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# Erosion Response to Landscape Unit Changes in Eastern Niger: The Case of Bagara and Issari

**Moussa Abdoulkader[1,2,3], Somé Yélézouomin Stéphane Corentin[2,4*], Garba Zibo[1,3], Abdourhamane Touré Amadou[1,3] and Yacouba Hamma[2]**

*[1]University Abdou Moumouni, Sciences and Technology Faculty, Laboratory of Geology, Niamey, Niger.*
*[2]International Institute for Water and Environmental Engineering, Laboratory of Hydrology and Water Resources (Foundation 2iE), Burkina Faso.*
*[3]Young Team Associated with the Research Institute for Development (IRD, Anthropisation and Wind Dynamic –AMD- University Abdou Moumouni, Niger.*
*[4]University of Koudougou, Burkina Faso.*

***Authors' contributions***

*This work was carried out in collaboration between all authors. Authors SYSC and MA designed the study and managed literature searches. Authors MA and ATA performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SYSC, GZ and YH managed the analyses of the study. All authors read and approved the final manuscript.*

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## ABSTRACT

Since the drought of the early 1970s, the Niger part of the Lake Chad Basin has undergone significant changes. Its environment has evolved considerably, with land cover and use (cultivation, grazing) experiencing significant momentum. This change in land use has led to a decrease in natural habitats (savannas and forests), thereby increasing the vulnerability of soils to erosion agents. Erosion dynamics (wind and water) have also undergone an evolution. The resulting erosive response to these changes was discussed and particular attention paid to the gully network dynamics and the Komadougou Yobe banks during the periods of 1957-1975 and 1975-2007. Three maps of gully dynamics were produced. Shreve order gullies remained constant and equal to two (2) between 1957 and 1975, going up to 4 in 2007. The gully network total length has evolved. From 1957 to 1975, it multiplied by four (4) and from 1975 to 2007 by three (3) or by nine (9)

**Corresponding author: E-mail: some_y@yahoo.fr;*

from 1957-2007. The two Komadougou meanders (B1 and B2) studied cartographically showed a strong momentum. Thus, at B1 and B2 level, a 120 m and 92 m bank recession was observed between 1975 and 2007 and the wavelengths have respectively increased from 196 m and 1083 m in 1957 to 349 m and 943 m in 2007. A tendency to overlap is thus observed at these meanders. If this degradation acceleration trend continues, we will witness a short term rural exodus, the abandonment of villages and competition on land that can lead to internal as well as extraterritorial conflicts.

*Keywords: Land use; water erosion; gully erosion; bank receding; aerial photographs.*

## 1. INTRODUCTION

Landscapes on the earth's surface are shaped by water and wind dynamics. These remove matter where mass surpluses exist (as on dunes), to redeposit them where there is a deficit (basin, pond, river), or when they no longer have the energy to carry erosion products. Erosion is a problem whose severity varies greatly from one region to another and even from one site to another [1-3]. Erosion dynamics (wind and water) are related to the evolution of land use [4] and the strength of the dynamic agent (wind or water). Since the 1970's land use changes (cultivation, grazing) to the detriment of savannas have increased the vulnerability of soils in the Sahel. As soon as a soil is deprived of the vegetation cover that secures it, or when it becomes incapable of regenerating vegetation cover, that soil is exposed to wind and runoff [5]. Erosion can thus cause significant loss of soil structure, and also is an important factor in the silting of water bodies and infrastructure, as well as soil surface crusting. In the central Sahel, for example, water gully erosion is the main source of reservoir sediment, with 80%to 90% of the sediment derived from this type of erosion [6-9].

It is now known that increased cultivation of land has resulted in the transport of heavy loads of sediments and nutrients in flowing surface waters [10]. Gully erosion also increases drainage and soil desiccation [11-12], concentrating runoff in small channels and preventing the flow of water to irrigate a wider domain. Moreover, the complexity of gully networks [13-14] poses significant constraints to farmers in the management of cultivated areas, due to the decline in soil moisture, thus leading to a decrease in crop yields [15]. In addition, the proliferation of human activities along the Sahelian water courses has led to the degradation of the land surface and bank erosion [16-17]. An expansion of the riverbed and the disappearance of natural pits or ponds in some cases (when the river is made up of a chain of ponds) have been observed. The objectives of this study are to quantify over the period 1957 - 2007, i) the impacts of anthropogenic pressures on water gully erosion processes in the Sahel, and ii) the changes of the Yobé riverbed due to lateral erosion.

## 2. PRESENTATION OF STUDY AREA

The two sites under study (Issari and Bagara) are located in the Lake Chad Basin in southeastern Niger. The two villages belong to the Diffa's region. The Village of Issari is located 55 km from the town of Maine Soroa and Bagara village only 3 km from the town of Diffa (Fig. 1).

The Sahelian climate in this area is determined by the Southern Oscillation of the Intertropical Convergence Zone (ITCZ) and is marked by two distinct seasons:

- a short rainy season from May to September with peaks in July and August. During this season, the monsoon wind, a moist wind from the southwest, brings rain in areas south of the ITCZ. The average annual rainfall is 250 mm [18]. Average monthly temperatures during this season range from 28-37ºC.
- a dry season during which the harmattan winds from the north-east blow. During this season, temperatures range from 19ºC in the cold season (December-February) to 42ºC during the hot period (March to May).

The natural vegetation at Issari consists of shrubland savanna and in parts also tree-lined savanna.

The territory of Issari village features two geomorphological areas: the (Manga sandy plateau) wind fields and (the kadzell) river-delta (Fig. 1).

