Chapter

Water Resources and Their Management in an Increasing Urban Demography: The Case of Dakar City in Senegal

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Abstract

The United Nations classifies Senegal as a water-poor country (less than 1000 m^3 per capita of freshwater reserves) and about 20% of its population did not have access to a drinking water supply (estimates of 2015). Economic growth and the fight against poverty in Senegal depend essentially on the availability of water for the development of agricultural and industrial activities, in addition to satisfying domestic uses. As a developing country, Senegal's human, monetary and institutional capacities are often limited to providing clean and sufficient water efficiently to its citizens. This article examines the management of water scarcity in the city of Dakar (capital of Senegal) in a context of increasing demography and urbanization. However, Senegal has sufficient water resources to meet the demand if the available resources are properly managed. As a result, several initiatives are under way in Senegal to mitigate water problems and protect the country's water resources: reducing pollution, improving access to drinking water and setting up rational and equitable exploitation with a constant concern for sustainable development.

Keywords: water resources, management, urbanization, water scarcity, water policy

1. Introduction

The Republic of Senegal, located at the extreme western tip of the African continent, covers an area of 196,722 km^2 for a population of 13,508,715 inhabitants [1]. There are three climatic domains in Senegal, from south to north: the southern Sudan, northern Sudan and Sahelian domains, each domain having two variants (coastal and continental) [2]. Located in the tropical zone, Senegal has a Sudano-Sahelian climate with annual rainfall ranging from about 1250 mm in the south to just over 200 mm in the north. The potential of Senegal's water resources (surface and groundwater) is important. Three rivers originating from Guinea (the Senegal, Gambia and Kayanga rivers) irrigate a large part of the country [3, 4]. Alongside these two large rivers, there are smaller rivers characterized by intermittent flows (Casamance, Kayanga, Sine-Saloum (**Figure 1**). Five management and planning units (PMUs) have been established for the management of these different categories of water resources (1. Senegal River Valley, 2. Peanut Basin, 3. Senegal-East, 4. Casamance, 5. Cape Verde Peninsula) subdivided into 28 sub-units (**Figure 1**) [5].

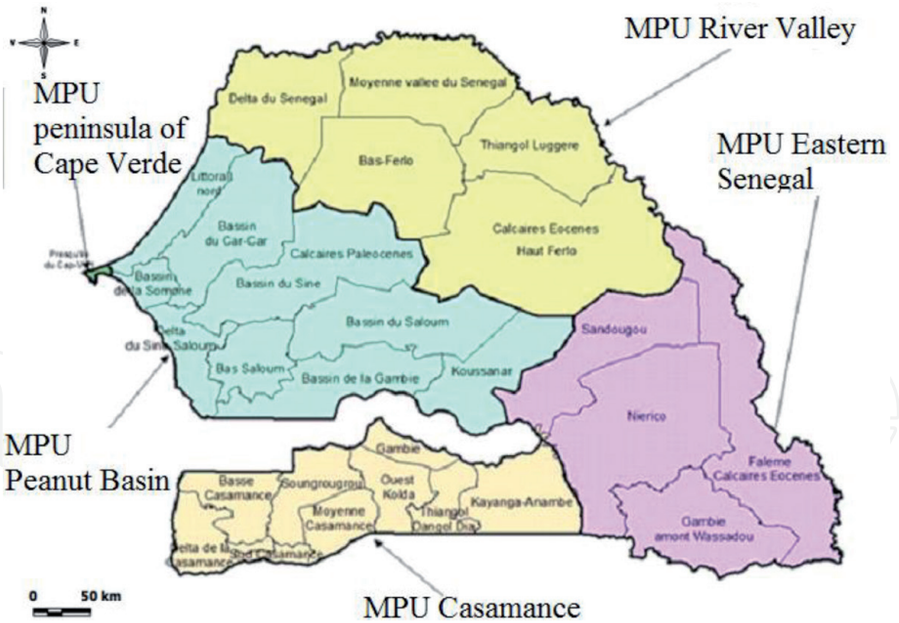

Figure 1.
Water resources management and planning unit in Senegal (source: DGPRE).

Groundwater is also an essential component of Senegal's water potential and generally consists of four major aquifer systems corresponding to the main geological formations: the superficial aquifer system or "terminal complex" (Quaternary); the intermediate aquifer system (Eocene and Paleocene); the deep aquifer system (or Maestrichtian); the aquifer system of the basement [6].

In Senegal, the potential for water resources (surface and groundwater) is high and the availability of renewable water is currently estimated at around 4747 m^3/inhabitant/year [6]. Estimates indicate about 80% of its population have access to a drinking water supply in 2915 [7]. However, the United Nations classifies Senegal as a water-poor country with less than 1000 m^3 per capita [8]. Thus, the issue of water has become a national concern given the range of issues facing the sector [9]. These problems include, among others, climate variability, vulnerability of water resources, poor distribution of water availability in space and time, poor water quality in some places. The water crisis can be explained both by the absolute lack of physical availability, poverty and inadequate water management policies. In general, Senegal has a large potential for water resources, but its uneven distribution, its overabundance in the rainy season often causes catastrophic floods and shortage in the dry season causes severe drought conditions resulting in crop losses, livestock, public health problems and environmental degradation [10].

These numerous factors, such as global warming (recurring and severe droughts and floods), contamination of drinking water and lack of investment in water resources have exacerbated the water crisis, whose role in the achievement of its development objectives is incommensurate [11]. Its economic performance and the reduction of poverty depend mainly on the availability of drinking water. A set of economic activities in Senegal (agriculture, industrialization, energy production and tourism) are inherent to the availability of water resources. At the same time, access to safe and sufficient water is necessary for the well-being of the population.

Senegal is home to some major cities, namely Dakar, Pikine and Touba, Thies. The capital of Senegal, Dakar, was founded by Faidherbe in 1862, on the site of a fishing village. It was the capital of the AOF from 1902. Enjoying a strategic geographical location, the city is since the colonial era, a maritime and air junction between Africa, Europe and America. It covers an area of 550 km^2 and has about

23% of the total population of Senegal estimated 15,256,346 inhabitants, according to demographic projections in 2017 [12]. It is the largest city in Senegal and is its political, administrative, economic and cultural center.

