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Groundwater Assessment Quality for Dakar City Supply against WHO Standards

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Abstract: ***Dakar city is located in the western part of Senegal, where groundwater plays an important role in drinking water supply. The present study helps to assess and determine the groundwater quality for domestic use in the area. For these purposes, groundwater samples were collected from 20, 19 and 12drinking water pumping and piezometer wells respectively in the Infrabasaltic, Maastrichtian, Paleocene aquifers and analyzed. The results of the chemical analysis indicate that $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ (infrabasaltic), $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ (Maastrichtian and Paleocene) was the most dominant cation sequence, while $Cl^- > HCO_3^- > SO_4^{2-} > NO_3^-$ was the most dominant one for anions in the aquifers water sampled. The chemical analysis of our samples showed, that the Cl- Ca-Mg facies was dominant in the infrabasaltic aquifer, while HCO_3-Na-K facies represent the dominant one inMaastrichtian and Paleocene aquifers. A comparison of the measured groundwater quality in relation to WHO drinking water quality standards revealed that 80, 75 and 86 % of the groundwater sampled in the infrabasaltic, Maastrichtian and Paleocene aquifers, respectively are suitable for drinking purposes.***

Keywords: Groundwater pumping, Maastrichtian, Paleocene, infrabasaltic, water quality

1. Introduction

Groundwater is a vital resource for drinking water, especially in most arid and semi-arid regions worldwide where surface water is poor in quality and often scarce [1, 2]. It is estimated that globally more than 1.5 billion people rely on groundwater for primary needs such as drinking and irrigation [3]. In semi-arid regions, intense urbanization led to high water demands and as a consequence, large extraction of groundwater is observed in these regions. On the other hand, water quality often dropped over the last years due to population and industrial growth and associated pollution of the aquifer systems [3, 4, 5]. 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 [6], 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} [7] 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 located in Thies region, 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. Nevertheless, the Dakar region still experiences problems of water supply for domestic and industrial needs. The water supply in Dakar region is largely provided by groundwater's which are mainly located outside the Dakar region, whose quality has to be studied. It is in this context of intensive exploitation of groundwater resources that this study aims to investigate the quality of aquifers that supply water to Dakar in relation to the WHO standards.

2. Materials and methods

2.1 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). 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 [7]. Senegal's general population and housing Census [6] 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 [8].

