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River Culture

Life as a dance
to the rhythm of the waters



Karl M. Wantzen (ed.)

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5 The Senegal River, a Disturbed Lifeline in the Sahel

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Summary

The Senegal River running through the arid and semi-arid parts of Senegal, Mauritania and Mali is of vital importance in this West African region. Multi-ethnic and multicultural populations have always been deeply dependent on its ecosystems and water for subsistence economies based on fishing, agriculture and livestock. Called the lifeline of the region, the Senegal River valley has experienced the earliest West African kingdoms as well as French colonization from 1624 onward, with the first French trading center at the river mouth remaining until independence in 1960. In hydrological terms, the Senegal River connects the humid upper parts of its valley with the drier basin area of its lower course, reflecting a strong climatological gradient that strongly affects biological and cultural diversity.

After serious climatic changes, first apparent in 1968, that have devastated the entire valley, the riparian states of Mali, Mauritania, Senegal and later, Guinea, decided to join forces to master the availability of water and seek ways for rational and coordinated exploitation of natural resources. However, the river regulation infrastructure built (Manantali and Diama dams, dikes and other irrigation schemes) have had unforeseen environmental and socio-economical consequences along the Senegal River valley and the estuary. Among the impacts, salinization of soils, degradation of vegetation, the disappearance of native animal and plant species, diseases, the vanishing of some economic and socio-cultural activities and rural exodus, are the most important. Different protected areas have been created since the 1960s, all along the river, in part to reduce these negative impacts. However, the Senegal River currently remains a disturbed lifeline in the Sahel. Elements of the traditional cultural use of the river and respect for nature may contribute to the improvement of hydrological and hydro-agricultural schemes.

5.1 Introduction

The Senegal River running downstream through the Sahelian arid and semi-arid parts of Senegal, Mauritania and Mali, has defined biocultural diversity in its valley for centuries. The abundance of water and wetlands in this arid region explains the close relationship between humans and the river and the development of a unique local culture with a specific social and economic organization. Over time, the Senegal River has progressively become more artificially engineered with the building of dams (Manantali, Diama and Felou), embankments, free-flow

canals, irrigation ditches and sluiceways. These constructions were motivated by the heavy drought degradation in the 1970s, the need for hydropower and to support irrigation agriculture in the downstream sections.

Induced changes flow regime of the Senegal River have deeply affected traditional agriculture (drawdown agriculture after flood recession in the valley, rain-fed agriculture on the non-flooded areas), and favored irrigated rice areas. Other major activities both in the floodplains (Waalo) and the unflooded areas (Jeeri), such as fishing and livestock raising, have also been affected by

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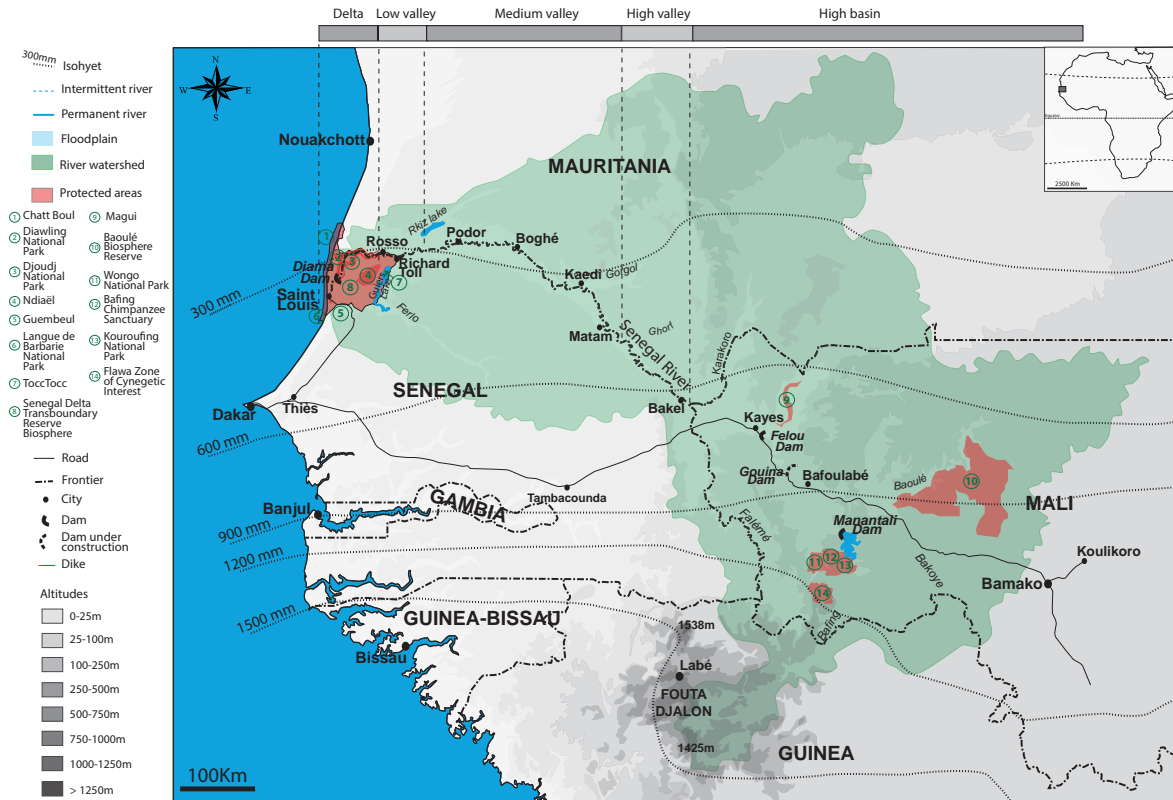


Fig. 5.1 The Senegal River watershed. Map: Aude N. Taïbi, based on data from Bruckmann (2017), Wikipedia, SRTM

flow alteration. As a consequence, the strong relationship between inhabitants and the river has been strongly threatened by these changes.

Different protected areas (see 5.4.3), created since 1965 or near the valley have been set up as a trial to cope with the detrimental impacts on biodiversity and cultural heritage caused by these infrastructures and by the changing human land use in the valley. Many scientific studies have been done to prepare and improve river regulation and irrigated agriculture in the Senegal Valley since the beginning of the 20th century, i.a., by the OMVS (Office de Mise en Valeur du Fleuve Sénégal), ORSTOM (French scientific institution working overseas) and FAO. Michel (1973) has documented the geomorphology of the valley and Maynard and Combeau (1960) studied the soils. The hydrology of the river has been continuously documented since 1903 (Kane 1985, Olivry and Chastanet 1989), and all data collected since the beginning of the 20th century have been synthesized by Bader (2015). Socio-economic topics have been studied, notably on social structures (Schmitz 1986, 1994), agricultural development and land use (Lericollais 1980). The impacts of dams and irrigated agriculture in the valley have also led to many other works, on their hydrological and biophysical consequences (Albergel et al. 1997, Kane 1997, Duvaill 2001, Wetlands International 2017) and

their socio-economical consequences (Adams 2000, 2004) as well as, later, the impacts of protected areas (Hamerlynck and Duvaill 2003, Taïbi et al. 2006). Few studies have been done on the cultural dimensions of the river, except for the works of Bourlet (2014) and Lorin (2015) on the literature of the river, a written and oral poetry in French and in Pulaar language. Yet this cultural dimension is fundamental to understanding the relations between men and the river beyond the technical aspects of river regulation.

5.2 Geophysical setting

The Senegal River, the 9th longest river in Africa and the second longest in West Africa, is 1,800 km long and its basin covers an area of about 300,000 km² (fig. 5.1). The basin is shared by Guinea (7%), Mali (35%), Mauritania (50%) and Senegal (8%). It is divided into three distinct geographical features: (i) the upper basin, which is mountainous and falls mostly in Guinea and Mali. (ii) The valley (divided into low, medium and high valley) and the delta in Senegal and Mauritania, which are sources of biological diversity and a set composed by (iii) ponds and channels such as Doué and Ngalanka all along the floodplains (figs. 5.1 and 5.4). We will focus on the second and third geographical units in this chapter. The Senegal River with its three

major tributaries originates in the sandstone highlands of Fouta Djallon, a West African water tower in Guinea (Falémé and Bafing Rivers), and in Mali (Bakoye River). The river flows across various bioclimatic zones, from the Guinean and Sudano-Guinean zones to the Sudan zone (each with a combination of different climatic and topographical factors) (Michel 1973). The main tributaries of the Senegal River are the Bafing (760 km long) and Bakoye (560 km) which join at the town of Bafoulabe to form the Senegal mainstream. Other tributaries are the Kolombine, Karakoro and Gorgol joining the mainstem from the right river bank and the Faleme River from the left bank (fig. 5.1).

5.2.1 Climate and hydrology

Smaller tributary streams and rivers include Ferlo, Gorgol and Doué, as well as lake outflows of Lake Guiers in Senegal fed by the Ferlo River, and Lake R'Kiz in Mauritania. The Senegal River flows into the Atlantic Ocean south of the city of Saint-Louis. Each year, the river transports 22 billions m³ of water past Bakel, considered to be the main reference station on the Senegal River due to its location below the confluence with the Faleme River, the last major tributary (UNESCO-WWAP 2003).

The atmospheric circulation in West Africa is determined by trade winds in the dry season and monsoon flows in the rainy season (fig. 5.2). All these atmospheric processes are governed by the Azores, Saint Helena high, the Saharan depression and the inter-tropical convergence zone. The monsoon winds are one of the necessary conditions for rainfall input (Nicholson 2013). However, the influence of oceanic and orographic factors are two elements to be considered in the evolution of temperatures, winds and precipitation.

The average annual rainfall in the Senegal Basin is 550 mm, however there are large regional differences (fig. 5.2). While in the South Guinean zone, rainfall is nearly 1,500 mm y⁻¹, the northern part of the basin records only 200 to 250 mm y⁻¹. The rainy season begins in June, reaches its maximum in August, and ceases in October, defining as for the whole Sahel region a clear distinction between the dry (low flow) season and the wet (high flow) season in summer called hiversage (Panthou 2013).

The coastal part of the Senegal River basin around Saint Louis has cool winters, with minimum air temperatures reaching about 17°C in January and maximums in May not exceeding 27°C. Inland, the weather is also cool in January, even if afternoon temperatures may top 35°C. In

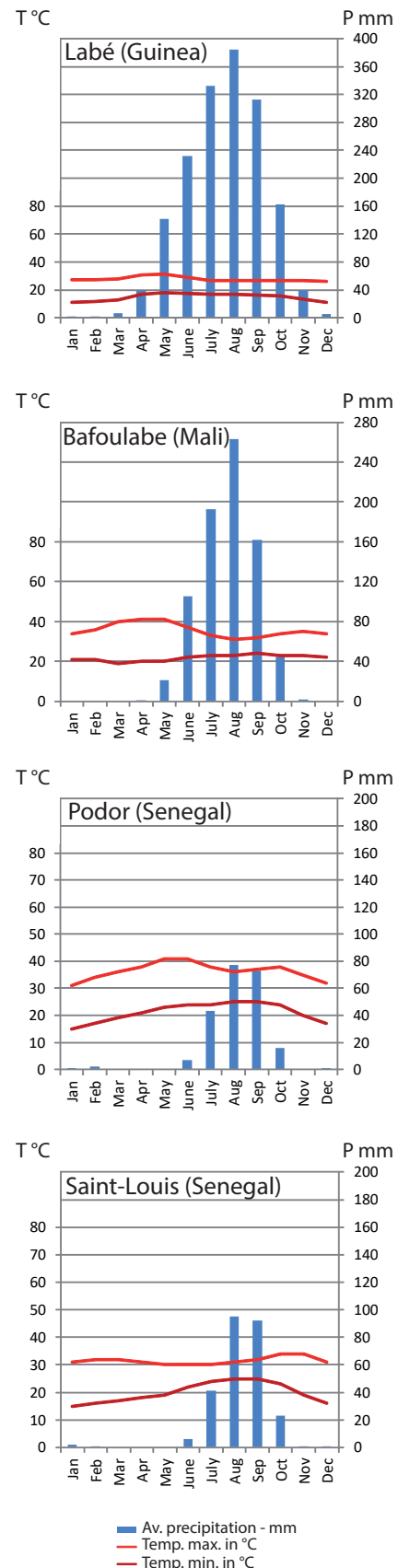


Fig. 5.2 Climate diagrams of representative sites in the Senegal River watershed: Labé (Upper Section, Guinea), Bafoulabé (Middle Section, Mali) and St. Louis (Estuary, Senegal). Graph: Aude N. Taïbi

May, minimum temperatures are no lower than about 22°C and maximums often rise above 40°C.

Thus in the Senegal River basin, the following climatic regions can be distinguished (figs. 5.1, 5.2): The Guinean domain, which encompasses almost the entire Fouta Djallon to Daka-Saidou part of the upper river basin with high rainfall (frequently amounts to 1,270 mm until 2,000 mm) and an eight-month rainy season (from April to November); the southern Sudanese domain of the northern foothills of the Fouta Djallon and the western part of the Mandingo plateaus with an average rainfall exceeding 750 mm and a rainy season of six to eight months (from April to November); the northern Sudanese domain extending into the remaining part of the upper basin to the Bakel station, with lower rainfall and a rainy season of four to six months (May to October); the Sahel region with very low rainfall and a rainy season lasts three months. The regions of Podor and Matam are particularly noted for their aridity and heat. There, the rainfall averages are about 360 mm y⁻¹, most of which fall between July and October, moderating the temperature somewhat, while maximum temperatures reach about 35°C and the dry season lasts from November to May.

The climate is also affected by prolonged drought phases. In this context, the Sahel zone has become well-known for the long drought and famine periods. After a humid period in the 1950s and 1960s, 1969 has been defined as the beginning of an extreme drought (fig. 5.3). From 1969 to 1998 for the western part of the Sahel which includes the Senegal River valley, the drought has been severe (Nicholson 2005, 2013).

The entire catchment experienced declines in precipitation in the order of 10–50% during the 20th century, with the greatest declines occurring in Senegal (Gonzalez et al. 2010, 2012). Since the

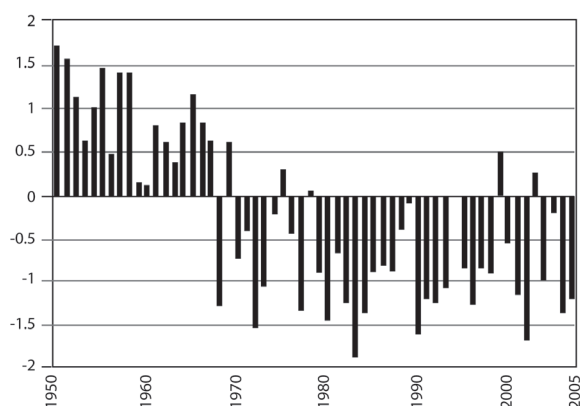


Fig. 5.3 Rainfall anomalies in the far western Sahel, with rainfall expressed in units of standard deviations. Graph: Aude N. Taïbi, modified after Nicholson (2013)

end of the 1990s, rainfall has increased again and from 1998 to today (2021), the mean of rainfalls is very close to the mean of a period long enough to cover decadal variations (Nicholson 2013). According to Descroix et al. (2013), the drought is continuing in the western part of the Sahel and the region of Senegal River with very low annual rainfall and increasing interannual variability (Conway et al. 2008).

The flow rate of the Senegal River is mainly determined by the rainfall in the upper watershed, however, the slope and morphology of the valley are also very important. The Senegal valley has a general very gentle slope. From Bafoulabé to Bakel the average slope is 0,30‰. Until Kayes, the river crosses sandstone banks forming rapids and falls with an altitude difference of only 20 m. After that, the slope becomes very low, reducing to 0.07‰ (Michel 1973).

The valley enlarges downstream of Bakel, where it is 10 to 25 km wide (fig. 5.1). From this high valley section until the delta, the valley is very flat and can be divided into waalo, flooded alluvial plain including the main river bed, and jeeri, corresponding to the non-flooded, sandy borders of the valley (fig. 5.4). The alluvial valley of the Senegal River is characterized by a network of high levees, flatlands, shallow depressions and meander belts studded with bands of smaller levees built after the Nouakchottian transgression (Michel 1973). Ponds of very variable size are found within the highly ramified network of high levees. Their soils are closely dependent on landform types and on the degree of annual flooding during periods of high discharge (Michel and Sall 1984). The geomorphological units distinguishing depressions and former river-banks (FAO-SEDAGRI 1973) are characterized by Vertisols and Fluvisols (FAO/ISRIC/ISSS 1998) locally known as Hollalde and Fonde soils, respectively (Maynard and Combeau 1960) hosting flood recession and rainfed agriculture (fig. 5.4).

The river has a tropical hydrological regime with alternating flood and low water seasons. Before dam construction, the high water period lasted from July to October and the low water season (less severe in the upper basin than downstream of Bakel), from early December to May–June (Michel 1973). Downstream of Kaedi in the middle valley, the high water period is from August to November (table 5.1). Almost all of the runoff contribution enters the Senegal River upstream of Bakel.