The water cuts that have become commonplace in many parts of the country, affect more seriously the capital, Dakar where the daily deficit is estimated at more than 20,000 m^3. With a consumption of 360,000 m^3/day, the capital struggles to quench its thirst and satisfy its water needs. The Senegalese Water (SDE) needs 300,000 m^3 per day to meet the demand of the Dakar population, but it drags a heavy deficit in the correct supply of water. At present, a large part of the city's population does not have access to running water 24 hours a day. From 200,000 subscribers in 1996, the SDE is now struggling to satisfy its 800,000 current subscribers.

In Senegal, the urban population is estimated at 6,541,504 people in 2015 including 3,360,728 for the Dakar region [12]. In these urban areas, the rate of access by connection within the covered perimeter stabilizes in December 2015 at 88.9% with 96.2% for the Dakar region. Thus the total production of water was 172.27 million m^3 against an annual forecast of 169.7 million m^3, or 110% of realization. For the Dakar water supply system (WSS), production reached 124.2 million m^3 [13]. As a result, there is a tendency to saturate the facilities of the Dakar AEP (for example, Mékhé is running at almost 24 hours). Because of the size of the population of Dakar, part of this population does not have access to either an improved water source or running water. For example, some outlying districts (in the suburbs of Dakar) do not receive water every day, while others almost never receive water because of the low water pressure.

In some cities in Senegal, the biggest challenge in the city is often lack of water supply. For example, residents obtain water from individual connections, public connections, wells, springs and water vendors that are not monitored [11]. In addition, water pollution does not save tap water and its consumption can often be harmful to the health of populations. It is for this reason that a good part of the population prefer bottled water for their consumption.

The city of Dakar has been chosen for the management of water scarcity in a context of growing demography and urbanization. Due to increased water demand in the Senegalese capital, residents of some neighborhoods are frequently randomly supplied with running water, with the suburbs being the most affected. The ever increasing hydraulic equipment fails to meet the needs of the population. The difficulty of supplying drinking water, which often strikes the Dakar inhabitants, comes in the context of global warming and the removal of resources that are increasingly important. Suddenly, the Senegalese government must expand its production capacity and distribution networks if it wants to keep pace with unprecedented population growth.

2. The challenges facing the water sector in Senegal's main cities

As a developing country, Senegal's human, monetary and institutional capacities are often limited to providing clean and sufficient water efficiently to its citizens. Water scarcity in large cities like Dakar is chronic and continues to worsen with increasing urbanization and pollution of the resource. Most of the time, SDE water disruption notices are the norm in urban areas (**Figure 2**). Water scarcity may worsen in the future for several reasons: (1) increased water demand due to rapid urbanization, (2) poor water management, (3) degradation continuous water sources, (4) irregular weather conditions, (5) old and dilapidated water infrastructure, and (6) the incompetence of the water distribution companies.

2.1 Growing populations and urbanization

Senegal, like many other developing countries in Africa, is experiencing rapid urbanization. In 1960, its population was estimated at 3.207 million people and in 2017, 15.851 million people (**Figure 3**) [14]. The urban population has grown from 738,000 in 1960 to 7409 million in 2017 (**Figure 4**). This urban population, which accounted for only 23% of the total population of the country in 1960, therefore rose to 45.9% in 2015. The share of the urban population increased considerably between 1960 and 2014. The data show that 23% of the population living in urban areas in 1960 increased to 45.9% in 2015. The share of the population living in urban areas has increased dramatically in Senegal in recent decades. Thus, the urban growth rate is 4.78 and 3.46%, respectively over the periods 1960–1985 and

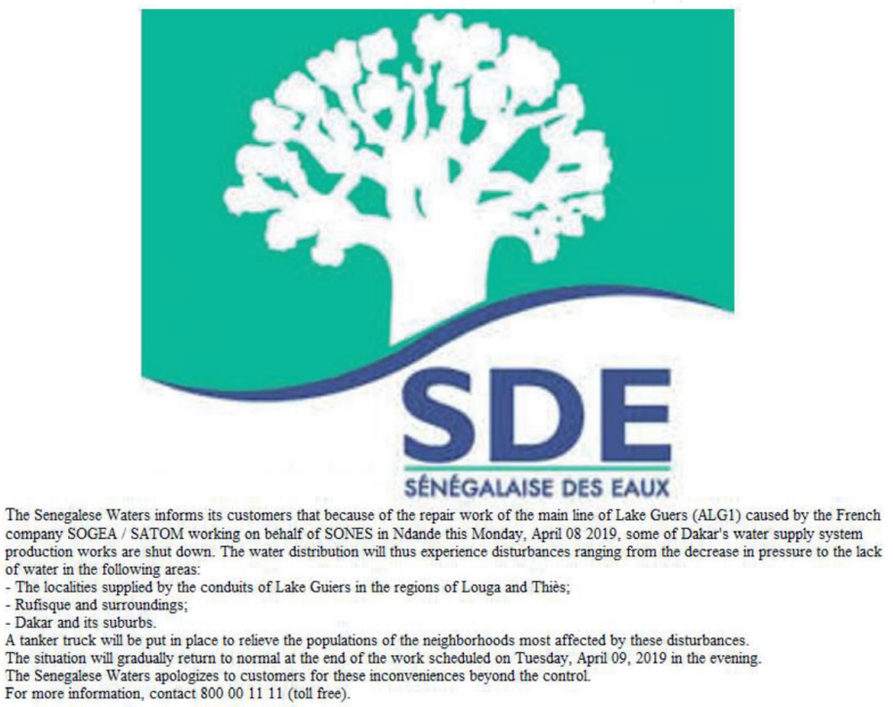

Figure 2.
Notice of disturbance of water supply by Senegalese water.

