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Contribution of Groundwater and Surface Water Resources in Dakar City Water Supply

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Abstract

Water supply study in Dakar area shows that surface and groundwater contribute about 39% and 61% respectively to the drinking water supply in this region over the last 20 years (2000-2019). Indeed, the 61% of groundwater contribution are distributed between 23%, 19%, 12%, 6% and 1% respectively by the Maastrichtian, Eocene, Paleocene, infrabasaltic and Thiaroye groundwater's. Population water demand estimation in the Dakar region reveals a gradually changing with population growth. Comparative analysis of water demand in relation to the water consumed for domestic purposes indicates that water consumption always remains below water needs between 2000 and 2019, thus showing a water deficit that is perpetual during this period. Results analysis show low water deficit between 2009 and 2013, especially in 2012 when the value was around 1 920 315 m^3/y.

Keywords : Groundwater pumping, Maastrichtian, Paleocene, Eocene, infrabasaltic, aquifer

Introduction

Senegal, like many developing countries, is experiencing difficulties related to drinking water supply to the population, particularly in large urban areas such as the Dakar region. Dakar city, which is the major seat of governmental institutions in Senegal, is the biggest urban agglomeration in Senegal and a major financial, commercial, manufacturing, and transport hub. The population of Dakar is about 3 million [1], whereby steady rural–urban migration causes problems typical of substropical and tropical megacities. Among others, these problems include sluggish infrastructural growth and poor sanitation drainage.

In the early 1920s, the water supply in Dakar city was drawn by a few groundwater extraction wells from the infrabasaltic aquifer at a rate of ~3,000 m^3 d^{-1} [1, 2] but the demographic expansion has led to an increase in water demand. Since the 1970s, the water supply of Dakar from local aquifers was no longer sufficient, and therefore, it was necessary to explore other resources to satisfy the urban and peri-urban water needs. Despite the exploitation of the Pout, Sebikotane, and Paleocene limestone aquifers, the north coast and the Maastrichtian groundwater's but also the Senegal River connected via pipeline to the 250 km far away Lake of "Guiers" (Keur Momar Sarr 1 and 2) were used for drinking water supply. It is in this context of intensive exploitation of water resources that this study aims to evaluate the contribution of groundwater and surface water resources to the water supply of Dakar area.

Materials and Methods

Study area

The study area is located between 16°55' and 17°30' west and 14°55' and 14°35' north. It is found in the extreme west of Senegal, with an area of 550 km², approximately 0.28% of the total country. This region occupies the peninsula of Dakar and is bounded to the north, south and west by the Atlantic Ocean and to the east by the Thies region, which is its only opening to the continent (Figure 1).

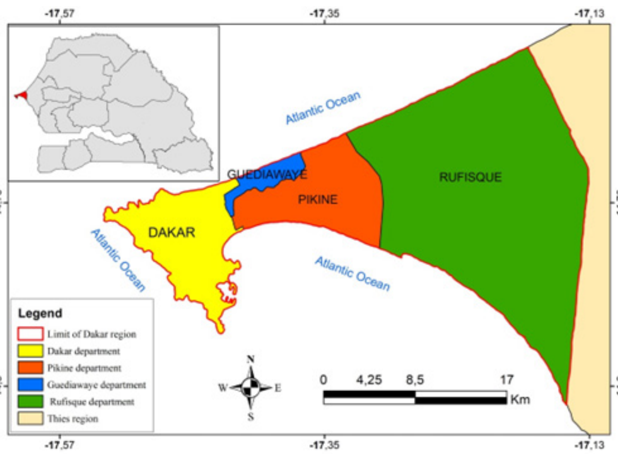

Figure 1: Localization of the study area

The Dakar region is characterized by a wide variety of soils, which explains the abundance of vegetation in certain areas. It is characterized by a slightly uneven relief distinguished by the presence of two horsts separated by a graben: the head of the peninsula to the west with a maximum altitude of 105 m; the "Diass horst" located to the east with a maximum altitude of 127 m; and the Rufisque graben [3]. Senegal's general population and housing Census (RGPH, 2019) and the results of population projections indicate that the population of Dakar increased from 1 561848 inhabitants in 1990 to 2 323370 in 2000; 2 956023 in 2013 and 3 732284 in 2019. Today, the Dakar region has more than 3 million inhabitants. In addition, the PDU (Urban Master Plan) projection estimates that the region will have more than 5 million inhabitants in 2025 [4].