The main characteristics of the flow regimes are a strong seasonality, a geographical concentration of tributaries contributing to the discharge, the overall flow decreasing from south to north, and

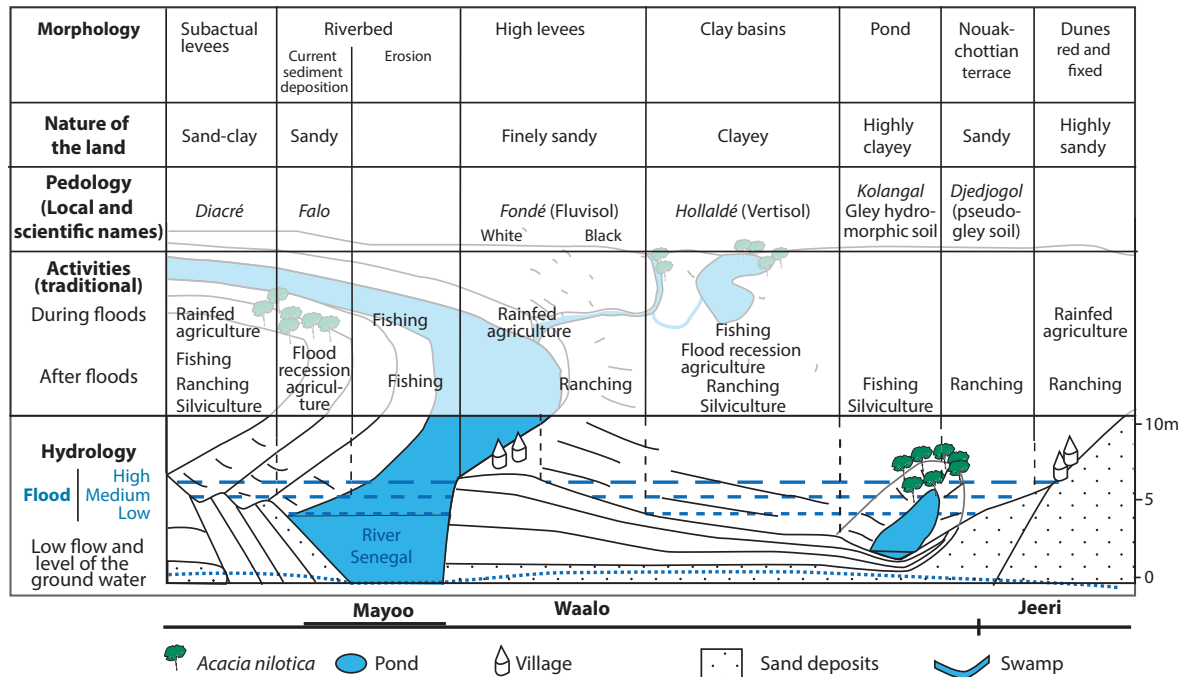


Fig. 5.4 Block diagram of the low valley of River Senegal (region of Podor). Graph: Aude N. Taïbi, redrawn after Michel (1973)

a high interannual variability. The mean annual discharges at Bakel vary from 1,349 m³s⁻¹ (1936–1937) to 220 m³s⁻¹ (1984–1985) (Bader 2015). The long-term average annual discharge is about 690 m³s⁻¹, which corresponds to an annual input to the sea of about 22 billion m³, ranging from 6.9 to 41.5 billion m³ (Bader 2015). During the annual flood season, the water level rises 3.5 m and downstream of Bakel, because of the very flat topography, the river occupies the entire valley covering from 15,000 ha in low-flow dry years to 400,000 ha in high-flow wet years (150,000 ha on average). This natural expansion and contraction of the flooded area causes a significant flood dampening and a decrease of the flood amplitude from upstream to downstream in this section of the river. Between Bakel and Rosso, the average flood propagation rates (in downstream direction) are 3.9 km h⁻¹ during the low waters and 0.6 km h⁻¹ during the high waters, when flow in the floodplain is hampered by obstacles (Bader 2015). During the dry season, the flow is some 300 times lower than in the flood (rainy) season. Quite fast at the beginning, the drying up slows until January then accelerates to the end of the dry phase, except in Matam and Kaedi (Bader 2015). During the last droughts in the 1970–80s, the percentage decrease in mean annual discharge of the Senegal River was almost twice as large as the decrease in rainfall for the period 1970–2010, even though the Sahel and most of West Africa also have experienced increasing runoff coefficients and stream flows

in most Sahelian areas over the past 40 years. This phenomenon has been named "The Sahelian Paradox" (Descroix et al. 2013). Streamflow extremes in West Africa (including the Senegal River) are non-stationary and currently increasing (Wilcox et al. 2018).

The drying up is accelerated by evapotranspiration and infiltration, particularly downstream Bakel, where flood overflows partially infiltrate the floodplain and significant volumes of water flow into the Guiers and R'Kiz lakes (Bader 2015). Over the 1903–1982 period, the average flow at Dagana (about 140 km from Diama) represents only 88% of the flow at Bakel. At Diama, over the period 1987–2009, this proportion drops to 75% (Bader 2015). Between Bakel and Diama (about 770 km) the total average loss is 115 m³s⁻¹ mainly because of evaporation (average: 89 m³s⁻¹) and net infiltration (average: 23 m³s⁻¹).

The pulsing flow regime influences the distribution patterns of the sediments. The average diameter of the suspended sediment particles in the river is 0.002 mm. The concentration of suspended solids varies from 25 to 250 mgL⁻¹ when the flow rate varies from 800 to 2,500 m³s⁻¹. By integration, the average annual quantities transported in suspension were estimated at 2.9 million tonsy⁻¹ at Bakel. Measurements of suspended solids carried out for OMVS (Office de Mise en Valeur du Fleuve Sénégal) gave an average value of 900,000 tonsy⁻¹, or an average of about 2,500 tons d⁻¹, with a maximum flood of 14,000 tons d⁻¹ (Ostenfeld and Jonson 1972). About 70% of the sediment transported

Table 5.1 Flow characteristics at the main hydrometric stations in the Senegal River Basin (from May 1950 to April 2012 for the natural regime; from May 1950 to April 2011 for the observed regime, initially natural and then influenced by river regulation from 1987). Source: Bader (2015)

River (station)	Interannual module (Q_0) ($\text{m}^3 \text{s}^{-1}$)	Runoff per unit catchment (Q_{sp}) ($\text{L s}^{-1} \text{km}^{-2}$)	Peak flood period	Maximum daily rates observed ($\text{m}^3 \text{s}^{-1}$)	Median values of daily low flow ($\text{m}^3 \text{s}^{-1}$)	Flow volumes coefficient of variation
Bafing (Balabori)	183	15.8	Late August-mid-Sept.	3,910 (1964)	5.53 (April)	0.30–0.32 (1950–2011)
Faleme (Kidira)	133	4.6	Early Sept.	3,184 (1961)	0.084 (May)	0.55–0.58 (1950–2011)
Bakoye (Oualia)	113	1.3	Early Sept.	2,493 (1958)	0.352 (May) 0 in June	0.56–0.66 (1950–2011)
Senegal (Kayes)	455	2.9	Mid Sept.	7,544 (1958)	2.53 (May-June)	0.42–0.44 (1950–2011)
Senegal (Bakel)	606	2.8	Mid Sept.	10,400 (1906)	4.33 (May-June)	0.42 et 0.44 (1950–2011)
Senegal (Matam)			Mid Sept.	3,750 estimated (1964)	7.09 (May- June)	
Senegal (Kaédi)				2,500 estimated (1955)	5.81 (May- June)	
Senegal (Podor)			Late Sept. to late Oct.	1,920 estimated (1956)		
Senegal (Diama dam)	115			2,094 estimated (1994)		

by the Senegal River reached the sea whereas only 30% was deposited on the floodplains (Gibb et al. 1987).

Aquifers also provide water resources in the Senegal River basin with mainly the deep Maestrichtian Aquifer, the Eocene Aquifer, the Continental Terminal, while the shallow alluvial or Quaternary Aquifer and the basement aquifer are being used (UNESCO-WWAP 2003).

5.2.2 Dam construction and their impacts

Dams have a strong influence on the discharge regime of the Senegal River (Dumas et al. 2010). The river discharge has been changed since 1987 by the Manantali Dam operation upstream, and the soil salinity has increased in the lower Senegal Delta because of the Diama Dam, built in 1986 (see section 5.6 and fig. 5.6 below). The Manantali dam has a capacity to store 11.5 billion m^3 of water with a surface area of 477 km^2 . Since the reservoir was established in 1987, a significant part of the natural flood volume of the Bafing River (approximately 50% of total flow)

is stored every year for three to four months between July and November, before being released for eight to nine months during the low season (Bader 2015). The reservoir was gradually filled over the period 1987–1991, then partially emptied until 1995, before being refilled again in 1999. Since then, the annual periodic change in reservoir water levels has been relatively stable (Bader 2015).

The main impacts of Manantali Dam observed at all stations downstream after 1987 are a lowering of the highest flood rates and an increase of low water flows. The daily flow observed since 1992 at Bakel is greater than $60 \text{ m}^3 \text{ s}^{-1}$ for 99% of the time and $100 \text{ m}^3 \text{ s}^{-1}$ for 94% of the time (Bader 2015). After dam construction, the flood flows have decreased from $4,000 \text{ m}^3 \text{ s}^{-1}$ to $2,000 \text{ m}^3 \text{ s}^{-1}$ measured at Bakel (Kane 2002). However, floods still occur in the valley downstream Bakel because the Manantali Dam only controls a part of the watershed upstream of Bakel. Dam-induced discharge changes have even increased since the Felou Dam became commissioned in 2013.

The Diama Dam in the lowermost section of the river, near the city of St. Louis, has been built to prevent saltwater intrusion from the nearby sea and to store 500 million m³ of water for the city, and to enable the development of irrigated agriculture. Before the construction of the Diama Dam in 1985, during low-water periods of some years, sea water could move upstream as far as Podor, about 300 km from the mouth (Kane 1985, 1997). However, only low quantities of river water reach the sea during the dry season or contribute to the flooding of the delta during the high water season, resulting in severe soil salination and loss of coastal floodplains. Shallow evaporite pans called sebkhas have developed in the delta. The Diama Dam results in higher water levels upstream but decreasing with distance to the dam (Bader 2015). The water heights in the valley have increased by more than 1.30 m at Bakel (500 km upstream from Saint Louis), 2.10 m at Rosso and 2.11 m at Podor (Kane 2002).

The two dams have also influenced sedimentation transport and related processes, i.a. in a reduction in the discharge of suspended and dissolved solids (Kane 2005). The Diama Dam also influenced the aeolian deflation (erosion process by winds) in the low delta wetlands, where the soils have been made vulnerable by the absence of flooding. To mitigate this and other problems the Diawling National Park has been created in 1991 on the Mauritanian side (western part of the delta) and since 1994, an artificial flooding project is in place (Duvail and Hamerlynck 2003).

Apart from dams, the Senegal River valley has progressively become artificially engineered, especially in the delta, but also in the lower and middle valley, with the building of embankments, free-flow canals, irrigation ditches and sluiceways. The water withdrawals from the river for irrigation have additionally influenced the level of water in the main channel and floodplains (Bader 2015). The estuary of the Senegal River is separated from the Atlantic by the Langue de Barbarie which is a sandy, north-south facing spit of land that stretches over a length of about 25 km. Strong marine currents cause marine sedimentation, forcing the river to erode the coast and lengthening the Barbary sand spit at its southern end (Gac et al. 1982). The natural fragility of the strait and dynamic sand spit has recently become intensified by the effects of the Diama and Manantali Dams, which have strongly reduced the sediment yield of the river (Niang 2002). From 1850 to 1973, 20 natural breaches were recorded in the sandy spit (fig. 5.5) but the structure was

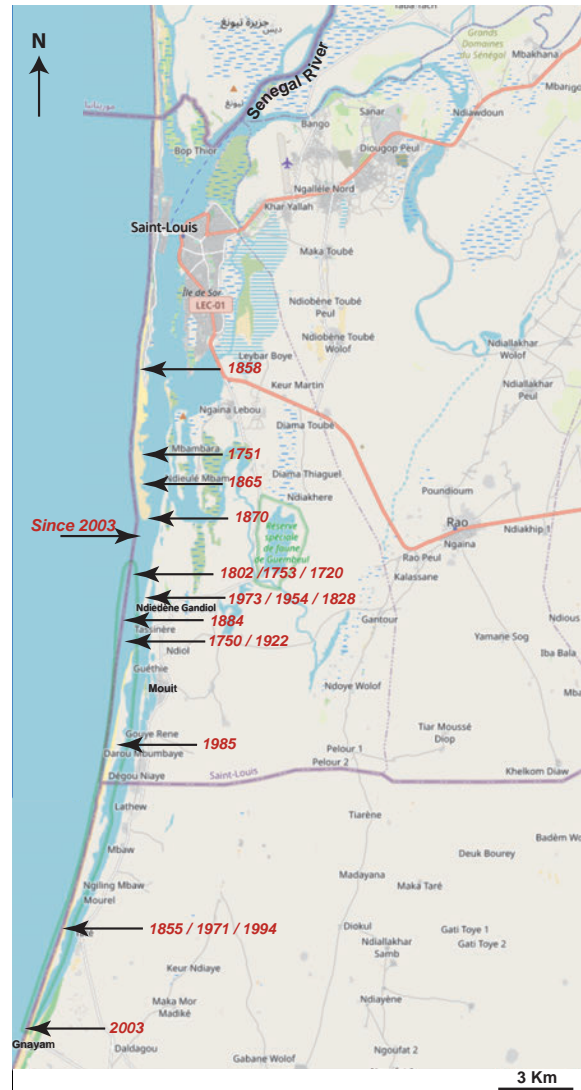


Fig. 5.5 Successive locations of the River mouth on the "Langue de Barbarie" since 1720. Graph: Aude N. Taïrbi, using an Open Street map as reference

relatively stable. From 1900 to 2002, the river mouth remained in a constant position 15 km south of the City of Saint-Louis (Niang and Kane 2014). In October 2003, following an early flood, a breach has been artificially opened on the Langue de Barbarie, which has become the new mouth of the Senegal River at less than 10 km distance from St. Louis (fig. 5.5). Until 2005, the opening in the Langue de Barbarie has widened from 4 m to more than 800 m (Kane 2005) and by January 2020, the breach had widened to 6 km, separating the southern end of the peninsula permanently from the main country, effectively transforming it into an island.

5.3 Historical introduction

This large river crossing the arid and semi-arid parts of Senegal, Mauritania and Mali has figu-

Table 5.2 Main characteristics of the Senegal River

Senegal River mainstem and major tributaries (Falémé, Bafing and Bakoye)	
Countries in the catchment	Guinea, Mali, Mauritania, Senegal
Catchment size (km ²)	300,000
Length (km)	1,800
Discharge (m ³ s ⁻¹)	The annual discharge varies from 250 to 1,400, long term annual mean Bakel: 676. Mean low dry season value: 10 in May, maximum flood value: 3,320 in September
Hydrological pattern	Very regular flow regime with annual flooding (early September at Bakel and mid-October at Dagana) covering from 15,000–400,000 ha (average 150,000 ha)
Degree of naturalness	Flow regime is increasingly modified by dams (Manantali, Diama and Felou) embankments, free-flow canals, irrigation ditches and sluiceways. Valley highly modified by human impacts downstream of the Manantali Dam. Delta completely artificialised by dikes blocking floods except when the floodgates are opened.
Natural landscape types	Downstream of Bakel: waalo (flooded alluvial plain) and jeeri (unflooded sandy edges of the valley). Network of high levees, ponds, elongate delta west of Bogué and meander belts studded with bands of smaller levees in the alluvial valley. Gonakier (<i>Acacia nilotica</i>) forests along the riparian zone of Senegal River. In the lower delta, mangrove forests occupy the estuary.
Impact types	Damming, water withdrawal, landuse change, salinization below the Diama Dam, diking (especially in the delta), die-back of mangroves after breaching the Barbarie sandy spit. Massive plastic pollution
Largest cities (inhabitants)	Saint Louis (200,000), Richard Toll (44,752) Matam (15,306) in Senegal. Kayes (> 125,000) in Mali. Rosso (> 60,000), Boghé (> 50,000), Kaedi (> 40,000) in Mauritania
Urbanisation	Urbanisation rates are low in the basin except in the cases of Saint Louis (Senegal) and Kayes (Mali), (2.4% in 2014 in both cities).
Protected areas	2 Biosphere Reserves: Senegal Delta Transboundary Biosphere Reserve of Senegal and Mauritania, Baoulé Biosphere Reserve in Mali. 5 national parks: Diawling (Mauritania). Djoudj and Langue de Barbarie (Senegal). Wongo and Kouroufing (Mali). Ndiaël and Guembeul avifauna reserves and Saint Louis protected marine area and the wildlife (Senegal). Bafing Chimpanzee Sanctuary (Mali). 2 World heritage sites: Djoudj National Park, city of Saint-Louis
Prevailing use form in the catchment	Agriculture: traditionally flood recession in the valley and rain-fed agriculture on the non flooded areas. Today: mainly irrigated rice perimeters. Fishing is the second largest activity. Livestock raising is also a major activity both in the Waalo and the Jeeri.
Famous elements of biodiversity	African Manatee (<i>Trichechus senegalensis</i>). Many afro-tropical and palearctic birds using the parks in the river delta as migratory stopovers or as breeding and wintering areas (e.g., white pelican <i>Pelecanus onocrotalus</i> , Greater Flamingo <i>Phoenicopterus ruber</i> , Lesser Flamingo <i>Phoenicopterus minor</i>). Northernmost <i>Rhizophora</i> mangroves on the Atlantic coast of Africa. Gonakier gallery forests
Famous elements of culture	Pékâne, fishermen poetry, very popular local representation of environment. Handicraft production with natural resources (ex: <i>Sporobolus robustus</i> mats). UNESCO world heritage in Saint Louis City

ratively been called the lifeline of the region for millennia.