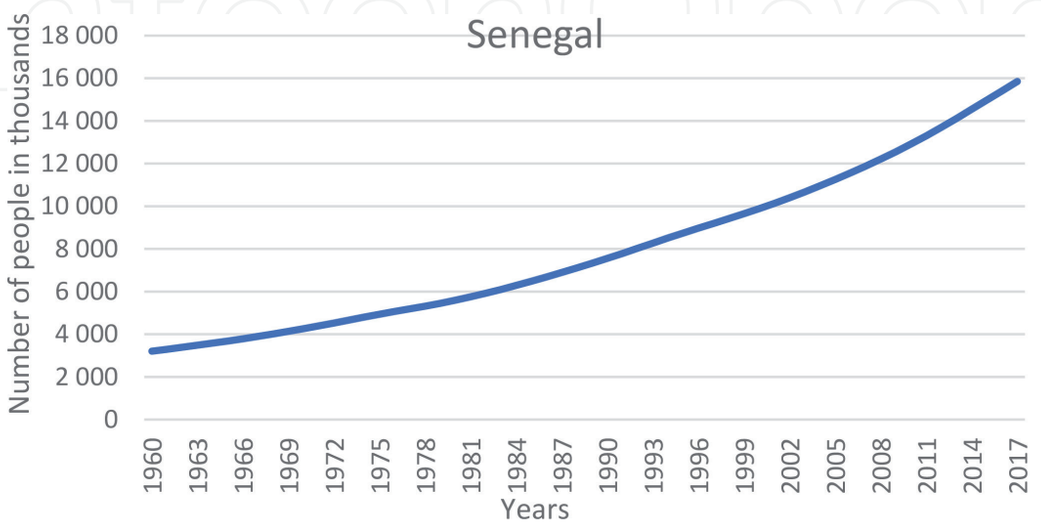

Figure 3.
Senegal's total population: semi-annual estimates of the resident population from 1960 to 2017 (source: World Bank database).

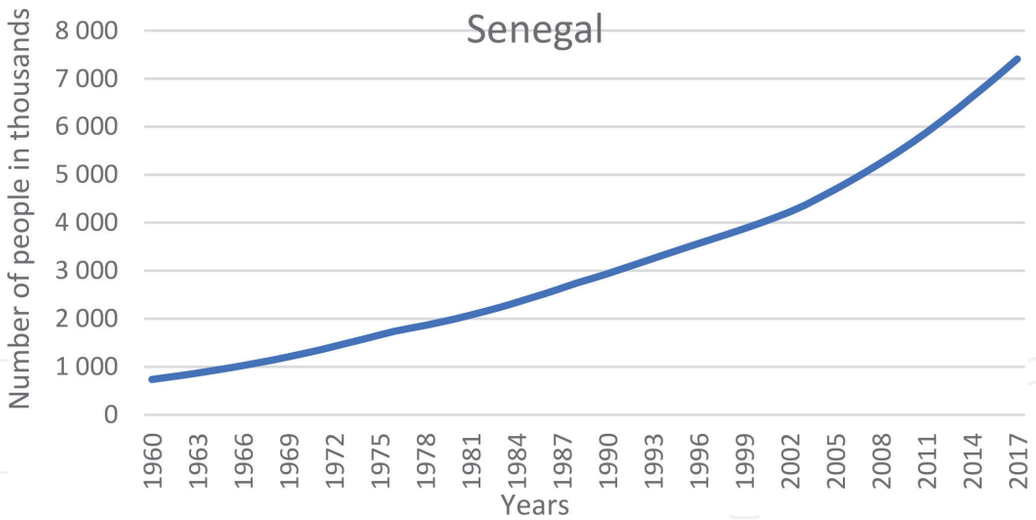

Figure 4.
Urban population of Senegal: semi-annual estimates of the resident population from 1960 to 2017 (source: World Bank database).

1985–2015. This rapid pace of urban growth can be explained by the drought of the 1970s [2] and its corollary rural exodus.

According to United Nations estimates, the urban population of Senegal will increase to 11.778 million by 2030, which will represent 53.24% of the national population (22.123 million in 2030). As for the city of Dakar, its population will increase to 4.339 million by 2030 (**Figure 5**), which will represent more than 38.84% of the urban population [14]. Urbanization does not only mean swelling of the population, but also an increase in the area requiring better services. The rural exodus from sub-Saharan Africa is the main cause of the rapid growth of the urban population. To cope with the strong urban growth, water production has risen drastically, from 95.32 million m^3 in 1997 to 172.27 million m^3 in 2015 (**Figure 6**). The growing population (**Figures 4** and **5**) continues to put pressure on available water resources, resulting in a reduction in per capita water availability. According to projections, 70% of the world's population will live in urban areas by 2050 [15]. The growing population continues to increase the demand for water for domestic, industrial and agricultural purposes.

Africa currently has three main causes: (1) displacement of people from rural areas to urban centers; (2) the increase in the urban population, especially when economic opportunities extend to previously rural areas; and (3) the development of previously rural areas in urban areas due to increased economic activity [11]. Although it is difficult to define exactly an urban environment, it is widely accepted that the term could be determined by location, size of population and percentage of non-agricultural activities, pressures on environmental resources such as water. In recent years, urbanization of rural areas has increased considerably.

Although urbanization has many economic and social benefits, it causes many environmental problems such as loss of biodiversity, air and water pollution and increased pressure on arable land [16]. It has directly affected the availability and quality of water due to increased demand and pollution resulting from its many applications. Many developing countries are facing the problem of access to safe drinking water. In Senegal, rapid urbanization has prevented some cities from coping with the huge demand for clean and sufficient water. In Dakar, faced with strong urban growth (an average of 120,000 people per year), the improvement and expansion of infrastructure is very expensive and, as a result, does not generally keep pace with the growth. This makes wastewater management very problematic.

