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Overview of water resources and sustainable development impacts in Senegal

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Abstract**—***Senegal's water resources and water economy system largely determines its sustainable socio-economic development. Water resources and water sustainability for future generations, water and environmental security, public access to clean water, reliability and sustainability of water supplies to meet needs economy, the condition of water bodies and water resources, and the ability to predict and prevent damage from water-related emergencies, all play an important role in safety. national country. Water resources are national goods and natural resources which undergo quantitative and qualitative changes throughout the national territory. Water resources have been described as an essential resource that underpins economic growth, social development and, of course, environmental protection. This article examines in detail the concepts and links between water resources and sustainable development, the different sectors, and also the current situation of water resources in Senegal. Information is gathered from secondary sources and available statistics (books and the Internet). The results show the state of the deterioration of water resources and the rising demand for water from the population which is worsening with population growth, development and climate change. In 2017, 78.5% of the total population had access to drinking water, 92.9% in urban areas and 67.3% in rural areas. As for the total renewable water resources per capita, they are only 2459 m3 / capita / year and places Senegal in a situation of water vulnerability, a situation that will deteriorate further by 2 030 when a good part of the world's population will live under the grip of a weak or catastrophically weak water supply.*

Keywords**— Water resources, Sustainable development, Water measurement, Water need, Senegal.**

I. INTRODUCTION

Freshwater is a vital resource for life. It is essential for the survival of natural ecosystems and human activities. Until the middle of the 20th century, water was considered an inexhaustible resource that each user could appropriate, possess and exploit according to his or her needs (Honegger and Tabarly, 2011). In order to satisfy their vital needs, people use water for their various economic activities. This situation has led to a sectoral and competitive use of the resource, a management that is the cause of many problems such as conflicts, degradation of water quality and environmental problems, unequal distribution and decline of water resources (Batcho, 2008). In a nation, water resources and water saving systems largely determine its sustainable socio-economic development, public access to clean water, reliability and sustainability of water supplies to meet the needs of the economy, the condition of water bodies and water resources, and the ability to predict and prevent damage from water-related emergencies, all of which play an important role in the national security of any state (Thipperudrappa and Dhananjaya, 2020).

The combined effects of population growth, rising incomes and urban expansion will lead to an exponential increase in demand for water, while the supply of the resource will become more irregular and uncertain (Camara and Bangoura, 2017). Without immediate action, water will become a scarce resource in areas where it is abundant today. The impact of water scarcity will be felt in all socio-economic activities, including agriculture, health, energy and income (Olivier, 2016). Faced with these multiple problems that do not guarantee the sustainability of water resources and the environment, water resources are increasingly limited and vulnerable (Sinarinzi, 2010). They are limited by a variety of factors such as climatic conditions, uneven distribution of rainfall, the shared nature of the resource, strong demographic pressure and poor water management. In order to cope with this and to establish rational management of water resources, the assessment of water availability is a fundamental step (Faye *et al.*, 2019).

In Africa, water is the primary vector of childhood illness, with more than 70-80% of diseases on the continent linked to poor water quality. Also, the resource is unevenly distributed geographically. According to the World Bank, water scarcity exacerbated by climate change could cause some regions of the world to experience a decline in GDP of around 6%, provoke migrations and trigger conflicts (Camara and Bangoura, 2017). In addition, there are imperfections in water management, a focus on developing new sources rather than better managing existing ones, and sectoral approaches to water management that result in uncoordinated development and management of the resource (CAP-Net, 2005).

In Senegal, the potential for water resources (surface and groundwater) is significant and the availability of renewable water is currently estimated at around 4,747 $^{m3/capita/year}$ (CONGAD, 2009). However, the issue of water has become a national concern given the series of challenges facing the sector: scarcity, randomness of rainfall, vulnerability of water resources, disparity in their spatial distribution, current or potential conflicts arising from their exploitation and overexploitation, degradation of their quality, inequity in access to water resources between areas, social groups, different socio-economic activities, etc. (Ministry of Hydraulics/Department of Agriculture, 2009). (Ministry of Hydraulics/DGPRE, 2007). The water crisis is explained by a combination of absolute scarcity of physical availability, poverty and inadequate water management policies.