The Senegal middle valley seems to have been a magnet for neighboring Sahelian and Saharan groups over time (Deme 2003) attracted by the different geomorphological units providing diverse subsistence activities, the more reliable access to water and the availability of wood and food. According to McIntosh (1999) cited by Deme (2003) "the Middle Senegal Valley political system was flexible enough to attract newcomers, to give them land and to make changes to their subsistence activity in time of environmental stress. [...] In the Middle Senegal Valley, the flood has always had a major influence on socio-political and economic activities".

5.3.1 Prehistoric period and kingdoms and empires

Archeological investigations document the very great age of river valley settlement. The valley section between Dagona and Kaedi, and its tributary the Faleme, today offer evidence of the oldest human settlement of Middle Stone Age in this part of Africa, ca. 150,000 years ago (Scerri et al. 2016). During the Neolithic, the population distribution was especially important on the periphery of the great river valleys, but as a result of an aridification phase 4,000–4,500 years ago human colonization concentrated more and more on the river banks. After 1000 BC, and especially from 800 BC onwards, domesticated pearl millet was being grown in the Middle Senegal Valley, based on evidence from Walaldé archeological site (Ozainne et al. 2014). First evidence of iron metallurgy is also documented at Walaldé during an occupation by agropastoralists that began by 800 BC and continued until 400–200 BC. At the same site, copper with the distinctive chemical signature of the Akjoujt mines in Mauritania was also present after 550 BC, attesting to trade and interaction over long distances (Deme 2003, Deme and MacIntosh 2006).

The present day region of Fuuta-Tooro in Mauritania and Senegal, and the valley, is considered to be the most likely location of Takrur, one of the earliest historically known West African kingdoms (Deme 2003) during the 11th century, and a strategic area that might have functioned as a refuge in times of environmental stress (Bocoum 1986, Deme 1991). It was previously named *Niamandiru* (land of abundance).

Later, the valley experienced a succession of different kingdoms, such as the Djolof kingdom founded in the 13th century by Njajaan Jaay, first 'king' or *bourba* which united the different populations related to the Wolof ethnic group. It later became the Kingdom of Oualo, coinciding with

the death of his last emperor, Lélé Fouli Fak in 1549 (Boulègue 1988). Afterwards the old Djolof was annexed to the empire of Mali (table 5.3).

Traditionally, the main activities were agriculture, both, drawdown agriculture in the waalo (floodplain) and rain-fed agriculture in the jeeri (unflooded land), fishing, and transhumance livestock breeding practiced both in the waalo and jeeri. These activities are still complemented with hunting practices for waterfowl, plant gathering and handicraft production, mainly in the lower delta (Vandermotten 2004, Taïbi et al. 2019). The Senegal River kingdoms and empires were also integrated in the international trading routes to North and East Africa.

5.3.2 Colonial period

With the arrival of Europeans, the Senegal River region was thrown into political and religious upheaval. Portuguese navigators established first trading posts in the 15th century, the Dutch West India Company purchased the island of Gorée in 1627, which (along with St. Louis) was later in the 17th century an object of Anglo-French rivalry, as both places served as important trading posts. Known as the 'River of Gold' by Europeans in medieval times, since the 16th century it was a route of advance for French colonial influence (Baba Kaké and M'Bokolo 1977). The city of Saint Louis in the river mouth was one of the harbors for slaves, gum, ivory, gold and leather trading. Slave trade, increased by European demand for the Americas at the beginning of the 16th century (Baba Kaké and M'Bokolo 1977), already existed earlier, slaves provided by the many wars between neighbor chieftaincies, kingdoms and empires (Coquery-Vidrovitch 2011), however, with the transatlantic slave trade, it reached unprecedented dimensions (see also chapters on the Niger and Congo Rivers, this volume). During the French colonial period, the city of Saint-Louis was founded on an island in the Senegal River estuary (fig. 5.5) as well as Podor or Kaedi respectively about 300 km and 900 km further east in the valley. The city of Saint-Louis was urbanized in the mid-19th century and became capital of Senegal from 1872 to 1957 when it played an important cultural and economic role in the whole of West Africa. In 2000, it was listed as world heritage by UNESCO for its distinctive appearance and identity given by its regular town plan, the system of quays as well as the Faïdherbe Bridge and the characteristic colonial architecture (WHC-UNESCO 2000). The other towns in the valley are Rosso, Kaedi and Boghé on the Mauritanian part, Podor, Richard Toll, Bakel, Matam in Senegal and Kayes and

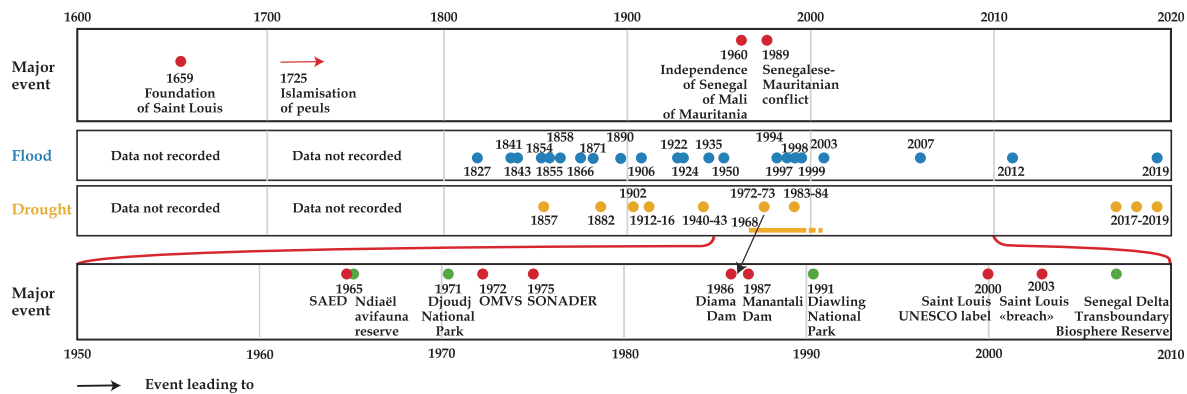


Fig. 5.6 Major events, floods and drought in the Senegal River watershed. Please note that the lowermost line has a different time scale. Graph: Aude N. Taïbi

Bafoulabé in Mali. Until the end of the 18th century, the territories outside of Saint-Louis were managed by traditional institutions (Baba Kaké and M'Bokolo 1977). After that period begins the European political authority inside the continent. Following the abolition of slavery (in Britain, in 1833, in France, in 1848), the slave trade was changed into a product trade (Coquery-Vidrovitch 2009). River transport based on triangular trade gave way to exchanges between colonies and metropolises (Bruckmann 2017). Since the Berlin Conference and the division of Africa into colonies by European states in 1885, the French imperialism was imposed with violence completely disrupting African economic networks, modes of production, social structures, as well as customs and culture, and land tenure rights (Coquery-Vidrovitch 2009). During the French colonization, the exchange of goods and people along the river was intensified, agriculture was expanding and the local economic life of the Senegal Valley was concentrated at the commercial and military stations that the French have established along the river (Podor, Matam, Bakel, Medina) (Bruckmann 2017, and see chapters on the Niger and Congo Rivers, this volume).

After centuries of local management of the river and its resources by villages in the framework of chiefdoms, kingdoms or empires, it has been completely changed by the French colonization. Traditionally being a source of life and gathering (Vandermotten 2004), the river became a boundary with borders, renewed after independencies (Coquery-Vidrovitch 2011). The Senegal River nowadays forms the border between Senegal and Mauritania downstream of Bakel and along the Faleme River between Mali and Senegal upstream.

5.3.3 Modern period

After independence (1960), the trade river traffic almost stopped, except by local movements

on the Senegal River. During the last years, only the famous Bou El Mogdad ship gets back on its cruises for tourists from Saint Louis to Podor. From 1972 onwards, a new era started with the foundation of OMVS (Organization for the Development of the Senegal River) a supra-national authority with a specific mandate of integrated development and a legislative and institutional framework (fig. 5.6). Mali, Mauritania and Senegal (Guinea joined in by 2006) decided to join forces within OMVS to master the availability of water and seek ways for a rational and coordinated exploitation of the basin's resources and to adapt to drought impacts. Recurrent drought cycles, degradation of natural resources and agriculture lead to the impoverishment of the population and a high emigration of young people.

OMVS manages the water allocation and the dams built collectively on the river based on the water uses (and not in terms of the territorial size of the abutter countries) to overcome the conflicting interests. The entire river and all the structures built on it are jointly owned by the States, which share both the costs and income from the dams. In theory, farmers, as well as herders, fishermen and electricity operators, meet to establish a program based on sharing the resource and making decisions by consensus (UNESCO-WWAP 2003). A hierarchy of institutions at different levels are then involved in river basin management, including institutions at the village, national and transboundary levels (fig. 5.7). The institutional framework of each neighboring country comprises a representative of the OMVS, the ministry in charge of water resources, a national institution, SAED (National Company for the Development and Exploitation of the land of the Senegal River Delta, of the Senegal River valleys and of Faleme) in Senegal, SONADER (National Company for Rural Development) in Mauritania, institutions for water partnership (NGOs, donor agencies) and asso-

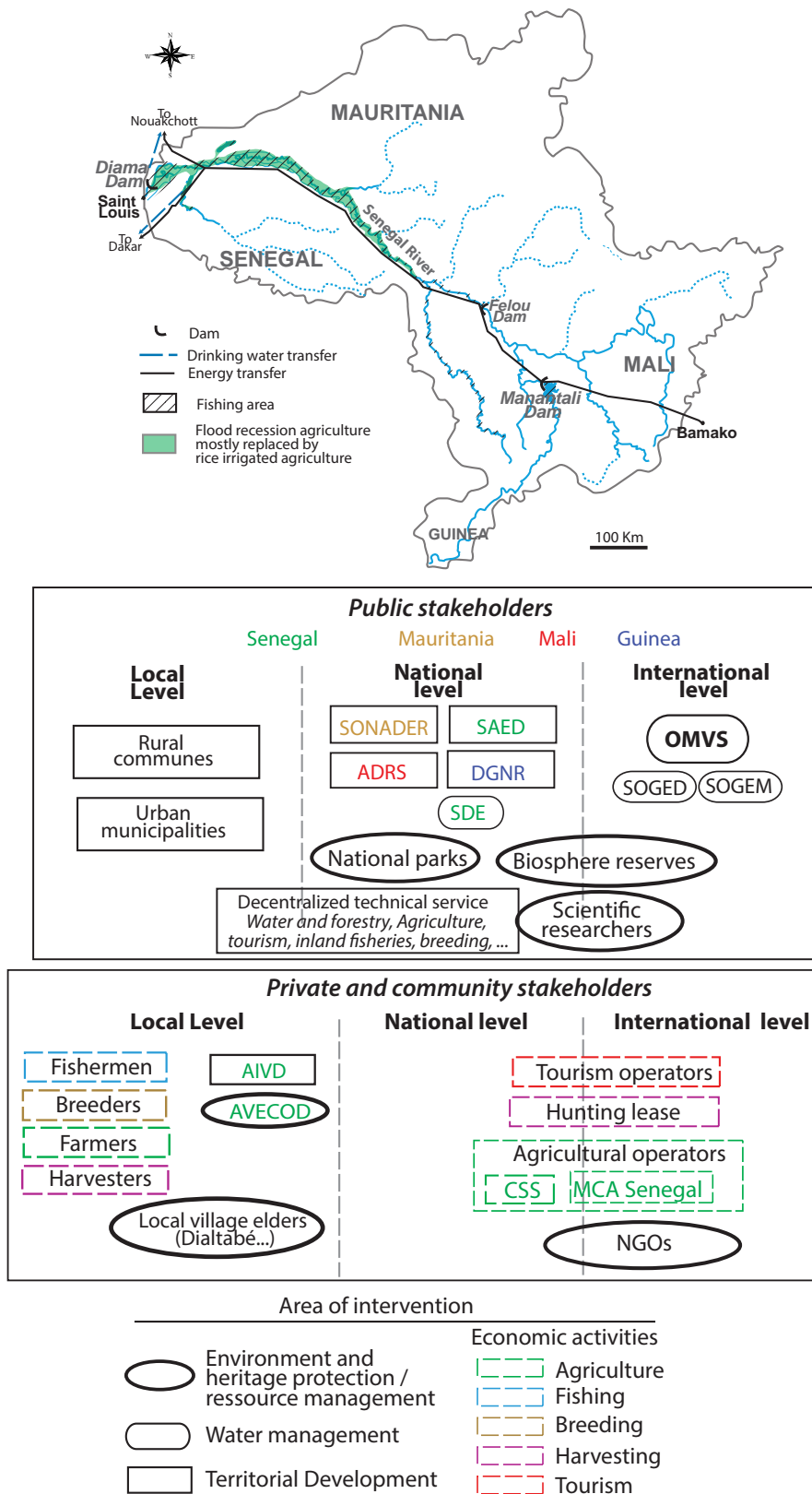


Fig. 5.7 Stakeholder structure in the Senegal River (ADRS: Malian Rural Development Agency for the Senegal River Valley; DGNR: Guinean General Directorate of Rural Engineering; AVECOD: Senegalese Association des Volontaires éco-gardes; AIVD: Senegalese Inter-village Development Association; CSS: Compagnie Sucrière Sénégalaise; MCA Senegal: Millenium Challenge Accounts (US grantmaking agency); SOGED: Company for the Management and Operation of Diama Dam; SOGEM: Company for the Management of Manantali Hydropower; SDE: Senegalese Water Society; SONADER: Mauritanian National Company for Rural Development; SAED: Senegalese National Company for the Development and Exploitation of the land of the Senegal River Delta, of the Senegal River valleys and of Faleme). Graph: Aude N. Taïbi

Table 5.3 Main historical periods and events of the Senegal River watershed. Sources: M'Bokolo E. (1980), Boulègue (1988), Baba Kaké and M'Bokolo (1977), Coquery-Vidrovitch (2011), Schmitz (1986)

Empire or Kingdom and major events	Period	Localisation
Middle stone age	ca. 150,000 years ago	
Domestication of pearl millet	800 BC onwards	Walaldé
First evidence for iron metallurgy	800 BC and continued until 400–200 BC	Walaldé
Trade and interaction over long distances	after 550 BC	
Empire of Ghana (Soninkés)	8 th –11 th centuries (full development in the 11 th century)	North of Senegal River and east of actual Mauritania
Takrur kingdom	11 th century	Mauritanian and Senegalese region of Fuuta-Tooro
Djolof kingdom	13 th century	Senegal River Valley
Kingdom of Oualo	13 th second part – 19 th centuries	Low valley and delta
Empire of Mali	13 th –15 th centuries (bloom period: 1312–1337)	Whole Senegal River basin and beyond
Empire Songhay	15 th – end of 16 th centuries	whole Senegal River basin and beyond until Tchad
Fuuta Tooro kingdom	16 th –19 th centuries	North and south Senegal River medium and high valley
Beginning of slave trade to the Americas	1517	
Foundation of Saint-Louis	1659	Beginning of the European exploration of the Senegal River
Islamisation of peuls	After 1725	
Federation of Mali	1959–1960	Grouping the two French colonies of French Soudan and Senegal
Independence from France	1960	Senegal, Mali, Mauritania
Conflict between Mauritania and Senegal	1989	

ciations (farmers, fishermen, women's associations, etc.).

In this context, the Manantali Dam was built upstream 1,000 km from the mouth of the river in Mali in 1988, to regulate the river flow, to generate hydroelectricity, to expand navigation between the cities of Saint Louis and Kayes and to support irrigated agriculture on 3,750 km² further downstream (Dumas et al. 2010). The Diama Dam has been built in 1986 downstream on the Mauritania-Senegal frontier (see section on geophysics, above), to irrigate 200,000 ha of arable land and to supply the cities of Nouakchott, capital of Mauritania by 100%, and Dakar, capital

of Senegal by 50% with water (Bader 2015). The Felou hydroelectric Dam is a run-of-river project commissioned in December 2013. It is located on the Senegal River in Mali, 15 km upstream from Kayes and produces 431 GWh for an installed capacity of 60 MW (Bader 2015).

