Chapter 12
Water Management Policy for Freshwater Security in the Context of Climate Change in Senegal

Cheikh Faye, Amadou Abdoul Sow, and Sidy Dieye

Abstract The impact of climate change on freshwater systems and its management have been ongoing for many years and is projected to intensify as temperature, sea level and rainfall variability increases. Senegal's water resources are now threatened by human activity of various origins and by the harmful effects of climate change. This chapter addresses the extent to which water management policy ensures freshwater security in the context of climate change. Given the scale of water scarcity, this study is limited to characterizing the relationship between water management policy and freshwater security in the climate change context, focusing on data and information from institutions with authority for water policy and minimization of water scarcity. The discussion includes a case study on the impact of climate change on water resources in the Gambia River Basin, which indicates that while there is a great deal of attention paid to freshwater security policy, there is no consensus on how to mitigate the effects of climate change to ensure water security. Water and climate change are managed by different ministries, resulting in predictable conflicts of authority and responsibility. Thus, it is necessary for the government to establish an effective water policy, with clear, sustainable strategies to mitigate the impacts of climate change for the sustainable freshwater security of the country.

Keywords Climate change · Water security · Water policy · Water management · Water scarcity

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1 Introduction

Freshwater is essential for the survival of natural ecosystems and for human activity. Until the mid-twentieth century, water was considered inexhaustible and accessible for anyone to use, own and exploit according to their needs (Honegger and Tabarly 2011). These needs vary by economic sector, but all economic development and industrial activity depend on water. In fact, water withdrawals have increased six-fold since the 1900s, twice the rate of population growth (UNESCO 2006). This has led to competitive use of water resources among and within sectors, which is a root cause of many challenges such as political and territorial conflicts, deterioration of water quality, degradation of the environment, disparities in water distribution and a decline of access to water resources (Batcho 2008).

Senegal's total renewable water resources are about 38.97 km^3 per year, of which about 25.8 km^3 come from within the country. Per capita renewable water volume is estimated at about 4747 m^3 per year (CONGAD 2009), well below the average of sub-Saharan Africa (7000 m^3 per person per year) and the world average (8210 m^3 per person per year). Senegal's internal renewable surface water resources are estimated at 23.8 km^3/year and renewable groundwater resources are on the order of 3.5 km^3/year. The overlap between surface water and groundwater is estimated at 1.5 km^3/year and internal renewable water resources are estimated at 25.8 km^3/year. The average annual rainfall is estimated at 686 mm (FAO 2016). The relative abundance of water and the fact that available freshwater supplies are 24.5 times greater than water consumption (1591 million m^3 in 2000) (FAO 2016) hide the real potential for water scarcity in Senegal.

The Senegal, Gambia and Kayanga rivers, all of which originate in Guinea, together irrigate a large part of Senegal. Most surface water reserves are located in the Senegal and Gambia river basins, whose waters come from the Fouta Djallon Massif in the Republic of Guinea (Sané 2015). Smaller rivers, the Casamance and the Kayanga, with intermittent flows, and their main tributaries, the Anambé, Sine and Saloum and coastal creeks (Fig. 1), complement the water supplied by the large rivers. A number of other lakes and basins complete the hydrographic network, the most important of which are Guiers Lake, the bolongs of estuaries and the bounds of the Niayes region of the northern coast and Ferlo. Available water in any area depends on the amount of surface and groundwater available from rivers, lakes, reservoirs and aquifers (Chitambi 2017).

Water scarcity is defined as insufficient water resources to meet long-term average needs. Variation from the norm results in long-term water imbalances when water availability from natural recharge is lower than the demand level (EU-Commission 2007). This, in turn, results in a shortage of rapid and reliable access to water resources for different economic and social groups. The risk of water scarcity and the potential to pre-empt or effectively address it depends not only on the physical endowment of water but also on the institutional, technical, political, economic and infrastructure capacity of a country to manage water to the satisfaction of all stakeholders (Chitambi 2017).

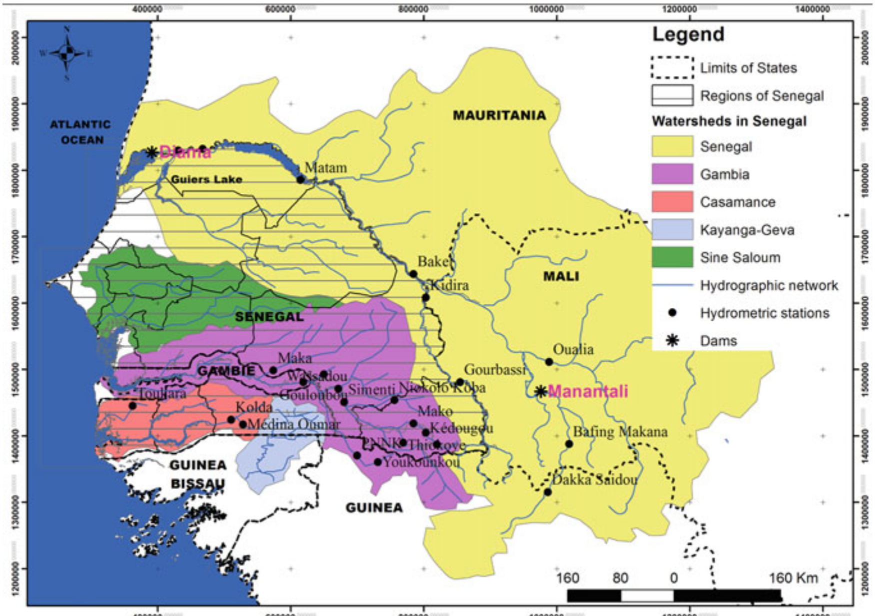

Fig. 1 Watersheds draining Senegalese territory (*Source* DGPRE)

The International Water Management Institution (IWMI 2007), classifies Senegal as a country with economic water scarcity. Although water resources are abundant, they are not effectively applied to the country's development goals because of limited institutional, technical and financial capacity. Water scarcity is driven by variation in rainfall, the vulnerability of water resources, disparity in spatial distribution, current and/or threatened conflicts caused by water exploitation and over-exploitation, degradation of the volume and quality of available water, inequity of access among and within zones and social groups, and various socioeconomic activities (MH/DGPRE 2007).

