Chapter 10

Semi-arid zones: the Sahel is sensitive to variations in rainfall

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Village on the River Niger at Gao in eastern Mali. The Sahel was hit by drought during the second half of the 20th century but precipitation has resumed since the 1990s.

The Sahel-Sudanian strip that runs from Senegal to Sudan is considered by IPCC experts as being one of the parts of the world that is most vulnerable to climate change. The temperature of this semi-arid region of Africa has risen for 60 years and the rainfall regime has changed. The climate forecast is a 3 to 4°C rise by the end of the 21st century, with dramatic consequences for food security, water supply and human health. Paradoxically, the IPCC Fifth Assessment Report indicates the absence of proof of the impacts of climate change that already affects the region in key sectors such as agriculture. This does not mean that climate change has not had any effects yet but that it is difficult to show them as clearly as in other regions of the world. The uncertainty is related to the very strong natural variability of precipitation in the region and also to the dominant role of human activities in the change of Sahelian environments. Rapid population growth in this part of Africa since the 1950s has, in particular, made farming more intense, changing environments and landscapes on a lasting basis.

The lack of information on proven impacts of climate change also results from the shortage of data and studies in the region.

The Sahel is a semi-arid zone among others. It is the focus of this chapter because development issues for the population are important. The interdisciplinary research conducted in the region by IRD allows a close view of the interactions between climate, environments and humans that is essential for understanding the effects of climate change at the regional scale.

Change in the rainfall regime in the Sahel

The Sahel has grown steadily warmer since the 1950s, with an average increase of about 1.5°C. However, the increase in temperature is not homogeneous over the year or throughout the region. The warming observed is particularly marked and regular in the spring, a time of year when temperatures are already very high. It is also distinctly greater at night than during the day (more than 2°C). The temperature can rise by more than 2.5°C when the monsoon arrives. The increase is linked in particular to that of the humidity that is a feature of the start of the rainy season. The temperature also increases more strongly at latitudes where the temperatures are already higher, as in northern Mali.

Although warming can be measured, it is more difficult to describe the evolution of precipitation. The Sahel suffered severe droughts in the 1970s and 1980s. This break in precipitation is one of the strongest climatic signals ever recorded since the start of meteorological measurements. However, precipitation has returned since the 1990s.

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Dunes in the Ténéré in Niger.
The temperature in the Sahel has risen by 1.5°C since 1950.

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Arrival of rain in Niger. Storms in the Sahel have been more severe for about 20 years.

‘Intensification’ of the rainfall regime

Nevertheless, the increase in rainfall is not a return to normal, to the 1960s reference period. First, it concerns only part of the continental Sahel (Mali, Burkina Faso, Niger). Rainfall is still short in the west of the continent and in particular in Senegal. Second, the increase in precipitation for the last 20 years or so results more from the intensity of storms than their frequency. There are fewer storms today than there were before the drought. But they are more severe and consequently the volumes of water recorded are closer to those of the 1960s. Precipitation has also become more uncertain and there are intermediate drought years. Given these alternating extreme events, scientists talk in terms of the ‘intensification’ of the rainfall regime.

Even though there is strong uncertainty concerning the evolution of rainfall in the Sahel under the effect of the warming of the climate, an increasingly probable scenario seems to be taking shape in the scientific literature. It depicts a western Sahel (Senegal, western Mali) that is dry above all at the beginning of the monsoon season and a central and eastern Sahel with rain especially at the end of the winter season.

Box 25

Increasingly numerous extreme precipitation events since 1990

One of the features of climate change is the increase in the number of extreme events but very few studies address the subject. Work by the LTHE unit in the Sahel shows that rainfall extremes have become more marked after 1990, confirming the marked change in the rainfall regime at the turn of the century.

There have been very few studies of rainfall extremes in the Sahel. The reasons are the shortage of data and also methodological difficulties in studying the most intense rainfall. Indeed, extreme events are rare by definition and particularly difficult to quantify and this, together with strong inter-annual and decennial variability of rainfall in the Sahel, makes it difficult to identify trends.

LTHE researchers overcame these difficulties by working in a set of 43 daily rainfall series available for 1950-2010. Statistical analysis based on extreme value analysis gave a regional view of the spatial organisation of extremes and made it possible to develop innovative methods for detecting trends. This was used to study the evolution of extreme precipitations linked to the decennial variability of the cumulated annual rainfall.