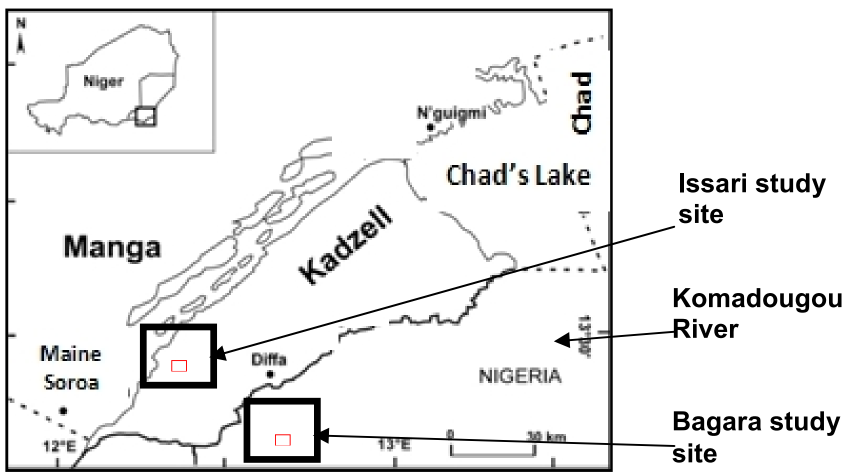


**Fig. 1. Localization of study sites**

The Manga sandy plateau is a wind field, consisting of an ancient erg flattened by (ancient) runoff and (current) wind erosion [19]. It is dotted with a series of basins between dunes, the most southern connected to the groundwater table during the rainy season. The Manga plateau slightly slopes to the southeast towards the Kadzell. It forms a slope 10 to 15 km wide and 120 km long, and is oriented NE - SW [19].

The Kadzell is a fluvio-deltaic area. It corresponds to the Niger part of the Komadougou Yobe alluvial plain (temporary tributary of the Lake Chad), most of which is in Nigeria (Bornu plain). It consists predominantly of an ancient erg flattened by winds, spread by the Komadougou Yobe and mixed with clayey fluvial contributions. The plain is bounded on the NE by elements of a sandy beach barrier that separates it from the Manga plateau.

## 3. MATERIALS AND METHODS

For the quantification of the erosion processes, the following cartographic materials were used:

- Two mosaics of aerial photographs of 31/1957 and 01/1975.

- Two Landsat TM satellite images (185 km x 185 km and the pixel size of 30 m x 30 m), 1975 and 2000.
- Topographic maps (at scales of 1/50 000 and 1/200, 000).

To monitor the gully network a square-shaped site with an area of five (5) $km^2$ was mapped (Fig. 3). Gullies were digitized as polylines. For each period the sum of the lengths of polylines, corresponding to the total length of gully network was calculated. The densities of the gully network were estimated and growth rates calculated. The network complexity was estimated according to the Shreve order (Shreve, 1966).

To quantify the Komadougou Yobe lateral bank erosion, two meanders around Bagara village, not far from Diffa, were cartographically followed for the period of 1957-2007. The riverbank recession, corresponding to the distance between the two polylines of two different periods was estimated and the wavelengths of two meanders (Figs. 10, 11) were also estimated for three selected periods (1957, 1975 and 2007).To deduce the impact of man on these erosive processes, the mapping results (erosive quantification processes), were first compared with the changing hydrometric data acquired in IRD at Niamey (1953-1972; [20] and the Diffa Regional water Directorate (1972 -2010). These represent the daily chronicles of water levels and flow rates, and the average annual discharge volume and the number of flow days. Mapping results were then also compared to land use changes. Then to known changes in anthropogenic units [21].

## 4. RESULTS AND DISCUSSION

### 4.1 Evolution and Changes in the Morphometric Characteristics of Gully Networks in the Lake Chad Basin Dune Area

Gullies remain a major problem in the Sahel, contributing with 80-90% to the filling up of Sahel water bodies with sediment [6-9]. In southeastern Niger, they grow mainly on dunes slopes (Fig. 2) and are responsible for filling oasis basins whose holdings represent a significant source of income for the populations [22]. These gullies were involved in shaping the landscape at Issari. In 1957, the total length of koris (gullies) hardly exceeds 1 km (Figs. 3 and 4) and their connectivity was low: Shreve order gullies being equal to 2. Between 1957 and 1975, the total length of koris was multiplied by a factor of four, increasing from nearly 1 to 4 km (Fig. 3), without connectivity increase. In 2007, the total length of koris reaches nearly 14 km (Figs. 3 and 4). Their connectivity increased and Shreve order reached 4, while their total lengths increased by a factor of 9 relatively to 1975.

Gullies are experiencing a net increase at Issari since 1957 (Fig. 3). In the Sahel region in general, lower annual rainfall in recent decades did not induce a decrease in rainfall events of high intensity capable of producing runoff and erosion [23-24]. Therefore it seems that climatic changes are not the cause of the dramatic increase in kori extent. However, anthropogenic factors seem likely. The region has seen an expansion of cultivated surfaces to the detriment of savanna areas, especially after 1975 (Fig. 12). It is recognized that the loss of soil organic matter directly or indirectly related to cultivation and deforestation reduces soil structural stability and promotes crusting, runoff and therefore gully erosion [25]. Grazing has also contributed significantly to promote gully erosion. Livestock trampling contributes to soil compaction leading to a decrease in the water absorption capacity of the soil, resulting in higher runoff [26,5].