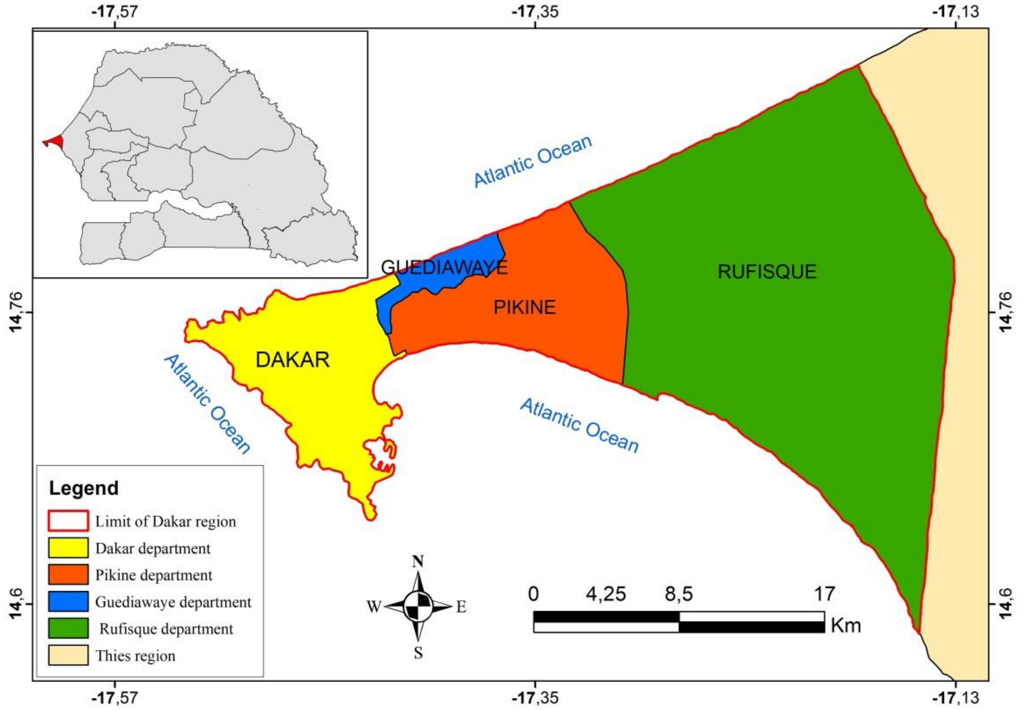

Figure 1: Localization of the study area

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} [9].

The geology of the Dakar region is part of the Senegalo-Mauritanian sedimentary basin, which covers an area of 340, 000 km². 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 [10]. The Paleocene is assimilated to the marl and limestone formation of the Madeleine whose average thickness in boreholes is 75 to 100 m [10, 11]. 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 Pasteur beach [10]. The Neogene is encountered at the top of the volcanic flows of the Cap Manuel system in the form of lateritic formation [10]. 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 [12, 13].

The Dakar area has two aquifers systems [13], a semi-confined infrabasaltic aquifer in the western part and the unconfined Thiaroye aquifer in the eastern part. 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.

2.2 Data collection and sampling

Chemical data were obtained following sampling campaigns that were carried out on the Infrabasaltic, Maastrichtian and the Paleocene aquifers in June 2019 and December 2019 respectively. Prior sampling of the groundwater at the piezometer wells pumping was carried out in order to obtain a representative sample. On the other hand, no extra pumping was performed at the groundwater extraction wells as they continuously pump water anyway. At each sampling point, two water samples were collected in polyethylene bottles and kept cool at 4 °C. Subsamples for cation analyzes were acidified to pH-values below 2 by adding HNO_3^- and the non-acidified samples were used for anion analyzes. All chemical analysis were performed at the chemistry laboratory of Geology Department of the Cheikh Anta Diop University of Dakar. Major ions were measured by ion chromatography using a Dionex DX 120 (ThermoFischer Scientific). Physicochemical parameters such as pH-value, temperature, and electrical conductivity were determined in situ with a multi-parameter probe (WTC multi 3430 Set G).
Total hardness (TH) is defined by the hydrotimetric title, which corresponds to the presence of calcium and magnesium ions. Water hardness associated with its acidity defines its aggressiveness: soft water associated with an acid pH is thereby aggressive water [14].

Total hardness (TH) was calculated from the values of the Ca^{2+} and Mg^{2+} ion concentration in the groundwater samples according to [15].

$$TH = 2.497 \times Ca^{2+} + 4.115 \times Mg^{2+} \quad (1)$$

where Ca^{2+} and Mg^{2+} were expressed in mg L^{-1}. TH values for water can be distinguished into four classes according to [16]. TH values less than 75 feature class I characterized by soft water, class II shows TH values between 75 and 150 and is characterized by moderately hard water, hard water have TH values between 150 and 300 (class III). Very hard water (class IV) exceeds TH values of 300.