In general, Senegal has significant water resource potential but its uneven distribution, overabundance in the rainy season often causes catastrophic floods and shortage in the dry season causes severe drought conditions resulting in crop and livestock losses, public health problems and environmental degradation (Faye and Diéye, 2018). The challenges facing the Senegalese water sector are due to increased water consumption and wastage in urban areas, water-borne diseases, industrial growth, political and regulatory conflicts, imbalances in the water cycle, increased demand for irrigation and agriculture, lack of technology, etc.

The country has a significant water resources potential that can increase agricultural productivity, industrial production, income, healthy human development and eradicate poverty. Water resources play a special role in developing the national economy and supporting social and economic programmes in the country's regions. However, there is an urgent need to move to new forms of water management, in order to comply with the recommendations of the World Summits (Rio-Dublin in January 1992 and Johannesburg in August 2002). In the context of water resources management for the achievement of the Sustainable Development Goals (SDGs), this article examines in detail the concepts and links between water resources and sustainable development, the different water needs and sectoral measures, and also the current water resources situation in Senegal.

II. MATERIALS AND METHODS

This study is based on secondary data only. The main data were collected from the databases of the Directorate of Water Resources Management and Planning (DGPRE), the National Agency for Statistics and Demography (ANSD), the Ministry of Hydraulics, other ministries and other institutions. For other data, various files, books, articles, newsletters and published journals relevant to this theme were used. This extensive literature review allowed us to collect various available data and information related to the relationship between water resources and sustainable development in Senegal, and in areas where similar studies have been conducted.

III. RESULTS AND DISCUSSION

3.1. Links between water resources and sustainable development

Water resources: Water resources have been described as an essential resource that underpins economic growth, social development and, clearly, environmental protection now and in the future. (Love and Luchisinger, 2014). Currently, 76% of the total population has a specific water availability of less than 5,000 m3 per year per capita, with 35% having a very low or catastrophically low water

supply. This situation will deteriorate further early in the next century; by 2025, most of the world's population will be living under the influence of low or catastrophically low water supply (Thipperudrappa and Dhananjaya, 2020). According to Irina Bokova, Director-General of UNESCO, in an official statement, "*Water resources are a key element of poverty alleviation policies, but are sometimes themselves threatened by development. Water directly influences our future, which is why we must change the way we value, manage and use this resource in the face of ever-increasing demand and overexploitation of our groundwater resources*. In his official statement for World Water Day (2013), Ban Ki Moon, UN Secretary General, states that "*Water is the key to sustainable development, we must work together to protect and carefully manage this fragile and limited resource*".

Sustainable development: In its 1987 report, Our Common Future, the United Nations World Commission on Environment and Development (Brundtland Commission) defined "sustainable development" as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". The concept of sustainable development, agreed at the UN Conference on Environmental Development in Rio de Janeiro in 1992, has become a major strategy for most countries. It aims to improve human life while preserving environmental potential and allowing for the prudent use of natural resources. Sustainable development can be achieved by introducing progressive nature and energy conservation technologies, while not depleting resources or harming the environment.

Links between water resources and sustainable development: Herman E. Daly, former Chief Economist of the World Bank, proposes the following three operational rules defining the condition of ecological sustainability: (i) Renewable resources such as fish, soil and groundwater should not be used faster than the rate of their regeneration. (ii) Non-renewable resources such as minerals and fossil fuels should not be used faster than renewable substitutes can be developed. (iii) Pollution and waste should not be emitted faster than natural systems can absorb, recycle or render them harmless. To describe sustainability, human activity should at least use nature's resources only at a rate that allows their natural replenishment. One way to implement these rules is to examine how the use of renewable resources can be compared to the rate of renewal, as follows:

Table 1: Definitions of sustainability (source: Smith and Zhang, 2007)

Consumption of renewable resources	State of the environment	Sustainability
More than nature's ability to reconstitute	Environmental degradation	Not sustainable
Equal to nature's ability to replenish	Environmental balance	Stable state
Less than nature's ability to replenish	Renewal of the environment	Sustainable development

While at the beginning of the new millennium the more developed countries have managed to stabilise the ecological situation, the developing countries still persist with unsustainable practices and techniques of natural resource use. In the more developed countries, the stable ecological situation has been achieved through intense promotion of scientific and technical progress. New resource-replenishment technologies, large investments in industrial reconstruction and nature protection measures are well implemented. In contrast, most other countries, generally underdeveloped, preside over large-scale exploitation and sale of natural resources, which further degrades the environment.