This runoff increment, and therefore of water erosion in a context of drought in the Sahel has been observed since the early 1970s [27-28,18]. In southwestern Niger for example Leblanc et al. (2007a) found an impressive complexity and increase of gully networks between 1950 (wet season) and 1992 (dry period): the Shreve order (1966) sub watershed was multiplied by 9, while gullies total length increased by 65% between 1975 and 1992. It thus appears that the complexity of water erosion leading to gullies was higher in western than in eastern Niger. This is explained by the fact that it rains more in the West on the one hand and secondly because anthropogenic pressures (land clearing, deforestation, cultivation, fallow disappearances, bushfire,) are much stronger (give the number of inhabitants by km ² of the west and east of the country).

**Fig. 2. Gully on the side of a dune (Moussa, 2013)**

## 4.2 Komadougou Yobe Riverbank Erosion

### 4.2.1 Hydrologic overview of the Komadougou Yobe

The Yobe River is the terminal part of a larger Hydrographic system common to Niger and Nigeria (Fig. 5). The Komadougou takes its source in the highlands of Jos and the hills around Kano before emptying into Lake Chad. The average altitude of the basin ranges from 1200 m (upper basin) to 282 m at Lake Chad. Its main tributaries are the Hadéjia the Jama'are and Gana River (also known as Missau). In the Niger Basin Tagwai El Fadama in the Zinder region is part of the system of Komadougou.