Figure 23 shows a distinct difference in the evolution of total annual precipitation figures (annual cumulated totals) and daily annual maximums in the central Sahel since 1950. Whereas annual totals are well below the average for the wet 1950-1970 periods, average annual maximums are greater than those for 1950 to 1970. The two curves differ markedly from the end of the 1990s. This confirms that a marked change in the rainfall regime took place at the turn of the century as rainfall extremes became more marked.

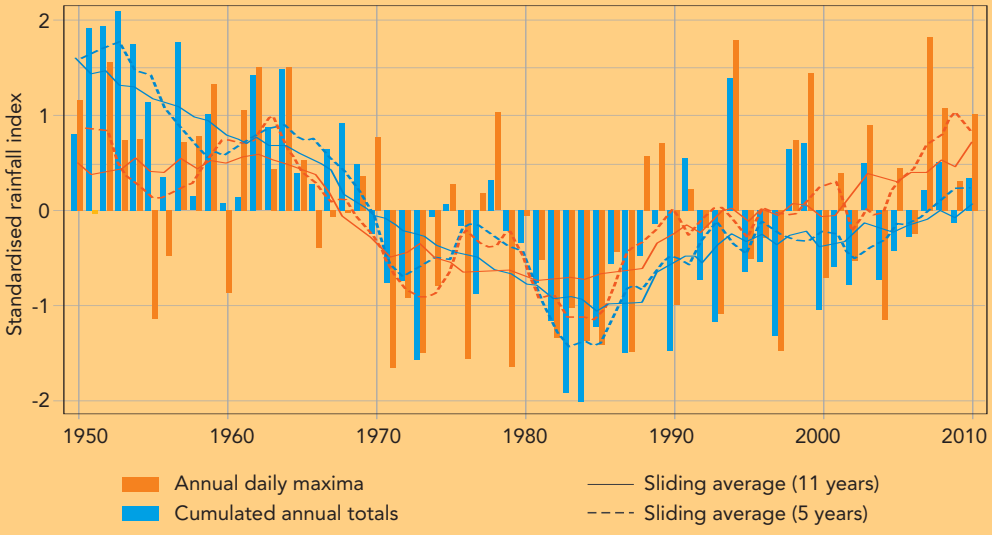

Figure 23.
Comparative movement of annual rainfall totals and maximums in the central Sahel (window: 9.5° N-15.5° N 5° O-7° E) from 1950 to 2010.
Source: after PANTHOU *et al.*, 2014.

Climate change or natural climate variability?

Describing changes in the Sahelian climate is nevertheless not enough to pinpoint the cause. It is very difficult for scientists to understand the mechanisms of warming and of the change in rainfall regime—linked to both global climate circulation and local effects. And at global circulation level, it is necessary to be able to distinguish between the effects of the increase of greenhouse gases and the natural variability of the climate. IRD researchers and their partners have focused on the impact of climate change with anthropic causes on the evolution of the climate in the Sahel. Their research shows that the warming observed recently is imprinted with anthropic forcing to a considerable degree. In contrast, their results suggest that the latter played a minor role in the rainfall transition of the 1980s and 1990s that was driven mainly by the internal variability of the climate system (in particular by the Atlantic Multidecadal Oscillation) (see Part 1, p. 66).

The 'Sahelian paradox': less rain, more water

The hydrological research conducted in the Sahel by IRD clearly shows the importance of long-term observation for anticipating the responses of environments. The great drought of the 1970s first caused a strong decrease in the flows of the major watercourses in West Africa (the Niger, the Senegal, the Gambia, the Volta and the Chari). However, the Sahelian watercourses were seen to behave in a special way: when the decrease in precipitation in the drainage basins was more marked than in the basins further south (more rainy), the flows increased paradoxically and there were record floods. In 2010, the first flood caused by monsoon rains reached twice the highest level previously observed since 1929. The record was beaten again in 2012.

Exceptional Niger River flood in Niamey in August 2012.
The serious flooding caused by heavy rainfall caused 60 deaths and 300,000 victims in Niger.

The phenomenon is sometimes referred to as 'the Sahelian paradox'. But it is only an apparent paradox. The numerous hydrological observations in the Sahel and especially those of the AMMA-CATCH observation service show that runoff has increased in recent decades. This causes water to concentrate more rapidly, changing the regime and flows of watercourses.

Tree roots exposed by floods of the river Bani, a tributary of the Niger (Mali).

