trend in the incidence of diarrhoeal diseases, irrespective of the study site. It should be noted that in Mali, diarrhoea remains the third cause of hospital consultation after malaria and accute respiratory infections. Data collected and the establishment of correlation between the various parameters show that:

Temperature seems to have no influence on diarrhoea incidence in Nara. However, it is inversely correlated with diarrhoea incidence ($r = 0.442$) in Commune VI, and this correlation is statistically significant ($p = 0.001$). Rainfall and relative humidity seem to influence the incidence of diarrhoeal diseases. This influence seems to be more intense in rural areas than in urban areas. Specifically, we notice that diarrhoea incidence peaks are extreme in 2002 and 2007 in Commune VI (urban site) while they are extreme in 2004 and 2010 in Nara (rural site).

The link between rainfall and diarrhoeal diseases could be explained by the fact that water resource quality is impacted by rains in Mali where they most often take the form of downpour, with waves of soil surface erosion and wash-off, provoking drainage of all kinds of waste towards most often poorly protected water sources (rivers, pools and wells). Coupled with this is insufficient or lack of maintenance of basic sanitation facilities (latrines, mini-sewers, gutters, etc.) likely to contaminate sources of water supply to the population, especially in rural areas.

The contrast between rural and urban areas stems from non-climate factors, namely water supply conditions, sanitation and hygiene habits. According to 2006 Demographic and Health Survey (DHS IV) figures, in Mali only 45% of households have an improved source of water supply, with a wide disparity of 79% in urban areas against 46% in rural areas. Concerning excreta disposal facility coverage of households, the overall coverage rate stands at 23%, that is 28% in urban areas and barely 7% in rural areas. These statistics show that Nara (rural area) is more exposed to diarrhoeal diseases than Commune VI (urban area). It should also be noted that with no water supply in Nara District, drinking water coverage of households is insignificant and the population most often uses poorly developed or undeveloped wells and pools as supply sources, in contrast to Commune VI a good part of which has drinking water supply. Lastly, proper personal hygiene habits promotion activities, such as washing hands with soap, are more intense in urban areas (Bamako) than in rural areas.

Owing to its close link to relative humidity, rainfall partly accounts for the correlation between diarrhoeal diseases and relative humidity.

5.2.2 Cholera Episodes

During the study period, no cholera episode was observed in urban areas (Commune VI), in contrast to rural areas where we observed three cholera episodes (in 2002, 2007 and 2009). The appearance of cholera cases (2005 and 2009) does not seem to have any link with rainfall or humidity, given that these cases occurred in November and December (non rainy season period in Mali). In view of the position of Nara District (not close to a river), these cases seem to have been imported from another health district that experienced cholera episodes in 2005 and 2009 (Kayes or Koulikoro District). In fact, 2005 was one of the years during which the highest number of cholera cases was recorded in Mali.

5.2.3 Simple and Severe Malaria

According to Mali's Local Health Information System (LHIS), in 2010, malaria was the leading cause of consultation with 38% of cases, followed by accute respiratory infections and diarrhoeal diseases. It therefore remains a major public health problem in Mali [10].

For study data analysis, we calculated the disease incidence rate using fever cases presumed to be simple or severe malaria and treated as such. This was data from CSCOM monthly reports and LHIS quarterly progress reports (QPR) of the health districts of Nara and Commune VI of Bamako District. After that, we looked for the link between malaria incidence and climate parameters.

In both the Nara and Commune VI health districts, malaria transmission is seasonal, that is endemic, with a seasonal peak during the rainy season. *Plasmodiumfalciparum* accounts for close to 95% of parasite formula [12]. The main vectors are of the *anopheles type*: *An gambiae,An gambiae ss, An Funestus* and *An arabiensis* [12].

During the study period, we observed an uptrend in the incidence of simple and severe malaria in Nara, while in Commune VI (Fig. 27 and 30), there was a slight downtrend. This difference could be explained by the demographic factor. In fact, 1093 malaria cases were recorded in 2000 in Nara, that is a 0.54‰ rate, against 25 561 cases in 2010, that is an 8.08‰ incidence rate. In contrast, 24 670 cases were recorded in Commune VI in 2000, that is a 118.36‰ incidence rate, against 71 809 cases or a 105.81‰ incidence rate in 2010.

The monthly malaria incidence rate showed a unimodal distribution in both sites. There is a rise from June, with a peak in October (9.99% in Nara and 112.68% in Commune VI).

These differences between rural and urban areas could be explained by several non-climate factors, including population. Between 2000 and 2010, the population of Commune VI increased 2.5 times. It thus moved from 263 862 inhabitants in 2000 to 678 673 inhabitants in 2010. To the population factor should be added health care access conditions which are easier in urban areas than in rural areas; health-care personnel capacity building, improvement of case detection through the availability of appropriate and adequate diagnosis means improvement of the case reporting system, increase in the population's economic resources and improvement of the urban population's knowledge of malaria.