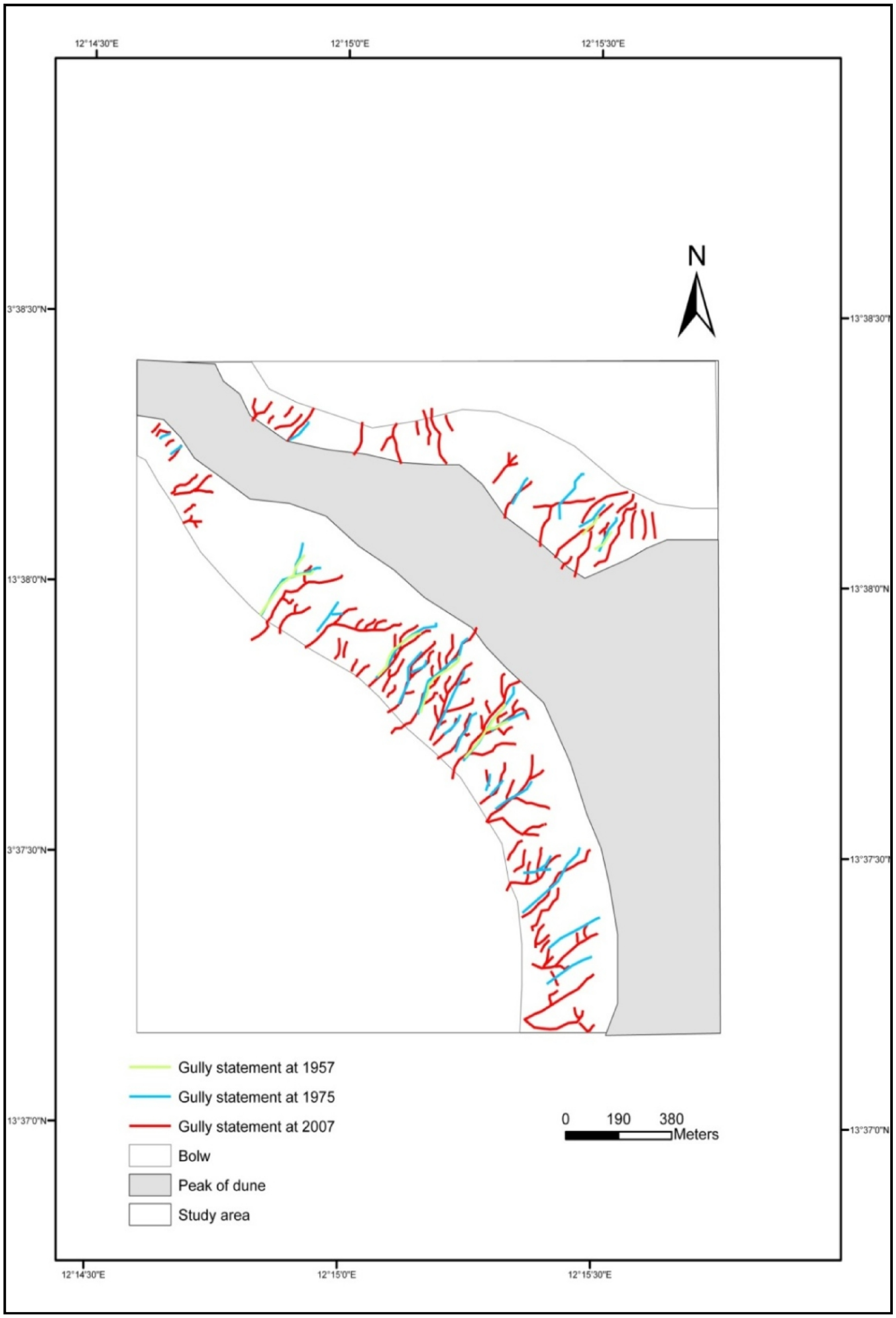


**Fig. 3. Occurrence of gullies in the Manga dune area, 1957-2007**

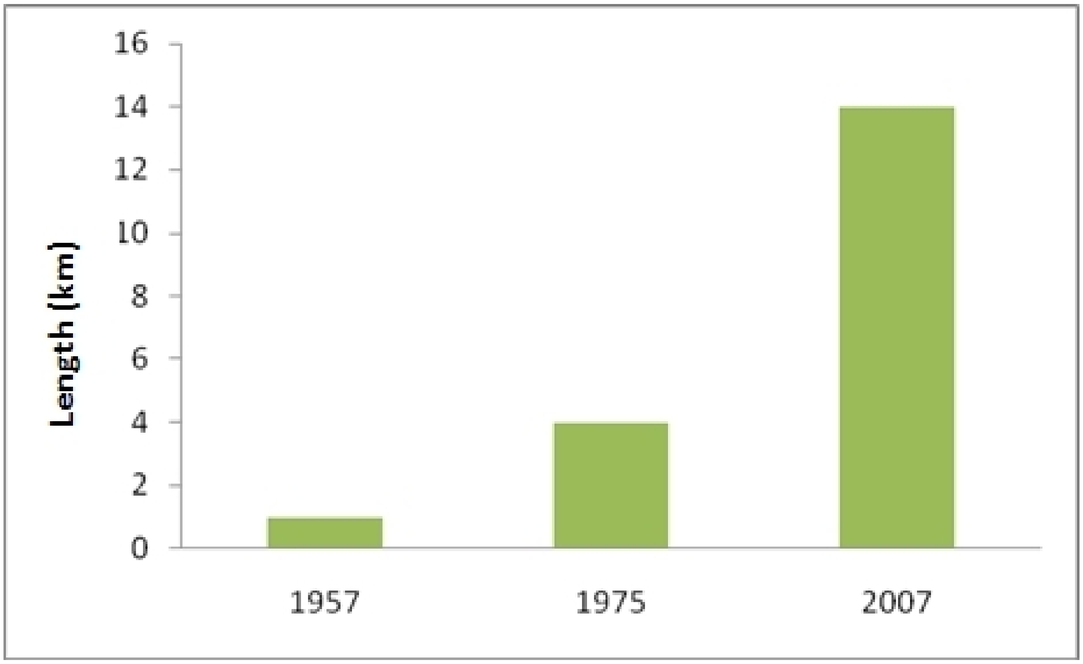


**Fig. 4. Evolution of gully network length on the Manga Plateau**

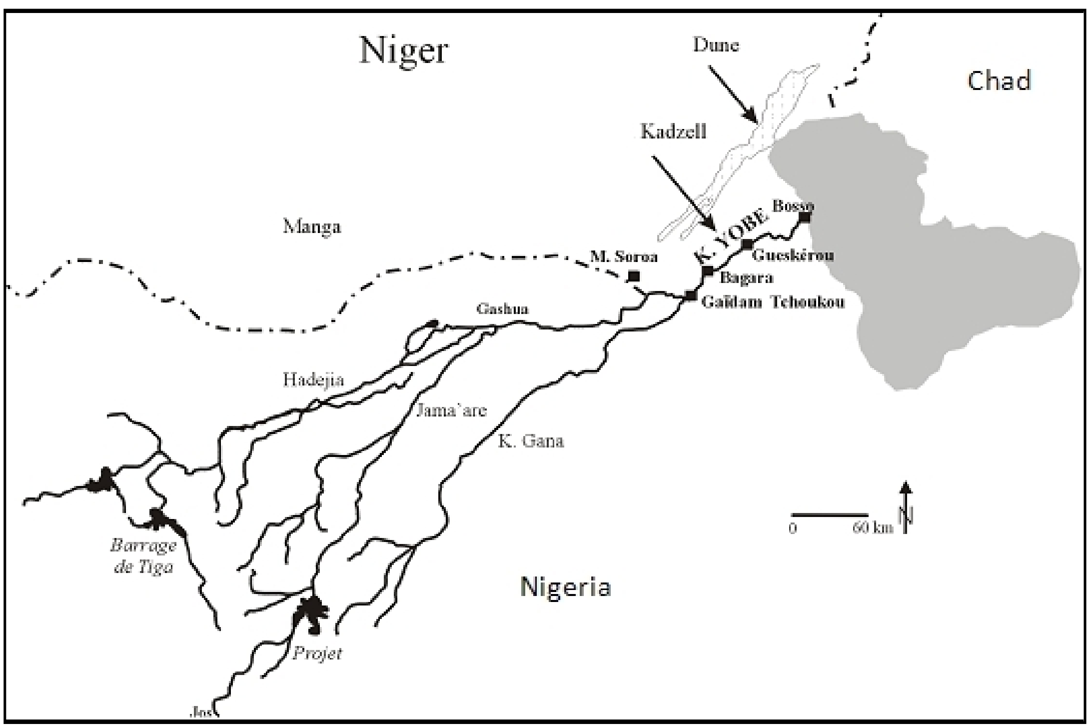


**Fig. 5. Overview of the Komadougou Yobe watershed**

The Komadougou Yobe riverbed has a length of about 439 km. The terminal portion of this river is the natural border between Niger and Nigeria, running 150 km from the village of Kanama (Department of Maine-Soroa) to the village of Bosso on the shores of the Lake Chad (Fig. 5). In Niger the Komadougou flows were monitored by three (3) main hydrometric stations. The stations of Bagara and Guéskerou were established since 1957, and that of Gaidam tchoukou was established in 1989. Currently, in addition to the last three, two other stations were established on the main course of the Komadougou. These are the stations of Mamouri and Kanama established in 2000. This study is only centered on data from the station of Bagara, because it is the oldest station and most monitored due to its proximity to Diffa (Diffa region capital). Data from other stations are not reliable due to lack of monitoring.