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Increased runoff caused by human activities in Niger…

Work by IRD in Niger shows that the decrease in the water retention capacity of the soil is a direct consequence of human activities. Population increase (from 3.2 million in 1960 to 15.5 million in 2010 in Niger according to the World Bank) was accompanied by increased pressure on the environment to increase agricultural production. The clearing of bush and sparse forest caused a rapid increase in bare surfaces that caused the intensification of runoff. The shortening of fallows also caused the impoverishment of soils, often resulting in crusts, the main factor in runoff.

… but not in Mali

However, the Sahelian paradox is not seen only in the cultivated part. In the northern Sahel, a pastoral zone where rainfall is too small to allow agriculture, ponds that used to be temporary now contain water all the year round and new ponds are appearing. The mechanisms involved have not yet been fully elucidated but the explanation might also lie in an increase of the flow capacity of degraded soils. Indeed, even without land clearance, a significant proportion of the landscape has been stripped and eroded after periods of severe drought. Observations in Mali show that once the soil has been stripped off the vegetation cannot recover when the rains return.

Box 26

Changes in fishing in the Inner Niger Delta

The work of the PRODIG research unit and its Malian partners has shown how the decreased flow of the Niger has reduced fisheries resources and finally led to the reorganisation of the regional fish market.

Fish catches in the Inner Niger Delta in Mali decreased from 100,000 tonnes in the 1960s to about 70,000 tonnes in recent years. This decrease in fishery resources is the result of a variation of the rainfall regime in the region that has lastingly changed the flow of the river and flood areas.
But humans are also involved in this degradation as reservoir dams reduce the flow of the river downstream of the dams and reduce flood areas.

The inner delta provides 80% of fish production in Mali.
During the last 40 years, domestic fish supply decreased while demand increased as the population tripled.
Meeting demand has led to the complete reorganisation of trade flows with imports of some 15,000 t per year of frozen and dried fish, mainly from Senegal, Mauritania, Côte d'Ivoire and Guinea.
The decrease of resources in the inner delta has also resulted in Niger losing the dominant position in regional exports of fish that it had in the 1970s, when exports went in particular to Côte d'Ivoire and Ghana.
The substantial increase in catches of small pelagic species in neighbouring coastal countries and the adaptation of Sahelian traders made it possible to adjust the market quickly.
However, this example shows how the deterioration of hydroclimatic conditions in the Sahel has hit the organisation of the regional fish market.

Unloading fish at Mopti in the central Niger delta (Mali).

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A serious decrease in flows further south

No hydrological 'paradox' is observed further south in the Sudanian savannah zones where the decrease in rainfall is accompanied by a strong decrease in flows. However, this region is also one where much deforestation has been carried out to make agricultural zones. These contrasting responses in Sahelian and Sudanian zones with similar forcings (drought and a change in land use) show the complexity of the mechanisms involved. The different factors have not yet been totally identified but the path taken by water (mainly surface flow in the Sahel and subsurface flow further south), soil type and structure and plant cover play a major role.

The increase in runoff in the Sahel is not the sole explanation of all the severe floods of the last five years. The latter also coincided with a return to wetter conditions and the more intense precipitation observed in the region for the past 15 years. The floods have had serious consequences for the population. In 2012, an exceptional River Niger flood seriously affected the Niamey region. The authorities counted more than 340,000 persons affected, 44 deaths and considerable material damage.

Desertification or re-greening of the Sahel?

The Sahel is a semi-arid region and particularly sensitive to the variability of precipitations. The periods of severe drought in the 1970s and 1980s had devastating effects on ecosystems, the population and the resources of the latter. The massive change in land use, linked in particular with rapid population growth, has also been a driving force in this land degradation.

Village and irrigated gardens, Akodédé, Niger.

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The theory of the desertification of the Sahel thus became topical again, together with that predicting the rapid spread of the Sahara to the rest of the continent. Desertification is the degradation of land in dry zones as a result of various factors including climate variations and human activities. The degradation takes the form of the deterioration of plant cover, soils and water resources and ends, on the human scale of time, with destruction of the biological potential of soils and their capacity to support the population of the area concerned.

The reality of desertification has long been a subject for debate and it is difficult to settle the question for lack of global, continuous data. The arrival of satellite remote sensing in the 1980s has solved this problem by providing daily images of plant cover. Analysis of the first Normalised Difference Vegetation Indices (NDVI) in the early 1990s revealed a distinct increase in vegetation since 1980. This re-greening thus contradicts the idea of the desertification of the Sahel.