Good governance and accountability, with a view of the interests of all stakeholders within an appropriate legal and institutional framework, must be properly planned, exploited and maintained for effective infrastructure and capacity development (UN-Water 2011). Every aspect of security worldwide—for example, food, economic and health—depends on water (Boge 2006).

To improve water management, Senegal is working to comply with the recommendations of the World Summit (Rio-Dublin, January 1992 and Johannesburg, August 2002). Senegal's water policy as it applies to achieve the Sustainable Development Goals (SDGs) is managed by the Directorate of Water Resources Management and Planning (DGPRE).

2 Description of the Study Area

The Republic of Senegal, located on the extreme western tip of the African continent, covers an area of 196,722 km^2 with an estimated population of 16,200,000. With 700 km of Atlantic coastline, Senegal is located between 12.5° and 16.5° North latitude and 12° and 17° West longitude. The variation in the quantity and frequency of rainfall from South to North creates three climatic zones: southern Sudanian, northern Sudanian and Sahelian. Each zone has two sections: coastal and continental zone (Faye et al. 2017).

Senegal has a Sudano-Sahelian tropical climate with annual rainfall between about 1,250 mm in the South to just over 200 mm in the North. There is a rainy season and dry season: the former corresponds to the monsoon period, extending roughly from June to October with a peak in August-September. The rain in this period varies depending on the latitude. The dry season lasts from November to June and is characterized by hot, dry wind, known as "the Harmattan."

Senegal's surface and groundwater resources are rich, with heterogeneous soils and a dense hydrographic network. Most surface water reserves are located in the Senegal and Gambia river basins (Sané 2015). Groundwater consists of four major aquifer systems: shallow, intermediate, deep and basement (CONGAD 2009). Senegal currently has sufficient water resources to meet demand, but it is threatened by drought and climate change.

3 Methodology

3.1 Characterizing Climate Change Impacts on Water Resources

3.1.1 Context

Climate change is defined by trends in the global mean sea and atmospheric temperatures, variation and quantity of rainfall, and increase of the magnitude and frequency of natural disasters and extreme events (drought, floods, etc.) (IPCC 2007). Global warming, combined with increased variability of rainfall, is driving an upsurge in extreme events, including floods and low flows, which in turn will increase in frequency and in intensity across the African continent. Various studies reveal the evolution of flows in rivers and their impacts on natural and human ecosystems, subject to the hydro-climatic conditions in various regions (Faye et al. 2015a).

The African continent is among the most impacted by climate fluctuations on water resources (Kanohin et al. 2009). Several studies carried out in West and Central Africa have shown a decrease in surface and groundwater flows since the 1970s as a result of a decrease in rainfall (Dione 1996; Sow 2007; Faye 2013; Faye et al. 2015b), but an increase in flows (Niang et al. 2008; Ali and Lebel 2009; Ozer et al. 2009;

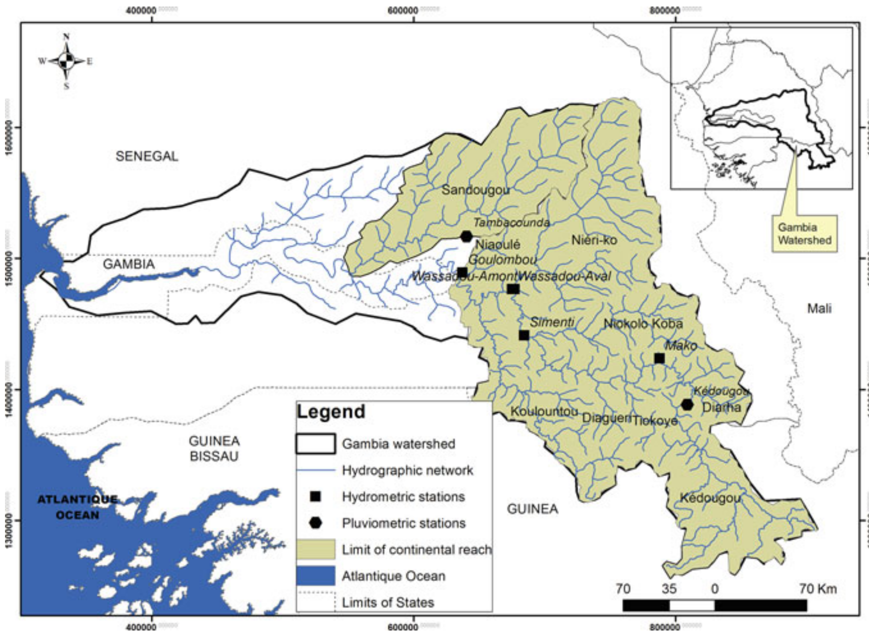

Fig. 2 Gambia River Basin situation

Ouoba 2013; Bodian 2014) since the 1990s, suggesting an improvement of water balance in this period.