Komadougou Yobe is a semi-permanent river (Fig. 6). Flows generally occur in mid-July and stop in April for the period 1962/1971, but stopped already in March for the period 1971-1985 and already in February for the period 1985-1993 (Fig. 6). October receives an average of 25% of the annual flow volume, September 22% and November 21%. Maximum daily flows recorded since the establishment of the station ranged from $84m^3s$-1 and 25 $m^3s^{-1}$. The highest average daily flow volumes are 28.5 $m^3s^{-1}$ and the lowest 4.83 $m^3s^{-1}$, corresponding to a total annual flow volume of 898 and 152 million $m^3$ respectively.

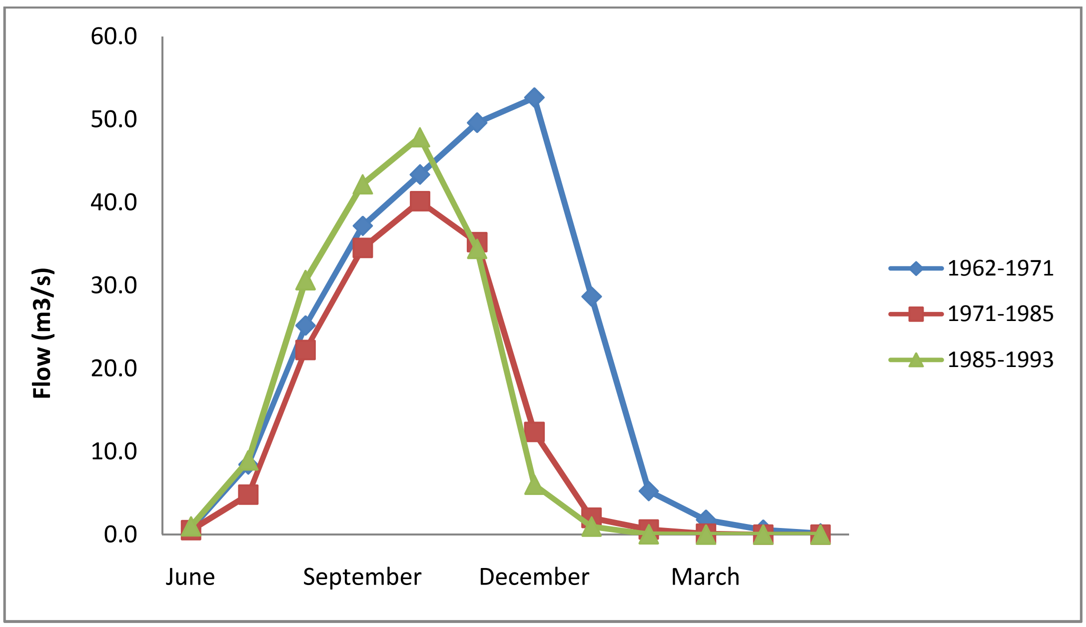


**Fig. 6. Averaged hydrographs for the Komadougou river, Bagara gauging station (1962-1971, 1971-1985, 1985-1993)**

The average flow observed at the station of Bagara is 188 days. However this number can be highly variable from year to year. Thus, the least flow days ever recorded occurred during the hydrological year 1983/84 with 137 days, while the maximum was observed from 1966 to 1967 with 322 days (Fig. 7).

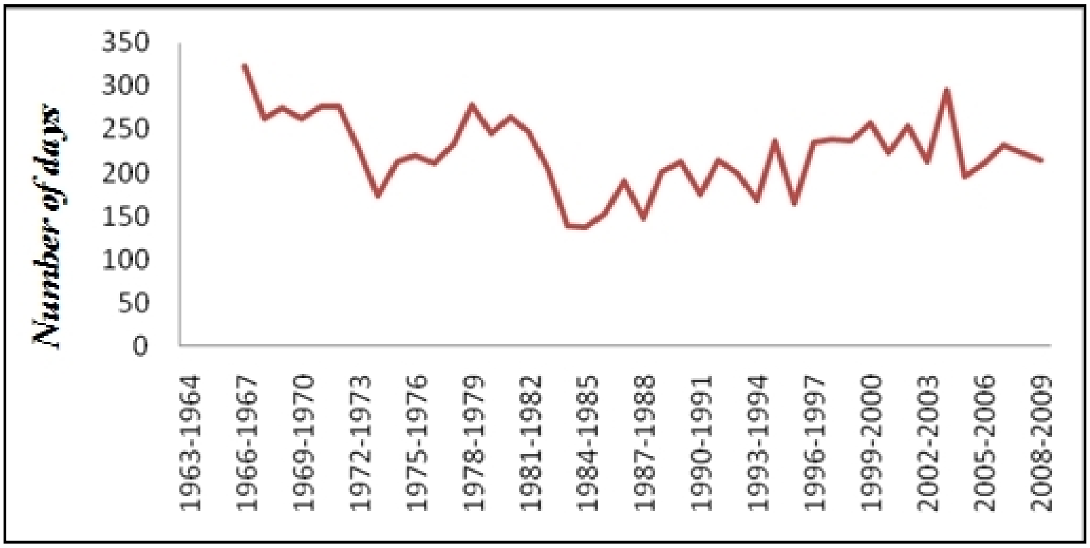


**Fig. 7. Evolution of Komadougou number of days average annual flow**

The past annual flow analysis highlights alternating sequences of wet years and relatively dry ones: the average annual flow rate was 24 $m^3s$-1 between 1965 and 1971 (relatively wet years), 17 $m^3s$-1 for the period 1971-1985 and 23 $m^3s$-1 from 1985 to 1999 (relatively wet year; Fig. 8). Despite an improvement of flow rates observed since 1990, the general trend is declining, especially since the early 1970s.

