Chapter 18

The Senegal and Pangani Rivers: Examples of Over-Used River Systems Within Water-Stressed Environments in Africa

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1. INTRODUCTION

Climate variability and the resulting effects on river flow dynamics increasingly affect socio-ecological systems in Africa, particularly in the Sahel zone. Human-induced changes to river catchments increase these climate-related sensitivities, resulting in increasing vulnerability of local populations already aggravated by inequalities in access to natural resources and ecological services.

Degradation of ecosystem goods and services is a major challenge in Africa, particularly for countries in sub-Saharan Africa, such as Senegal, where agriculture occupies more than 60% of the active population (Institut de Recherche pour le Développement, 2016). Climatic change, including decreasing rainfall, is pushing the needing populations more and more toward overuse of surface and groundwater, whose renewal is compromised in the more or less long term. Often, in these very precarious and fragile environments, overexploitation of resources has been the response of communities to such changing environments. The examples of the Senegal River (Fig. 1), provided in this chapter, are an illustration of the realities across many river basins in Africa.

In the eastern part of Africa, the situation is similarly complex. This region is particularly troubled by droughts, floods, and “famines” as a result of high hydro-climatic variability, which has often led to regional-scale humanitarian crises. The Pangani River basin (Fig. 1), located between Tanzania and Kenya, does not escape this fate. Despite efforts in developing best practices and sustainable management, the Pangani River is experiencing an advanced degradation of its water resources. This puts local communities, especially those in its estuary, at great environmental and social vulnerability.

Whether in West or East Africa, the resilience of estuarine social-ecological-systems remains a big issue, particularly in the context of emerging climate change impacts.

2. THE SENEGAL RIVER BASIN

2.1 Site Description

The Senegal River estuary in the north of Senegal is a highly vulnerable ecosystem, housing primarily disadvantaged and low-income communities. Located in the Sahel zone where the 1970s drought triggered a series of cyclic crises, undermining livelihood of dwellers and local populations with negative impacts on household economies, the Senegal River estuary has experienced several changes that result both from natural and anthropogenic factors.
The Sahelian climate crisis has particularly affected the northern part of Senegal, manifested in an important decrease in rainfall in Saint-Louis since the early 1970s (Fig. 2). Despite a slight recovery in the early 2000s, a very notable increase in the frequency of occurrence of droughts has been recorded throughout the Sahel region (Fig. 3). The total reduction in annual rainfall as recorded is 35% in the Sahelian part of the Senegal River basin (Albergel et al., 1997), while a rainfall deficit of around 20% was recorded for all stations in the basin (Servat et al., 1999; Bodian, 2010). These recordings confirm the trends observed throughout the Sahel, and have resulted in an advanced degradation of environmental conditions throughout the estuarine zone.

In the 1980s, the weakness of the floods in the Senegal River led to more severe salt intrusion; in some years, they were even recorded up to Podor, located 150 km to the river mouth. Data from the Bakel station is a good illustration of

![FIG. 2 Annual rainfall in the Senegal River Estuary, Saint-Louis station from 1900 to 2016.](image)

![FIG. 3 Standardized Precipitation Index (SPI) of the Sahelian zone and Saint-Louis (Senegal River Estuary) from 1900 to 2010. (Source: JISAO and ANACIM-Senegal.)](image)
this flow reduction in the Senegal River basin (Fig. 4). As groundwater recharge was no longer ensured in these conditions, food security was being compromised for local communities.

Most of the climate analyses and outlooks conducted in West Africa for 2020 and 2050 indicate that current rainfall patterns are likely to continue in the coming years, that is to say, highly variable and irregular, with a high probability of occurrence of extreme events such as droughts or floods (Ardouin, 2004; IPCC, 2007, 2013; Niang, 2014; Mbaye et al., 2015; Tall et al., 2017). In fact, in light of the continuing changing global environment, and the consequent increase in temperature and decrease in rainfall, it is expected that, over the next 5–10 decades, a further decline in river runoff and depletion of groundwater tables is predicted to occur (IPCC, 2013).

2.2 The Damming of the River as a Response to Environmental Degradation

In response to the recurrent series of droughts, during the 1970s, and the resulting reduction of freshwater inflows in the valley and the delta, large dams were established on the Senegal River (Diama dam downstream, Manantali and Felou dams upstream—see Fig. 1). The major objectives of these transnational dams were to produce hydroelectricity, decrease saline intrusion during the dry season, and maintain enough water for domestic freshwater and irrigation purposes. The Diama dam, for example, has created an artificial lake of 235 km² surface with a storage capacity of over 250 million m³, dedicated to the irrigation of 120,000 ha (1200 km²) of land, as well as for freshwater supply. The Manantali dam is even more important, at a storage capacity of 1200 million m³. The Felou dam was inaugurated on December 16, 2013; it is located in Mali, 15 km upstream of Kayes; its vocation is hydroelectricity production (431 GWh of capacity and 60 MW of installed power).