The Gambia Basin covers an area of nearly 77,100 km, shared between three states (Lamagat 1989): Guinea (where it originates at 1125 m. altitude around Labé); Senegal (from which it drains almost all the Tambacounda region and part of Upper Casamance and southern Sine-Saloum); Gambia (of which it is the backbone). It extends, in latitude, from 11°22 North (in Fouta-Djalon) to 14°40 North (in the south-eastern Ferlo) and, in longitude, from 11°13 West (Fouta-Djalon) to 16 “42 West (in Banjul at the mouth). It is of interest to the territories of Guinea, Senegal and Gambia. It is divided into two distinct zones: the continental basin and the estuary basin, respectively, east and west of Gouloumbo, the last station where the flow of freshwater inputs is measured (Dione 1996; Sow 2007) (Fig. 2).

3.1.2 Data

Rainfall and high- and low-temperature data were measured at Tambacounda and Kedougou stations from 1970 to 2012 to represent climate change in the Gambia River Basin. Data from the hydrological stations at Gouloumbou, Mako, Simenti, Wassadou Upstream and Wassadou Downstream from 1970 to 2012 indicate changes in surface water in the Gambia River Basin. Groundwater measurements for the basin were taken from Mako station over the same years. The selected stations followed consistent criteria for each parameter measured to ensure the duration of available information and data quality.

3.1.3 Standardized Precipitation and Flow Rates Indices

A standardized precipitation index (McKee et al. 1993; Hayes 1996) was developed to quantify rainfall deficit over time, adopted in 2009 by the World Meteorological Organization (WMO) as a global instrument for measuring meteorological droughts. According to the "Lincoln Declaration on Drought Indices" (Jouilil et al. 2013), it is expressed mathematically as:

$$SPI(SFI) = \frac{(X_i - X_m)}{S}$$

where
X_i = annual rainfall (or flow) i
X_m = mean rainfall of series over the considered time scale
S = standard deviation of series over the considered time scale

This standardized flow rate index (SFI) is similar to the index used for hydrology and has been developed to quantify the water deficit over time to reflect the impact of drought on the availability of different types of water resources for a given period (Sharma and Panu 2010).

3.1.4 Depletion Coefficient and Water Volume Mobilized by Aquifers

The depletion of water from all the aquifers of the basin is an important factor in the tropical hydrological regime (Briquet et al. 1995). The calculation of the depletion coefficient is based on the Maillet model (Sow 2007; Faye 2013; Faye et al. 2015a), which demonstrates the degree to which rivers are drying up. Maillet's model shows that, by factoring out precipitation, depletion corresponds to the exponential decay of flow as a function of time. This corresponds to the emptying of groundwater as the only contribution to the water flow of a basin. The Maillet model is represented by:

$$\mathbf{Q_t = Q_0 e^{-\alpha(t-t_0)}}$$

where
Q_0 is the initial flow at time t_0, $(t-t_0)$: the time expressed in days between the observation of the flow rate Q_0 and that of the flow rate Q_t (flow at the end of the dry period)
α is the dry-out coefficient
The volume of water mobilized by aquifers is represented by:

$$V_{mobilized} = \frac{\mathbf{Q}_0}{k}$$

The Maillet model makes it possible to determine the temporal evolution of depletion coefficients and water volumes mobilized by aquifers in the Gambia watershed, and to assess the duration of the drying up of rivers under the effect of climate change, enabling the use of methods based on trend detection and break in series.

3.1.5 Pettitt and Mann–Kendall Tests

The Pettitt test (1979) represents a break at an unknown moment in series from a formulation derived from that of the Mann–Whitney test. This test represents differences in values that make up the sample, corresponding to a resulting time series. The calculation of the p-value indicates whether or not the threshold break is statistically significant.

The Mann–Kendall test represents the linear trend (up or down) within a time series. This tendency test was first studied by Mann (1945), then Kendall (1975), then improved by Hirsch and Slack (1984). The test has been validated by several comparison studies by Yue and Wang (2004).

3.2 Characterization of Water Policy in a Climate Change Context

Data and information from various institutions were selected based on the institution's mandate for water policy, security/water management and/or climate change. Among the institutions and ministries from which data were derived are the Ministry of Hydraulics and Sanitation, the Ministry of Environment and Sustainable Development, the Directorate of Management and Planning of Water Resources, the National Agency of Civil Aviation and Meteorology, the National Agency of Statistics and Demography, the Organization for the Development of the Senegal River and the National Water Company of Senegal. Some semi-structured interviews of key players were conducted to complement policy analysis. Data were sourced mainly from the documentary/policy reviews of selected institutions. Institutional documents, progress reports and institutional water resource management libraries were used to gain a deeper perspective on water policy and water security in the context of climate change. The analysis focuses on water security, water resource management and climate change.

4 Results and Discussion

4.1 *Characterization of Climate Change Impacts: The Gambia Watershed*

4.1.1 Temperature and Precipitation Trend

Trend shifts and/or breaks in annual temperature and precipitation are used to characterize climate change in the Gambia River Basin. Table 1 shows the results of the Pettitt and Mann–Kendall tests using data for minimum, maximum and average temperatures from Kédougou and Tambacounda stations for 1970–2012. Both tests indicate the presence of a break and/or trend: for example, in 1987 in Kédougou and in 1990 in Tambacounda for T_X and T_N. These breaks are confirmed by the Mann–Kendall test, which shows positive and significant Kendall τ of 0.511 °C for T_X and 0.3321 °C for T_N at Tambacounda. At Kedougou station, Kendall τ, although not significant, is positive: 0.0171 °C for T_X and 0.7261 °C for T_N.