Climatic data collected from the Senegal National Civil Aviation and Meteorological Agency (ANACIM) shows, that annual rainfall varies strongly between the years being for example 161 mm in 2014 and 723 mm in 2009, while the long-term mean is 378 mm (1990-2019). Maximum air temperature is on average 28.4°C (1990-2019) and occurs from May to June and October to November corresponding to the beginning and the end of the rainy season. Minimum air temperature is observed during the period from December to February (21.9 °C). Daily mean FAO-PM reference evapotranspiration estimated between 2000 and 2013 ranged between 2 and 4 mm d^{-1}[5].

The geology of the Dakar region is part of the Senegalo-Mauritanian sedimentary basin, which covers an area of 340,000 km^2. The main part of the outcrops in the study area consists of Quaternary formations (recent sandy overburden).

However, the Paleocene and Eocene also outcrop as does the terminal part of the Cretaceous (the Maastrichtian). In the Dakar region, the Maastrichtian formations pass laterally to an entirely clayey series recognized in the vicinity of Retba lake [6]. The Paleocene is assimilated to the marl and limestone formation of the Madeleine whose average thickness in boreholes is 75 to 100 m [6-7].

The Eocene corresponds essentially to silicified clays while the Oligocene is equivalent to limestones which are preserved in the state of blocks enveloped in the Miocene volcanic tuffs of Anse Bernard and Plage Pasteur [6]. The Neogene is encountered at the top of the volcanic flows of the Cap Manuel system in the form of lateritic formation [6].

The Quaternary is essentially characterized by alternating episodes of transgressions and regressions of the sea which essentially determine the deposits of shell sands which characterize a period called the Inchirian, the accumulation of gravelly alluvium (sands, gravels, quartz pebbles, basalt) in the shallows depth which corresponds to the Acheulean, the setting up of Ogolian dunes and the accumulation of shell deposits in the interdunal depressions and depressed areas which corresponds to the Nouakchottian [8,9].

The Dakar area has two aquifers systems[9], a semi-confined infrabasaltic aquifer in the western part and the unconfined Thiaroye aquifer in the eastern part[7]. The infrabasaltic aquifer is composed of pure sand capped by volcanic lavas (Quaternary volcanism), while the unconfined Thiaroye aquifer varies from coarse to clayey sand. The thickness of the confined aquifer varies from 50 to 80 meters from west to east.

Data Collection and Sampling

Pumping water and chemistry data used in this study are taken from the database of the Management and Planning of Water Resources of Senegal. Water consumption data for the Dakar region was provided by the National Water Company of Senegal. The demographic data used are taken from the projection reports of the National Agency for Statistics and Demography. Water withdrawals for the Dakar region cover the period from 2000 to 2019. The sources of drinking water production are the infrabasaltic, Thiaroye, Eocene, Maastrichtian and Paleocene aquifers, as well as surface water (lac of "Guiers").

In order to assess water withdrawals for the Dakar region, the annual volumes supplied by each aquifer and the volumes produced by each water type (surface water, groundwater) were calculated to study their variations between 2000 and 2019. The annual contribution of each water source was determined to derive the 20 year averages.

Water consumption data for the Dakar region are obtained for the period 2009 to 2019 from the volumes of water invoiced by the Senegalese Water Company ("SDE") (now "SEN'EAU"). The volumes of water consumed per year were calculated to determine the evolution of water consumption during this period.

Drinking water supply purposes in the Dakar region is studied by determining the volumes of water consumed and the water need in the region. This enabled us to determine the water deficit using the following terms:

- water requirement (W) is the quantity of water needed to meet the population demand and to live in good conditions;
- water consumption (Ce) represents the quantity of water consumed by the population, i.e. the part of the water that is invoiced by the Senegalese Water Company ("SDE") in the area;
- the water deficit (De) represents the amount of water that populations lack to meet their needs. It is estimated using the following equation:

$$D_e = B_e - C_e \qquad (1)$$

if $D_e > 0$ then there is a water deficit;
and if $D_e < 0$ then there is sufficient water supply.