3.2 Current water resources situation in Senegal

The Republic of Senegal, located on the westernmost tip of the African continent, covers an area of 1,722 km². Its population is 13,508,715 (ANSD, 2013). A coastal country with 700 km of Atlantic coastline, Senegal is located between 12.5° and 16.5° north latitude and 12° and 17° west longitude. Given the variations in rainfall in space and time, there are three climatic domains in Senegal, from south to north: the southern Sudanian, northern Sudanian and Sahelian domains, each with two variants (one coastal and one continental) (Faye *et al.* , 2017). Annual rainfall varies on average from about 1250 mm in the south to just over 200 mm in the north. This climate is marked by an alternation between a rainy season and a dry season, a period during which water becomes a truly scarce resource, while the demand for water is at its highest.

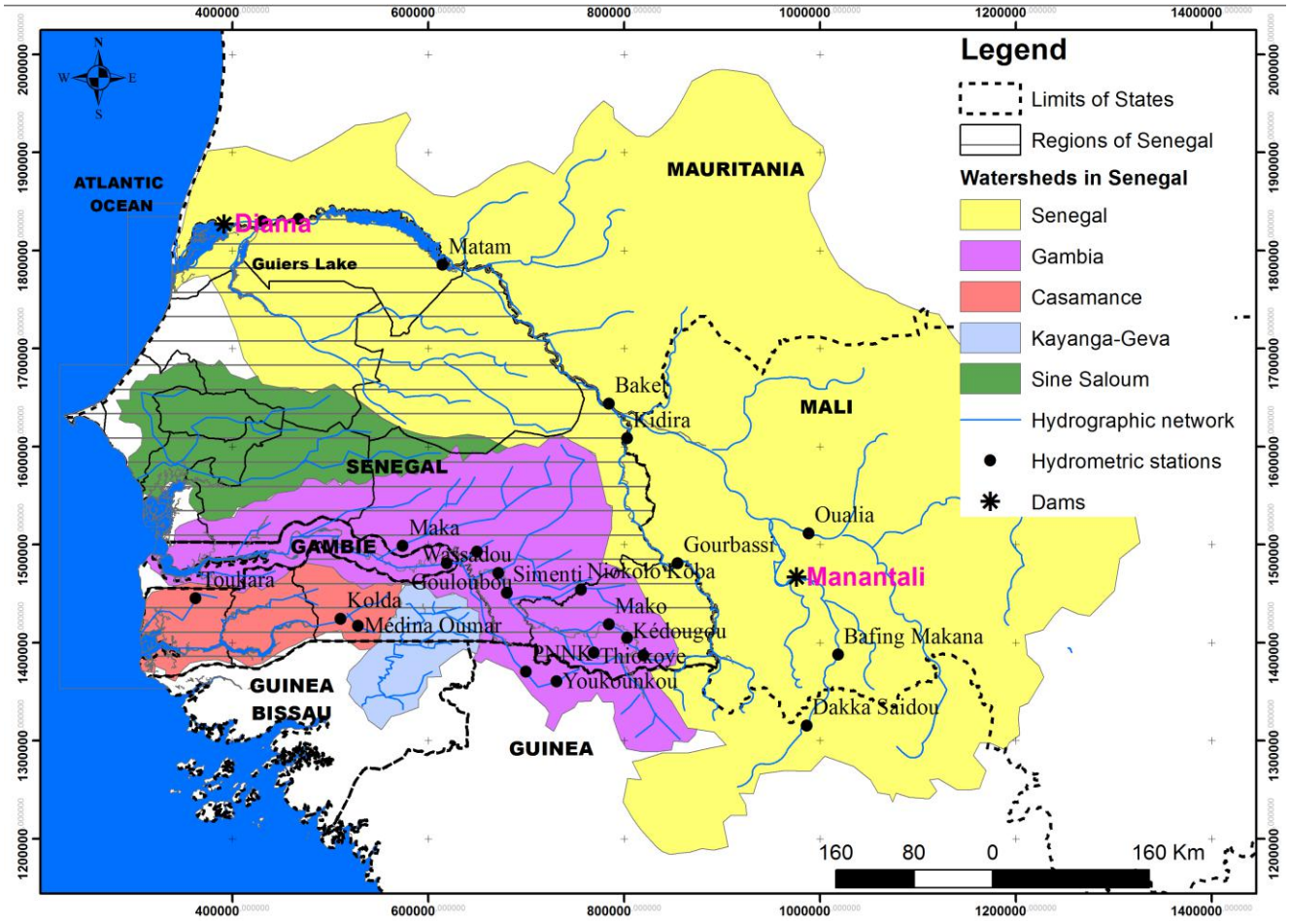

Fig. 1: Watersheds draining Senegal (Source: DGPRE)

Senegal's water resource potential (surface and groundwater) is significant. Three rivers that have their source in Guinea (Senegal, Gambia and Kayanga rivers) water a large part of the country. Thus, Senegal has a fairly rich and diversified hydrological potential. Most of the 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). In addition to these two large rivers, there are smaller rivers with intermittent flows. These include the Casamance, the Kayanga with its main tributary the Anambé, the Sine, the Saloum and the coastal marigots (Fig. 1). A number of listed lakes and ponds complete this hydrographic network; the most important being: the Lac de Guiers, the bolongs of the estuarine areas and the ponds of the Niayes region of the northern coast and the Ferlo (Faye and Diéye, 2018).

Groundwater has always been an essential component of Senegal's water potential, but even more so since the onset of the drought. The country has four major aquifer systems corresponding to the main geological formations: the superficial aquifer system (estimated reserves of 50-75 km²); the intermediate aquifer system (estimated reserves of 100 km²); the deep aquifer system (estimated reserves of 300-500 km²); and the basement aquifer system (low reserves) (Faye *et al.*, 2019).