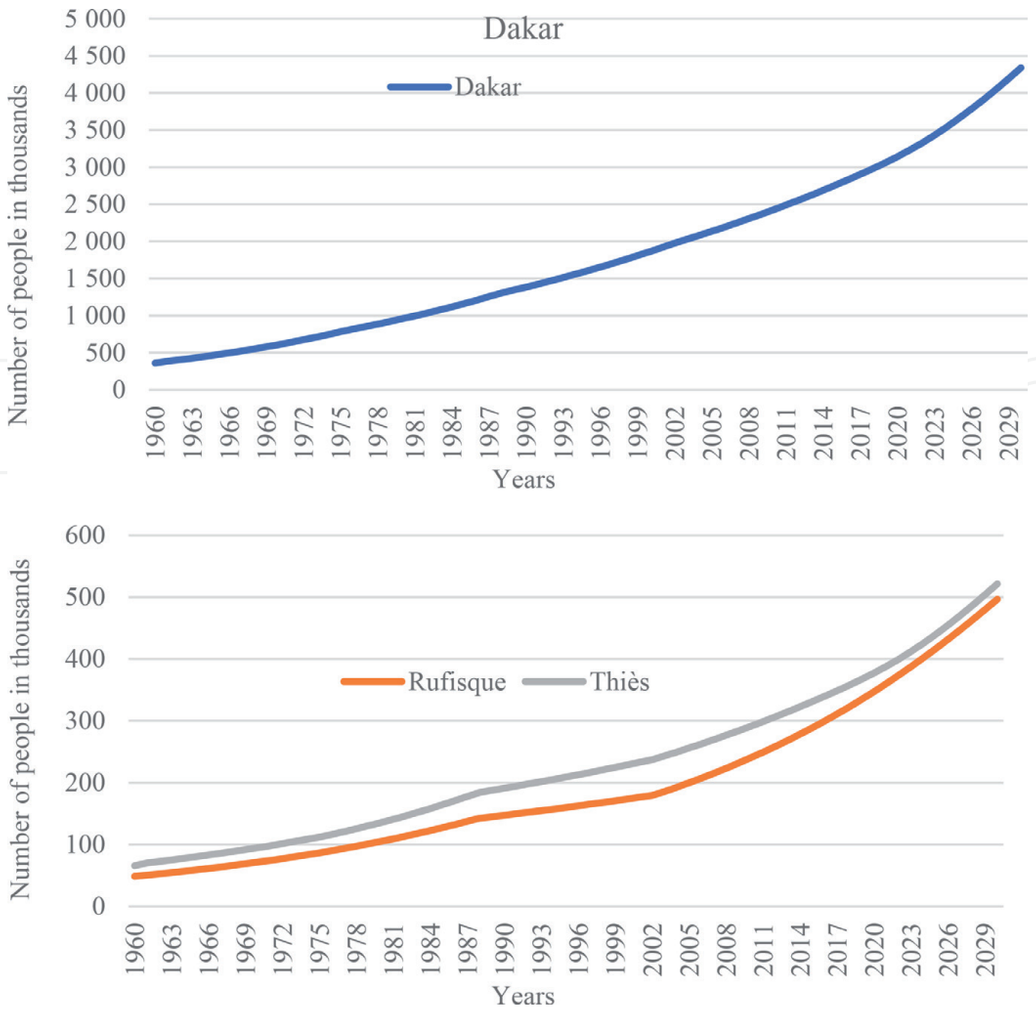

Figure 5.
Urban population of three cities in Senegal: semi-annual estimates of the resident population from 1960 to 2035 (source: World Bank database).

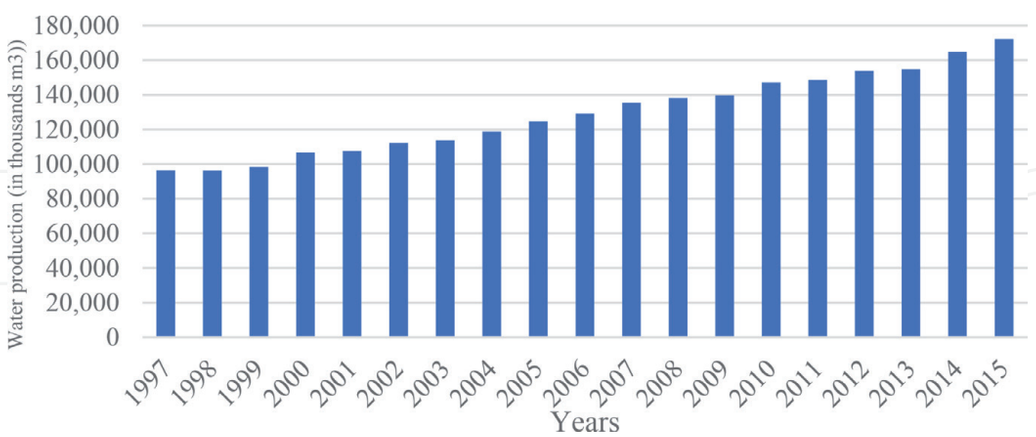

Figure 6.
Evolution of water production by the SDE (SONES perimeter) from 1997 to 2015.

In addition, pollution from agricultural production (urban farmers irrigating their crops with untreated wastewater) and industrial production has become one of the biggest challenges for Senegal's water resources [17]. In addition, because of the growing population and its corollary the increase in water needs, the lack of protection of water sources, the scarcity of the resource and the pollution it faces are a source of hindrance improved and protected water.

2.2 Contamination of available water

The water sources available in Senegal are frequently affected by pollution of chemical, microbiological or thermal origin. Chemical contamination of this water, often used for drinking, can result from the presence of excess nutrients, acidification, salinity, heavy metals and organic pollutants [18]. Reports indicate that industries at 32.5% and agriculture at 14% are the sectors that contribute most to the economic development of any population [19]. On the other hand, 80% of the water contamination comes from these two important sectors. Agricultural practices, industrialization, mining, and open sewer lines parallel to the water system are responsible for most of the problems affecting water quality (**Figure 7**).

The lack of adequate management of liquid and solid waste results in the deposit of this waste directly into water bodies (**Figure 7**), which contributes to the vicious circle of water destruction. In fact, the growth and development of agriculture in Senegal has led to an increase in the use of fertilizers. Agrochemicals end up in bodies of water causing considerable pollution. In addition, most industrial water treatment plants discharge partially treated or totally untreated effluents into surface water sources, which often contain high levels of toxic substances. These pollutants and other pollutants of domestic origin continue to cause environmental problems [11]. Many Senegalese living in informal urban areas lack access to safe drinking water, often resulting in multiple epidemics that affect their health and livelihoods. In addition, large leaks in water pipes (**Figure 7**), dilapidated infrastructure and illegal connections still hinder the availability of drinking water supply. Due to the large leaks in the water channels, the treated water is sometimes contaminated before reaching the users.

Figure 7.
Water quality degradation factors in Senegal: (1) CSS effluent discharges into Lake Guiers; (2) water line between the lake and Dakar damaged; (3) domestic uses on Falémé; (4) equipment for washing gold on the banks of the Falémé.