5.4 Key elements of biotic diversity

5.4.1 Fauna and flora

The Senegal River basin crosses successively different vegetation zones (fig. 5.8): Forests transitions and mosaics of lowland rainforest and secondary grassland in the Fouta Djallon highlands.

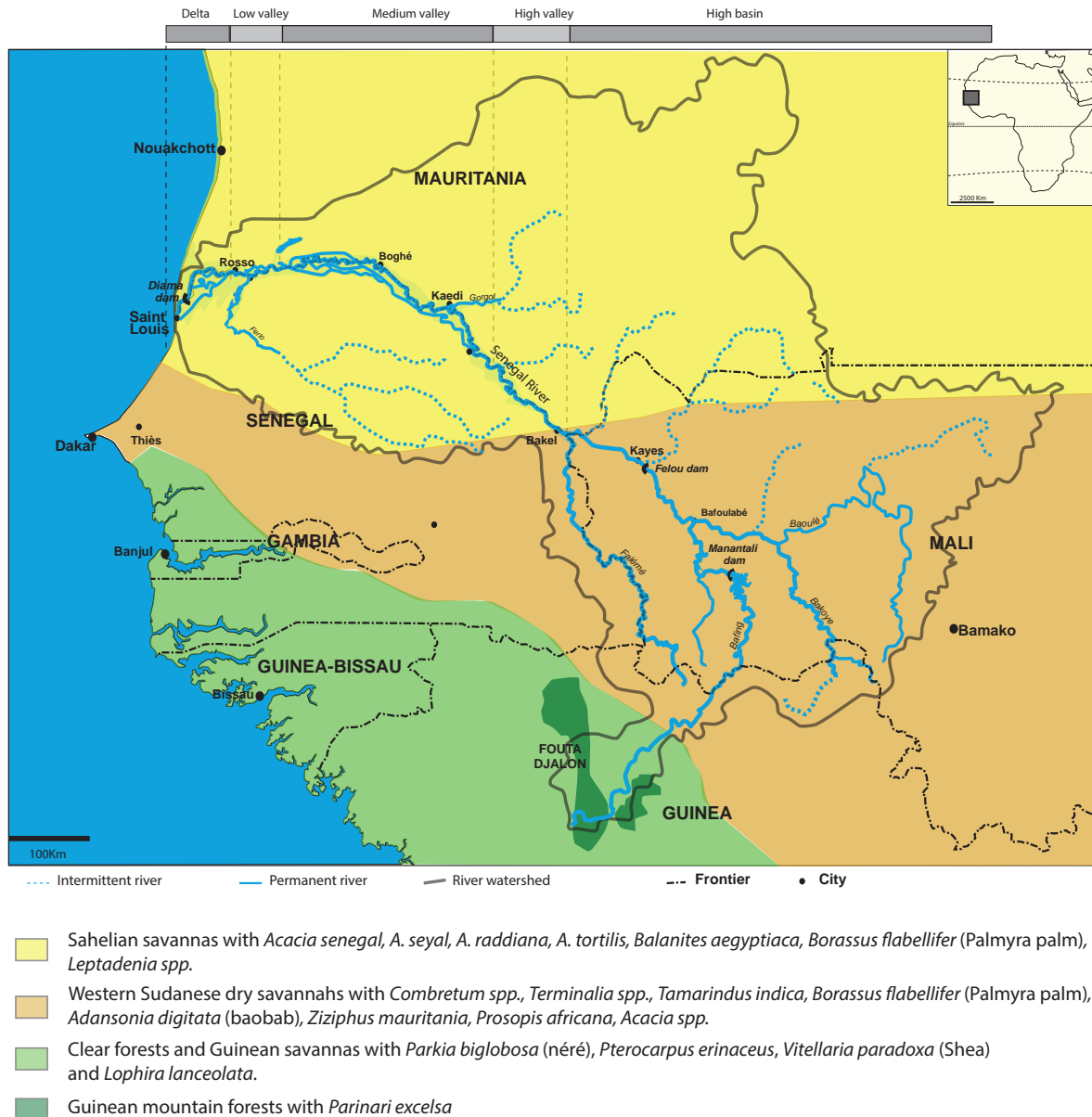


Fig. 5.8 Biomes of the River Senegal watershed. Map: Aude N. Taïbi, based on White (1983)

Undifferentiated Sudanian woodland in the high basin. Bushland and thickets from Bakel to the delta with Sahel Acacia wooded grassland and deciduous bushland, and finally, mangroves in the delta (White 1983). The rich biodiversity and natural heritage of the Senegal River ecosystems, particularly the lower delta, explains the early enlisting of many sites as wetlands of international importance. The Senegalese Djoudj National Park (PNOD) was created in 1971 and initiated a process of conservation, followed by the Mauritanian Diawling National Park (PND) in 1991 and the Senegal Delta Transboundary Biosphere Reserve (SDTBR) in 2005 (table 5.4).

The National Parks (PNOD and PND) support a mosaic of dunes, floodplains and mangroves, as well as a network of lakes, lagoons and ponds

which are important habitats for fish and crustaceans. The wetlands of the PND and PNOD host a large number of migratory birds such as Palearctic and Afrotropical birds using the parks as a migratory stopover or as a breeding and wintering area (Hamerlynck et al. 1999). The bird colonies include more than 250 bird species, such as the white pelican (*Pelecanus onocrotalus*) and pink-backed Pelican (*Pelecanus rufescens*), and Greater and Lesser Flamingos (*Phoenicopterus ruber*, *P. minor*). In the 1960s, large breeding colonies of different species could be observed, including herons (*Ardea purpurea*, *A. ralloïdes*, *A. cinerea*) and storks (*Ciconia ciconia*, *Ciconia nigra*), egrets (*Egretta ardesiaca*, *E. alba*, *E. garzetta*, *E. gularis*), cormorants (*Phalacrocorax lucidus* and *P. africanus*), terns (*Gelochelidon nilotica*), ducks, and

some species considered as vulnerable by IUCN, such as the Black crowned crane *Balearica pavonina* (PND 2013). These colonies disappeared during the drought phase of the 1970s and after the Diama Dam building, however, they partially recovered after the creation of the Diawling park and the artificial flood management in this area.

The protected and maintained floodplains are used as spawning grounds, and nursery and feeding area by a diverse fish fauna with more than 98 species. These include *Mugil cephalus*, *Ethmolosa fimbriata* and *Tilapia guineensis* in the estuary, and *Chrysichthys nigrodigitatus*, *Lates niloticus* (Nile perch), *Schilbe mystus* (African butter catfish) and *Tilapia niloticus* in the Valley, and *Clarias gariepinus* (African sharptooth catfish) and *Polypterus senegalus* in ponds and lakes (PND 2013).

The Senegal River waters also accommodate *Pelusios adansonii*, a fresh water turtle, and manatees (*Trichechus senegalensis*), both endemic to West Africa (see also chapter on the Sanaga River, this volume). The manatee, considered as vulnerable by IUCN, occurs in the Senegal River (though permanently isolated from the coast by Diama Dam), and upstream of the Felou Dam in Kayes, which prevents them from moving further eastward (Keith Diagne 2015). Manatees are no longer reported downstream of the Diama Dam. However, they have been sighted throughout the Senegal River and its tributaries east of the dam (Powell 1996, Keith-Diagne et al. 2021). Manatees are frequently seen in Lake Guiers year round, and in 2005, the Tocc Tocc Community Reserve was created for their protection along the northwestern shore of Lake Guiers. They also probably inhabit the Gorgol Marigot, a large, seasonally-flooded tributary east of Kaedi. During the rainy season when the Senegal River floods, Manatees are regularly seen near Kanel and Matam in eastern Senegal. As flood waters recede during the dry season, manatees often become stranded in seasonal lakes at Wendou Kanel and the local people, along with assistance from NGOs, have been rescuing and releasing them back into the main Senegal River since 1984 (Keith Diagne 2015). These Manatees used over 265 km of the Senegal River to the north and south of the release site and made directed trips to feeding areas (Keith Diagne 2015).

The last hippopotamus (*Hippopotamus amphibius*) was observed in the early 1960s (Barry 2004). Crocodiles (*Crocodylus niloticus*) have been reported near Kaedi in Mauritania (Sehla 2001) and can be observed in the Djoudj and Diawling National Parks in Senegal and Mauritania. Other reptiles, such as *Varanus exanthematicus*, *Bitis*

aruetans and *Python sebae* are also present in or near the parks.

There are also mammals in or near the valley, even if drought and excessive hunting caused the demise of the larger mammals. The last lion, *Panthera leo*, was shot in 1970, and the red-fronted gazelle (*Gazella rufifrons*) was last observed in 1991. The remaining larger mammals are jackals (*Canis aureus*), warthogs (*Phacochoerus aethiopicus*), wild cats (*Felix sylvestris*), hares (*Lepus capensis*) and patas monkeys (*Erythrocebus patas*).

The regional vegetation on the drained sandy soils consists of a mosaic of different types and successional stages of deeply anthropized savannas (White 1983): Sahel Acacia wooded grassland and Acacia deciduous bushland (White 1983). Among the dominant woody species, *Acacia tortilis* (name recently changed to *Vachellia tortilis*) is a structuring physiognomic element.

On the fixed dunes of the Sahelian part of the Senegal River watershed (jeeri), the landscape is characterized by thorn or shrub savannas with sparse trees, namely *Acacia tortilis*, *Commiphora africana*, *Balanites aegyptiaca*, *Boscia senegalensis*, *Maerua crassifolia*, *Leptadenia pyrotechnica*, *Combretum glutinosum* and others (fig. 5.9a). The short grass is more or less continuous and includes mostly annual species, principally *Cenchrus biflorus* and *Schoenefeldia gracilis*. These savannas are generally subject to a strong pressure from cattle grazing which locally leads to extensive degradation, such as the mortality and damage of trees, the destruction of the grass layer and the proliferation of low or unpalatable species (*Guiera senegalensis* and *Calotropis procera*). However, due to the low biomass quantity and the discontinuity of the grass layer, bushfires are generally absent.

In the valley itself, the vegetation is determined largely by the hydrological and edaphic conditions (Keith et al. 2013). It can be distinguished into two types: that of freshwater floodplain and that halophytic plants of the delta and the lower valley. In the floodplain *Acacia nilotica* (locally called gonakier, fig. 5.9b) constituted important gallery forests, of which significant stands still persist locally. *Acacia nilotica* is associated with *A. raddiana* and *A. seyal* and less frequently with other woody species such as *Acacia albida*, *Piliostigma rufescens*, *Balanites aegyptiaca*, *Mitragyna inermis* and *Ziziphus mauritiana*. Depending on the height and length of the flood, these forests alternate with different types of wetlands such as ponds (Cyperaceae, *Echinochloa* spp., *Oryza barthii*, *Typha domingensis*, *Phragmites australis*) or grass meadows (*Panicum laetum*, *Chloris priurii*, *Dactyloctenium aegyptium*) (fig. 5.9d). Due to regular inunda-



a) Shrub savanna with sparse trees of a jeeri red dune and interdune with *Acacia tortilis*, *Leptadenia pyrotechnican* and *Balanites aegyptiaca* trees and dry *Cenchrus biflorus* and *Schoenefeldia gracilis* grasses. Photo: Aude N. Taïbi (Feb. 2020)



d) Cyperaceae wetland prairie in the Djoudj National Park. Photo: Aude N. Taïbi (Feb. 2020)



b) Gonakier forest, irrigated fields and Maw pond near Donaye. Photo: Pascal Dubes (2020), with permission



e) *Avicennia germinans* mangrove in the River Senegal Low delta. Photo: Aziz Ballouche (2006)



c) Riparian forest and fishermen in the Senegal River middle valley. Photo: Aude N. Taïbi (2019)

Fig. 5.9 Terrestrial and wetland habitats along the Senegal River Basin

tion, these ecosystems provides critical habitat for fish and migrating birds (Tappan et al. 2004).

The natural vegetation in the delta is subject to marine influence. The mangrove forest is composed by *Rhizophora racemosa* and *Avicennia germinans*), which here reaches one of its northernmost positions on the Atlantic coast of Africa (fig. 5.9e). The halophilic grass formations are characterized by *Sporobolus robustus* grass.

5.4.2 Anthropogenic changes of ecosystems in the 20th and 21st centuries

The habitats described above, have changed dramatically in the recent past, due to dam construction (Taïbi et al. 2006) and diking (see section 5.3 for details), as well as deforestation and a combination of other anthropogenic and natural fac-

tors. In the early 1990s, most of the Senegal River lower delta has basically turned into a saline desert because of the Diama Dam (Hamerlynck and Duvail 2003), leading to the die-back of the original vegetation (mangroves and gonakier forests), which had already suffered from the impacts of the 1970s–1980s drought. A comparison of Landsat images captured in 1984 and 2003 shows a decline in Gonakier forest area of 51% (Tappan et al. 2004). Important grass and macrophyte species such as *Sporobolus robustus*, a perennial grass that used to cover thousands of hectares of floodplain, *Echinochloa colona*, a grass of high pastoral value, have been substantially reduced. *Oryza barthii*, a wild rice, and *Nymphaea lotus*, a water lily, virtually disappeared (Hamerlynck and Duvail 2003). The only plants observed to

are the halophile pasture species of *Salsola* and *Arthrocnemum*. Sandy areas without any vegetational cover were increasing near dunes of the low delta and coastal areas, previously covered by stands of several *Acacia* species.

The Diama Dam and the irrigated rice plantations in the floodplain also lead to the development of invasive aquatic plants in the valley, which causes many ecological and socio-economical problems. The freshwater lake above the dam was quickly colonised by cattail (*Typha domingensis*) and the exotic *Pistia stratiotes*, *Salvinia molesta* and *Paspalum vaginatum* also spreading. These plants have a negative impact on water quality and favor the development of water-borne-diseases.

Irrigated rice production areas, dams and dikes reduce the size and the connectivity of wetlands and mainstem, and block migrations of fish along and across the river-floodplain system, which causes a strong decline in fishing catches (Manikowski and Strapasson 2016). Water mammals such as manatees are permanently isolated from the coast by the dams. In 2008, five Manatees died as a result of entrapment behind a new agricultural dam at Navel, near Matam. Seven live Manatees were rescued in early 2009. As a consequence, dam grates were removed in 2010 to allow passage by manatees (Keith Diagne 2015).

Rice and sugar plantations also appear as a degradation factor in the Senegal River basin because of the chemical inputs. Mainly herbicides, such as atrazine or propanil, but also insecticides and fungicides degrade the water quality (Thiam 1996). The Ndiaël Basin is evolving as a salt flat (*sebkha*) because it serves as an outlet for salty water from the Richard Toll sugar plantation. Another major threat to water quality in the Senegal River and its wetlands is eutrophication due to the release of untreated wastewater. Natural coastal regions near river deltas are highly productive fish hatcheries, but with the closing of the Diama Dam, the nutrient contribution of the Senegal River to the delta is strongly reduced (Cecchi 1992).

5.4.3 Protected areas as remediation tools

The creation of the Ndiaël avifauna reserve in Senegal in 1965 covering 46,550 ha including 10,000 ha of Ramsar wetlands marked the beginning of this conservation process (Taïbi et al. 2019). As a compensatory measure for the biodiversity loss caused by dams, a protected area was finally created in 1991 on the Mauritanian side of the delta. The Diawling National Park (PND) with 16,000 ha faces the Djoudj National Park (PNOD) created earlier in 1971 on the Senegalese side of the river and designated

under the Ramsar convention in 1977 (table 5.4, fig. 5.6). In 2005, the Mauritanian and Senegalese protected areas of the Senegal River delta have been integrated into a transboundary biosphere reserve called Senegal Delta Transboundary Biosphere Reserve (RBTDS) including five Ramsar sites (PND and PNOD, Chatt Boul, Ndiaël and Guembeul bird Reserves), two World heritage sites (PNOD and city of Saint-Louis) and other protected areas such as the Langue de Barbarie Park in the estuary and the Saint Louis protected marine area, covering a total area of 641,768 ha including 562,470 ha in the continental zone and 79,298 ha marine areas (Taïbi et al. 2019). The waters of the Senegal River basin support many other protected areas and Ramsar sites such as the Magui permanent freshwater lake or the Tocc Tocc community nature reserve near Dagan designated as Senegal's 5th Ramsar site in February 2014. The upstream area hosts a second biosphere reserve, along the Baoulé, a Senegal River tributary, and the Kouroufing and Wongo National Parks (table 5.4, fig. 5.1).

One goal of the Diawling National Park was to create an artificial flooding from the Senegal River, the first of which took place in 1996. Along with the first water release from the Diama Dam in 1997, it has succeeded in rehabilitating a substantial portion of ecosystems of the lower delta, with an increase of plant diversity and vegetation cover, and a comeback of *Acacia nilotica* woodlands both inside and outside of the protected area (Taïbi et al. 2006). Mangroves are now healthy and produce large quantities of seedlings which are successfully recolonizing the estuary (Taïbi et al. 2006). The nursery function for estuarine and marine fish and shellfish has been restored, and freshwater fish catches have increased concomitantly with the expansion of the flooded area. Migratory and nesting waterbirds have returned in numbers that often more than satisfy the criteria for inclusion in the List of Wetlands of International Importance under the Ramsar Convention on Wetlands (Hamerlynck et al. 2006).