The amount of water available, as reported by FAO (2020), is presented in Table 1. Total renewable water resources (surface water, groundwater, inland water and external water) are estimated at 38.97 km3/year in 2017. Surface renewable water resources are estimated at 36.97 km3/year and internal renewable water resources at around 25.8 km3/year, giving a dependency index of 33.8% (Table 2). Today, unfortunately, Senegal's water resources are threatened by the extent of drought and climate change.

Table 2: Available renewable water resources from 1992 to 2017 in Senegal (Source: FAO, 2020)

Parameters	1992	1997	2002	2007	2012	2017
Total population (1000 inhabitants)	8030	9197	10397	11874	13704	15851
Rural population (1000 inhabitants)	4899	5540	6175	6931	7832	8825
Urban population (1000 inhabitants)	3131	3657	4222	4943	5872	7026
Population density (inhabitants /km2)	40.82	46.75	52.85	60.36	69.67	80.58
Total inland renewable water resources (10^9 m3/year)	25.8	25.8	25.8	25.8	25.8	25.8
Total external renewable water resources (10^9 m3/year)	13.17	13.17	13.17	13.17	13.17	13.17
Total renewable surface water resources (10^9 m3/year)	36.97	36.97	36.97	36.97	36.97	36.97
Total renewable groundwater resources (10^9 m3/year)	3.5	3.5	3.5	3.5	3.5	3.5
Total renewable water resources (10^9 m3/year)	38.97	38.97	38.97	38.97	38.97	38.97
Dependency index (%)	33.8	33.8	33.8	33.8	33.8	33.8
Total renewable water resources per capita (m3/capita/year)	4853	4237	3748	3282	2844	2459
Inland renewable water resources per capita (m3/capita/year)	3213	2805	2481	2173	1883	1628
Total freshwater withdrawal (10^9 m3/year)			2.221			
Operating index (in %)			5.71			
Total capacity of dams (km3)	0.25	0.25	0.25	0.25	0.25	0.25
Capacity of dams per capita (m3/capita)	31.13	27.18	24.05	21.05	18.24	15.77
Total population with access to safe water (%)	61.4	65.2	68.9	72.6	76.3	78.5
Rural population with access to safe water (%)	43.4	48.6	53.8	59.0	64.2	67.3
Urban population with access to safe water (%)	89.4	90.2	90.9	91.7	92.5	92.9