General re-greening for 30 years

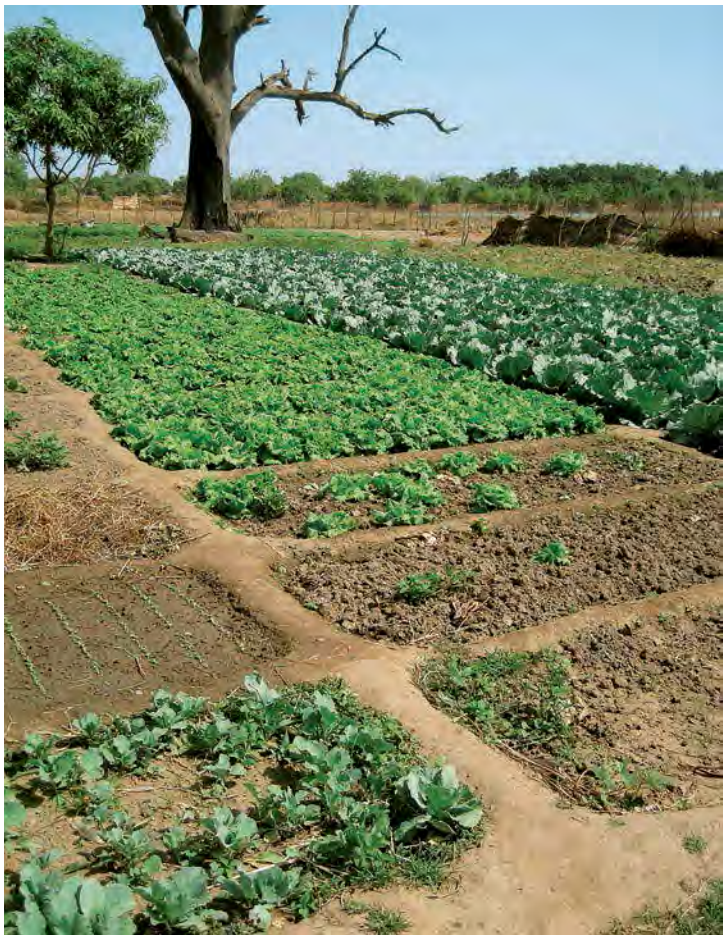
More recent work even makes it possible to say that there has been a general re-greening of the whole of the Sahel region over the last 30 years. It is explained overall by the return of rainfall, just as the advance of the Sahara in the 1970s was caused by a decrease. The explanation of these phenomena lies to a considerable extent in the inter-annual variability of precipitations.

Nevertheless, plant cover is continuing to worsen in some regions, such as in the Fakara in Nigeria and the central regions of Sudan. In addition, the satellite mesh (9 km) is too large for the perception of the coexistence of degradation and re-greening at a smaller scale.

Today, although there is no doubt about re-greening, scientists are cautious about the future evolution of vegetation, which will be linked with precipitation in particular.

Rainfed agriculture faced with climate change

Most farming in the Sahel is rainfed (93% of the cultivated land) and hence extremely dependent on the rainfall regime. The variability of precipitations affects food production, as is shown by the direct link between droughts and famines in the region (1974, 1984-1985, 1992 and 2002). In this context, researchers are trying to better understand and anticipate the consequences of climatic fluctuations for agriculture. For this, they use complex models that combine climatic, agronomic and economic data. In the IPCC Fifth



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Market garden crops (cabbage and lettuce) in Burkina Faso. Rainfed farming in the Sahel is likely to be strongly affected by climate change.

Assessment Report, the results of crop modelling show losses in world agricultural yields averaging 2% per decade in the 21st century. Particularly severe impacts are expected in Africa where recent research (Box 27) shows that yields could fall by 20% in the western Sahel.

However, forecasting is still difficult because of the strong uncertainties in both regional climate change projections and the response of plant cover to environmental changes (rainfall, temperature, CO_2 concentration in the atmosphere). In addition, the gradual adaptation of farming systems to environmental changes should not be underestimated. Indeed, the climate/plant relationship is not sufficient for forecasting crops. Studies on millet, the main crop in the Sahel, show how varieties have gradually adapted to drought. The biodiversity of millet is well preserved and has allowed natural and human selection: the earliest plants have better resistance to drought and grow better and so are thus selected by farmers for the following season (see Part 3, p. 211).