However, except in these protected areas and despite being among the most biologically productive ecosystems, the wetlands along the Senegal River are often just regarded as potential areas for agriculture, or as 'wastelands', habitats for pests and a threat to public health. Moreover, outside the protected areas many ecological problems remain. Fishermen bewail that there is no more fish in the river.

5.4.4 Biocultural values

The 'natural capital' of the Senegal River is not strictly biological in nature but biocultural. Be-

Table 5.4 Important protected areas in the Senegal River basin

Name	Location	Type	Date of creation	Size (ha)
Ndiaël special wildlife reserve	Senegal, delta	Avifauna reserve + Ramsar site	1965	46,550 (Core area 26,000)
Diawling National Park (PND)	Mauritania, delta	National Park (cat II IUCN) + Ramsar site (1994)	1991	16,000
Djoudj National Park (PNOD)	Senegal, delta	National Park (cat II IUCN) + Ramsar site (1977) + World Heritage Site (1981)	1971 (extended in 1975)	16,000
Chatt Boul	Mauritania, delta	Ramsar site	2000	15,500
Guembeul special wildlife reserve	Senegal, delta	Ramsar site	1986	720
Langue de Barbarie Park	Senegal, estuary	National Park (cat II IUCN)	1976	2,000
Saint Louis protected marine area	Senegal, estuary	Marine protected area	2004	49,600
Magui permanent freshwater lake	Senegal	Ramsar site	2013	24,740
Tocc Tocc community nature reserve	Senegal, Guiers lake	Ramsar site	2014	273
Baoulé Biosphere Reserve	Mali, Baoulé tributary	Biosphere reserve	1982	2,500,000 (Core area 533,037/Buffer zone 177,345)
Kouroufing National Park	Mali, Bafing tributary	National Park + Ramsar site	2002	55,770
Wongo national park	Mali, Bafing tributary	National Park + Ramsar site	2002	53,400
Senegal delta Transboundary Biosphere Reserve	Senegal – Mauritania	Biosphere reserve	2012	641,768 (Core area 95,460/buffer zone 86,142)

cause people living in or near the Senegal Valley are depending on natural resources for livelihoods, they are close to nature (table 5.6). Over the past years, even if traditional activities such as fishing, cattle breeding, and flood recession agriculture have been drastically affected by inadequate river management, water resources still play the leading role in the ecosystems of the Senegal Basin and in the economic development of the region. In the past decades, however, all the ecological, social and political upheavals in the valley are leading to a risk of disconnection between the population and their river. Nowadays, in Podor and Matam and Bakel, the docks are deserted while they were teeming with ac-

tivities before the 1970s, because of the end of commercial transit through the river. They are still crowded in Saint Louis south of the district of Guetndar, due to the sea fishing. However, in the valley or in the estuary the great difficulties of fishing are leading to the abandonment of this activity. In the alluvial valley, the collective system is threatened by the collectivization of the land within the development of rice irrigated agriculture and the forced land conversion.

5.5 Key elements of cultural diversity

Rivers are cradles of human development (Wantzen et al. 2016, Macklin and Lewin 2020). Spe-

Table 5.5 Key elements of biodiversity of the Senegal River

Key element	Link to the natural flow regime	Ecosystem services	Human use and threats
Migratory wetland birds	The river wetlands, mainly in the low delta, are used as migratory stopover or as breeding and wintering area for migratory palearctic and afrotropical birds.	2 of the 3 West African birds sanctuaries are in the Senegal River low delta (Djoudj and Diawling National Parks).	Ecotourism in the low delta is focused on birdwatching. Migratory bird habitats are threatened by droughts, dams embankments and water pollution.
Floodplain Gonakier forests (<i>Acacia nilotica</i>) with <i>A. raddiana</i> and <i>A. seyal</i>	Periodic floods are vital for sustaining forest structure and water-dependent biota. Overbank flows redistribute resources and disperse propagules of plants and aquatic biota.	The forest provides critical habitat for fish and migrating birds.	Drought-induced declines conversion into irrigated agriculture. Cutting of wood for charcoal production. Insufficient reinforcement of conservation laws
Fish (98 known species)	Fish depend on seasonal flooding to create spawning, nursery and feeding areas.	Important foodweb function, food for migratory birds and humans	Fishing is the second largest economic activity in the valley. Dams, embankments and rice perimeters have disrupted longitudinal and transversal connectivity. Water pollution
Manatee (<i>Trichechus senegalensis</i>)	Before the building of dams manatees occupied the whole river and seasonal lakes during the wet season	Herbivore, ecosystem engineer	Habitat fragmentation (dams), habitat loss (diking for rice fields), entrapment (grates)
Mangrove (<i>Rhizophora racemosa</i> and <i>Avicennia germinans</i>)	Depend on both, riverine and marine inundations	Important biogeochemical turnover, fish nursery, complex habitat structures above/below the water	Traditional use for wood and fisheries, today great anthropogenic pressures (salt production, shrimp farming, wood collection and altered flow regime), enhanced by climate change. Locally recovering after restoration

cific lifestyles based entirely on the resources of the Senegal River as well as different adaptations to the climate and the hydrological regime have developed along the valley. The population of the basin is more than 3.5 million people (UNESCO-WWAP 2003), 85% of whom live near watercourses (table 5.7, fig. 5.12). The population growth rate is estimated at 3%, which is slightly higher than the individual averages for Senegal, Mauritania and Mali (UNESCO-WWAP 2003), and the population is expected to double every 25 years, which will lead to an increasing competition for natural resources.

The four countries bordering the Senegal River Basin are among the poorest countries in the world, with 42–53% of the population living below the poverty line. Almost the entire riverside population consists of subsistence or smallholder farmers and fishermen, which are among the most vulnerable groups in the region. The new irrigated rice agriculture last decades did not improve economic stability for the small farmers. On the contrary, they are becoming poorer because rice production is less productive than envisaged and causes unprecedented operating costs for fuels and the maintenance of irrigation pumps (Koopman 2007).

Table 5.6 Proficioning, regulating and cultural ecosystem services of the Senegal River

Ecosystem services	Specification
Provisioning food	Production of fish and other aquatic animals/plants
Provisioning freshwater	Storage and retention of water behind the Diama Dam for domestic water in Saint Louis. Storage and retention of water at Manantali for hydroelectricity, industrial and agricultural use
Provisioning fiber and wood	Production of fodder (gonakier leaves, bourgou (<i>Echinochloa stagnina</i>) and wet grasslands), fuel wood and logs
Provisioning genetic material	Plants are used for the traditional pharmacopoeia.
Provisioning biodiversity	Species and gene pool
Regulating climate	Wetlands support carbon sequestration. Water and vegetation regulate local temperatures and impact climatic processes.
Regulating hydrological flows	Storage of drinking water and water for agriculture (modern irrigated rice and traditional flood recession agriculture) and industry. Groundwater recharge and discharge
Regulating pollution and detoxification	Floodplains and river fauna and vegetation are a way for retention, recovery and removal of excess nutrients and pollutants.
Regulating habitat	Ponds, pools and mangroves are nursery and breeding grounds for fish and waterbirds. Hydro-sedimentary processes are supporting nutrient cycling.
Regulating natural hazard	In the estuary, mangroves are storm and marine submersion protections. Floodplains help the flood control.
Spiritual and inspirational cultural service	The river landscapes and linked activities provide personal feelings and wellbeing. Religious or spiritual significance are attached to the river whose mediator are the Dialtabé.
Cultural service of recreation	The river gives many opportunities for recreational activities such as swimming, bathing, boating. Pekâne fishermen poetry is a very popular parties activities inspired by the river and its ecosystems.
Aesthetic cultural service	Appreciation of natural features is a major element of wellbeing. The beauty of the river is celebrated by pekâne poetry and is one of the support of ecotourism in the Valley.
Educational cultural service	River gives opportunities for studying natural ecosystems. Ecosystems influence the type of informal knowledge systems developed in the valley. Historically deep relationships with the river have often led to an intimate knowledge of ecosystem components and interactions.
Economical service	Animal products such as skins, and plants are used to produce sold objects (<i>Sporobolus robustus</i> to make mats etc.).

Table 5.7 Summary of socio-economic data in the OMVS (Senegal River treaty) member states (UNESCO-WWAP 2003)

	Senegal River Basin	Mali	Mauritania	Senegal
Population (million inhabitants)	3.5	11	3	10
Annual growth rate (%)	3	2.97	2.9	2.8
Urbanization rate (%)	NA	41	53	51



Fishing and washing every day activities in Donaye near the Senegal River. Photo: Aude N. Taïbi (2019)



Fishing from the shore in the Doué River, distributary of the Senegal River. Photo: Aude N. Taïbi (2019)



A village near the Senegal River middle valley. Photo: Aude N. Taïbi (2019)

Fig. 5.10 Traditional activities at the Senegal River

5.5.1 Flow-dependent land use and social structures

The flood and drought cycle results in seasonally changing habitat structures and resources and a local gradient of more or less fertile habitats, depending on the connectivity to the main river (and the flood pulse advantage, see Junk and Wantzen 2004, and chapter on the Illinois River, this volume). This results in seasonal movements of the human population between sites, which is found in many floodplain systems (see, e.g., chapters on Niger, or Paraná Rivers, this volume).

The Senegal River is possibly the best-defined example of how the flood regime directly determines the land use pattern and subsequent social structures in the spatial and temporal dimensions. Downstream of Bakel, the Middle Valley of the Senegal is divided into three related geographical areas that each bear their own name in the Peul language and were characterized by specific activities (Kyburz 1994). Human settle-

ments and activities are located and organized in adaptation to the river regime (fig. 5.4).

The first geographical area, *daande maayo*, literally 'the neck of the river', means the winding strip of land that runs along the watercourse. It was the place of establishment of subalbe fishermen who, in addition to their main activity, were involved in the cultivation of the river banks, dividing them into small transverse bands called *pale* (singular: *falo*). Above and below the river bends, in an alternating pattern on both sides of the river, soil fertility is highest due to the deposition pattern of fine, nutrient-rich sediments. This allows riverbank cultures with niebe beans and corn called *falo* (Schmitz 1986). The quality of the floodplain ponds (locally called *kolangal*) for fisheries, is directly linked to the flood gradient, and shapes a social hierarchy of use forms (fig. 5.4). The lowest parts of the ponds, which are most regularly flooded (and contain the largest fish), are controlled by the nobles. The rarely flooded ponds in the upper parts were general-

ly granted to slaves or tenant farmers (Schmitz 1986).

The second landscape unit, the *waalo*, refers to the extent of the valley where annual floods – if they occur – enrich the soils. Due to their fertility, the land of the *waalo* was the most popular and it was in this part of the valley that the land fragmentation was the most important. The *waalo* was the site of important agricultural activities. However, fishing was also practiced there during early drawdown of the water, and ranchers bring their herds to feed on the freshly sprouting herbs after the floodplain has dried. The *waalo* that houses the largest villages is therefore the most structured geographical area of the valley.

The third one, the *jeeri* means 'land that is beyond flood range'. Less fertile than the previous ones, they were less coveted, but allowed the cultivation of small millet during the rainy season. The *jeeri* is above all a vast grassland which, during the rainy season, provided the Peul with high-quality pastures (Lericollais 1972, Kyburz 1994).

Agricultural production systems in the valley were built around this complementarity in space and time: rainfed crops and pastures in the *jeeri* highlands, followed by drawdown crops and pastures in the lowlands of the *waalo* (Adams 2000). Traditionally, because these three main activities followed one another in time and space in the flooded areas of the middle valley, it was called the "village with three huts" (Schmitz 1986, 1994).

Because of the unpredictability of floods, communities have developed cultural mechanisms for buffering variability and risks, such as a type of land organization called *leydi* (Schmitz 1986). This word from the Peul language describes the zones of the floodplain that can be used for agriculture or pastoralism during the dry phase (see also chapter on Niger River, this volume). The agricultural calendar always started with the rainfed cultures in the *jeeri* (early planted crops from the first rains in June, with watermelon, pearl millet etc.). The second activity was livestock breeding, practiced both in the *waalo* and the *jeeri* with goats, sheep and cows herds. The riparian populations practiced transhumance and extensive cattle raising moving between the *waalo* flood plains and the *jeeri* grasslands. The third activity, fishing was practiced all year long in the river, and also in the tributaries and floodplain water bodies during drawdown. Today, fish stocks have become strongly reduced (see 5.6). The Senegal River provides a wide variety of freshwater fish. Upstream, in the high valley, fishery was only a secondary activity but since

1988, between 250 and 500 new fishermen coming from the Niger River basin have established in the Manantali Lake (Alhousseini 2002). In the middle valley, siluriform catfish (such as *Synodontis*) and Cyprinidae are very abundant in the river (Alhousseini 2002). In the delta, the most frequently fish caught are *Clarias gariepinus*, and also Tilapiines and some *Schilbe species* and *Lates niloticus* (Hamerlynck et al. 2006). Fishing is carried out from boats or the shore with nets the mesh size of which is regulated.

Fishing activity as well as hunting has led to social and cultural specific events and actions. *Dialtabé* (*Jaaltaabe*), undisputed masters of the river, chosen by fishermen in their community, supervise these activities, managing the crossing points, the traffic on the river, the collection of land royalties and the management of cultivable banks on both sides of the river.

In the low delta, these activities are associated with regular hunting practices for waterfowl (very abundant) and plant gathering; *Nymphaea lotus* or *Oryza barthii*, a wild rice, for consumption, *Sporobolus robustus* to make mats sold in whole West Africa, or *Cyperus articulatus* for producing perfume (Hamerlynck and Duvail 2003). *Acacia nilotica* growing in the wetlands is a very important source of tannins for the leather handicrafts mainly in the delta of the Senegal River (Hamerlynck et al. 2006). These cultural activities of plant gathering led to specific practices mostly by women. *Acacia* trees have also been shaped by herders practices. The branches are regularly bent to the ground to feed the herds. In the middle valley, historically, the secular clearing of the forest was also carried out to make it more suitable for grazing by promoting the development of the ground layer with incursion of shrubs and grasses from the surrounding savanna (Stancioff et al. 1985). The clearing of the falo banks for agriculture also modified the river bank morphology. Breeders also had a special connection with the river. Ramps watering for animals called *tufnde* were their favorite places where they counted their cattle, which is returning every two days to drink (Schmitz 1986).

All these interactions with the natural environment and the cultural perception of these plants have shaped the biocultural traditions of societies living in this area. But most of these activities in the valley have been deeply impacted and nowadays weakened by droughts, by all the hydrological and hydro-agricultural infrastructures and locally by the protected areas.

Current conservation planning aims at integrating these traditional activities and relationships into landscape management.

5.5.2 Written and oral literature

Several dominant ethnic groups are located in the valley: *Sarakollé* upstream Bakel, *Toucouleur* in the middle valley, *Wolof* in the delta, while the *Fulbe* inhabit the south towards Ferlo, and the *Moors* (Mauritanian arabophone population) the north (fig. 5.10). Fulbe and Moors are originally nomadic populations.

All along the river, the most widely spoken language is *Pulaar*, one of the major variants of Fulfulde. Pulaar literature, in its memorial dimension and the diversity of its forms, testifies to a special relationship with a constantly changing environment. It is "deeply inflected by the multiplicity of ways of living and the political and geoclimatic contexts in which its speakers are evolving in a culture marked by mobility" (Bourlet and Lorin 2018). Another major cultural element is religion, as this region is a historical birthplace of Islam in West Africa (most of the great saints of Islam such as El Hadji Malick Sy or Cheikh Ahmadou Bamba Mbacké, come from the department of Podor.

On both sides of the Senegal River, the Pulaar language produces a very dynamic oral literature. Rich, varied and deeply rooted in the local culture, it is composed of stories, poems, tales and songs that have an important memorial dimension, but also an ability to tell of the present. Many texts contain traces of important and traumatic events, such as natural disasters, that have defined the environmental history of the region. A very well-known myth called *Tyamaba* (*Caamaaba*), seen and heard all along the river from Senegal to Guinea, has been studied as a migration myth (Kesteloot et al. 1986) that explains the geographical dissemination of the Fulbe people along waterways across the Western Sahel and their transhumance paths. According to those studies, this myth conserves the traces of successive waves of drought in the Sahel. The updates of this literature also testify to more recent environmental upheavals (1970s drought and dams impacts), interpreted by local populations as being caused by a complete dis-



Fig. 5.11 Dominant ethnic groups in the Senegal River watershed. Map: Aude N. Taïbi, based on Abbé Boilat (1853) and Schmitz (1986)

regard for the river and the surrounding vegetation (Lorin 2015). It can then become a lever of resistance and adaptation in the face of traumata during decisive historical moments (drought, colonization, or the 1989 mauritano-senegalese conflict, leading to regional and international migrations, etc.).