The total volume of renewable groundwater available is estimated at 3.5 km3/year (Table 1). This groundwater is the main source of reliable and safe drinking water in rural areas and many cities, for the irrigation of thousands of hectares of arable land and for livestock watering. Many mines and industries also rely on groundwater for their supplies. In 2002, withdrawals from water resources in Senegal amounted to 2,221 million m3, of which 2,065 million for agriculture (93%), 98 million for communities (4.4%) and 58 million for industry (2.6%) (FAO. 2020). The irrigation potential varies, according to the different estimates, from 160,000 ha to over 640,000 ha. Given the considerable potential of the country's water reserves, the exploitation index was relatively low (5.75% in 2002).

In Senegal, social development is leading to an increasing demand for water. Water plays a central role in most national planning initiatives, such as agricultural development, energy security, tourism and recreation, mining, industry and municipal water supply (Mwendera and Atyosi, 2018). Population and urban growth in the region is putting great pressure on available water resources, which are often limited in dry saoson. According to the FAO (2020), renewable freshwater resources per capita are constantly decreasing. They have thus gone from 11612 ^{m3} in Senegal in 1958-62 to only 2459 ^{m3} in 2017. These results show that Senegal is already in a situation of water vulnerability (below 2,500 $^{m3/capita/year}$), an evolution that should lead it in the future first to a situation of water stress (below 1,700 $^{m3/capita/year}$) and then to water shortage (below 1,000 $^{m3/capita/year}$).

Although the country has rivers of great hydraulic capacity (more than 26 billion ^{m3} per year), vast areas that were once crossed by watercourses have become almost totally deprived of surface water as a result of the drying up of rivers (Sané, 2015). This is a cause for concern as water consumption is increasing exponentially in relation to Senegal's population growth. The logical outcome of such a situation could be competition for the resource (Boinet, 2011). Senegal could seek to reduce its own uncertainty with regard to water resources by developing the rivers that cross its territory to improve water availability for users, without using force to safeguard the interests of other riparian countries on this issue of national security (Descroix and Lasserre, 2003).

Generally, in Senegal, while the water resource potential is in theory relatively abundant (38.97 km3/year in 2017), it is starting to become unsatisfactory in relation to the population (2459 ^{m3} per capita), and could eventually place the country in a situation of physical water scarcity. Added to this is the relatively low level of development (GDP per capita of US$911) which translates into a lack of investment in water or a lack of human capacity to meet the country's water demands. Senegal would therefore be faced with a 'social' scarcity of water (Julien, 2006), i.e. a probable economic water shortage, hence the interest in establishing human control of water resources. Human control of water resources, understood here as the ability of societies to mobilise and control (fresh) water across space and time, represents a formidable tool for sustainable socio-economic development (Grey and Sadoff, 2006).

3.3 Measures for water resources and sustainable development in Senegal

Faced with the deterioration of water resources due to pollution, agricultural activities and the increase in the population's demand for water, the Senegalese state has for several decades pursued a policy of water management aimed at providing the various sectors with sufficient water in appropriate quantities and of appropriate quality according to use in order to accelerate balanced development (Faye *et al.*, 2019). In order to be in line with the Sustainable Development Goals (SDGs), notably SDG 6, Senegal has committed to sustainable water resource management to ensure universal and equitable access to safe and affordable drinking water for all populations by 2030. The urgency of channelling more effort into monitoring and reporting on this aspect of water sustainability is reinforced by the broad coverage of the Sustainable Development Goals related to water infrastructure.

A holistic approach needs to be adopted to measure the quality of water infrastructure against national and rural water resource objectives related to increasing access to safe water and sanitation (Thipperudrappa and Dhananjaya, 2020). In addition, the demand for water infrastructure in Senegal is expected to increase, mainly due to the rising domestic demand for agricultural products (rice, maize, millet, sorghum, onions, potatoes, sugar, etc.) among the growing Senegalese population and the shift in dietary trends towards middle class diets.