2.3 Degradation of water sources

The main sources of water in Senegal, beyond the groundwater, are surface water (rivers and lakes that are very attractive for agriculture and populations). The watersheds that cross the national territory have experienced two major pressures in recent years on their water resources: (a) pressures from natural sources (climate variability and change); (b) anthropogenic pressures (dams, rapid population growth and various productive activities) [3]. These pressures have had repercussions on the natural environment of the basin and its ecological diversity [20]. They have resulted in watershed degradation that has diverse and unpleasant consequences, often resulting in increased runoff, flash floods, reduced infiltration, erosion and siltation, to name just a few examples. The impacts of human activities (development, rapid population growth and various productive activities) related to the exploitation of resources for the satisfaction of the daily needs of the populations sometimes manifest themselves negatively on all the natural resources of the basin. Environmental protection of the watershed is important for the safety and sustainability of urban water supply. A healthy ecosystem ensures quality water for cities, reducing treatment costs and the danger to human health.

Activities such as gold mining are causing degradation of natural resources in the basin through reduced vegetation cover and deterioration of water quality. With the use of chemicals in the practice of this activity (leaching technique with cyanide or mercury and tailings ponds), pollution of water resources in the basin is multiplying. With the major developments (Diama and Manantali dams), flow control and water permanence in the basin have led to the partitioning of mining activities (extraction and washing with mercury release) and agricultural activities (large consumer fertilizers and pesticides) with far-reaching consequences [21]. This results in severe degradation and deterioration of animal and plant resources [22]. With this destruction of freshwater ecosystems, the Senegal River finds itself in a situation of loss of some of its functions, how important, and may alter its hydrological functioning [23].

2.4 Invasive species

Biotic factors affect water resources. For example, the presence of invasive species such as hyacinth, Salvinia, Pistia and Typha causes ecological imbalance. The proliferation of plants and invasive species in major bodies of water, including aquatic plants, is of increasing concern. Typha and algae are plants that contribute to the deterioration of the water quality of the lake because of the very toxic substances secreted that can reduce the good water quality (**Figure 8**). They degrade surface water resources and may even have contributed to the eutrophication of freshwater lake ecosystems. These invasive species block rivers and greatly influence water quality. In Senegal, built dams (such as Diama and Manantali on the Senegal River) play an important role in the reliable and sustainable supply of water. However, these developments, by permitting the permanence and softening of the water, have led to the proliferation of certain species such as Typha australis and *Pistia stratiotes* and the appearance of new species such as Potamogaton Schweinfurthis and *Ceratophyllum demersum* [24]. Overall, the country faces serious problems of resource protection.

Several environmental impacts, at the origin of the deterioration of water quality, result from the invasion of water bodies by vegetation [25]: siltation of hydraulic axes; the formation of caps with loss of hydraulicity; increased evapotranspiration; the threat to adjacent wetlands; the decrease of the dissolved oxygen level. The proliferation of macrophytes can therefore make it difficult to access water, slow down the flow of water in the canals, block the pumps.

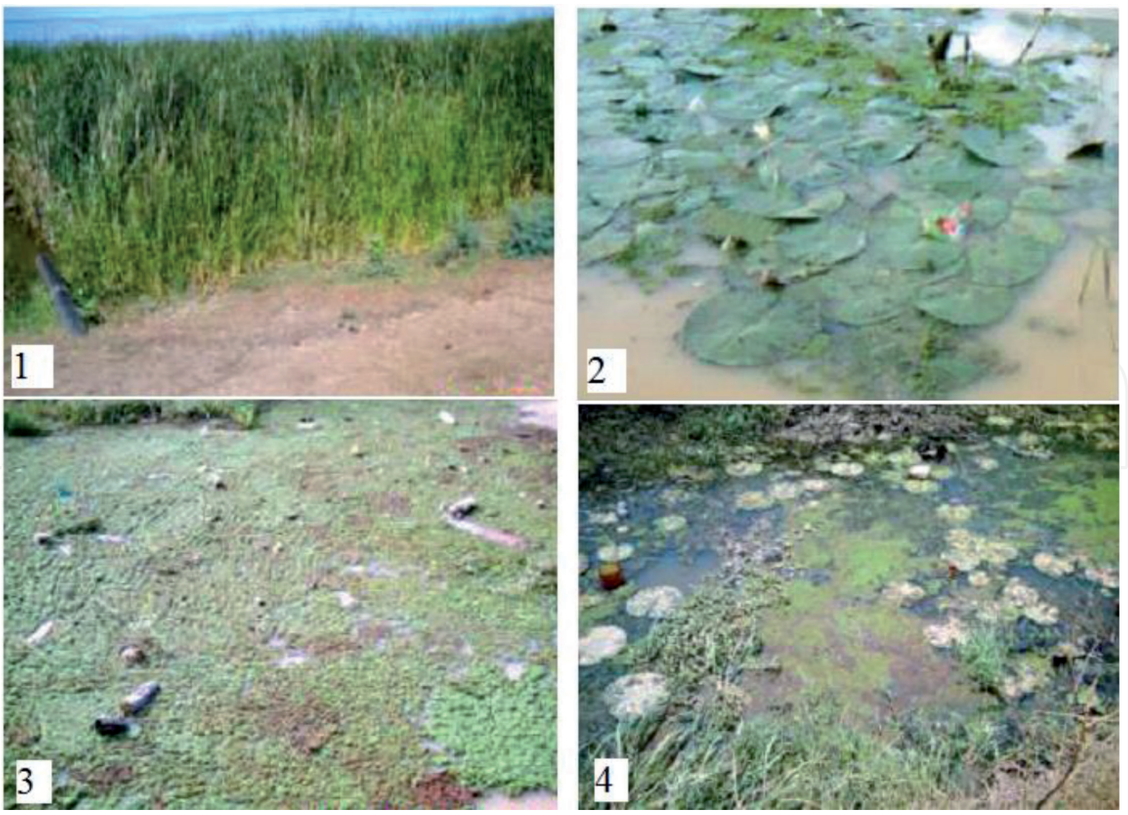

Figure 8.
Degradation of water quality in Senegal by invasive plants: (1) Typha australis on the lake of Guiers; (2) freshwater algae in the lake water; (3) invading lake water plan; (4) degradation of the water quality of the lake.

3. Interventions on the water challenges

Despite the water problems facing urban populations, Senegal has sufficient water resources to meet demand if available resources are properly managed [6]. Senegal's internal renewable surface water resources are estimated at 23.8 km^3/year and renewable groundwater resources are in the order of 3.5 km^3/year. The common part between surface water and groundwater is estimated at 1.5 km^3/year and internal renewable water resources estimated at 25.8 km^3/year [26]. The diversity of water resources offers opportunities for exploitation ranging from surface water abstraction to the use of boreholes in areas with limited surface water resources [10].