To quantify the variation of temperatures through the break date, we cut the time series into two subperiods, before and after the break dates. A comparison of the two sub-periods shows that the latter one reveals a surplus of 2.61% for T_X and 1.35% compared to the earlier one for T_N at Tambacounda.

Neither the Pettitt nor the Mann–Kendall tests show a significant break or trend in precipitation, with the p-values for both tests >0.01. The trend in precipitation rises slightly after 1994 and breaks are noted in 1994 and 2003 in Tambacounda and Kedougou, respectively. Thus, indices are generally negative from 1970 to 1994 and positive between 1994 and 2012, as illustrated by positive Kendall τ with −0.074 mm at Tambacounda and 0.098 mm at Kédougou. These suggest that, in addition to the

Table 1 Results of annual temperature and precipitation tests (1970–2012)

			Mann–Kendall test			Pettitt test	
			p-value	τ of Kendall	Slope of Sen	Date of break	% surplus or deficit
Tambacounda	Temperature	TX	<0.0001	0.511*	0.035	1990	2.61
		TN	0.958	−0.006	0	1979	−0.65
		TM	0.002	0.332*	0.014	1990	1.35
	Annual precipitation		0.492	0.074	2.158	1994	13.3
Kedougou	Temperature	TX	0.017	0.259	0.015	1987	−2.61
		TN	0.141	−0.167	−0.019	1987	−4.27
		TM	0.726	0.041	0.002	1987	−0.76
	Annual precipitation		0.359	0.098	2.257	2003	21.0

(−): negative trend; (+): positive trend; (*): significant trend; TX = maximum temperatures; TN = minimum temperatures; TM = average temperatures drought of the 1970s as confirmed by multiple studies (Sow 2007; Faye 2013; Faye et al. 2015b), another important change in rainfall pattern is observed at the turn of the twenty-first century as indicated by studies (Ali and Lebel 2009; Ozer et al. 2009; Ouoba 2013; Bodian 2014) that suggest the end of Sahelian drought during the 1990s. Thus, in the year before and year after the break, rainfall increased by 13.3% in Tambacounda and 21% in Kédougou.

4.1.2 Impacts of Climate Change on Surface Waters in the Gambia Basin

The impact of climate change on surface waters in the Gambia River Basin have been analyzed using standardized flow indices. Deriving these indices from different stations allows better comparison of station data as basins of different sizes drain. The indices subjected to Mann–Kendall and Pettitt tests reveal significant fluctuations with multiple consequences for the environment, making them worthy of study. The analysis shows that there is an upward trend and a break in 1994 (Table 2) at the five stations. However, neither the trend nor the break was significant at the 1% level. Thus, distinct periods are established before and after 1994. The first one, from 1970 to 1994, shows a negative outflow trend relative to the drought of the 1970s (Faye et al. 2015b). The second, from 1994 to 2012, although not significant, shows a rising trend and corresponds to an improvement in rainfall conditions starting in the 1990 s (Ozer et al. 2009). This upward trend in a runoff in the Gambia River Basin is consistent with the findings of Ali and Lebel (2009) in the Sahelian zone, Ouoba (2013) in Burkina Faso, Ozer et al. (2009) in Niger, Niang (2008) in Mauritania and Bodian (2014) in Senegal.

The trend analysis indicates that this variability is synchronized with two hydro-climatic periods: a dry period between 1970 and 1994, and a wet period between 1994 and 2012. Thus, beyond the hydrological drought of the 1970s, a new hydrological

Table 2 Results of Pettitt and Mann–Kendall runoff tests analyzed in the Gambia River Basin (1970–2012)

	Mann–Kendall test			Pettitt test		
	p-value	τ of Kendall	Slope of Sen	p-value	Date of break	% surplus or deficit
Gouloumbou	0.611	−0.062	−0.010	0.651	1981	23.6
Mako	0.479	0.094	0.020	0.025	1994	48.8
Simenti	0.241	0.154	0.030	0.011	1994	64.7
Wassadou upstream	0.710	−0.052	−0.008	0.564	1979	51.5
Wassadou Downstream	0.065	0.227	0.026	0.002	1994	44.6

(−): negative trend; (+): positive trend; (*): significant trend change occurred again in the 1990 s, with river flows rising. We believe that, on an annual scale, rainfall measured at the stations is quite similar to the date of the break in 1994. However, the magnitude of the surplus is smaller (23.6%) in Gouloumbou than at other stations where it exceeds 50% (64.7% in Simenti, 51.5% in Wassadou and 48.8% in Mako).

Flow changes in the Gambia River Basin are caused by various upheavals, including climate change. One of its impacts was the severe drought of the 1970s (Sow 2007; Ozer et al. 2009; Faye et al. 2015b). On the other hand, during the 1990s, the improvement in rainfall conditions (increase in rainfall) led to an increase in runoff observed at the various stations.

4.1.3 Climate Change Impacts on Groundwater in the Gambia Watershed

While accumulated rainfall deficits during the 1970s resulted in diminished underground reserves of river basins (Briquet et al. 1995), the increase in flow in the Gambia River Basin has increased the volumes drained by groundwater. The natural low water level in the Sudano-Sahelian rivers are directly affected by changes in climatic conditions. This depletion is typical of all the aquifers in the basin and is an important characteristic of the Gambia River Basin. Depletion data are provided in Table 3 and show that variation at Mako station is particularly dramatic.