The prospects of widening gaps between demand and supply in Senegal's main and most agricultural river basins - the Senegal River (in the valley), the Kayanga (in the Anambé basin), by 2030, underline the need for robust monitoring and reporting on the capacity of Senegal's water infrastructure to meet future needs effectively. In the context of the rice self-sufficiency project, many projects, notably in the field of water control and rice production, are in the pipeline or in the early stages of implementation to strengthen the dynamics of agricultural development on the left bank of the Senegal River (Senegal River Valley) and in the Anambé basin (Faye and Diéye, 2018). Finally, our analysis of the state of reporting on water resources by state-owned enterprises in Senegal highlights a lack of temporal measurement of the sustainability of water resources in the Senegalese water economy. For the Senegalese government and the companies within its economy, the failure to measure temporal trends across different water sustainability indicators summarises the progress Senegal has made in navigating towards a sustainable water resources future.

Table 3: Projected water withdrawals from various sectors of the Senegalese economy (Source: FAO, 2020)

Parameters	2002	2010	2030	2050
Total population (inhabitants)	10283694	12678142	21551461	33186850
Total renewable water resources (10^9 m3/year)	38.97	38.97	38.97	38.97
Total renewable water resources per capita (m3/capita/year)	3789	3074	1808	1174
Water withdrawal for agriculture (10^9 m3/year)	2.065	2.546	4.328	6.664
Water withdrawal for industrial uses (10^9 m3/year)	0.058	0.072	0.122	0.187
Water withdrawal for municipalities (10^9 m3/year)	0.098	0.121	0.205	0.316
Total water withdrawal (sum of sectors) (10^9 m3/year)	2.221	2.738	4.655	7.167
Operating index (in %)	5.70	7.03	11.94	18.39

The Water Resources Framework - Current State of Sustainable Development shows how water policy is linked to policies in other sectors, including agriculture, industry, ecology and energy, health, transport. The average annual water availability of a region or country depends largely on hydrometeorological and geological factors and is generally constant (e.g. in Senegal it is estimated at 38.97 km3/year from 1962 to 2017). In contrast, the average annual per capita water availability estimated in Senegal has decreased from 11506 ^{m3} in 1962 to only 2459 ^{m3} in 2017, which could further decrease, if the 2.5% population growth is maintained, to 1808 and 1174 cubic metres respectively in 2030 (with a total population of 21551461 inhabitants) and 2050 (with a total population of 33186850 inhabitants)

According to the FAO (2020), total renewable water resources are estimated at 38.97 km3/year, while the long-term average annual rainfall is 134.9 km3/year. Estimated in proportion to the size of the population, based on water withdrawals in Senegal which amounted to 2221 million ^{m3} in 2002 (FAO, 2020), projections of water withdrawals from various sectors of the Senegalese economy are shown in Table 3. These water withdrawals are estimated at 4655 and 7167 million ^{m3} in 2030 and 2050 respectively.

This increase in water abstraction is explained by the rise in water needs linked to the increase in population and the multiplication of projects with an agricultural connotation. In order to achieve self-sufficiency in rice, the pace of hydro-agricultural development has increased. In this context, 23691 ha of new developments and 18830 ha of rehabilitation are underway in the Senegal River valley (Diouf, 2017). Moreover, out of an irrigable potential of 240,000 ha, an area of 1,964,040 ha has been developed. In the Anambé basin, the revival of the agricultural and particularly rice production in the irrigated area of the Anambé basin has always been a major concern of the Senegalese government in order to better face the food and socio-economic crisis. In the 2016 winter season, more than 3,700 ha were sown in the developed area (Mballo, 2017).

With the intensification of irrigated agriculture, water needs have increased sharply, as have the needs for drinking water supply for an ever-growing population. Indeed, for almost a decade, the supply of drinking water to Dakar has been characterised by high demand due to population growth, the construction of new economic development centres (Diamniadio, Lac Rose, Diass) and tourist centres in the Petite Côte. The current production capacity of 421,000 m3/d is highly insufficient to meet the estimated water needs of around 659,000 m3/d in 2025 in the Dakar-Thiès-Mbour/Petite Côte triangle. In 2013, for the entire urban area conceded to SONES and operated by SDE, peak consumption reached 328,000 m3/d for an installed capacity of 331,000 m3/d, which reflects a significant tension between supply and demand, frequently affecting the continuity of service in several neighbourhoods in Dakar and its suburbs. This tension exposes the supply system to major malfunctions in the - event of production disruptions (Faye and Diéye, 2018).