3.1 Implementation of relevant policies

Like many other countries, Senegal has adopted several policies at the national and regional levels to guide the conservation and management of its water resources. It has put in place crucial reforms in the water sector which have led to the promulgation of certain regulatory texts and conventions, such as Law 81-13 of 4 March 1981 on the Water Code creation of various associations of water resource users [3]. Thus, in 1995, the public authorities give a very marked inflection to the organization of the sector, as well in urban as rural. Indeed, a reform of the urban water subsector was initiated through the Water Sector Project, which led to the separation of drinking water from sanitation. This reform embodied by Law No. 95-10 of 7 April 1995 resulted in the creation of two different entities that are responsible for the management of the sub-sector of urban water: the National Water Company of Senegal (SONES), a heritage company, and Senegalese Waters (SW), operating company, private operator [6, 27].

3.2 Groundwater, an important additional source in urban centers

The exploitation of groundwater through wells/boreholes is widespread but is generally not regulated or monitored in many parts of Africa. As in many cities in Africa, there is a growing demand for groundwater in Senegal's main cities, mainly fueled by boreholes. Senegal has groundwater resources of about 4 billion cubic meters renewable every year and all the drilling currently carried out that pump this resource mobilizes a maximum of 6% of this resource. Thus, in terms of water availability, Senegal is relatively well endowed, especially since this resource is captured at depths that vary around 100 m. Freshwater stored in underground aquifers can be used effectively to divert the consequences of climate change. The availability of groundwater resources and their replenishment rates are uncertain, posing a serious problem for their management and protection [28]. Therefore, in the future, improved regulation and monitoring of groundwater withdrawals, in addition to appropriate management, will be essential for effective and sustainable monitoring of available water resources in Senegal's cities.

For the abstraction of groundwater in Senegal, dewatering works can be grouped into five major systems in order of importance: boreholes and modern motorized wells; modern wells and wells equipped with wind turbines; modern wells and wells equipped with hand pumps; modern wells with manual or animal drainage; traditional wells with manual or animal drainage [29]. Over the past decades, Senegal has therefore made significant efforts on national resources and with the support of its development partners to meet people's drinking water needs from groundwater. However, it must be recognized that despite the large investments, the demand for drinking water is far from being fully covered.

3.3 Monitoring of conditioned water

In the various cities of Senegal, a good number of inhabitants use bottled water in bottles and sachets. From tap water to the bottle, to the plastic bag, there is a ladder of confidence in the quality of the water to drink, while the older practices of water consumption paradoxically provoke an attachment territorial, while presenting a status apart, since they are detached from any commercial thought. This is why it can be said that modern conditioning practices such as bottling and bagging create a new image of drinking water. Calibrated or formatted through models of different capacity, it pays off, and access is through formal and informal commercial distribution networks. Bottled water is present almost everywhere, from the big supermarket sign to the small neighborhood retailer, to the petrol stations, while water in sachets is mostly sold in small shops, in the urban neighborhoods of Dakar (Medina, Rebeuss ...) for example, but also beyond, the capital [30].

Sachet water conditioning in Senegal is mainly in the informal sector of the economy. Anyone who has access to tap water and owns a refrigerator can create a "small business." This is a common practice in working-class neighborhoods. For modest families, it provides extra income. This ranges from bagging water in fine and transparent plastics, without any indication of source or quality of water, to water bags subject to prefectoral authorization with indications of the origin and characteristics of contained water. It is the work of individual and family initiatives, and represents an activity that involves the respect of certain health standards. The conditioning of the water is more a practical necessity, that of providing the body with the occasional need for water, with a taste that is supposed to be better than that of tap water. In Senegal, its consumption reaches significant proportions. In the streets of Dakar, at any time, it is marketed in bottles and especially in small plastic bags, exchanged for parts of 25 or 50 F CFA. Numerous, by the way, are those who

have invested in this business, from children to adults, hence the importance of setting up a structure for its supervision.

3.4 Rainwater harvesting

There is a regional imbalance in the recovery and distribution of water, and therefore in water security. In addition, the uneven distribution and variability of rainfall in sub-Saharan Africa impacts the annual water availability of households. In addition, climate change is constantly increasing extreme events such as droughts and floods with disastrous consequences for people's lives. Sub-Saharan Africa has abundant rainfall, but it is not evenly distributed and highly seasonal. Senegal experiences droughts and floods every year. It receives rainfall ranging from 200 mm in the dry parts (Sahelian domain) to more than 1500 mm in the southern and southeastern parts of the country (southern Sudan) [2]. Senegal's renewable freshwater resources vary considerably with time and region and cannot adequately meet the growing demand in large cities. Water harvesting could be an additional means of alleviating the problems of drought, scarcity and depletion of water resources. Surface water is scarce and groundwater exploitation is often not profitable. As a result, sustainable rainwater harvesting systems can be a very important solution to the problem of water scarcity. However, the collection of rainwater for domestic use in cities is not sustainable due to the configuration of the building and the diversity of activities that pollute the environment. However, for this rainwater to be a solution to the permanent shortages of water currently observed, it should first be captured and then treated before use [11].

3.5 The construction of additional hydraulic infrastructures

Very important results were obtained during the 2005–2015 decade, marked by the implementation of the Millennium Drinking Water and Sanitation Program (PEPAM), both in terms of the definition of policies and strategies, the mobilization of financing and setting up of access to services. However, there are still major obstacles still to be overcome, including the still inefficient management of drinking water quality issues due to localized pollution of certain groundwater or surface water levels, accessibility still average water points due to the low rate of access to water by connection to homes and the average density of distribution points in rural areas ... [7]. To remedy this, the Government of Senegal, under the Ministry of Hydraulics and Sanitation, has launched projects to increase water infrastructure to combat water scarcity. Such infrastructures should make it possible to increase qualitatively and quantitatively access to water and sanitation services, promote sustainable management of water resources, reduce the incidence of water-related diseases, strengthen sector governance through targeted institutional support, with a view to signing a sector budget support program.