Depletion coefficients show that before 1994, the year of break, according to the Pettitt test (Table 3), values are fairly steady. Drying coefficients are generally low and range from 0.024 (in 2011–2012) to 0.076 (in 1977–1978) in Mako. In contrast, the 1994–2012 coefficients average 0.044, and correspond to the highest water table

Table 3 Results of the Pettitt and Mann–Kendall tests on drying variables in the Gambia River Basin at Mako station (1970–2012)

Mako	Mann–Kendall test				Pettitt test			
	p-value	τ of Kendall	Significance Threshold (between 10% and 1%)	Sensitivity of trend	p-value	Date of break	Significance Threshold (between 10% and 1%)	% deficit or surplus
Q0	<0,0001	0,44	Presence of trend	Rise	0,0001	1986	Presence of break	102
Qt	0,07	0,19		Rise	0,0105	1994		285
t	0,06	0,20		Rise	0,004	1985		9,1
K	0,29	−0,11		Decline	0,10	1994		−15
V m^3/an	<0,0001	0,50		Rise	<0,0001	1993		115

Q_0: flow at the beginning of the dry period; and Qt: flow at the end of the dry period; t: the number of days; α: the drying coefficient; V m^3 / year: the support volume of the slicks volumes. Over this period, the average support volume for aquifers is 6531 m^3/year, with a maximum of 16,454 m^3/year (in 2012–2013) in Mako.

Table 3 indicates that starting from the 1994 break, the rise in flows corresponds to a real drop in the depletion coefficient, as shown by Kendall's τ on the order of −0.11 in Mako. This decrease in the coefficient resulted in an increase in the volume of groundwater contribution to the general flow of the Gambia River Basin, in turn resulting in a positive net Kendall τ of 0.50 (in Mako), part of a trend of the increase in groundwater contribution in recent période (1994–2014) in the basin (115% in Mako).

The decrease in the coefficient of dryness in the current dry period corresponds essentially to an increase in the extension and width of the groundwater tables in the basin. The 1994–2014 period, compared to the 1970–1993 period, is in surplus for the duration of the dry period and for support volumes, and in deficit for the coefficient of dryness.

4.2 Water Policy During Climate Change

4.2.1 Water Management Policy and Freshwater Security

Water policy as it relates to freshwater security is addressed in the sectoral water policy of 2005. In response, programs and projects (National Water Partnership of Senegal in 2002; PAGIRE in 2007) were implemented in close collaboration with the responsible ministries to contribute to and protect the environment, including water resources. We believe that these efforts represent a strong commitment of the Government of Senegal to promote Integrated and Sustainable Water resource management through:

- improving knowledge and means of water resource management;
- creating an environment conducive to the application of Integrated Water Resources Management (IWRM) through legal, organizational and political reforms;
- improving communication, information, education and awareness about water resources, etc.

Table 4 lists laws regulating water use, pollution control and conservation as part of natural resources management. They complement water policy objectives for water resource management and development to enhance collaboration and cooperation among key stakeholders in Senegal. Water resource management and water use in Senegal are based on a combination of sectoral policy papers (urban and rural water policies), laws, decrees, and ministerial and inter-ministerial orders, circulars and codes on water, hygiene, environment, etc.).

Sectoral policy on water and sanitation was the dominant instrument for the implementation of the Millennium Drinking Water and Sanitation Program (PEPAM). After 2015, extending the progress made by PEPAM, a coordination and monitoring

Table 4 Water policy laws relating to freshwater security

Enabling legislation	Purpose of the water sector policy
Law No. 81-13 of March 4, 1981 on the Water Code	– Establish the protection and safeguarding of water resources, good water management (especially in the sanitary field); – Assure good planning of resources, their good management and equitable distribution between different uses and each according to their needs within the framework of strict respect of general interest
Law No. 2008-59 of September 24, 2008 on the organization of public service for drinking water and collective sanitation of domestic wastewater	– Organize modernization and rationalization, in the longer term, of public water and sanitation service, in order to face the challenges of the future and meet the needs of Senegal; – Delegate the public water and/or sanitation service to maintain the water and/or sanitation installations in good working order
Law No. 83-71 of July 5, 1983 on the Hygiene Code	– Ensure the protection of water quality; – Establish a protection perimeter to be respected around water intake points intended for human consumption; – Protect the works of the catchment, treatment, storage and elevation of water
Law No. 90-07 of June 26, 1990 establishing the SONES–PEPAM	– Realize conditions for a better division of roles and the profitability of sub-sector of urban hydraulics through a more adapted private management mode and a more assertive commercial dimension
Law No. 2001-01 of January 15, 2001, on the Environment Code	– Establish good management and protection of the environment, which is one of the concerns of the public authorities in Senegal; – Put in place a national policy for the protection of environmental resources
Law No. 2008-43 of August 20, 2008 on the Town Planning Code	– Manage the projects of drinking water supply and sewerage (rainwater and black water) of the districts; – Manage urban green spaces, including areas of wet depressions, urban planes and waterways
Law No 2009-24 of July 8, 2009 bearing the Sanitation Code	– Enable people to have adequate sanitation and access for all to the rule of law regarding sanitation in Senegal

(continued)

Table 4 (continued)