3. Results and Discussion

3.1 General groundwater characterization

Physico-chemical parameters (T°, pH and EC) measured in-situ during the sampling campaigns performed in the infrabasaltic (June, 2019), Maastrichtian (December, 2019) and Paleocene (December, 2019) aquifers and from the hydrochemical analyses carried out in the laboratory showed different physico-chemical and chemical parameters for assessing the quality of these groundwater's. Tables 1, 2 and 3 show the descriptive statistics of the physicochemical and chemical data of the water sampled. The pH is measured without units and is used to determine the acidity or alkalinity of the water. For drinking water use, the pH should be between 6.5 and 8.5 [17]. Thus, the pH values from the infrabasaltic, Maastrichtian and Paleocene groundwater sampled varies between 6 to 8; 7.7 to 12.6 and 7.5 to 9.6, respectively. These values show that most of the water samples from these aquifers are alkaline. Temperature is a parameter that gives an indication of the depth of the groundwater flow. The temperature values obtained vary between 29-32°C (infrabasaltic), 28.1-31.8°C for (Maastrichtian) and 27.9-31.2°C (Paleocene). The electrical conductivity (EC) is a parameter expressing the mineralization of water and high water EC values refer to significant mineralization. The measured EC values of the infrabasaltic, du Maastrichtian et du paleoceneaquifers vary between 365-37181, 9 µS cm^{-1}, 173 et 4770 µS cm^{-1} and 366 et 7040 µS cm^{-1}, respectively. [18] and [19] classified water on the basis of EC into three categories: freshwater (<1500 µS cm^{-1}), brackish water (1500-3000 µS cm^{-1}), and saline water (>3000 µS cm^{-1}). Based on this classification 75 and 84.2% of the water sampled in the infrabasaltic, Maastrichtian and Palaeocene aquifers, respectively fall within the fresh water class and are suitable for domestic use. However, 10, 16.6 and 5.3% of the water sampled of the infrabasaltic, Maastrichtian and Paleocene aquifers, respectively, are saline waters.

Table 1: Summary statistics of the infrabasaltic (June 2019), Maastrichtian and Paleocene (December 2019) groundwater quality parameters.

Aquifer	In situ parameters	Mean	Median	Minimum	Maximum	WHO international standards (2017)	% of samples below WHO limit
Infrabasaltic	CE (µS cm^{-1})	**3270.2**	792.5	365.0	37181.9	1500	75
	T° (°C)	**30.6**	30.7	29.0	32.0	25	0
	pH	7.2	7.1	6.4	8.4	6.5-8.5	95
Maastrichtian	CE (µS cm^{-1})	1020.2	747	173.0	4770.0	1500	84.21
	T° (°C)	**30.0**	30.2	28.1	31.8	25	0
	pH	**8.7**	8.5	7.7	12.6	6.5-8.5	47
Paleocene	CE (µS cm^{-1})	**1651.3**	925.5	366.0	7040.0	1500	75
	T° (°C)	**29.6**	29.7	27.9	31.2	25	100
	Ph	8.2	7.9	7.5	9.6	6.5-8.5	67

Values plotted in the Piper trilinear diagram [20] identified dominant Cl-Ca-Mg water type in the Infrabasaltic aquifer, while in the Maastrichtian aquifer both HCO_3-Ca-Mg and Cl-Na-K water types occur. The Paleocene aquiferis characterized by HCO_3-Ca-Mg water type (Figure 2).

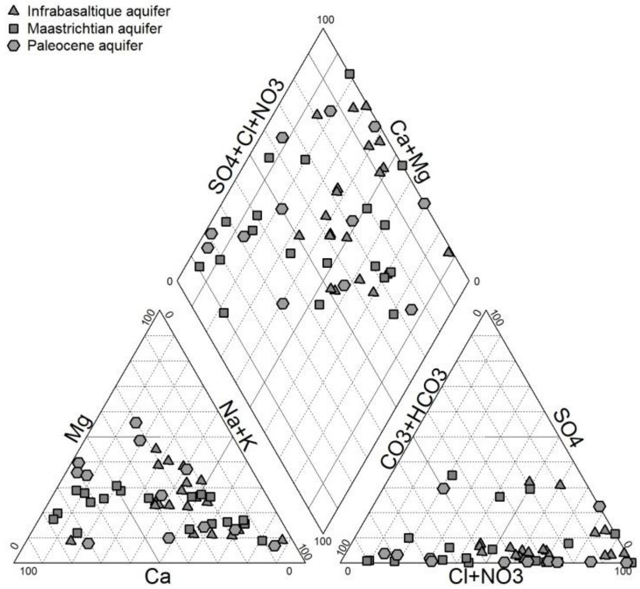

Figure 2: Piper diagram of the Infrabasaltic, Paleocene and Maastrichtian aquifers.