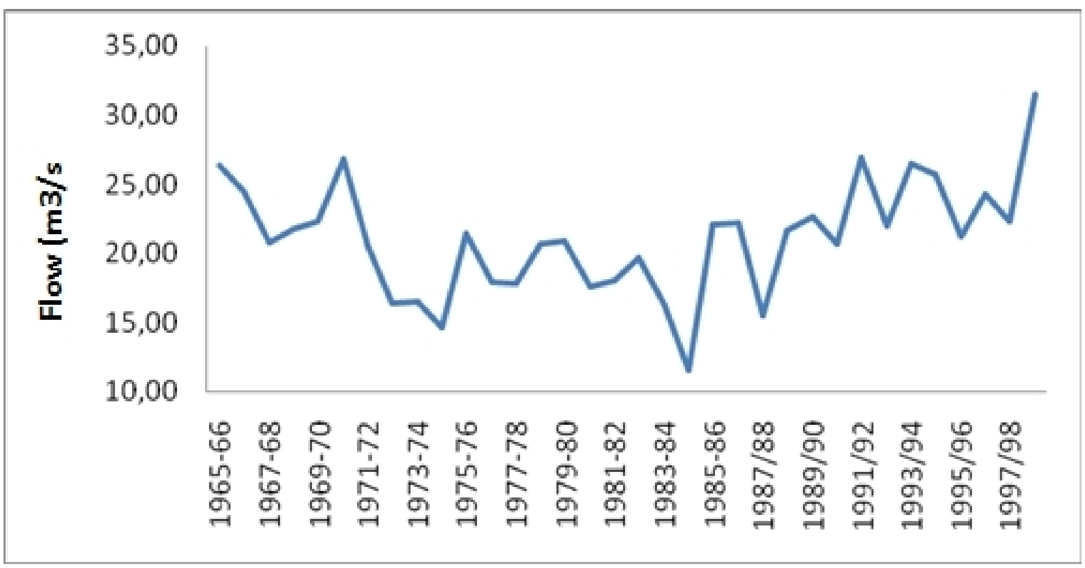


**Fig. 8. Evolution of Komadougou average annual flow volume**

Chemical analyses of Komadougou waters undertaken on samples taken at Bagara and Yau not far from the river mouth at Lake Chad show a consistent homogeneity [29]. Average values are of 60 S / cm in conductivity, 5.9 mg / l of sodium, 1.2 mg / l of chloride, 7.5 mg / l of calcium and 1.9 mg / l of magnesium.

### 4.2.2 The Yobe River fluvial dynamics

*4.2.2.1 The yobe riverbed*

The Yobe riverbed is a fluvial system consisting of a single continuous main channel having a width between 30 and 60 m and describing a number of meanders (Fig. 9).

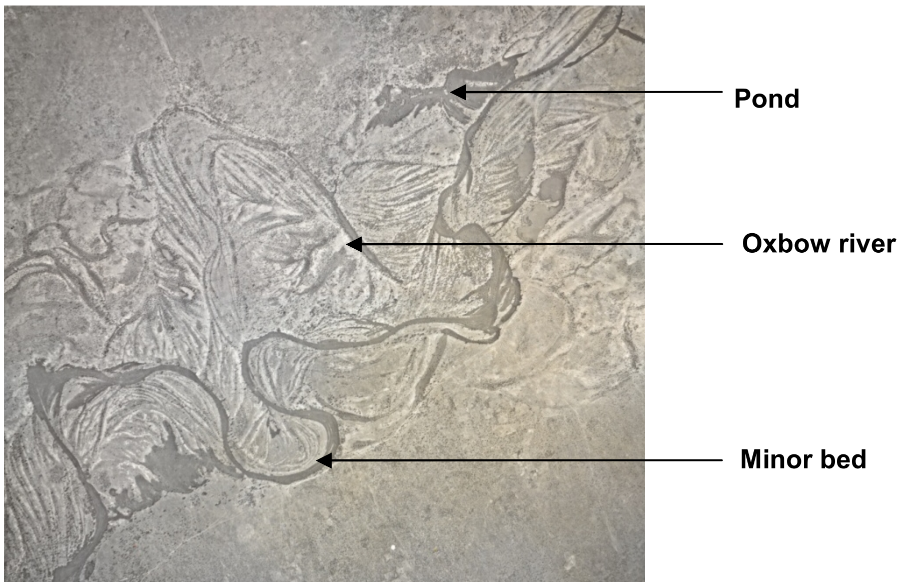


**Fig. 9. Aerial photograph (31/1957) showing the Komadougou Yobe fluvial system**

The total length of the minor riverbed is 338 km, while the associated valley length is 165 km, with an average sinuosity of 2.05 $km.km^{-1}$ [30]. The riverbed average slope is estimated at 0.092%.

The minor Yobe riverbed is composed of highly mobile meanders (Fig. 9), bordered by many intersected arms [31] forming ponds and completely clogged arms, which reflect the instability of the river course. The river was originally bordered by open forest, now only visible in a few spots [19].

The mobility of the Yobe banks reflects a lateral erosion of the river [32]. The aim here is to monitor the lateral evolution of the minor bed of the Yobe River and to quantify this movement around Bagara. Bank recession and meander wavelength were estimated.