Results and Discussion

Water resources that supply Dakar with drinking water

History of the Dakar water supply

In the absence of sufficient local resources to ensure the drinking water supply to Dakar region, several aquifers as well as the lake of "Guiers" have been used over time. Dakar region has always been confronted with difficulties related to water supply before the discovery of the infrabasaltic aquifer in 1925. Pumping of this latter has experienced many problems, including the saltwater intrusion [10] detected in the 1950s, which led to the stopping this pumping in some boreholes to avoid the advance of the saltwater [8]. Thus, in 2014, there were only 15 functional pumping boreholes tapping the infrabasaltic aquifer. However, between 2015 and 2018, 14 new boreholes were drilled in this aquifer. This shows that the infrabasaltic groundwater pumping is becoming increasingly intense, which may lead to risks of saline intrusion.

The Thiaroye aquifer was the first groundwater resource (1945), except the infrabasaltic aquifer, to be used for Dakar's water supply. Pumping from this groundwater was stopped because of its nitrate pollution (concentration > 50 mg/l). Only a few boreholes (F19 and F22) are operational during the rainy season to lower the groundwater table and mitigate the recurrent flooding in the peri-urban area.

From 1957-1958, the Paleocene aquifer in the Sebikotane area was tapped with 4 boreholes. They became operational in december 1958 with a pumping rate of 28000 m^3/d [9]. These boreholes are presently stopped because of the saline water intrusion.

Surface water from lac of "Guiers", located in the north of the country 250 km from the Dakar region, has been used since the 1970s. Water pumped from this lake is treated in the Ngnith water treatment plant set up in 1971 with a production capacity of 64000 m^3/d, and in the Keur Momar Sarr 1 (KMS1) plant started in 2004 with a production capacity of 65,000 m^3/d [11].

The KMS2 plant was built in 2008 with the same capacity as KMS1, increasing the plant's production to 130000 m^3/d. This water is carried to Dakar through two underground pipes called the ALG System ("Adduction du Lac de Guiers").

In 1976, the Eocene aquifer in the northern coast area was tapped with the construction of the Kelle/Kebemer well field built within the framework of the Sector Water Project [11]. This field composed by 5 boreholes (F1 Kebemer, Kelle F1, Kelle F2, Kelle F3 and Kelle F4). These provided a pumping rate of 27000 m^3/d which is injected into the ALG system pipeline. This well field now has 9 boreholes, in addition to the F1 Gueoul which was drilled in 2014.

In 1998, a new well field called FLN (north coast well field) consisting of 11 boreholes (FLN 1 to FLN11) was realized in the Gueoul area. It taps the same groundwater as the one in Kelle/Kebemer. The hydrogeological study carried out by[12] had allowed this field to produce a pumping rate of 35000 m^3/d [11]. Thus, the contribution of the northern coast aquifer to Dakar's water supply amounts to 62000 m^3/d. Currently, the FLN well field has 9 functional pumping boreholes.

Maastrichtian and Paleocene aquifers are beginning to be exploited at the Diass horst system to enhance water supply to the Dakar region [11,13]:

- in 1978, at the Pout North (PN) well field with a total production of 48000 m3/d of which 4 boreholes producing 15000 m^3/d in the Paleocene limestone and 9 boreholes extracting 33000 m^3/d from the Maastrichtian sandy aquifer;
- in 1984, in the Pout South Pumping station (PS), 5 boreholes of which tap the Maastrichtian aquifer and 2 tap the Palaeocene limestone aquifer. These boreholes provide an average of 4000 m^3/d. The production of the latter has been reduced over the last thirty years in order to avoid the risks of saline intrusion. The water from the Pout South extraction well field is injected into the BONNA pipeline which it shares with the Sebikotane boreholes;
- in 1993, at the Pout Kirene (PK) well field, which have 5 boreholes in the Maastrichtian, accounting for 18000 m^3/d. At present, this well field has 11 boreholes with the one at Keur Sega, constructed in 1997.

Recently in 2018, two new wells were established, one in the Bayakh area and the other in the Tassette area. The Bayakh well field has 13 boreholes, all of which tap into the Paleocene groundwater. The Tassette well field has 6 and 4 boreholes tapping the Paleocene and Maastrichtian limestone aquifers respectively (FM3, FM4, FM7 and FM8). The operating flows of the boreholes are variable and range between 130 and 200 m^3/h at the Bayakh wellfield and 40 and 150 m^3/h at the Tassette well field.