4. Strategies to address the water scarcity in Dakar

The shortage of water, temporary or structural, results from a quantitative and/or qualitative insufficiency of the available water resource compared to the demand. His study contributes to the reflection for a better distribution and preservation of water. Water scarcity is a critical issue when it comes to dealing with the sustainable development of societies. A precise study of the different types of conflicts observed is necessary. These occur recurrently between areas of use, commercial and non-market water uses—in practice urban water supply and irrigation [31].

Difficulties in the supply of drinking water in Dakar are also due to a poorly controlled urbanization policy, which translates into a sort of "let do" in the settlement of the populations, which proceed to anarchic constructions, in zones undeveloped. The housing and housing crisis ended up condemning people to a frantic race to find a piece of land [32].

To this problem is added that created by the increase in the number of consumers, which aggravates an already tense situation, due to the natural increase of the population which largely benefits Dakar and the sustained movement of immigration as well as of the rural exodus, the migrants having as their point of departure the "low quarters," already confronted with the precariousness of the system of supply of drinking water. Given the increase in water demand with the high population growth, in a context of climate change, Senegal, like many countries in the world, is beginning to have an imbalance between its water supply and the demand of citizens in perpetual rise. To remedy this, the different actors in charge of water resources issues (government institutions, development partners, civil society and the private sector) must undertake a sustainable management of the water resources that are available on the territory.

For Lacoste [33], "In the third world countries, municipalities in big cities must now respond to many demands for a fairer distribution of water between rich neighborhoods and slums or slums. Some have water in abundance, while the others, where the vast majority of the population lives, have almost none. How, in these conditions, to make reach a maximum of populations with a drinking water? The answer to this question lies in a significant increase in the budgets allocated to the financing of social facilities. Having understood this, the Senegalese authorities in charge of the issue have approached access to drinking water as a public health imperative, which has become a social priority for the country. This is even more true since the links between water and health on the one hand and water and economic development on the other are no longer in doubt [32]. As access to drinking water requires undeniable financial efforts, innovative strategies are being put in place to enable a larger section of the population to benefit. These strategies are based on a concerted approach that brings together non-governmental organizations (NGOs), the private sector and governments in synergy.

Dakar's drinking water supply has long been a major problem in Senegal. Indeed, since the 1980s, Dakar had begun to register a significant deficit in the water supply of its population. From 4% in 1984, the deficit exceeded the threshold of 30% in 1991 to reach the record level of 100,000 m^3/day in 1998. Thus, to prevent this situation from becoming a disaster, Important means have been put in place to manage this deficit, but this cannot completely solve the problem [34]. The schematic flow of the current Dakar water supply system in 2013 is illustrated below in **Table 1** [35].

The history of Dakar's water supply began in 1949, when groundwater from the sub-basaltic aquifers of Mamelles and Point B, as well as the quaternary sand aquifers of Thiaroye, were drilled and developed. Then, in 1960, to meet the increase in demand for water, taking into account the risks of over-pumping aquifers near Dakar, new Paleocene limestone aquifers were exploited at Pout and Sébikhotane. The steady rate of increase in water demand in the following years necessitated the continued development of water resources. Consequently, in 1970, aquifers of the Maastrichtian layer along the northern coastal zone (North Coast) were exploited and the surface waters of the Senegal River were taken from Lake Guiers [35]. In the absence of sufficient local drinking water resources, Dakar is supplied by a water supply system from Guiers Lake. This system transports water from the Senegal River to the capital over 250 km and represents 50% of Dakar's drinking water supply [24]. The strong population growth of recent years has led to the saturation

Water treatment plant	**Year in service**	**Extension**	**Nominal capacity (m^3/d)**	**Hourly volume (m^3/h)**
Ngnith factory	1971	2000 (transition to a theoretical capacity of 60,000 m^3/d)	40,000	1667
Keur Momar Sarr factory	2004	2008 (transition from 65,000 to 95,000 m^3/d) 2011 (transition from 95,000 to 130,000 m^3/d)	130,000	5417

Drilling	Number of drilling	Year in service	Extension	Nominal capacity (m^3/d)	Hourly volume (m^3/h)
Northern littoral drilling (Gueoul at Ndande axis)	9	1999	—	35,000	1591
Kelle/Kebemer drilling	7	from the 1970s	—	30,000	1364
Pout Nord drilling	13	from 1978 (PN6 and PN10)	—	47,248	2148
South Pout drilling	7	from 1979 (PS5)	—	20,000	909
Pout Kirene drilling (including KSW)	4	1993 (PK3, PK5)	—	6000	273
Sebikotane drilling	1	1957	—	4500	205
Thiaroye drilling	2	1951	Not used due to deterioration of water quality	0	0
Point B/Mamelles/ Point G drilling	8	1966	—	18,000	818

Booster	Year in service	Extension	Nominal capacity (m^3/d)	Hourly volume (m^3/h)
Mekhe booster	2006	—	233,557	10,155
Carmel booster	2013	—	241,708	10,509

Pumping station	Year in service	Extension	Nominal capacity (m^3/d)	Hourly volume (m^3/h)
Thiaroye factory	1951	—	29,900	1300
Point B factory—Madeleine pumping	1966	—	20,700	900
Point B factory—pumping Mamelles	2006	—	64,400	2800
Point B factory—pumping point	1966		7000	700

Transmission line	Year	Characteristics

Water treatment plant	Year in service	Extension	Nominal capacity (m^3/d)	Hourly volume (m^3/h)
ALG1 (Ngnith pipe)	1971	DN 1000 PN 25 steel		
ALG2 (driving KMS)	2004	DN 1200 PN 25 cast iron		
800 Sebi	2008	DN 800 cast iron		
600 discharge Thiaroye	1951–1994	DN 600 cast iron		
700 output tanks PTY	1951	DN 700		
800 Mamelles repression	1993	—		
600 South Pout repression	—	DN 600 PN 16 steel		
Tanks	Year	Characteristics		
Tanks of Thies	1971 (R1, R2); 2005 (R3, R4)	25,000 m^3		
Tanks Y-point	1951	10,000 m^3		
Tanks of Madeleines high service	1966	1200 m^3		
Tanks of Madeleines low service	1966	6000 m^3		
Tanks of Mamelles	2003	35,000 m^3		
Tanks of G point	1966	5000 m		

Source: JICA study mission based on information provided by SDE.