*4.2.2.2 The dynamics of the yobe minor bed*

Between 1957 and 1975, the lateral erosion of the minor bed of the Yobe was not very noticeable on the scale of aerial photographs. On the contrary, between 1975 and 2007 the minor Yobe bed has evolved significantly. This was measured for the B1 and B2 meanders bordering Bagara (Fig. 10). At the B1 meander, the receding banks reached almost 120 m eastward towards Bagara; for the B2 meander the receding bank was 92 m westwards towards Bagara. The movement of the bed at these levels is accompanied by an increased sinuosity of the watercourse. Indeed, the B1 meander length was 396 m in 1957 versus 349 m in 2007, and that of B2 1083 m in 1957 versus 934 m in 2007. The dynamics of the minor Yobe bed were stable between 1957 and 1975. This period was mostly wet (1957-1969), before the beginning of the drought of the 1970’s. The stability of the Yobe riverbank would have certainly been linked to the presence of open savannas along its banks. Plants prevent shoreline erosion starting at the ground. This has been particularly obvious in western Niger along the Boubon’s kori [33]. This exoreic tributary feeding the Niger River has seen its eastern bank stabilized by hedges planted in 1985, while its west bank, without hedges, is subjected to a lateral erosion of more than 2 m per year. It was between 1975 and 2007 that the migration of the minor Yobe bed was most pronounced, exceeding 3 m per year. This occurred in the context of a rainfall crisis, with the Yobe experiencing reduced flow and flood intensity [34-35]. It is expected that such conditions should result in reducing riverbed erosion. However, the banks of the Yobe are under strong anthropogenic influence (Fig. 12). Indeed, open woodlands, protecting its banks have lost 75% of their total area (600 hectares) between 1975 and 2007 to irrigated land (Fig. 12). The speed of the Yobe riverbank migration is therefore probably linked to the intense clearing of its banks and the sharp increase in irrigated areas. Moreover, the widespread deforestation of the Yobe watershed by the exploitation of natural habitats (savannas and forests), as well as the high runoff rate that may result, are likely to be the source of sand contributions to the Yobe bed, promoting bank undercutting. In the waterfront village of Boulamari, 5 $km^2$ and 3 $km^2$ of land have been lost between 1957/1958-1999/2000 and 1986/1989-1999/2000 respectively [31].