Box 27

A decrease in agricultural yields in West Africa as a result of warming

West Africa is very vulnerable to climatic events. Better understanding of the impact of climate change on agricultural yields is therefore essential for designing adaptation strategies. IRD climatologists and their international partners forecast a 16 to 20% decrease in sorghum yields in certain regions in West Africa.

What are the impacts of climate change on sorghum yields in West Africa? To find a reply to the question, IRD climatologists in collaboration with American, Malian and Australian teams used agronomic models simulating agricultural yields according to climatic conditions and then compared them with future climate scenarios. In the light of the uncertainties of these different models, the simulations produced by 9 IPCC models and 2 crop models were used in the study.

Future climate scenarios

Climate projections based on theIPCC RCP 8.5 emission scenario forecast average warming of +2.8°C from 2031 to 2060 in relation to a reference period running from 1961 to 1990.

The 9 models used also forecast significant change in precipitation in West Africa, with less rainfall in the western part of the Sahel (Senegal, south-west Mali) and more rain in the central Sahel (Burkina Faso, south-west Niger). The rainfall deficit forecast is concentrated at the beginning of the monsoon in the western part of the Sahel whereas increases in precipitation occur at the end of the monsoon season, suggesting a change in the seasonality of the monsoon.

A greater fall in yields in the western Sahel

In response to this climate change and without taking into account the response of crops to a higher CO_2 level, the researchers' projections show a decrease in yields of about 16 to 20% in the western part of the Sahel. The impact would be more moderate in the eastern part with a decrease in yields of between 5 and 13%. These yield fall projections are consistent from one model to the other and result from a rise in temperature that shortens the length of crop cycles and increases water stress as evaporation increases. This negative effect of temperature is combined with a decrease in rainfall in the western Sahel.

A field of sorghum in Niger.

The vulnerability of rural populations

The Sahel has become an emblematic region as regards the vulnerability of rural populations in the South since the great droughts of the 1970s and 1980s. Their direct dependence on natural resources and rainfed agriculture puts them in the front line with regard to the climatic risks identified in the region. The IPCC highlights in particular the impacts of climate change on water resources, with consequence for food production and access to potable water. However, it is impossible to forecast the impact on the population. Numerous studies have shown how it has always succeeded in adapting to variations of the climate and resources (Box 28 and Part 3, p. 233). Will this adaptation capacity be sufficient to withstand coming climate change? This also depends on the intensity and rapidity of the latter.

Annual return of the river Komadougou Yobé at the frontier between Niger and Nigeria. This is an important moment for the local population (fishing, irrigation, livestock) and for groundwater recharge.

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Box 28

Lake Chad: the population is adapting to the falling water level

Lake Chad used to be one of the largest inland water bodies in the world but has lost nine tenths of its area since the 1960s. Although the level of the lake has always fluctuated, its steady decrease in area has become a symbol of on-going climate change. The phenomenon has caused serious changes in the way of life of the 20 million people around it who live mainly from fishing, cattle farming and crop farming.

Located in the heart of the Sahelian strip, Lake Chad is an essential water resource for the fishermen, livestock farmers and crop farmers in the four countries around it: Niger, Nigeria, Chad and Cameroon.
The lake has changed considerably in recent decades.
With an area of 20,000 sq. km, it was like an inland sea 50 years ago.
The series of droughts in the 1970s and 1980s resulted in rapid drying that reduced its area to about 2,000 sq. km.

The variability of the level and surface area of Lake Chad has been a well-known phenomenon since the 1960s, mainly thanks to work by IRD hydrologists.
The lake is very shallow, with an average depth of 2 metres, and functions as an evaporator with very large losses of water.
Thanks to pluriactivity, rural communities have long developed a system that is well adapted to the annual, inter-annual and even decennial fluctuations in the level of the lake.
High water periods were good for fishing and the regeneration of land while low water periods were used for polder crops. The fall in the level of the lake left numerous shallows between dunes that have been developed as cereal crop polders over the years.

A Franco-Nigerian team including the HydroSciences unit studied the changes in ways of life around Lake Chad in recent decades.
The results show how Sahelian societies have adapted to a major environmental change through the evolution of farming systems in the Bosso region of Niger.

As the lake receded, the population used the accessible fertile, humid land to plant maize, cowpea, rice and sorghum that grow without irrigation or fertiliser, gradually abandoning rainfed millet on the banks that had become a particularly uncertain crop.

Port of Doro Léléwa in Niger, near Lake Chad.

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