During the independence movements of the 1960s, new literature began to develop in connection to these geographical and societal transformations both in Africa and in Europe. This new literature can be seen as a response, a refusal, or as a resistance to the lack of official status of African languages within the post-independent states of Senegal and Mauritania. It is written with the Latin alphabet and de-Arabized (Bourlet 2009) by authors literate or not but sharing a similar life trajectory, as they are constantly moving from one country or continent to another. This literature has a testimonial value but it is written in a language that has no official educational status in Senegal, Mauritania or Mali (Bourlet 2009, 2014). In a context of inter-community tensions between Mauritanian blacks and Beidans (white moors), illustrated by the events of 1989, the Pulaar language played an important role in the consolidation of community. The poets were considered the guardians of unwritten, painful history. Referring to imaginary lands born from cultural, economic and social dispossession, this literature attracts readers to authors who share a common need to write in order to, transmit, imagine, envisage and survive in an area in constant movement.

5.5.3 *Pékâne*, the fishermen poetry

Many inhabitants of the valley with historical deep relationships with their surroundings have an intimate knowledge of ecosystem components and interactions. They celebrate natural rhythms of the river and its fauna through poems, songs, dances and other events in their daily lives. *Pékâne* is a Fulani oral poetry sung a capella by fishermen of the River Senegal (table 5.8) honoring the River and its inhabitants (Lorin 2015). Very popular, it is celebrated nowadays during the River blues festival (<http://www.festivalbluesdufleuve.com/>) held in Podor every year. *Pékâne* is a living geography of the area. It allows indigenous people to situate themselves in a collective and aesthetical way of seeing their environment. Furthermore, *Pékâne* establishes a sort of informal law, a justice system of customs, in which the river, as a living entity, has rights and integrity that must be fully respected. Take for example the distribution of responsibilities concerning the use and management of the environment: fishermen are in charge

of enforcing the rules enacted to protect the river, ranchers manage the animals and the adjacent land by respecting the river's ecological balance, while all are reaping their benefits. The system of rules carried within this poetry can be considered as a sort of "ahead of its time" environmental law, comparable to current institutional decisions put into place to give certain rivers the status of a legal personality and the rights that come along with it (see chapter on the Yamuna River, this volume, for discussion). In poetry, environmental justice is deeply ingrained in a social dimension.

A character like Penda Sarr, a great *Soubalbé* (fisherman) connecting privileged relationships with the river and its inhabitants with his deep mystic knowledge out of the ordinary, is still celebrated for example during the River Blues festival in Podor (table 5.8).

In the estuary, figures like Mame Coumba Bang, to whom fishermen make offerings by throwing them into the water, can be considered as mystic protection against floods. Portrayed as a mermaid, she is the guardian of waters and the protective genius loci of the city of Saint Louis, warning people about the dangers of the river and the sea.

5.5.4 Tourism

The colonial heritage of the Senegal River of the 17th century was recognized by UNESCO in 2004 (WHC-UNESCO 2000), including forts, docks and houses in Saint Louis (table 5.9), as well as ports from Dagana to Kayes. This built heritage can be considered as a tangible part of the River Culture. Tourism in Senegal and Mauritania, both cultural and discovery, is closely linked to the river. The rich biodiversity resources, as well as architectural and artistic forms, have fostered touristic activities in the valley. Thus, the Djoudj National Park is one of the most-visited touristic places in the Senegal for bird watching (table 5.8). Hunting lodges have been created by private entrepreneurs near the Mauritanian and Senegalese protected areas, such as in Keur Macène and Débi. The architectural heritage in Saint Louis is attracting tourists, mainly from Europe. The unique Bou El Mogdad ship (table 5.8) returned to service in 2005 and allows tourists to visit all these heritages with a circuit from Saint Louis to Podor. Cultural festivals are held, such as the river blues festival celebrating and promoting *pekâne*.

5.6 Trends, challenges and threats

The populations living in or near the river are deeply dependent on the Senegal River ecosys-

Table 5.8 Key elements of cultural diversity of the Senegal River

Key element	Link to the natural flow regime	Ecosystem services	Threats and recovery
Traditional fisheries	Fishing periods are linked with flow patterns. Traditional seasonal migration of people is related to fish migration.	Dialtabe, master of fishermen is one major element structuring society. He makes the link with the spirit world.	Due to dams and possibly due to water pollution and overexploitation (no data), fishing activities are declining quickly.
Traditional oral poetry of fishermen (Pekâne)	Senegal River fishermen sing this unique poetry celebrating the river and its inhabitants.	Major element for Peul revival. Celebrated during the musical River Blues festival in Podor	As fishing activity is on the decline, there is a risk of weakening of this oral tradition.
Traditional handicraft	In the low delta traditional handicrafts are made with wetlands plant gathering such as <i>Sporobolus robustus</i> to make mats.	Mostly made by women, these mats are sold all over West Africa and are a major economic and cultural activity.	The alteration of ecosystems because of the last "big drought" and the building of dams and dikes has led to the almost disappearance of these activities.
Architectural colonial heritage in Saint Louis, Richard Toll and Podor	Most of the colonial heritage labeled World heritage site by UNESCO in Saint Louis, Richard Toll or Podor is closely linked with the river (fluvial docks and buildings, Faidherbe bridge).	Major tourism attraction in the valley UNESCO funds are very important for Saint Louis and river cities maintenance.	The degradation of many labeled architectural elements threatens the UNESCO label.

tems and waters for irrigation, dams, fishing, water and, nowadays, electricity supply for cities. As a consequence, the Senegal River is under great pressure, mainly by human impacts which are seriously threatening water flows and biodiversity, as well as traditional activities and culture.

Major changes have occurred in the valley uses since the 1970s. First, the last "big drought" started at the end of the 1960s led to deficits in flood discharge and ensuing dramatic socio-economical consequences for the populations dependent on flood-recession agriculture and fishery. Secondly, the dams and dikes constructed for multi-purpose but mainly to react to the consequences of this drought and to meet rising demands for water, energy and food, have unfortunately led to other adverse environmental and socio-economical impacts (table 5.9).

The two dams allowed an expansion of irrigated agriculture in the middle valley after 1988, but the first experiences of rice crops were already made in the 1940s at the city of Richard

Toll in Senegal. Irrigated areas increased from 10,000 ha in 1951 to 173,897 ha in 2009, in the middle valley (Bruckmann 2018) under the supervision of OMVS assisted by SAED in Senegal and SONADER in Mauritania. On the left side of the river, which concentrates 64% of the irrigated fields, 74,000 ha were cultivated in 2012–2013 (Bruckmann 2018). Community-based small irrigated fields developed thereafter on the left bank of the river, with 20 ha in 1974 and about 100,000 ha today (UNESCO/WWAP 2003) producing rice, onions, tomatoes, potatoes, sweet potatoes during the rainy season and the dry season.

The dam constructions helped regulate the river flow, satisfying part of the electricity needs of the four riparian countries of the basin (Brunet-Jailly et al. 2014), as well as a significant agricultural production (INBO 2014). On the other hand, they also resulted in a series of environmental and socio-economical impacts along the Senegal River valley and the estuary (Dumas et al. 2010). Dams, embankments and other irriga-

Table 5.9 Positive and negative effects of the dams built on the Senegal River

Dam (technical data)	Positive effects	Negative effects
Manantali Dam - Multipurpose dam - Impounds Bafing River - Height 65 m - Length 1,460 m - Surface area 477 km ² - Total capacity 11.3 x 10 ⁶ m ³ - Construction completed in 1988	Hydroelectric power production (740 GWh per year) - Irrigation of rice and sugar perimeters (3,750 km ²) - Fishing - Drinking water production - Regulation of floods - Routing of the highest flood rates and strengthening of low water flows	Direct: Waterborne diseases (malaria, schistosomiasis) - Interruption of fish migrations - Decreasing of flood recession agriculture Indirect: Disappearance of ponds under the ground leveling of rice fields - Land tenure change in Mauritania
Diamas Dam - Gravity dam - Impounds Senegal River - Height 18 m - Length 610 m - Surface area 235 km ² - Total capacity 250,000,000 m ³ - Construction completed in 1986	Drinking water production (100% of Nouakchott, capital of Mauritania, and 50% of Dakar, capital of Senegal) - Irrigation of rice and market gardening perimeters (200,000 ha) - Interruption of saltwater upwelling	Direct: Waterborne diseases (malaria, schistosomiasis) - Interruption of fish and manatee migrations - Disconnection of delta wetlands from the river and interruption of their flooding - Heavy decrease of migratory birds in the delta - Disappearance of freshwater fish downstream - Disappearance of marine fish upstream - Decreasing of fish in the river - Salinisation of soils - Degradation of wetlands vegetation in the delta - Aeolian deflation in the low delta Indirect: Disappearance of vegetation gathering and related economic and cultural activities in the delta
Felou hydroelectric plant - Run-of-the-river dam - Impounds Senegal River - Height 2 m - Length 945 m - Construction completed in 2014	Hydroelectric power production (431 GWh for an installed capacity of 60 MW) - Irrigation of rice perimeters - Routing of the highest flood rates and strengthening of low water flows	Direct: Waterborne diseases (malaria, schistosomiasis) - Interruption of fish migrations

tion schemes have negative externalities such as the reduced productivity of the valley ecosystems, protection cost of human health, environmental degradation and social impacts (Manikowski and Strapasson 2016) because of the diversion of water for agriculture and reduction of flood volumes.

The resulting alteration of ecosystems has led to the disappearance of most traditional sustainable use forms, including the gathering of *Sporobolus* for the making of mats, the harvesting of *Nymphaea lotus* for food and pods of *Acacia nilotica* for leather tanning (Duvail 2001). The dams had also a negative impact on fishing. Fishing, once a substantial income-generating activity for the population, has become increasingly difficult with reduced catches and because

of invasive plants. In the Mauritanian delta, fishery had almost disappeared in 1993, and at the beginning of the 2000s, only three old remaining fishermen remained, whose yields did not exceed 30 kg of fish per day (Hamerlynck et al. 2006). In the middle valley, fishermen use to say that there is no more fish in the river. For several years now, there has been a steady drop in the tonnage caught throughout the OMVS region, which some observers connect to the hydraulic infrastructures and their impact on the environment, along with a decrease in salinity, a proliferation of floating water weeds (*Eichhornia*, *Salvinia* and *Pistia*) and other invasive plants, as well as eutrophication (UNESCO/WWAP 2003). On the Senegalese part of the valley, the fishing potential has been reduced by about 75%



Crocodile (*Crocodylus niloticus*) in the Djoudj Bird National Park (PNOD). Photo: Aude N. Taïbi



Pelican (*Pelecanus onocrotalus*) at Langue de Barbarie. Photo: Karl M. Wantzen, with permission



Acacia nilotica (Gonakier) forest of the maw pond near Donaye. Photo: Aziz Balouche



Ngaari Ngaolé, Pékâne singer living in the village of Ngaolé, on his way to a singing tour in Podor. Photo: Marie Lorin



The Saint Louis UNESCO world heritage with river, quays and old colonial houses. Photo: Aude N. Taïbi



Labeled soudanian style mosque of Donaye. Photo: Aude N. Taïbi

Fig. 5.12 Left column: iconic examples of biological diversity, right column: iconic examples of cultural diversity



Invasive *Typha* sp. in the Diama Dam reservoir. Photo: Aude N. Taïbi



Rehabilitation of wetlands in the Diawling National Park (PND). *Sporobolus robustus* recovery leading to mat handcrafts restoration. Photo: M.H. Barry, with permission



Risk of conflict between tourism and bird protection in the Djoudj National Park (PNOD) in Senegal. Photo: Aude N. Taïbi



Penda Sarr, daughter of Moussa Boukari Sarr, both of whom are great soubalbé from the village Ngaolé, represented during the River Blues festival in Podor and symbols of the strong relationship with the Senegal River. Photo: Aude N. Taïbi



Discharge of saltwater loaded with pesticides from irrigated rice fields in the delta. Photo: Aude N. Taïbi



Development of navigation and river tourism with the Bou El Mogdad boat. Photo: Aude N. Taïbi

Fig. 5.12 (continued) Left column: iconic examples of threats, right column: iconic examples of sustainable management

in comparison to the situation in 1970. In particular, the floodplain fish catches were reduced from 32,000 tons in 1978 to between 6,900 and 24,350 tons around 2006, which represents a median loss of 16,125 tons of fresh fish a year (Manikowski and Strapasson 2016). The national net value loss of inland fisheries is estimated around US\$ 105,223 million (Manikowski and Strapasson 2016).

Yields from flood-recession agriculture have also been reduced due to the decrease of water and nutrient availability after changes of inundation patterns and reduced deposition of sediments on the floodplain as a result of the construction of the Manantali Dam. The inundated area has been considerably reduced from 65,000 ha to 35,000 ha since the early 1970s, whereas the human population in the valley has considerably increased (Manikowski and Strapasson 2016). This corresponds to a loss of a net present value of US\$ 5,956 million since 1970s. This also means that the flood-recession agriculture can no longer ensure sustainable food production for the local markets.

Nowadays, the regulation of the river floods by dams and rice irrigated agriculture infrastructures has completely reshaped the valley wetlands landscapes. Upstream, many ponds have disappeared under the ground leveling of rice and vegetable fields. In the delta, dikes have interrupted the river flows in the wetlands. Artificial floods in the Diawling and Djoudj National parks now define which plants may survive, depending on the height of the water applied (for example *Cyperus articulatus* or *Sporobolus robustus*).

Moreover, even if the Manantali and Diama Dams had been built to mitigate drought consequences, the climate crisis still remains to be a threat. A decrease in rainfall and river discharges, such as occurred during the 1970s to 2000s across the Sahel, might strongly affect the Senegal River ecosystems and inhabitants in the future.

The period after dam construction was also marked by a resurgence of waterborne diseases (malaria, schistosomiasis) throughout the valley (Ndione et al. 2019). Small and large dams, embankments and the new agricultural activities favor the creation of breeding sites for freshwater snails transmitting human schistosomiasis and the intensification of human contact with infected water, resulting in a rise of infections, including intestinal schistosomiasis, in the region (Ndione et al. 2019, Talla et al. 1990).

As the population in the catchment of the Senegal River is expected to further increase, and

because there is a potential to increase food production through irrigation, water demand for irrigation will inevitably continue to grow. Senegal's population has grown tenfold since 1900 (table 5.7). However, since the middle of the 20th century, combined effects of climate change and direct human impact on the Senegal River have limited arable land and water resources (Tappan et al. 2004a, b). Rising demands for increasingly scarce freshwater resources are leading to growing concerns about future access to these shared resources, particularly in the context of global climate change. This will occur in a context where the livelihoods still depend on hydrosystems and the related ecosystems. For example, the Gonakier forests of the Senegal River floodplain, are already under IUCN criterion A1 Critically Endangered (Keith et al. 2013), but will be even under greater pressure in the future.

Nowadays, even if some old collective practices in the exploitation of the agricultural and fishing areas of the valley are still present and respected (Lericollais and Seck 2002), the management and planning of the Senegal River is mainly done within a supra-national framework. In spite of its robustness in the troublesome past, the ongoing multinational management and planning of the Senegal River by OMVS can also be considered as a risk, as the interests of institutions at different levels are likely to be in conflict (Rasmussen et al. 1999). The management of the water resources of the Senegal River has caused controversy between the countries involved and between the various stakeholder groups (fig. 5.7). The multiple uses of Senegal River resources have always been a source of conflict that was commonly regulated by local village elders (such as *dialtabé* for fishermen). These are still respected today, however, their reputation is being weakened within a political understanding and economic relations of individualized lobbies (trade of fish, millet, milk or butter, etc.). Nowadays, conflicts of interests have been associated with hydroelectric power production, allocation of and access to water for irrigation and domestic supplies, modern and traditional agricultural water requirements, and the conservation of ecosystems, specifically wetlands (Kipping 2005, Bruckmann 2018).

The socio-political development of the Senegal River can indirectly be considered as one of the causes of the violent conflicts between Mauritania and Senegal in 1989, as the new prospects of commercial agriculture in the valley have led to rewriting land legislation in Mauritania and land rights along the riverbank, and secondly to land grabbing to the benefits of the moors

(Mauritanian arabophone population) (Kipping 2005). The conflict between farmers and herders from Mauritania and Senegal along the Senegal River boundary triggered an outbreak of ethnic violence with people killed and the expulsion of some 70,000 Mauritians to Senegal.

However, except this tragic event, cooperation is successful at the states level, in part because no country could find proper funding on their own and because it is the final users who plan and design the uses within the OMVS coordination (technical services and management agencies of every states, scientific community, different users and associations).

Nevertheless, the multiple institutional actors involved in Senegal River spatial planning and management including OMVS, ministries, national parks, NGOs and local communities (fig. 5.7), generates a risk of use conflicts between the different stakeholders, who are competing for environmental, economic, social, cultural and touristic objectives. This fragmentation of responsibilities and competencies results in a sectoral approach to river management, which targets only a single-use (or set of related uses) at a time, and in potential conflicts between concurrent stakeholders and uses (Taïbi et al. 2019).