Even if those hydraulic works have partly remediated the situation of drought, the changes in the hydrological regime of the Senegal River related to the dams have induced serious impacts on the morphological evolution of the region, as those infrastructures did not take into account factors such as the sedimentology and the ecology of the environment of the Senegal delta.

2.3 The Consequences: Changes in the Hydrological Regime and Morphology, Hyper-Salinization of Lands, Flooding, Changes in Fish Population

In the lower estuary and in the natural region of Gandiolais (see Fig. 1), the management of the dams on the Senegal River has caused serious environmental problems, including freshwater scarcity and recurrent flooding of the city of

**FIG. 4** Annual average discharge at the Bakel station (upper basin) from 1903 to 2010.
The impending floods in Saint-Louis capital justified the breaching of the “Langue de Barbarie” sandy spit in October 2003. After rapid drainage of waters for the preservation of the city of Saint-Louis, the breach became the new mouth of the Senegal River. With an initial opening of 4 m, the gap rapidly grew and reaches nowadays a width of +6 km, according to the monitoring carried out from LANDSAT satellite imageries (Niang and Kane, 2014; Niang et al., 2015—Fig. 5). The environmental and socioeconomic impacts of these morphological changes are of concern today, putting this socio-ecological system at a critical stage of its evolution.

The accumulation of signs of vulnerability such as hyper-salinization of water and agricultural lands upstream and the rapid morphological changes of the “Langue de Barbarie” spit sand caused by severe erosion along the coast constitutes nowadays a major challenge for the daily activities of the local communities. Fishing communities living along the sand spit of the “Langue de Barbarie” are threatened by sea-level variations; they are experiencing regular storm surges with serious loss of social and economic facilities including their settlements, fishing boats, and gears. This is particularly the case during extreme events with high-level tides. The number of accidents and casualties are now more frequent than before. Moreover, in the ecological zone of the Gandiolais, salinity levels are a standing challenge to economic development. These farmer communities, traditionally specialized in market gardening and livestock breeding, are now facing decreasing income due to salt intrusion into the aquifers and soils that impact their agricultural activities (Koulibaly, 2015).

It also appears that biodiversity has been affected by both the breach and the salinization of surface and groundwater. Certain fish species have been disappearing due to their inability to adapt to the new conditions. On the other hand, fishermen have noted the appearance of new fish species such as Sardinella, white carp, cheekfish, or tilapia (Kane, 2010), which has resulted in increased fishing landings in Saint-Louis. According to the Regional Fisheries Service of Saint-Louis, the 60,000 tonnes mark was reached in 2008 (Fig. 6), the highest catch on record since 1992 (Seck, 2014).

### 2.4 Adaptation: How People Respond by Relocating and Developing Alternative Economic Activities

Since the opening of the breach in October 2003, the consequent (hyper)salinization of the waters in the lower estuary has been paralyzing agricultural activities of local populations. Due to the salinization of soils, irrigation agriculture has become increasingly difficult in the entire delta of the river, with the total area affected amounting to ~15,000 ha (SAED, 2012; Gning, 2015). To escape such challenges, populations have started to relocate their activities, when and where possible, to areas less affected by salinization processes. Cases have been reported in particular in the lower estuary,
specifically in Ndiebene Gandiole and Lahrar (see Fig. 1). One could consider this relocation a way of adapting, although on-going socioeconomic surveys will still have to show in which way this shift affects people’s livelihoods.

Traditionally, salt exploitation in Gandiolais area has always been practiced by women but managed by men and placed under the exclusive authority of Jaaraf and its Jambur. The Jaaraf or Diaraf is a customary chief of Djolof and Jambur constitutes the Assembly of Elders of the Djolof Empire. In colonial times, the Gandiolais salt was under the exclusive control of the Damel of Cayor who then delegated the administration to his vassal, the Montel whose descendants are the Jaaraf (Faye and Sambe, 2012). At present, salt exploitation requires official authorization on the basis of a 10-year renewable contract. Each operator has the obligation to pay an annual fee to the local government. After every campaign, the harvest is divided into three parts: one for the farmer and two for the Jaaraf (Faye and Sambe, 2012).