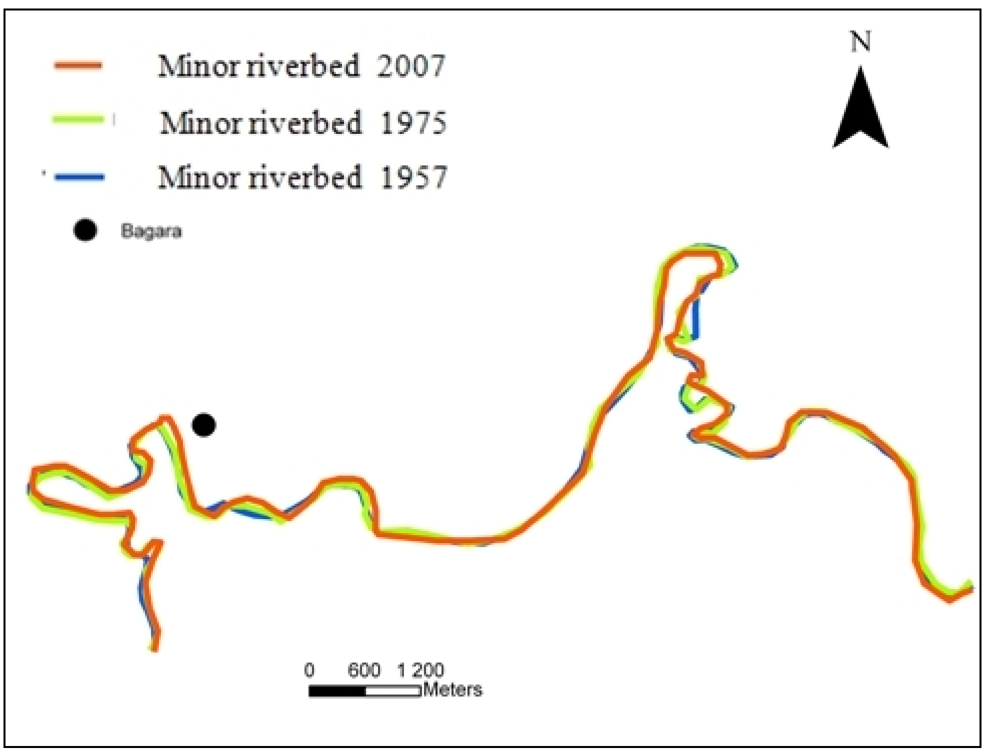


**Fig. 10. Polylines representing the minor riverbed of the Yobe (B1 = Meander 1 and B2 = Meander 2)**

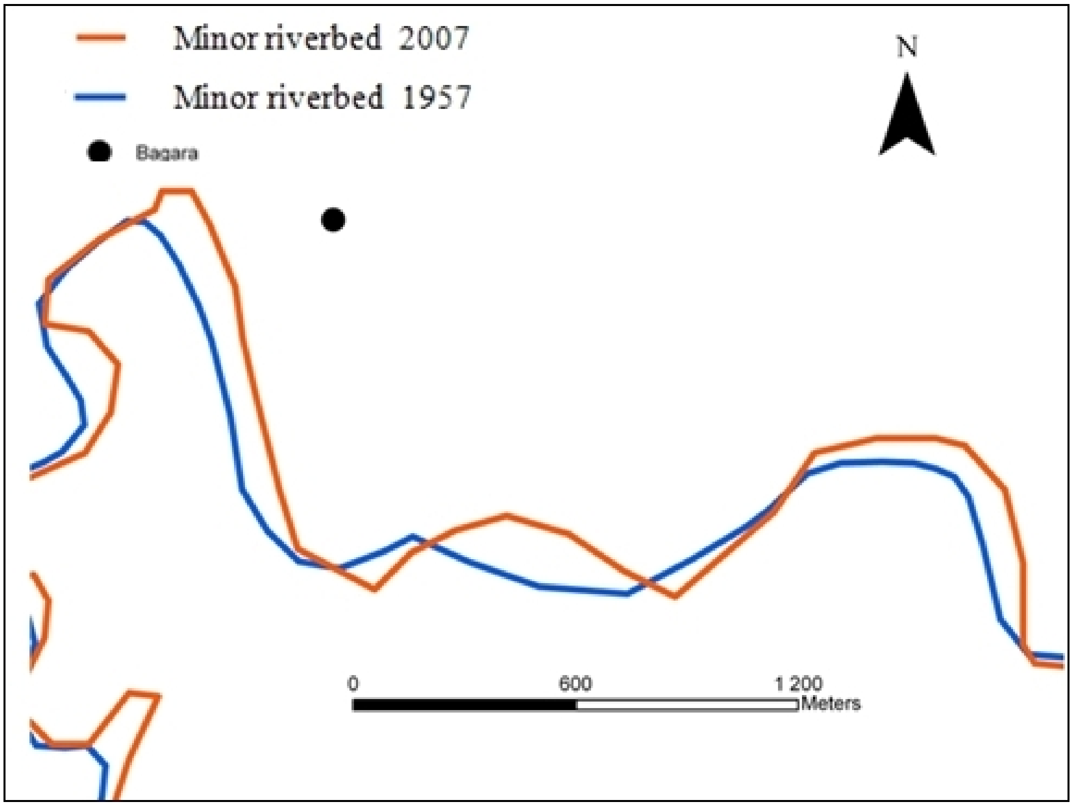


**Fig. 11. Zoom of the polylines representing the minor Yobe riverbed**

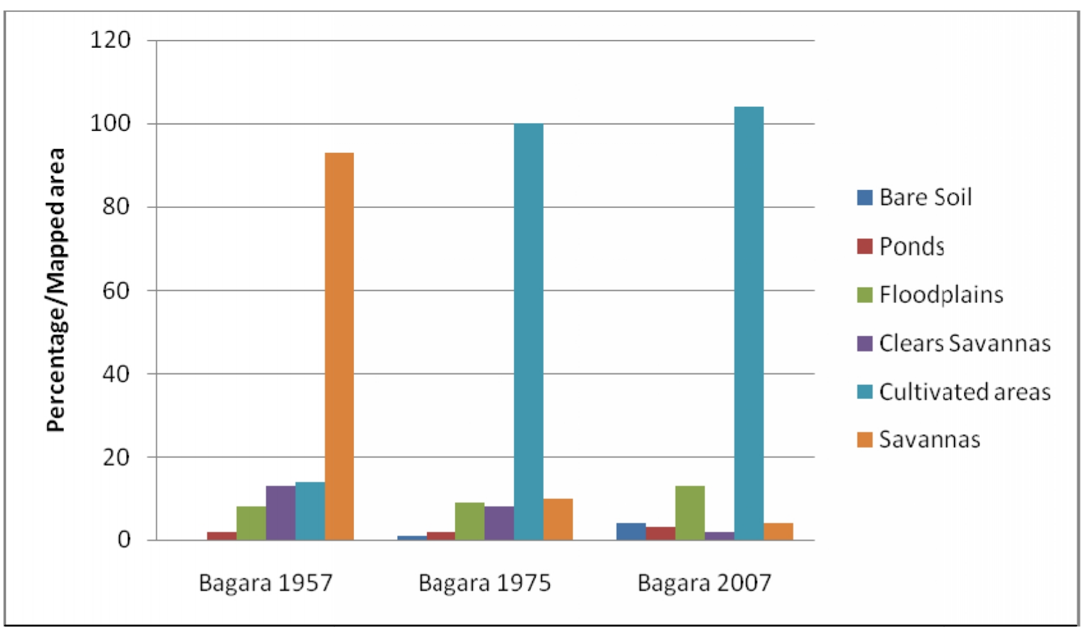


**Fig. 12. Land cover changes in the study area from 1957-2007 [22]**

## 5. CONCLUSION

This analysis of the erosion response to changes in land cover and use at the Bagara and Issari study sites shows that these sites are affected by serious natural resource degradation due to aggressive erosion processes. These are controlled by climatic and anthropogenic factors (agricultural intensification). A dynamic and accelerated complexity of gully networks have been highlighted during the period from 1957 to 2007. On the Yobe side, an acceleration of the Komadougou Yobe bank erosion and thus a cross meander trend phenomenon was observed for the same period. Of these observed changes between 1957 and 1975, climate changes of the early 1970s are thought to be responsible for the first gullies. These climatic variations have not, however, caused a significant Komadougou bank erosion during the period from 1957 to 1975. From 1975 until 2007 there has been an acceleration of the erosion dynamics that started in the early 1970s. The Komadougou meanders under study have shown a significant change and the banks have dramatically receded. This acceleration of erosive dynamics was concurrent with growing human activities during that period. The rate of population growth in Diffa (5% / year) is the highest in the country, livestock numbers are growing and crop areas are being extended. We conclude that human activities (land use changes) in general had a much greater impact on erosion than climate change.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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