Most local structures and civil society organizations such as rural communities, urban municipalities, farmers' organizations, GIE (Economic Interest Grouping), NGOs or producer associations do not actually participate in water management and hardly receive any information on water management decisions (Sène 2009). The national actors who represent them (SAED in Senegal, SONADER for Mauritania), are generally subject to reserve obligations for reasons of confidentiality to guidelines and decisions. On the other hand, large private users such as CSS (Compagnie Sucrière Sénégalaise) and SDE (Société des Eaux) are overly represented in the decision-making bodies. The local population did not participate in preliminary socio-economic surveys before the dams and hydro-agricultural infrastructures building (Baldé 1999). The opinion of the population concerning the distribution of plots, the size of the hydraulic network, the structuring and the functioning of the agricultural production was not asked for beforehand (Baldé 1999). This form of inequality in the participation of different actors and water users is considered an injustice by the people and is a source of tension (Sène et al. 2006). It reflects a real difficulty on the part of decision-makers, managers as well scientists to define water management that is both rational and "social", that is to say, that

takes into account the needs of all users (Duvail et al. 2002). However, OMVS pursues a more participatory approach to water management since 2000 (Bruckmann 2018).

There are also conflicts at the level of protected areas (fig. 5.7). The Diawling National Park (PND) as well as the first water releases from the Diama Dam after 1999, brought some solutions to dam impacts. However, many threats and problems still remain, such as incomplete participation, leading to conflicts between local population and parks with ranchers not well involved for instance, fragmentation of habitats, or soil salinization (Taïbi et al. 2014). These unsatisfactory results leave the populations and ecosystems in a fragile and vulnerable situation if confronted with any further environmental (drought, flood, etc.), socio-economical, or political (relations between Mauritania and Senegal) crisis (Taïbi et al. 2014). Even if the PND participative management process has been unanimously praised, it remains fragile and has been belatedly expanded in the PNOD, and the new protective zoning proposed since 2005 by the Senegal Delta Transboundary Biosphere Reserve seems to be challenging previous achievements (Taïbi et al. 2019).

Floods are another natural hazard threat in the valley. They have always been evidenced as a risk by the accounts of travelers, historical documents and old maps. However, they are still frequent despite the drop in flood maxima after construction of the dams (Kane 2002) such as in 1999 or 2003 (fig. 5.6). The very low altitudes of the Senegal estuary favor flooding in the city of Saint-Louis, induced either by rain or the river (Kane 2010, Seck 2010). Until 2003, when the Senegalese authorities opened a breach on the Langue de Barbarie spit sand, these floods were all the more frequent as the urban expansion in the last decades was carried out in the floodplain, increasing the vulnerability of the city. The "breach" has greatly contributed to changing the hydrological regime in the estuary and has profoundly affected the hydrodynamics downstream of the dam through a strongly increased tidal influence, a reduction of salinity fluctuations in the estuary and a reduced propensity for flooding (Hamerlynck et al. 2006). The opening of the breach limited the dynamics of the river current over a distance that went from 55 km (old mouth - Diama Dam) to 33 km (between the new mouth and the Diama Dam). As a result, the river is now more subject to tidal wave fluctuations. It has also caused disturbances in estuarine ecosystems and increased the vulnerability of societies in the lower estuary whose activities

are mainly based on the exploitation of water resources. Gandiolais' local communities a dozen kilometers south of Saint Louis (fig. 5.5) are particularly affected by this situation. The highly artificialized and very reduced Senegal River estuary is currently undergoing an increased vulnerability to marine hazards but still dependent on the management of the Senegal River upstream of the Diama Dam.

5.7 Management suggestions

Even if the dams and hydro-agricultural infrastructures have been identified as creating environmental and socio-economic threats, they still remain necessary for the four riparian countries, even more so in a context of climate change and the increasing need for food sovereignty in Sub-Saharan Africa. One can say as did Adams (1977) that "*Developing the resources of the Senegal River is an essential task for river people and for the riverine countries as a whole. However, were it to be done according to current plans, it would be better for them that it not be done at all*". Indeed, the biodiversity and culture of the Senegal River are under great pressure, which needs to be taken into account by systemic planning, sustainable management, use and monitoring of river ecosystems.

One of the main challenges associated with Senegal River spatial planning is the large number of institutional actors and their competing objectives (fig. 5.7) resulting in a sectoral approach to river management. Effectively tackling the sustainable management of the Senegal River requires systemic and holistic planning, taking into account how these competing and cumulative uses affect ecosystems and how to establish the necessary trade-offs and balances among different interests.

Informed participation of all stakeholders across the different sectors is an important pre-requisite to ensure broad support for taking actions towards meeting these objectives. Therefore, this focus should primarily be geared towards strengthening coordination among, and enhancing capacities of, differing relevant administrations and stakeholders, specifically in the areas of planning and monitoring.

The challenge lies in improving the Senegal River management to minimize the negative impacts on the environment and allow a wider range of stakeholders to benefit from them (Hamerlynck and Duvail 2003). Water management has to be seen from a historical perspective of the interactions between environment and society (Aspe and Jacque 2012) and not be reduced to a biological

and hydrological perspective or to that of politics and public action (Faye and Dieye 2018).

It should be emphasized that decision-making in water resources management associated with the operations of the Manantali, Diama and Felou Dams, cannot be solely based on hydrological reasoning. Obviously, agronomic, economic, social and environmental issues also need to be considered. It is important to achieve a proper reconciliation process between ecosystem restoration, protection and conservation and socio-economic and cultural development of local people.

Protected areas management also has to address all stakeholders and changes of conceptions and practices over nature conservation last decades. The Delta Transboundary Biosphere Reserve created in 2005 is a first step towards management at the watershed scale, but its managers struggle to harmonize the different management practices in all protected areas. For instance, even if a natural resource management policy was implemented in 1994 in the PNOD, defining user rights and enhancing participation and recognition of local knowledge of ecosystem use, latent conflicts still remain for the use of resources and territories (Taïbi et al. 2019). Moreover, in these protected areas, management models concerning ecosystem preservation must clearly indicate their objectives, for instance whether they focus or not on bird habitats.

There is also a need for monitoring key ecological parameters that could warn natural resource managers such as those of OMVS and protected areas of future thresholds of socio-ecological changes, helping them to find preemptive responses and to evaluate the efficiency of current management practices (Gonzalez 2010).

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Bibliography

- Adams, A. 1977. *Le long voyage des gens du Fleuve*. Maspéro, Paris, 222 pp.
- Adams, A. 2000. *River Senegal: Flood management and the future of the valley?* International Institute for Environment and Development, 27 pp. ISSN: 13579312.

- <https://pubs.iied.org/sites/default/files/pdfs/migrate/7419IIED.pdf>
- Adams, A. 2004. Social Impacts of an African Dam: Equity and Distributional Issues in the Senegal River Valley. World Commission on Dams contributing paper, prepared for thematic review I.1: Social Impacts of Large Dams – Equity and Distributional Issues. <http://www.dams.org/kbase/submissions/showsub.php?rec=SOC094>. Accessed 18/06/2004
- Albergel, J., Bader, J.-C., and Lamagat, J.-P. 1997. Flood and drought: application to the Senegal River management. Pp. 509-517 in Rosbjerg, D., Boutayeb, N.-E., Gustard, A., Kundzewicz, Z.W., and Rasmuss, P.F. (eds.): Sustainability of Water Resources under Increasing Uncertainty (Proceedings of Rabat Symposium S1, April 1997). International Association of Hydrological Sciences (IAHS) Publ. 240
- Alhousseini, S. 2002. Le poisson, une nouvelle ressource au barrage de Manantali. Pp. 501-513 in Orange, D., Arfi, R., Kuper, M., Morand, P., and Poncet, Y. (eds.): Gestion intégrée des ressources naturelles en zones inondables tropicales. IRD Éditions, Paris
- Aspe, C., and Jacque, M. 2012. Environnement et société. Maison des Sciences de l'Homme, Quae, coll. Natures sociales, Paris, Versailles, 279 pp.
- Baba Kaké, I., and M'Bokolo, E. 1977. La dislocation des grands Empires. Histoire générale de l'Afrique, Vol. 3, ABC, Paris, 112 pp.
- Bader, J.-C. 2015. Monographie Hydrologique du Fleuve Sénégal. IRD Éditions, Marseille. http://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers16-01/010065190.pdf
- Barbiero, L., Mohamedou, A.O., Laperrousaz, C., Furian, S., and Cunnac, S. 2004. Polyphasic origin of salinity in the Senegal delta and middle valley. *Catena* 58:101-124
- Barry, M.H. 2004. Le parc national du Diawling dans le processus de développement durable du bas delta mauritanien du fleuve Sénégal: conflits d'usages et d'acteurs dans un contexte de changements environnementaux et socio-économiques. MSc Thesis, University Angers, 199 pp.
- Barry, M.H., and Taïbi, A.N. 2011. Du Parc National du Diawling à la Réserve de Biosphère Transfrontalière: jeux d'échelles à l'épreuve du développement durable dans le bas delta du fleuve Sénégal. Pp. 147-156 in Bart, J.F. (ed.): Natures tropicales: enjeux actuels et perspectives. *Espaces tropicaux* 20, Bordeaux University Press
- Bocoum, H. 1986. La métallurgie du fer au Sénégal: approche archéologique, technologique et historique. PhD Thesis, University Paris 1, 333 pp.
- Bocoum, H. 2002. Introduction générale. Pp. 9-20 in Bocoum, H. (ed.): Aux origines de la métallurgie du fer en Afrique. UNESCO, Paris. ISBN: 9789232038074
- Bocoum, H., and McIntosh, S.K. 2002. Fouilles à Sincu Bara, moyenne vallée du Sénégal. Institut Fondamental d'Afrique Noire (IFAN) Dakar, Centre Régional Inter-africain d'Archéologie (CRIAA), Nouakchott, 197 pp.
- Boulègue, J. 1988. Le grand Jolof, XIII^e–XVI^e siècle, Vol. 1: Les Anciens Royaumes Wolof. Éditions Façades, Blois Karthala, Paris, 207 pp.
- Bourlet, M. 2009. Littératures orales africaines. Perspectives théoriques et méthodologiques. Pp. 467-470 in Baumgardt, U., and Derive, J. (eds.): Cahiers de Littérature Orale 63-64
- Bourlet, M. 2014. Mobilité, migrations et littératures en réseaux. Exemple des romans poulâr. *Cahiers d'Etudes Africaines* 213/214, (1):309-340
- Bourlet, M., and Lorin, M. 2018. An environmental history of literary resilience: "Environmental refugees" in the Senegal River Valley. *Journal of Postcolonial Writing* 54(6):821-834. DOI: 10.1080/17449855.2018.1555210
- Bruckmann, L. 2017. Les territoires du fleuve: une analyse par l'image de l'intégration territoriale du fleuve Sénégal. *EchoGeo* 42. <http://journals.openedition.org/echogeo/15160>
- Bruckmann, L. 2018. Crue et développement rural dans la vallée du Sénégal: entre marginalisation et résilience. *Belgeo* 2. <http://journals.openedition.org/belgeo/23158>
- Brunet-Jailly, J., Charmes, J., and Konaté, D. 2014. Le Mali contemporain. IRD Éditions. Marseille. ISBN: 9782709926171. <http://books.openedition.org/irdeditions/21053>. <https://doi.org/10.4000/books.irdeditions.21053>
- Cecchi, P. 1992. Phytoplancton et conditions de milieu dans l'estuaire du fleuve Sénégal: effets du barrage de Diama. PhD Thesis, University Montpellier II, Orstom Éditions, Paris, 427 pp.
- Conway, D., Persechino, A., Ardoin-Bardin, S., Hamandawana, H., Dieulin, C., and Mahe, G. 2008. Variability in sub-Saharan Africa during the 20th century. Tyndall Centre for Climate Change Research Working Paper 119, 37 pp.
- Coquery-Vidrovitch, C. 2011. Petite histoire de l'Afrique. La Découverte, Paris, 222 pp.
- Coquery-Vidrovitch, C. 2009. Un essai de périodisation de l'histoire africaine. Pp. 43-58 in Ba Konaré, A. (ed.): Petit précis de remise à niveau sur l'histoire africaine à l'usage du président Sarkozy. La Découverte/Poche, Paris
- Dia, A.M., Wade, S., Deroin, J.P., Frison, P.L., Kouamé, J., and Rudant, J.P. 2006. Apport des données Spot et Landsat au suivi des inondations dans l'estuaire du fleuve Sénégal. *Photo-Interprétation* 42(4):35-46
- Descroix, L., Bouzou Moussa, I., Genthon, P., Sighomnou, D., Mahé, G., Mamadou, I., Vandervaere, J. P., Gautier, E., Faran Maiga, O., Rajot, J. L., Malam Abdou, M., Dessay, N., Ingatan, A., Noma, I., Souley Yéro, K., Karambiri, H., Fensholt, R., Albergel, J., and Olivry, J.-C. 2013. Impact of Drought and Land – Use Changes on Surface – Water Quality and Quantity: The Sahelian Paradox. Pp. 243-271 in Bradley, P.M. (ed.): Current Perspectives in Contaminant Hydrology and Water Resources Sustainability. InTech, Zagreb, Croatia. <http://dx.doi.org/10.5772/54536>

- Deme, A. 1991. Evolution Climatique et processus de mise en place du peuplement dans l'île à Morphil. Master Degree, University Cheikh Anta Diop, Dakar
- Deme, A. 2003. Archeological investigations of settlement and emerging complexity in the middle Senegal Valley. PhD Thesis, Rice University, Houston, Texas, 439 pp.
- Deme A., and McIntosh, S.K. 2006. Excavations at Walaldé: New light on the settlement of the Senegal Middle Valley by Iron-Using Peoples. *Journal of African Archaeology* 4(2):317-347
- Dumas D., Mietton, M., Hamerlynck, O., Pesneaud, F., Kane, A., Coly, A., Duvail, S., and Ould Baba, M.L. 2010. Large dams and uncertainties. The case of the Senegal River (West Africa). *Society and Natural Resources* 23(11):1108-1122
- Duvail, S., and Hamerlynck, O. (2003). Mitigation of negative ecological and socio-economic impacts of the Diama dam on the Senegal River Delta wetland (Mauritania), using a model based decision support system. *Hydrology and Earth System Sciences* 7(1):133-146
- Duvail S., Mietton, M., and Gourbesville, P. 2001. Gestion de l'eau et interactions société-nature: le cas du delta du Sénégal en rive mauritanienne. *Natures Sciences Sociétés* 9(2):5-16
- Duvail, S. 2001. Scénarios hydrologiques et modèle de développement en aval d'un grand barrage. Les usages de l'eau et le partage des ressources dans le delta mauritanien du fleuve Sénégal. PhD Thesis, University Louis Pasteur Strasbourg I, 313 pp.
- Duvail, S., Bergkamp, G., Ould Baba, M.L., Acreman, M., and Hamerlynck, O. 2002. Modélisation hydraulique et gestion sociale de l'eau. Pp. 815-834 in Orange, D., Arfi, R., Kuper, M., Morand, P., and Poncet, Y. (eds.): *Gestion intégrée des ressources naturelles en zones inondables tropicales*. IRD Éditions, Paris
- Dyer, C. 2014. New names for the African Acacia species in *Vachellia* and *Senegalia*. *Southern Forests: a Journal of Forest Science* 76:4
- Faye, C., and Dieye, S. 2018. Valorization of water resources in Senegal for economic, social and sustainable development. *African Journal of Environmental Science and Technology* 12(12):449-460
- FAO/SEDAGRI. 1973. Etude hydro-agricole du bassin du fleuve Sénégal. Etude pédologique, Multigr. SEDAGRI, FAO, Rome, 251 pp.
- FAO/ISRIC/ISSS. 1998. World Reference Base for Soil Resources. FAO, Rome, Italy. ISBN: 92-5-104141-5. <http://www.fao.org/3/W8594E/w8594e00.htm>
- Fralav, P., Bader, J.-C., Mané, L.K., David-Benz, H., Lamagat, J.-P., and Diop Diagne, O. 2002. The quest for integrated and sustainable water management in the Senegal River Valley. *ENVIROWATER* 2002. 5^e Conf. Inter-Régionale sur l'Environnement et l'Eau. Ouagadougou, Burkina Faso. http://agritrop.cirad.fr/511230/1/document_511230.pdf
- Gac, J.-Y., Appay, J.-L., and Labrousse, B. 1990. L'intrusion des eaux océaniques dans la basse vallée du Sénégal au cours du XX^e siècle. Rapport CEE, Projet EQUÉSEN et Rapport ORSTOM, Dakar, Multigr., 52 pp.
- Gac, J.-Y., Appay, J.-L., Carn, M., and Orange, D. 1990. Le haut bassin versant du fleuve Sénégal. ORSTOM, Dakar, 116 pp.
- Gibb, A., and Partner. 1987. Etude de la gestion des ouvrages communs de l'OMVS. Electricité de France & Euroconsult, OMVS, Dakar
- Gonzalez, P. 2001. Desertification and a shift of forest species in the West African Sahel. *Climate Research* 17:217-228
- Gonzalez, P., Neilson, R.P., Lenihan, J.M., and Drapek, R.J. 2010. Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change. *Global Ecology and Biogeography* 19:755-768
- Gonzalez, P., Tucker, C.J., and Sy, H. 2012. Tree density and species decline in the African Sahel attributable to climate. *Journal of Arid Environments* 78:55-64
- Groupe de Recherche et de Réalisations pour le Développement Rural. 2014. La moyenne vallée du fleuve Sénégal, centres et périphéries. Mali, Mauritanie, Sénégal. Atlas, GRDR, Montreuil, 78 pp.
- Hamerlynck, O. 1996. Plan de gestion du Parc National du Diawling et de sa zone périphérique, 1996-2001. PND, UICN, Mauritanie, 63 pp.
- Hamerlynck, O., Ould Baba, M.L., and Duvail, S. 1999. The Diawling national park, Mauritania: joint management for the rehabilitation of a degraded coastal wetland. *Vida Silvestre Neotropical* 7(1):59-70
- Hamerlynck, O., and Duvail, S. 2003. The rehabilitation of the delta of the Senegal River in Mauritania: fielding the ecosystem Approach. Blue Series, UICN, Gland, Switzerland, Cambridge, UK, viii + 88 pp.
- Hamerlynck, O., Duvail, S., Ould Messaoud, B., and Benmergui, M. 2006. The restoration of the Lower Delta of the Senegal River, Mauritania (1993-2004). Pp. 195-210 in Symoens, J.J. (ed.): *Les Ecosystèmes côtiers de l'Afrique de l'Ouest*. Diversité biologique - Ressources - Conservation. FFRSA, CNBSB, PRCZCMAO, Bruxelles
- INBO (International network of basin Organization). 2014. Report on experiences of transboundary basin organization in Africa, good practices and recommendations. IOW, AFD, ANBO, Paris, 103 pp.
- Junk, W.J., and Wantzen, K.M. 2004. The Flood Pulse Concept: New Aspects, Approaches, and Applications - an Update. Pp. 117-149 in Welcomme, R., and Petr, T. (eds.): *Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries, Food and Agriculture Organization & Mekong River Commission*. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2004/16
- Kane, A. 1985. Le bassin du Sénégal à l'embouchure: contribution à l'hydrologie fluviale en milieu tropical humide et à la dynamique estuarienne en domaine sahélien. PhD Thesis, University of Nancy II, 205 pp.
- Kane, A. 2002. Crues et inondations dans la basse vallée du fleuve Sénégal. Pp. 197-208 in Orange, D., Arfi, R.,