Enabling legislation	Purpose of the water sector policy
Decree No. 2013-1270 of September 23, 2013, on the powers of the Minister of Environment and Sustainable Development	– Ensure the protection of the environment (protection of nature, fauna and flora); – Fight against pollution; – Participate in the implementation of water and soil conservation policy through the construction of retention basins and artificial lakes
Decree No 2012-654 of July 4, 2012 relating to the attributions of the Minister of Hydraulics and Sanitation	– Ensure the supply of drinking water to populations in rural, urban and peri-urban areas; – Ensure the quality of water supplied to households and businesses; – Ensure the availability of water for the satisfaction of the needs of agriculture and livestock over the national territory
Law No. 2016-32 of November 8, 2016 on Mining Code on Mining Code	– Ensure the protection of the environment during exploration, extraction and abandonment of mines
Law No. 96-06 of March 22, 1996, on the Local Authorities Code	– Provide and maintain water supplies; – Characterize the regime and the methods of access and use of water points of all kinds; – Manage inland waters (excluding national and international rivers); – Ensure the protection of groundwater and surface water
Constitutional Law No. 2016-10 of April 5, 2016, revising the Constitution	– The guiding principles of state policy set a framework within which regulation and allocation of water can take place

unit for water and sanitation programs was created (DGPRE 2016; ANSD 2017). Senegal is committed to the IWRM approach as a strategic option consistent with the Africa Water Vision 2025 and other international water policies. However, a lack of adequate information on water availability limits the strategic planning of water resources and constrains efforts to regulate the development of surface water and groundwater.

The objective of water resource management is to conserve and maintain acceptable quality standards (Chitambi 2017). To achieve this level of water resource management, the following goals must be realized by the appropriate ministries to:

- reduce the impact of water-related disasters such as drought and floods by the implementation of early warning systems;
- create institutions for the management of shared watercourses within Senegal in collaboration with national institutions to ensure the protection of Senegal's interests;

- prevent water shortages by the collaborative implementation of early warning systems;
- coordinate regional and international organizations to respond effectively to emergencies.

Water resource knowledge and monitoring are essential to the development and implementation of good policy to preserve resources from all forms of pollution and degradation as population growth inevitably increases pressure on water resources. The population of Senegal is projected to increase to over 19,390,000 in 2025. A reliable water monitoring system that allows for input by all stakeholder constituencies is essential to build an understanding of water availability, abstraction and consumption in various contexts. Senegal has improved access to drinking water, but at the same time faces weak access to basic social services and reliable databases to support harmonized, comprehensive and sound policymaking.

The proportion of the population with access to drinking water in Senegal is estimated to have been 87.2% in 2015, compared to 84.1% in 2014. Even if Senegal had reached the water target set by the Millennium Development Goals (MDGs), geographic coverage of 58.3% (in 2016) combined with the new more ambitious objectives of SDG 6 mean that much greater progress must be made.

4.2.2 Water Management Policy and Climate Change

Although Senegal has sufficient water for its population, the water sector faces many challenges related to climate change which threaten access to sufficient and clean water and, therefore, the socioeconomic development of the country. Poor distribution of surface water in many parts of the country, particularly in the north, impedes wealth creation, poverty reduction and disease prevention, resulting in major challenges to environmental regulators, and ultimately to Senegal's economy, health, food and security.

According to the National Agency of Civil Aviation and Meteorology (ANACIM), Senegal is among the African countries most exposed to the negative effects of climate change, which is causing an increase in temperatures and frequency of extreme events (floods and droughts) and late-onset and/or early cessation of rainfall (resulting in shorter seasons and more intense rainfall). Adverse effects of climate change have impacted water reserves in marine waters in Casamance and Sine-Saloum, and have driven the drying up of the Ferlo and associated valleys, a general decline of groundwater levels, a decrease in water flow in continental rivers and other flood plains and the salinization of fresh water and cultivated land in coastal areas.

The climatic deterioration of recent years (from the years 2000 to now), combined with overexploitation of the resource, has led in places (West of the country) to a drop-in water table (sometimes with withdrawals exceeding the renewal capacity) and marked saline intrusions in the low valleys of the Sine Saloum, at the level of the deltas of the Casamance and Senegal rivers, as well as the Grande Côte (Niayes area). At the same time, in some areas, especially the Dakar region, surface water tables are polluted by discharges linked to sanitation deficits (bacteria, chemicals, heavy metals, nitrates). In these areas, the quantity of water available is not the problem, but rather water quality and the cost of its mobilization are the major concerns (Senegal National Blue Book Committee 2010).

Solutions have been proposed to reduce vulnerability and strengthen the adaptive capacity of populations and ecosystems. Ensuring freshwater security through more efficient water management will contribute to development objectives, adaptation to climate change and disaster risk reduction (AMCOW 2013). Climate disruption introduces new constraints and exacerbates those already faced by the Senegalese government and its water partners. Variables include water availability, variations in weather and extreme weather phenomena, and increasing uncertainty (World Water Council 2016).

Water is inextricably linked to climate, so global climate change and how it is managed worldwide has serious implications for water resources and regional development. Indeed, climate change impacts on water resources are already visible in the Sahel countries, including Senegal, in the forms of variation in the average and geographical distribution of rainfall, increase of evapotranspiration, recrudescence of periods of drought and heavy rainfall (World Water Council 2016) and recurrent droughts and floods. These resurgent effects have socioeconomic impacts which are weighing on the country financially, necessitating that the government implements urgent action to mitigate their effects and build resilience. These additional pressures, compounding the existing over-exploitation in many parts of the country, intensify the challenges ahead.