Table 1.
Main lines of major structures in the water supply network for the Dakar region.

of production and transfer capacities. Currently, nearly 1 million people in the capital suffer from intermittent service. The Dakar region, which comprises 25% of Senegal's population and concentrates 80% of the country's economic activities, has its water needs estimated at around 320,000 m^3/d, which represents nearly 75% of the total production water supply [35]. In 1993, 80% of water consumption in the Dakar region consisted of groundwater, while the remaining 20% came from Lake Guiers. In 2013, this ratio was reversed due to over-exploitation of groundwater [36].

To ensure an optimal water supply for the city of Dakar and fight against water scarcity, the government has mobilized since 2014 an additional production of 100,000 m^3/day through the realization of 60 boreholes and the rehabilitation of seven others. This additional volume represents 26% of the average daily production (360,000 m^3). From 2014, a peak of 390,000 m^3/day is reached with the commissioning of Bayakh's new drinking water production center in July 2018. This production is provided by the factories of Keur Momar Sarr and Ngnith installed on the site of Guiers Lake (40%) and boreholes of the North Coast, South Pout, Pout Kirène, Kelle-Kébémer and Dakar (60%). With the commissioning of the two Bayakh-Thieudème-Diender and Tassette phases, additional production will reach 179,000 m^3/day overall, or nearly 50% of the capital's peak needs.

From January 2011 to June 2018, production increased by 22%, from 297 million L/day in December 2011 to 355 million L/day in June 2018. The peak of 439 million L/day will be reached in December 2018, i.e., +29% with the commissioning of Bayakh and Tassette, as well as the three new boreholes of Dieuppeul, Yoff and Nord Foire. SONES has implemented the various phases of the Emergency Program with the SDE. Thanks to the impact of this work, the deficit neighborhoods had better access to the drinking water service: Nord Foire, Ouest Foire, CPI, Cité Alternance, Scat Urbam, Grand Yoff, Liberté 6 extension, Mixta, Keur Damel, Socabeg, Cité Léopold Sédar Senghor, Hlm Grand Yoff, part of the Unit 26 of Parcelles Assainies, Toubab Dialaw. In 2017, the Ministry of Hydraulics and Sanitation has developed the Special Program for Drinking Water Supply in Dakar (PSDAK) which is an intermediate solution pending the completion of structural works such as: the third production plant and Keur Momar Sarr drinking water treatment (KMS3) and the des Mamelles seawater desalination plant in Dakar.

The PSDAK has two phases that aim to strengthen production, improve the quality of the water distributed and secure the supply of electricity. The first phase of the PSDAK consists of hydraulic works at Bayakh, covering a battery of five new boreholes, a pumping station, a storage tank of 1500 m^3 and an adduct line of 18.6 km between Bayakh and Rufisque. It has allowed a production of 15,000 m^3/day which is injected into the network and several deficit areas have better access to drinking water in 2018. The second phase of this program consists in particular, of six boreholes, a station of pumping, a reservoir and a large diameter transfer line on the axis Diender-Thieudème. Ultimately, these structures will bring a volume of water of 15,000 m^3/day complementary.

Apart from additional drilling, and social connections provided by SONES, the KMS 3 and the des Mamelles water desalination plant are the keystones of a water security policy. This option will consolidate production and preserve the capital and the Small Coast from any water stress until 2035. These two major projects of the state are committed to the challenge of water, in the perspective of population growth established at 3% annually. The third Keur Momar Sarr plant (KMS 3) should cover the drinking water needs of the Dakar populations, the new urban center of Diamniadio, the Rose Lake, as well as all the localities crossed by the Lac de Guiers pipeline from 2021 It is expected to represent in 2020 more than 20% of the drinking water supply capacity of the water supply system from Guiers Lake. As for the other structuring project that is the Mamelles seawater desalination plant, with a capacity of 50,000 m^3/day expandable to 100,000 m^3, the water problems of Dakar will be conjugated to the past.

In order to ensure the supply of water to cities, it is therefore essential to improve the availability of sustainable water supply, the conservation and restoration of water bodies as well as strategic investments in additional water infrastructures. Additional water facilities would help increase water storage capacity for long-term uses and avoid recurring disasters such as scarcity. In addition, urban water and sanitation companies should prioritize the construction of efficient wastewater treatment plants to facilitate the treatment and reuse of water.

5. Conclusions

In the face of strong urban growth in Africa as a whole, people's water supply is often lagging behind. Many African cities find it difficult to provide adequate water services to the growing number of occupants. The demand for clean and adequate water is increasing due to population growth and the global obligation to achieve

the Sustainable Development Goals, including Goal 6: "Ensuring access for all to water and sanitation services managed sanitation" [37].

Senegal suffers from a chronic water crisis due to various causes including drought, landscape degradation, floods, contamination and unprecedented population growth. If solutions exist against mismanagement and water pollution, the main problem lies in the frequency and severity of extreme events such as droughts and floods due to ongoing climate change, phenomena that will likely be more unpredictable in the future. Adequate provision of drinking water to populations could also be strongly influenced by environmental pollution. Therefore, to preserve water security, it is necessary to focus on the protection of sources, the more judicious use of fertilizers and pesticides, the reduction of domestic and industrial pollution as fundamental elements of the complete water management strategy.

In order to achieve the Sustainable Development Goals (SDG 6 in particular), new strategies for the sustainable management of water resources are needed. In fact, in urban areas that use large quantities of water (which also puts a lot of pressure on the country's resources), the modernization of water infrastructure is an important step to implement for the sustainable preservation of water. Pure water. These strategies must also take into account the improvement of access and access to drinking water, the fight against waste of the resource, the treatment and reuse of water used for agricultural purposes, the storage of water in period of rainfall abundance and its reuse in times of scarcity, preservation of aquatic ecosystems.

On the issue of the recurring water shortage in Dakar, it is recommended a device with the following objectives: to reinforce the hydraulic equipment; reduce the vulnerability of people and goods; appreciate, treat and reduce the risk of water scarcity; put in place the required prevention, response and recovery measures; maintain essential activities and services; identify external actors and integrate them into the planning process.

Acknowledgements

We thank all the national and international organizations that provide us with the data that helped write this article.

Conflict of interest

There are no conflicts of interest for this document.

Notes/thanks/other declarations

There are no other notes/thanks/statements.

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