The coefficient of correlation between malaria incidence and maximum temperature was negative in both Nara and Commune VI. This result corroborates the results obtained by Ousmane N'DIAYE in Niakhar, Senegal, within the framework of a study of the impact of climatic variations on malaria-related mortality from 1984 to 1996, and Sidy DOUMBIA, in the study entitled «Impact du changement climatique sur l'incidence du paludisme au Mali de 1998 à 2007 » [14 ;15]. In Commune VI, however, this value was considerable (r = - 0.425), while correlation was moderately inversed. Through a cross analysis, we obtained a correlation coefficient of about r = - 0.557. These results could be explained by the fact that as one of the major climate components, temperature intervenes in the distribution process and abundance of anopheles vectors, the possibility and success of the sporogonic development of the parasite within the vector, the modulation of contact between man and the vector, the duration of vector pre-imaginal development and the survival of the adult anopheles. Above 35 °C and below 18

°C, the sporogonic development of *P. falciparum* is stopped and the lifespan of the female anopheles threatened. However, an increase in temperature could also reduce the time required for the parasite to develop in its vector, which would increase the vectorial capacity of the anopheles.

Rainfall in both Nara and Commune VI showed a distribution similar to that of relative humidity and minimum temperature. These climate parameters were at extremes in both sites in August: it was maximum for rainfall and relative humidity, and minimum for temperature. Malaria incidence, for its part, was at maximum in October, that is two months after maximum temperature and relative humidity. Correlation between malaria incidence, rainfall and relative humidity is positive. These results corroborate those obtained by Ousmane N'DIAYE in Niakhar, Senegal, and Sidy DOUMBIA in Mali.

With a 0-month gap in Nara, there was no correlation (r = 0.160) for rainfall; correlation was low (r = 0.222) for minimum relative humidity and moderate (r =0.320) for maximum humidity. A cross analysis, with a 1-month and 2-month gap, produced the highest correlation coefficients (Table IV).

In Commune VI, a cross analysis carried out with a 0-month gap showed that there was a correlation that was low (r = 0.357) with rainfall, moderate (r = 0.432) with minimum relative humidity, but higher (r = 0.565) with maximum relative humidity. These correlations were statistically significant. A cross analysis, with a 1-month gap, gives higher correlation coefficients (r = 0.612) with rainfall, (r = 0.661) with maximum relative humidity and (r = 0.620) with minimum relative humility. These correlations are statistically significant. With a 2-month gap, the correlation coefficient is even higher, but only with rainfall (r = 647) (Table VI).

The correlation between malaria incidence and climate parameters, namely rainfall and maximum and minimum relative humidity, is significant in both sites. However, the correlation is higher in Commune VI than in Nara health district.

The results obtained highlighted the link between malaria incidence and the three meteorological parameters studied. Climate parameters like rainfall influence the availability and quality of breeding sites, relative humidity and minimum temperature, as well as anopheles vector lifespan. A cross analysis with a 1- and 2-month gap produced higher correlation coefficients (Tables IV and VI) and consequently showed the importance of the links between rainfall, relative humidity and malaria incidence.

The correlations established through cross analysis with 1- and 2-month gaps are justified by the results of studies carried out on the link between climate and disease vector and parasite biology.

In fact, some time is required to set up mosquito breeding sites after the first rains before the irruption of the first anopheles. According to N'diaye et al, the prevalence of *P. falciparum* gametocytes is relatively low at the beginning of the malaria transmission season; we can therefore deduce that the first anopheles will infect less and that we will have to wait for the multiplication of carriers to see an increase in the number of malaria attacks. Furthermore, only female anopheles aged ten days at least (duration of parasite sporogonic cycle) are capable of inoculating a subject with sporozoites. Lastly, the parasite must complete the hepatic phase (one week) and several erythrocyte cycles (at least one week) before, eventually, being able to provoke a malaria attack.

6. CONCLUSIONS

In the two study sites (Nara and Commune VI of Bamako District, Mali), results highlighted an upward trend in climate parameters, namely maximum temperature, rainfall and relative humidity, for the 2000 to 2010 period. This increasing trend may reflect climate change in both sites and may have had a direct or indirect impact on the health of the populations of Nara and Commune VI. Data, however, did not permit us to demonstate the direct impact of indicative climate change on diarrhoeal disease and malaria incidence. However, this work enabled us to show some linkage between the variability of climate parameters, namely rainfall, temperature and relative humidity, and their impact on diarrhoeal disease and malaria incidence that were statiscially significant. This study provides a basis to pursue similar study and analysis in the future using a longer timeframe (at least 30 years or more).

7. STUDY LIMITATIONS

In fact, while it was easy for us to obtain data on meteorological parameters collected over a 20-year period, it was not the case with data on diseases. Lack of reliable data over a period of more than 10 years compelled us to limit ourselves to an 11-year period (2000 to 2010) for data on diseases. Our work was unable to establish simple and severe malaria incidence rates because such classification of the disease was effective only from 2007. Incidence distribution by age bracket could not be done both for diarrhoea and malaria. Mortality related to the two diseases could not be analyzed owing to lack of data. Indeed, severe malaria cases are referred to Hospital Gabriel Toure and there is no information on the fate of referred cases.

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World Health Organization Centre for Health Development (WHO Kobe Centre – WKC)

I.H.D. Centre Building, 9th Floor1-5-1 Wakinohama-Kaigandori
Chuo-ku, Kobe 651-0073 Japan
Telephone: +81 78 230 3100
Facsimile: +81 78 230 3178
E-mail: wkc@who.int
URL: http://www.who.int/kobe_centre/

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