Senegal has implemented measures to mitigate the impact of climate change (Table 5), including awareness campaigns to ensure that the public is informed about climate change and related issues, such as mitigation and adaptation measures (Chitambi 2017), and adoption of new strategic planning instruments such as the National Action Plan for Environment (NAPE), the National Action Plan to Combat Desertification (NAP/TCD), the Senegal Forest Action Plan (SFAP), the National Strategy for the Implementation of the Framework Convention on Climate Change, the Program of Action on Biological Diversity, the Action Plan for the Protection of the Ozone Layer and the Hazardous Waste Management Plan (Environment Code). Senegal has also increased water supply strategically through a hydraulic mobilization policy, using dams and wells. Since 2015, Senegal has been actively implementing its National Adaptation Plan (NAP) and benefitted in 2016–2019 from the Scientific Support Project to the National Adaptation Plans processes (PAS-PNA).

Laws and codes are often essential for managing freshwater security in Senegal. The policy is developed through a decentralized process that increases local capacity that can be otherwise limited by the lack of financial and technical resources (Assetto et al. 2003). For water management to be effective and politically feasible, it must balance policy, economics, the environment and national security (Allen 2002). For example, Law No. 2001-01 (Environment Code), Law No. 81-13 (Water Code) and Law No. 2009-24 (Sanitation Code) remain to a large extent adequate to ensure the safety of the water. However, as circumstances evolve and weaknesses are identified, some codes are being revised in Senegal to adapt them to the current conditions.

Table 5 Water policy laws relating to climate change

Enabling legislation	Objective of climate change policy
Decree No. 2013–1270 of September 23, 2013 on the attributions of the Minister of Environment and Sustainable Development	– To establish the development of environmental education; – Manage a mechanism for monitoring trends in climate change and changes in the state of the environment; – Participate in international technical meetings dedicated to the protection of the environment, sustainable development, climate and biodiversity
Law No. 2001-01 of January 15, 2001 on the Environment Code	– Adopt new strategic planning instruments; – Put in place a national strategy for implementing Framework Convention on Climate Change; – Addressing desertification (land degradation in arid, semi-arid and dry sub-humid areas) as a result of various factors, including climatic variations and human activities; – Establish sustainable development that meets the needs of the present without compromising the ability of future generations to meet theirs; – Conduct environmental impact studies, such as effects on climate and atmosphere.
Law No. 81-13 of March 4, 1981 on the Water Code	– Deal with harmful situations related to water problems such as floods (and some floods) and droughts that are increasing with climate change
Law No. 2009-24 of July 8, 2009 bearing on the Sanitation Code	– Provide pumping stations to transport rainwater from their source to a treatment plant or receiving natural environment; – Develop a rainwater collection system that allows, after a rain, the effective evacuation of runoff water without causing the inundation of other public or private places, near or far
Law No. 96-06 of March 22, 1996 on the Local Authorities Code	– To ensure prevention, by suitable precautions, and intervention, by the distribution of necessary help, in the event of calamitous scourges, such as floods are accentuated with Climatic Changes

Some laws, such as Law No. 96-06 (Code of Local Authorities) have proven to be ineffective from the beginning because they were formulated without sufficient accounting for interdependencies and supported by limited municipal budgets.

Projects described in Table 6 allow sustainable development of water resources, including the improvement of knowledge of hydro-climatological data, water

Table 6 Some achievements in adaptation to climate change in Senegal (*Source* Ministry of Environment and Sustainable Development)

Sectors	Actions/infrastructure	Actors
Coastal zone	– Coastal protection works Direction – Dams and protective wall; – Reforestation at littoral level; – Coastal Act	Direction of Environment and Classified Establishments; Network of Parliamentarians for the Protection of Environment in Senegal; Third World Environment and Development
Agriculture/ Water Resources / Livestock	– Control of soil salinization; – Control of land degradation; – Landscaping and watersheds; – Anti-salt dikes; – Hydro-agricultural developments; – Sustainable land management practices; – Agroforestry; – Basins of retention, pastoral ponds	Direction of Environment and Classified Establishments; Retention Basins and Artificial Lakes Branch; Agency of Great Green Wall; Sustainable and Participatory Energy Management Project; Water and Forest Service; National Institute of Pedology; Senegalese Institute of Agricultural Research
Local governance	– Development of integrated territorial climate plans mapping of zones' vulnerability, carbon footprint; – Setting up and training of Regional Committees on Climate Change	*Texas Advanced Computing Center*; *United Nations Development Programme;* Direction of Environment and Classified Establishments; Regional Committees on Climate Change
Risk and disasters Management	– Establishment of an interdepartmental Crisis Management Operational Center conditioned by an integrated early warning system; – Floods management; – Installation of undersized structures against floods	Continuous Professional Development; National Agency for Civil Aviation and Meteorology; Direction of Environment and Classified Establishments; Direction of Planning Restructuring of Flood Areas; National Office of Sanitation of Senegal
Fisheries and biodiversity	– Creation of Protected Mayors Areas; – Aquaculture development; – Community Nature Reserves	Municipal Development Agency; Direction of Marine Protected Areas; National Parks Direction; International Union for Conservation of Nature

conservation, development of hydraulic infrastructures, management of risk, and environmental preservation, particularly in sensitive and fragile areas.

Senegal has also developed new guidelines, commonly known as National Adaptation Plans (NAPs), in coordination with the 16th Conference of the Parties on Climate Change (COP16), held in 2010 in Mexico. Thus, adaptation to climate change has been integrated into water resource planning in the medium and long term. Good water policy in Senegal is also based on promoting the active contributions of stakeholders in the design, implementation and management of water resource programs and projects.