Salt extraction is practiced by women in most villages of Gandiolais, particularly in Tassinère, Mouit, and Ndiebene Gandiole, around the Ngaye-Ngaye basin (Fig. 7), tributary of the Gueumbeul basin where the salinity level generally exceeds 35 psu at the beginning of winter season (Corea, 2006). The volumes of salt produced have been steadily increasing over the last 10 years, according to Gandon Local Development Plan (PLD; Gandon, 2008), a fact related to the opening of the offloading canal and mainly since the closure of the old Senegal River mouth, which was transformed into a lagoon since 2005 and then evolved almost like a salt swamp. The size of the salt farms is in this respect revealing of the very increase of salt in the estuary.

Salt extraction activity can be seen as an attempt to adapt to changing environmental conditions by developing alternative economic activities. However, the income from salt is not enough to improve the livelihoods of the
population, as Gandiolais salt has a low commercial value, despite efforts to improve the product quality through iodization processes.

Despite adaptation efforts of communities through the development of alternative activities such as salt extraction or transfer of agricultural activities to more favored areas, the situation is rather alarming, given the level of impoverishment. There remains, therefore, serious concern about the future of those fragile environments and their communities. Politically, moreover, the situation is complicated by regional interests from the OMVS (Senegal River Basin Management Organization) projects (river navigation, hydroelectricity, and large-scale irrigation schemes) and national policy such as one of the present major “Plan Sénégal Emergent” (Senegal Emerging Plan) that aims to develop national irrigation plans for food self-sufficiency, mainly from rice culture. In addition, such a fragile and changing environment is likely to be further weakened by the construction of a maritime-river harbor in Saint-Louis as part of the main Senegal River Navigation Program.

The main risk here is once again, a modification of the dynamics of the estuary and the river mouth, after the major upheaval experienced in October 2003 with the breaching of the Langue de Barbarie. The question is therefore, what will be the future of this region, especially after the construction of the maritime river harbor of Saint-Louis? How will this affect the Gandiolais communities, which have gone from a flourishing market gardening occupation to large-scale salt marshes?

3. THE PANGANI RIVER BASIN

3.1 Site Description

The Pangani River drains a transboundary river basin shared by Kenya and Tanzania (Fig. 1), with its headwaters located in the Kilimanjaro and Meru mountains, fed by cloud-forest precipitation and snowmelt from the glaciers (IUCN, 2007; Hamerlynck et al., 2008). The Pangani is formed through the confluence of Kikuletwa and Ruvi rivers at the Nyumba ya Mungu Dam, after which the river flows across dry plains, through the extensive Kirua swamps, being finally joined by the Mkomazi River at Korogwe and the Luengeri River, then traversing the Pangani Falls before entering the Indian Ocean south of the town of Pangani (Akitanda, 2002).

The Nyumba ya Mungu Dam is one of the largest dams in Tanzania; with a total surface area of 15,000 ha (150 km²), a maximum water depth of 40 m, and a storage capacity of 875 million m³, the dam supports a storage reservoir for the power plant at Nyumba ya Mungu (8 MW) and two other power plants, Hale (21 MW) and New Pangani Falls (66 MW), located further downstream. Irrigation schemes in the basin can be divided in two categories (Shaghude, 2016): large-scale irrigation systems in the lowland areas, where inadequate rainfall requires the farmers to irrigate their farms to ensure optimum productivity, and small-scale traditional irrigation systems, typically found in the highland areas where irrigation is taken as a safeguard measure to maximize the productivity of the small farms. In particular, the latter are generally characterized by high losses (up to 85%), which combined with high population density (80% of population in the basin resides in the more fertile highlands), results in considerable demand for irrigation water. Population statistics from 1967 to 2012 show that the basin population increased from 2,034,256 people in 1967 to 6,804,733 in 2012 (Shaghude, 2016), resulting in ever-increasing demand.

The current irrigation abstraction systems (both traditional and large scale) are estimated to use at least 400 million m³ of water per annum, with evaporation losses in the reservoirs estimated at 410 million m³ per year (Shaghude, 2006), resulting in a total of around 810 million m³ per annum, or roughly 90% of the total available water flow (900 million m³). The impacts of high levels of retention and abstraction are further aggravated by climatic change, with a total decrease of at least 250 mm of total annual rainfall at the Mount Kilimanjaro weather station against a total average of ~ 2000 mm per year over the past century (Shaghude, 2006).

3.2 Consequences: Environmental Degradation

The high water abstraction levels, and consequent strongly reduced river flow, comes with considerable implications. Firstly, increased salt-water intrusion in the lower river ranges has been reported, causing upstream migration of species (Shaghude, 2004, 2006) and changes in underground water quality and salinization of coastal soils, both with considerable socioeconomic impacts for farmers and fishermen in the lower ranges of the river (Sothewes, 2008; IUCN, 2009). The study of Pamba et al. (2016) noted that saline water intrusion was highest in December and January (low river flow) when saline water intrusion extended inland 15 km from the river mouth. Furthermore, coastal erosion on the immediate north of the Pangani River mouth, and changes in sediment deposition patterns in the estuary itself have been
reported as one of the major environmental issues of concern (Shaghude, 2004, 2006; Pamba et al., 2016). The potential hydrodynamic implications of these morphological changes are expected to have an impact on shipping and port operations, among others.