Currently, the third water treatment plant (KMS 3), with a capacity of 100000 m^3/d, is operational in July 2021. It aims to meet the water needs of the Dakar population, the small coast area and the localities crossed by the ALG pipeline. The seawater desalination plant project at the "mamelles" is being implemented. It will make it possible to cover the drinking water needs of part of the Dakar region.

Surface water contribution (Lake of "Guiers") to Dakar's water supply (2000 - 2019)

The lake of "Guiers" has been supplying drinking water to Dakar since 1971. The water extracted from this lake is treated at the Ngnith and KMS plants before being transferred to Dakar through two pipelines ALG 1 and ALG 2.

Variation of water pumping from the lake shows an increase that is not constant (Figure 2). Indeed, from 2000 to 2004, the contribution of surface water varies between 19 and 18 million m^3/y. However, beyond this period, we observe on one hand an evolution of pumping up to 70 million m^3 in 2017 and on the other hand a slight decrease in withdrawals in 2018 (63 million m^3) and 2019 (62 million m^3). This increase in pumping could be linked to the start-up of the KMS 1 plant in 2004 and its extension in 2008.

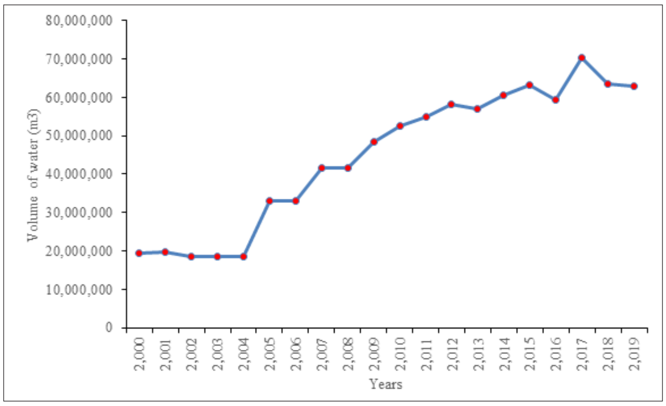

Figure 2: Water extracted variation amount from lake of "Guiers" to supply the Dakar region (2000 - 2019).

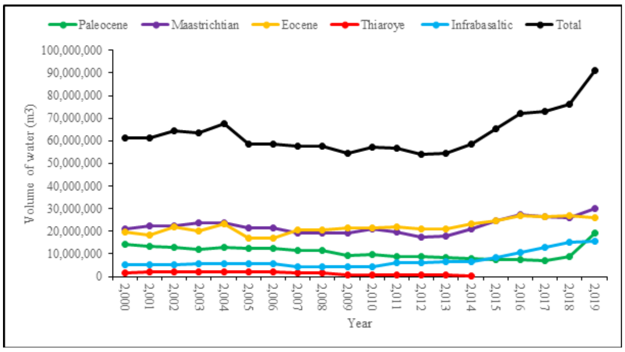

Figure 3: Variation of groundwater resources pumping for Dakar region water supply (2000 - 2019).

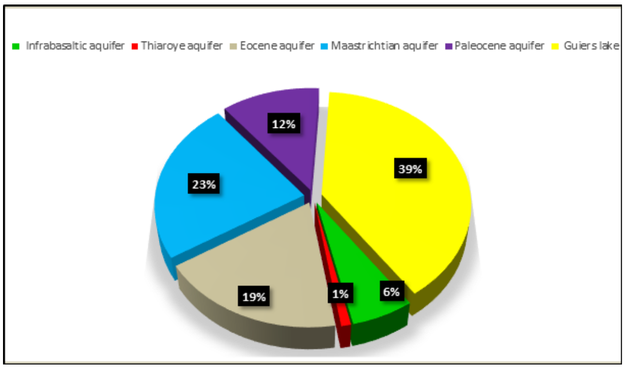

Figure 4: Contribution of surface and groundwater to Dakar's water supply (2000 - 2019)

The contribution of Groundwater to Dakar's water supply (2000 - 2019)