Although Senegal has a sufficient supply of water during the rainy season, poor geographical distribution and high rainfall variability as well as inadequate management, lead to water scarcity in some areas. Thus, in spite of significant advances, water availability remains uncertain for areas facing quality problems (fluoride, water pollution), supply challenges (overexploitation of aquifers) and access, because of the very high cost of resource mobilization. Compounding these difficulties are insufficient budgets for the water sector. Regulation and enforcement are not consistently coordinated among ministries, and there has been inadequate investment in storage infrastructure due to recurring droughts and floods. These needs have been shortchanged because water resource management tends not to prioritize freshwater security in the climate change context.

In Senegal, water monitoring is mainly the responsibility of the Directorate of Water Resources Management and Planning (DGPRE) in collaboration with other national entities. However, water management in Senegal is implemented at the sector level, which limits the development of a comprehensive national water resource management strategy. Many different national authorities oversee various aspects of water management, such as policy, law creation and enforcement, delivery of services and consumption (Chitambi 2017). Thus institutional arrangements can be unclear and/or conflicting.

The number and cross-cutting nature of various authoritative entities creates dysfunction and therefore serves as a major constraint for freshwater safety. A big issue is the fragmentation of skills and lack of coordination among organizations responsible for implementing policies in Senegal and the other countries that share its basins, as well as questions of authority within and between countries and duplication of effort. Jointly, this fragmentation has undermined sustainable livelihoods (Murenga 2003) and driven economic, social and ecological costs to human societies and to the environment (Kouam-Kenmogne et al. 2006). At the same time, a certain level of redundancy has advantages in assessing natural land surface waters and integrating water resource management at the national level. In addition, Senegal must strengthen regional cooperation on water resource management as well as improve research, data collection and information-sharing on water resource assessment and management.

4.2.3 National Initiatives and Strategies for Responding to Climate Change in the Water Sector

The laws and codes described are a key mechanism for the adaptation of water resource management to climate change, but their implementation must balance mitigation and adaptation policies, and claim sufficient legal scope in relation to other land-use planning documents. Adaptation strategies emphasize water stress and drought management, which addresses adaptation for water demand and development of freshwater supply and flood risk management, which in Senegal has favored infrastructure protection (retention basins, dikes, etc.) over prevention and infrastructure adaptation. Water stress and flood risk management, as part of the National Flood Prevention Plan, must be developed and adapted in all vulnerable areas.

Responding to a “water crisis” is in itself insufficient. The real challenge is to adjust strategies to local contexts in order to overcome obstacles inherent to climate change. This requires the adoption of the right laws, the right policies, the right institutional guidelines and clarification of the roles and responsibilities of all stakeholders. As water governance is also a global concern complicated by cross-border water-sharing along the Senegal river (represented by the OMVS and OMVG frameworks), it is critical to pool resources and efforts among all partners and neighboring countries (predominantly Mali, Guinea, Mauritania and Gambia) in order to deal with the consequences of climate change, to strengthen the resilience of populations.

Governments must also coordinate their respective laws and policies that touch on a broad range of societal issues that impact, directly or indirectly, water resources and align management, service delivery and demand. Appropriate measures are likely to support a shared vision of the water sector and the pooling of means and ideas in order to ensure sustainable development of water resources in Senegal.

Achieving the Sustainable Development Goals–particularly Goal 6–requires effective and sustainable resource management. A reliable supply of water is a prerequisite for the economic and social development of any country. This, in turn, requires protection and equitable sharing of water resources (Guesnier 2010) through fair and reasonable governance and the management of water resources as a common, local and also global heritage whose vital value is recognized by all (Baudru and Maris 2002). Given the role of water resource management for climate change mitigation and adaptation, freshwater safety is clearly a development priority for Senegal, which has integrated various strategies for water protection, provision, saving, distribution, etc. Access to drinking water and sanitation in Senegal must be enabled by integrated management (Senegal National Blue Book Committee 2010), which is why Senegal has invested in reconciling economic development with environmental protection across the country for the benefit of present and future generations to align with the SDGs (including SDG 6).

Because of the urgency of water resource management to comply with the recommendations of various world water summits, Senegal has been dedicated to coordinating and enabling national and regional actors and programs that mobilize and secure water resources, such as the Office of Lakes and Waterways and the Agency for Promotion of the National Hydrographic Network (APRHN) (formerly the Office of the Lake de Guiers) to enhance adequate and sustainable management of resources to meet demand and supply for freshwater.

5 Conclusion

Water resources in Senegal are fragile and subject to the many pressures driven by human activity and compounded by climate change. The effects of climate change have become real as the frequency and intensity of droughts and floods increase. Water pollution in its various forms is increasing and contributes to the degradation of water quality.

Freshwater security strategies must account for demand, ensuring that any calculation and approach reflect "real" needs as expressed by the population. Solutions must first address demand management before increasing net water supply, where possible. Mobilization of additional water resources to support the overall demand must include conventional as well as unconventional water resources (e.g., rivers, lakes and water re-use).

Programs must focus on water resource preservation, including from wetlands and other aquatic environments. Particular attention must be paid to the preservation of groundwater resources, including appropriate measures for avoiding overexploitation and pollution. Effective water management is based on relevant, comprehensive and reliable information and decision support tools. Water quality and quantity measurement networks must be maintained and modernized and information must be accessible to stakeholders involved in water management as stipulated by principles of good governance. To monitor progress and disseminate good practices, observatories and water information systems to monitor climate change effects and impacts on the water resources of the country must be established.

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