3.3 Management Strategies

Following the establishment of the Pangani Basin Water Board (PBWB) in 1991, a number of management measures have been put in place. Firstly, a new water right policy was established, under which water users are obliged to hold water rights issued by the PBWB (Mujwahuzi, 2001; Shaghude, 2006). Unfortunately, the policy’s introduction did not get full support from the traditional irrigation water users, reportedly as a result of inadequate stakeholder consultation, which led to an increasing number and intensity of illegal water abstractions (Mujwahuzi, 2001; IUCN 2003; Shaghude, 2006). In addition, according to Turpie et al. (2005), the water allocations are not adequately taking into consideration environmental flow demands. As a second measure, furthermore, effort has been put into improving the efficiency of the irrigation systems, in order to reduce the losses from the traditional furrow networks. This involves, among others, the introduction of modern piping systems, which would get rid of both water leakages by infiltration and evaporation along the transport path.

A number of additional management measures are still on the table, including the application of Aquifer Storage and Recovery (ASR) technology, which involves the recharge and storage of water in an artificial aquifer during the rainy season and the recovery of the stored water when it is required; the aquifer essentially functions as a water bank (Pyne, 1995; Sheng and Zhao, 2014; Shaghude, 2006). Additional measures as suggested by the World Commission on Dams (WCD, 2000) include improved basin and system level management, through afforestation and the promotion of better farming practices. In reality, however, appropriate watershed management is significantly impeded by a number of factors, including poor inter-sectoral coordination at the field level, diverging interests of watershed stakeholders, incompatibility between formal and informal institutions, poor highland-lowland integration, conflicting development interventions, population pressure and migration, and inadequate political support as shown in a recent study by Msuya et al. (2017).

4. CONCLUSION

The cases presented in this chapter, the Senegal and Pangani rivers, are just two examples of the many river systems in Africa that have been affected by human interventions, such as dams and irrigation schemes, designed with the objective to improve the livelihoods of communities through increased access to water for agriculture, energy through hydropower, as well other purposes. While well intended, such interventions often result in important negative consequences further downstream, in particular affecting the vulnerable estuarine environments and their dependent population. As the effects of climate change on rainfall patterns are becoming more obvious, the strong relation between rainfall and river run-off constitutes is indeed a growing constraint in such river basins, a factor that therefore needs to be fully integrated and mainstreamed into the development programs and policies of African countries.

As the two case studies demonstrate, many of the solutions and alternatives that are on the table require trade-offs between upstream water user needs and downstream effects. However, under pressure of an ever-increasing population and related demand for water and land for cultivation and other uses of river basins, solutions that restrain water abstraction or uses otherwise of river catchments tend to encounter a lot of resistance. While such solutions may make sense in a broader eco-economic context, the realities on the ground, and the social and political realities under which decisions are taken, are consequently impeding their effective implementation. What we see in many cases is therefore rather an adaptive response of affected communities migrating or developing alternative livelihoods opportunities.

Yet, it is obvious that the management of Africa’s river basins, and the challenges related to this, is increasingly an area of attention. The two river systems presented in this chapter, the Senegal River Basin Organization’s projects and the Pangani River Basin Management Project, are examples of efforts underway to establish appropriate management schemes and implement appropriate actions toward a more system-wide management approach. Unfortunately, the current efforts under these schemes are faced with tremendous challenges; it is clear that only through such integrated approaches that appropriate strategies can be developed to secure the long-term ecological future of Africa’s river systems.

The Senegal and Pangani Rivers do not constitute an exception; many rivers and other “wet” ecosystems across western and eastern Africa are under stress from natural and anthropogenic conditions (Alhassan and Kwakwa, 2014; Freitas, 2015). The Inner Delta of the Niger is a very good illustration of that situation. Nowadays, the shrinkage of this
delta is bound as much by the important water demand for irrigated rice growing as by the reduction of water resources due to modifications of climate conditions (Morand et al., 2014). In East Africa, other estuarine ecosystems like the Wami River in Tanzania and the Tana River in Kenya are also in an alarming situation due to a mix of social and ecological problems linked to climate change, damming and hydropower generation, and over-use of natural resources (Wambura et al., 2015; Kiwango et al., 2015; Sood et al., 2017).

REFERENCES


FURTHER READING