3.4 Sustainable water resource management in Senegal

Due to the multiplicity of water uses, the issues related to water resources management cannot be validly understood in a global manner through a sectoral approach. To this end, an integrated water resources management approach was initiated in 2004 by the Ministry of Agriculture and Hydraulics under the guidance of the Directorate for Water Resources Management and Planning (DGPRE).

SDG 6 proposes to ensure the availability and sustainable management of water and sanitation for all. A specific target is to achieve universal and equitable access to safe and affordable drinking water for all by 2030 (Ndour, 2016). The challenges and obstacles to the sustainable development of water resources in Senegal can be divided into transboundary and national categories. Most of Senegal's freshwater resources are located in transboundary river systems and shared river basins that need to be managed and protected through a strong commitment to regional collaboration (Thiam, 2016). Senegal's dependence on water flows from upper riparian countries is the primary cause of the vulnerability of this precious resource. Of the total annual renewable flows of 38.97 billion $^{m3\ of}$ water in the territory, 13.17 (33.8%) come from outside. Unilateral control of surface water flows in transboundary basins by upstream riparian countries (such as Guinea and Mali) would lead to water insecurity in Senegal and would be a major obstacle to sustainable water resource development. This explains the policy of cooperation established by Senegal with the countries with which it shares the same catchment areas: this is the case with the Organisation pour la Mise en Valeur du fleuve Sénégal and the Organisation pour la Mise en Valeur du fleuve Gambie.

Although many changes have been made to water policies in Senegal, many environmental, physical, socio-economic and other challenges remain to be solved. In general, while water resources are abundant in Senegal, their use is often inefficient. Thus, the challenges in the water resources sector are multiple due to the increase in water consumption and wastage in urban areas, water-borne diseases, economic growth, conflicts of use, imbalances in the water cycle, increase in demand for irrigation and agriculture, lack of technology, etc (Faye, 2017). Among other challenges, there is poor management, lack of

investment, weak policy and administration, weak technology. This justifies a number of suggestions that could be made from this study: improve incentive programmes for the effective and efficient use of water resources within the framework of sustainable development; get NGOs and the government actively involved in raising awareness of water resources programmes in rural and urban areas. The State must therefore ensure the supply of drinking water to urban and rural populations, develop sustainable agriculture through the optimal use of the country's water potential, meet the water needs of industries, and manage the sustainability of the country's water resources.

IV. CONCLUSION

Inspired by these efforts, "water for all" remains an unfulfilled programme of the Senegalese government. The existing water system does not effectively meet the water needs of the economy and the people. Water is an inseparable natural resource on this earth. The preservation of water resources should be a priority. The sustainability of water resources will determine the well-being of the population in the long term. Furthermore, an attempt was made to understand the state of water resources and sustainable development in Senegal. It was to identify that serious and truthful dimensions are needed to conserve water resources in terms of quantity and quality.

Monitoring and development of water resources have been important considerations in Senegal since 1960. The characteristics of water availability and supply have been influenced by environmental changes and socio-economic factors. Senegal has developed water management policies, through a series of progressive reforms, to provide an ongoing response to these environmental conditions. Nevertheless, the water sector faces a set of persistent challenges such as the increasing demand for water due to population growth, the need for acceptable water quality in many areas, the insufficient and inefficient practical implementation of the water management system, and the uncertainties associated with climate change.

Senegal is privileged and lucky to have a rich and varied water resource potential. However, the quality of this precious resource is deteriorating rapidly. Only by better understanding the sources of pollution and the processes that affect the quantity and quality of water can it be saved for present and future generations. In addition, there are collective management actions with its immediate neighbours with the establishment of basin organisations. The population of the basins can also play a role in the preservation of water quality. Moreover, all the riparian countries of the basins that cross the national territory must continue to unite their efforts (OMVS on the Senegal, OMVG on the Gambia) to protect this precious resource.

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