Groundwater contribution to Dakar's drinking water supply is made up of the volumes of water pumped from the infrabasaltic and thiaroye aquifers located in the Dakar region, those from the Maastrichtian and Paleocene aquifers in the Diass horst system and finally from those produced by the Eocene aquifer in the Louga region. Between 2000 and 2019, pumping from groundwater resources is variable (Figure 3). From 2000 to 2004, it increases from 61 to 67 million m^3, and between 2005 and 2014 the volumes of water pumped decrease and vary between 54 and 58 million m^3. Beyond this period, the volumes of pumped water increase until they reach 91 million m^3 in 2019. The situation from 2005 to 2014 could probably be linked to the fact that since 2005, a strategy of significant reduction of groundwater abstraction in the context of water supply in Dakar was in application in favor of an increase in abstraction from lake of "Guiers" [14]. The increase in pumping between 2015 and 2019 is linked to the fact that many boreholes tapping the Maastrichtian have been rehabilitated at the Pout Kirene and Pout Nord well field, but also to the construction of new boreholes tapping the infrabasaltic and Maastrichtian aquifers at the Tassette and Bayakh pumping field.

The contribution of the various water resources to Dakar's water supply between 2000 and 2019 shows that 39% of the water supply is produced by surface water, more precisely from the lake of "Guiers". The overall contribution of groundwater amounts to 61%, of which the Maastrichtian provides the largest quantity (23%). It is followed by the Eocene which provides 19% and the Paleocene which produces 12%. The aquifers of the Dakar region provided only 7%, divided between 6 and 1% for the infrabasaltic and thiaroye aquifers respectively (Figure 4).

Evolution of Water Demand in Relation to Demography

Water supply for human consumption is still considered everywhere as the priority use, as it corresponds to the satisfaction of the essential needs for human life. For this use a person needs approximately 35 l/d of water when living in a rural area and 60 l/d when living in an urban area. Thus, the water needs of the population of Dakar region are estimated based on Dakar population projections between 2009 and 2019 provided by the National Agency for Statistic and Demography of Senegal. Figure 5 shows the evolution of demography, water needs, water consumption and the water deficit in the area. It shows that water needs and consumption increase progressively with the evolution of Dakar's population. The population's water needs are estimated at 55 559380; 68 704592 and 81 737019 m^3/y in 2009, 2013 and 2019 respectively (Figure 5). Thus the volumes of water consumed amount to 51 197 658; 66 253680 and 76 555247 m^3/y in 2009, 2013 and 2019 respectively. Water consumption always remains below water needs between 2000 and 2019, thus showing a water deficit that is perpetual during this period. This deficit was low between 2009 and 2013, especially in 2012 when the value was around 1 920315 m^3/y. From 2014, despite the drilling of boreholes to reinforce the water supply to Dakar area, the water deficit remains high until 2018 (9 453964 m^3/year in 2014; 7 988351 m^3/y in 2016 and 9 055527 m^3/y in 2018). However, in 2019 with the construction of the two pumping well fields at Bayakh and Tassette, this deficit begins to decrease to 5 181 773 m3/y [13,14].

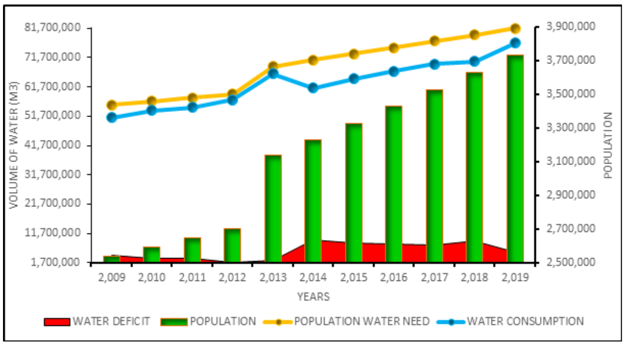

Figure 5: Relationship between population growth, population water needs, water consumption and water deficit from 2009 to 2019.

Conclusion

Water resource exploitation to supply the Dakar region is becoming increasingly intense and problematic, due to population growth and diversification of the economic activities. An analysis of the water resources quantity for Dakar region water supply between 2000 and 2019 shows that groundwater remains the main source of domestic water supply. This contribution is estimated at 61% despite the significant contribution of surface water (39%). The water needs of Dakar population are evolving with the increase in demography. A comparison between water needs and quantities of water consumed shows that there is a deficit in water supply despite the efforts made by the government in this area. Protection of water resources in order to ensure the drinking water supply to Dakar region requires maximum control of pumping to avoid overexploitation of groundwater and surface water resources. Thus, the construction of seawater desalination plant will certainly make it possible to fill the water deficit in the Dakar region. The delocalization of certain administrations outside the Dakar region is strongly recommended to reduce the demographic concentration in this region in order to reduce the water demand.

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