- Kuper, M., Morand, P., and Poncet, Y. (eds.): Gestion intégrée des ressources naturelles en zones inondables tropicales. IRD Éditions, Paris
- Kane, A. 2005. Vulnérabilité climatique et ses conséquences sur les écoulements du Fleuve Sénégal. Regional Hydrological Impacts of Climatic Change: Hydroclimatological Variability 296:146-157
- Kane, A. 2005. Regulation du Fleuve Senegal et flux de matieres particulaire vers l'estuaire depuis la construction du Barrage de Diama. Pp. 279-290 in Sediment Budgets 2 (Proceedings of symposium S1 held during the Seventh IAHS Scientific Assembly at Foz do Iguaçu, Brazil). IAHS Publ., 292 pp.
- Kane, A., and Niang-Fall, A. 2007. Hydrologie du Sénégal. P. 14 in Atlas du Sénégal. Éditions du Jaguar, Paris
- Keith Diagne, L. 2015. *Trichechus senegalensis* (errata version published in 2016). The IUCN Red List of Threatened Species 2015: e.T22104A97168578. <http://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T22104A81904980.en>
- Keith Diagne, L., Taibou, B., and Tappan, G. 2013. Scientific foundations for an IUCN Red List of Ecosystems. PLoS ONE Supplementary material. DOI: 10.1371/journal.pone.0062111.s002
- Keith-Diagne, L.W., de Larrinoa, P.F., Diagne, T., and Gonzalez, L.M. 2021. First satellite tracking of the African Manatee (*Trichechus senegalensis*) and movement patterns in the Senegal River. Aquatic Mammals 47(1):21-29
- Kesteloot, L., Barbey, C., and Ndong, M.C. 1986. Tyamaba mythe peul. Notes africaines 185-186, Dakar, IFAN, Dakar, 72 pp.
- Kipping, M. 2005. Conflits et coopération liés à l'eau du fleuve Sénégal. Géocarrefour 80(4):335-347
- Koopman, J. 2007. The challenges of post-dam environmental and economic rehabilitation in the Senegal River Valley. Program for the Study of the African Environment Research Series, 1. African Studies Center, Boston University, Boston
- Kyburz, O. 1994. Les hiérarchies sociales et leurs fondements idéologiques chez les Haalpulaar'en (Sénégal). PhD Thesis, University Paris X, 445 pp.
- Lericollais, A. 1972. Essai d'expression cartographique régionale dans la vallée du Sénégal. Cah. O.R.S.T.O.M., ser. Sci. Hum. 9(2):211-220
- Lericollais A., and Seck, S.M. 2002. Patrimoines anciens et territoires en gestation dans la région riveraine du fleuve Sénégal. Pp. 283-300 in Cormier-Salem, M.-C., Juhé-Beaulaton, D., Boutrais, J., and Roussel, B. (eds.): Patrimonialiser la nature tropicale: dynamiques locales, enjeux internationaux. IRD, MNHN, Paris
- Lorin, M. 2015. La poésie orale peule des pêcheurs de la vallée du Fleuve Sénégal (Pékâne): approche géopoétique. PhD Thesis, Inalco Paris & University Cheikh Anta Diop Dakar, 340 pp.
- Macklin, M.G., and Lewin, J. 2020. The Rivers of Humankind. Pp. 29-46 in Myers, S., Hemstock, S., Hanna, E. (eds.): Science, Faith and the Climate Crisis. Emerald Publishing Limited, Bingley, UK
- Madden, N. 1990. La Motivation dans l'alphabétisation en pulaar au Sénégal. Study not published for ENDA-MSID, Dakar, Sénégal
- Manikowski, S., and Strapasson, A. 2016. Sustainability assessment of large irrigation dams in Senegal: a cost-benefit analysis for the Senegal River Valley. Frontiers in Environmental Science 4:1-16
- Maynard, J., and Combeau, A. 1960. Effet résiduel de la submersion sur la structure du sol (mise en évidence à l'aide de l'indice d'instabilité structurale de Hénin). Sols Africains 5(2):123-148
- M'Bokolo, E. 1980. Le continent convoité. Éditions Etudes Vivantes, Paris, 281 pp.
- Michel, P. 1973. Les bassins des fleuves Sénégal et Gambie. Étude géomorphologique, mémoires ORSTOM, 3 tomes, Éditions ORSTOM Paris, 810 pp.
- Michel, P., and Sall, M. 1984. Dynamique des paysages et aménagement de la vallée alluviale du Sénégal. Pp. 89-109 in Blanc-Pamard, C., Bonnemaïson, J., Boutrais, J., Lassailly-Jacob, V., and Lericollais, A. (eds.): Le développement rural en questions: paysages, espaces ruraux, systèmes agraires: Maghreb-Afrique noire-Mélanésie. Mémoires ORSTOM 106, Paris
- Michel, P., Barusseau, J.P., Richard, J.F., and Sall, M. 1993. L'après-barrages dans la vallée du Sénégal; modifications hydrodynamiques et sédimentologiques. Conséquences sur le milieu et les aménagements hydro-agricoles. Ministère Coop. et Développement, Presses Universitaires Perpignan, 152 pp.
- Niang, A., and Kane, A. 2014. Morphological and Hydrodynamic Changes in the Lower Estuary of the Senegal River: Effects on the Environment of the Breach of the 'Langue De Barbarie' Sand Spit in 2003. Pp. 23-40 in Diop, S., Barusseau, J.-P., and Descamps, C. (eds.): Plantation Agriculture as a Driver of Deforestation and Degradation of Central African Coastal Estuarine Forest Landscape of South-Western Cameroon. Springer International Publishing, Cham, Switzerland
- Ndione, R.A., Bakhom, S., Haggerty, C., Jouanard, N., Senghor, S., Ndao, P.D., Riveau, G., and Ba, C.T. 2019. Intermediate host snails of human Schistosomes in the Senegal River Delta: spatial distribution according to physicochemical parameters. Pp. 1-10 in Sajal, R., Diarte-Plata, G., and Escamilla-Montes, R. (eds.): Invertebrates - Ecophysiology and Management. IntechOpen, London
- Nicholson, S. 2000. Land surface processes and Sahel climate. Reviews of Geophysics 38:117-139
- Nicholson, S.E. 2005. On the question of the "recovery" of the rain in the West African Sahel. J. Arid Environ. 63(3):615-641
- Nicholson, S.E. 2013. The west African Sahel: a review of recent studies on the rainfall regime and its interannual variability. ISRN Meteorology 2013:1-32
- Ostenfeld, C., and Jonson, N. 1972. Etude de la Navigabilité et des Ports du Fleuve Sénégal. Études Portuaires

- à Saint-Louis, Kayes et Ambidebi. Vol. 1: Travaux Préliminaires; Vol. 2, Annexe 2: Rapport Sur les Enquêtes Hydrauliques; Surveyer-Nenninger et Chevenert Inc. Montréal, QC, Canada
- Ozainne, S., Lespez, L., Garnier, A., Ballouche, A., Neumann, K., Pays, O., and Huysecom, E. 2014. A question of timing: spatio-temporal structure and mechanisms of early agriculture expansion in West Africa. *Journal of Archaeological Science* 50:359-368
- Panthou, G. 2013. Analyse des extrêmes pluviométriques en Afrique de l'Ouest et de leur évolution au cours des 60 dernières années. PhD Thesis, Grenoble University, France, 270 pp.
- Parc National du Diawling. 2013. http://www.pnd.mr/pnd/index.php?option=com_content&view=article&id=146&Itemid=155
- Powell, J.A. 1996. The distribution and biology of the West African manatee (*Trichechus senegalensis* Link, 1795). United Nations Environment Programme, Regional Seas Programme, Oceans and Coastal Areas, Nairobi, 68 pp.
- Rasmussen, K., Larsen, N., Planchon, F., Andersen, J., Sandholt, I., and Christiansen, S. 1999. Agricultural systems and transnational water management in the Senegal River basin. *Geografisk Tidsskrift, Danish journal of geography* 99:59-68
- Sagna, P., Ndiaye, O., Diop, C., Diongue Niang, A., and Sambou, P.C. 2015. Les variations récentes du climat constatées au Sénégal sont-elles en phase avec les descriptions données par les scénarios du GIEC? *Pollution atmosphérique* 227:1-17
- Salem-Murdock, M., Niassé, M., Magistro, J., Nuttall, C., Horowitz, M.M., Kane, O., and Sella, M. 1994. Les barrages de la controverse: le cas de la vallée du fleuve Sénégal. *Collection Alternatives rurales*, Paris, 318 pp.
- Scerri, E.M., Blinkhorn, J., Groucutt, H.S., and Niang, K. 2016. The middle stone age archaeology of the Senegal River valley. *Quaternary International* 408:16-32
- Schmitz, J. 1986. L'État géomètre les leydi des Peul du Fuuta Toro (Sénégal) et du Maasina (Mali). *Cahiers d'Études africaines* 103(26):349-394
- Schmitz, J. 1994. Cités noires: les républiques villageoises du Fuuta Tooro (vallée du fleuve Sénégal). *Cahiers d'études africaines* 133-135(34):419-460
- Seck, S.M., Lericollais, A., and Maugrin, G. 2009. L'aménagement de la vallée du Sénégal Logiques nationales, crises et coopérations entre Etats riverains. Pp. 31-76 in Raison, J.-P. (ed.): *Des fleuves entre conflits et compromis*. Éditions Karthala, Paris
- Sehla, D. Ould. 2001. *Ecologie Zoologique des Zones Humides de l'Est Mauritanien. Vertébrés: Mammifères sauvages, Poissons, Reptiles, Amphibiens et Oiseaux*. Mission Report, PND, Nouakchott
- Sène, A.M. 2009. Développement durable et impacts des politiques publiques de gestion de la vallée du fleuve Sénégal: Du régional au local. *Vertigo - la revue électronique en sciences de l'environnement* 9(3). <http://journals.openedition.org/vertigo/9221>
- Stancioff, A.S., Staljanssens, M., and Tappan, G. 1985. Mapping and remote sensing of the resources of the Republic of Senegal: A study of the geology, hydrology, soils, vegetation and land use potential. South Dakota State University, Brookings, Washington, DC, USA
- Talla, I., Kongs, A., Verle, P., Belot, J., Sarr, S., and Coll, A.M. 1990. Outbreak of intestinal schistosomiasis in the Senegal River basin. *Annales de la société belge de médecine tropicale* 70:173-180
- Taïbi, A.N., Barry, M.H., Hallopé, A., Moguedet, G., Ballouche, A., Ould Baba, M.L., and Ba, A. 2006. Diagnostic par télédétection satellitaire des impacts environnementaux et socio-économiques du Parc National du Diawling sur le Bas Delta du fleuve Sénégal. Pp. 211-229 in Symoens, J.J. (ed.): *Les Ecosystèmes côtiers de l'Afrique de l'Ouest. Diversité biologique - Ressources - Conservation*. Fondation pour Favoriser les Recherches Scientifiques en Afrique, Bruxelles
- Taïbi, A.N., Barry, M.H., and Ballouche, A. 2014. Protection des milieux et gestion des ressources en Afrique subsaharienne: l'exemple du bas Delta du fleuve Sénégal. Pp. 53-62 in Ballouche, A., and Taïbi, A.N. (eds.): *Eau, milieux et aménagement. Une recherche au service des territoires*, Presses Universitaires d'Angers
- Taïbi, A.N., Diarra, I., and Kane, A. 2019. Du Parc National du Diawling et du Djoudj à la Réserve de Biosphère Transfrontière: transformation des logiques de gestion du bas delta du fleuve Sénégal. In Ballouche, A., Gauché, E., and Guineberteau, T. (eds.): *Afrique(s) atlantique(s). Entre espace de transition et cohérence régionale*. *Norois* 252(3):73-88
- Tappan, G.G., Hadj, A., Wood, E.C., and Lietzow, R.W. 2004a. Use of Argon, Corona, and Landsat Imagery to Assess 30 Years of Land Resource Changes in West-Central Senegal. *Photogrammetric Engineering & Remote Sensing* 66:727-735
- Tappan, G.G., Sall, M., Wood, E.C., and Cushing, M. 2004b. Ecoregions and land cover trends in Senegal. *Journal of Arid Environments* 59:427-462
- Thiam, A. 1996. Les produits phytosanitaires dans le delta du fleuve Sénégal. *Cahiers Agricultures* 5:112-117
- UNEP. 2006. *Africa Lakes, Atlas of our changing environment*. United Nations Environment Programme. Nairobi, Kenya, 90 pp.
- UNESCO-WWAP. 2003. *Water for people, water for life: World water development report*. The United Nations, UNESCO-WWAP/Bergham books, Barcelona, 593 pp.
- UNESCO. Liste du patrimoine mondial, Ile de Saint Louis. <https://whc.unesco.org/fr/list/956>
- Vandermotten, C. 2004. *Géopolitique, de la vallée du Sénégal, les flots de la discorde*. Etudes africaines. Harmattan, Paris, 166 pp.
- Wantzen, K.M., Ballouche, A., Longuet, I., Bao, I., Bocoum, H., Cissé, L., Chauhan, M., Girard, P., Gopal, B., Kane, A., Marchese, M.R., Nautiyal, P., Teixeira, P., and Zalewski, M. 2016. *River Culture: an eco-social approach to mitigate the biological and*

- cultural diversity crisis in riverscapes. *Ecohydrology & Hydrobiology* 16:7-18
- Wetlands International. 2017. *Water Shocks: Wetlands and Human Migration in the Sahel*. Wetlands International, The Netherlands, 66 pp. ISBN: 978-90-5882-014-3
- White, F. 1983. *The vegetation of Africa*. Éditions UNESCO (Vol. 20), Paris, 390 pp.
- Wilcox, C., Vischel, T., Panthou, G., Bodian, A., Blanchet, J., Descroix, L., Quantin, G., Cassé, C., Tanimoun, B., and Kone, S. 2018. Trends in hydrological extremes in the Senegal and Niger Rivers. *Journal of Hydrology* 566:531-545

Glossary

OMVS	Office de Mise en Valeur du Fleuve Sénégal
SAED	Société nationale d'Aménagement et d'Exploitation des terres du Delta du fleuve Sénégal (Senegal)
SONADER	SOciété NAtionale pour le DEveloppement Rural (Mauritania)