3.2 Drinking water quality

The presence of excessive amounts of chemical elements in water intended for domestic use can lead to adverse effects on human health. It is in this context that the WHO has established standards to better manage the risks associated with hazards that may affect the safety of drinking water in order to ensure public health. Depending on the specific standards of the water quality, its suitability for drinking purposes can be determined, whereby in this study the World Health Organization [17] drinking water standard were used to determine groundwater quality for drinking purposes.

Water total hardness (TH) is caused primarily by the presence of cations such as Ca^{2+} and Mg^{2+}. In the water samples analyzed, the TH varies between 81 to 2, 700; 55 to 1, 278 and 98 to 1, 124 mg L^{-1}in the Infrabasaltic, Maastrichtian and Paleocene aquifers. Moderately hard, hard, and very hard waters were represented by 25 and 8, 45 and 33, 30 and 58 % of the infrabasaltic and Paleocene groundwater sampled, respectively. However, in the Maastrichtian aquifer, soft, moderately hard, hard, and very hard were represented by 16, 11, 42 and 32 % of the groundwater samples (Table 2).

Table 2: Suitability of groundwater's for drinking based on Total Hardness classification after [16].

Aquifer	TH (mg L^{-1})	Water class	% of water samples
Infrabasaltic	< 75	Soft	0
	75-150	Moderately hard	25
	150-300	Hard	45
	> 300	Very hard	30
Aquifer	TH (mg L^{-1})	Qualité des eaux	% of water samples
Maastrichtian	< 75	Soft	16
	75-150	Water class	11
	150-300	Hard	42
	> 300	Very hard	32
Aquifer	TH (mg L^{-1})	Water class	% of water samples
Paleocene	< 75	Soft	0
	75-150	Moderately hard	8
	150-300	Hard	33
	> 300	Very hard	58

Groundwater chemistry can be related to several processes such as dissolution of rock and soil minerals, interactions between dissolved minerals, saline intrusion, trapping of marine waters and anthropogenic pollution [1, 21]. The chemical data analysis on the Maastrichtian aquifer showed that the concentration of the chemical elements analyzed are generally lower than the WHO drinking water standards in the mean values (Table 3). Indeed, Cl^{-}concentration values vary between 67.9 and 14, 574 mg L^{-1}, 16.3 and 1972.8 mg L^{-1} and 41.5 and 2074 mg L^{-1} respectively in the infrabasaltic, Maastrichtian and Paleocene aquifers, indicating that the groundwater samples exceed the WHO recommended limit of 250 mg L^{-1} in the mean in the infrabasaltic and Paleocene aquifers.

Table 3: Summary statistics of the infrabasaltic, Maastrichtian and Paleocene groundwater quality parameters sampled in June 2019 and December 2019 respectively. Highlighted are those parameters exceeding the WHO standards in the mean values

Aquifer	Parameters (mg L^{-1})	Minimum (mg L^{-1})	Maximum (mg L^{-1})	Mean (mg L^{-1})	Median	WHO international standards (2017)	% of samples below WHO limit
Infrabasaltic	HCO_3^-	18.0	378.0	132.8	116.0	250	90
	Cl^-	67.9	14 574, 0	**1 096.4**	145.3	250	80
	SO_4^{2-}	6.0	232.0	55.2	16.0	250	100
	NO_3^-	1.2	292.0	43.1	12.6	50	88
	Na^+	23.0	8 557.0	**539.3**	72.5	150	90

	Ca^{2+}	17.6	410.8	79.1	45.3	100	85
	Mg^{2+}	7.0	479.0	**60.6**	22.7	50	85
	K^{+}	1.8	213.0	**17.3**	6.15	12	80
Maastrichtian	HCO_3^-	61.0	475.8	216.4	146.4	250	71
	Cl -	16.3	1972.8	221.7	117.4	250	84
	SO_4^{2-}	0.7	156.9	29.4	6.4	250	100
	NO_3^-	0.9	354.2	29.2	3.4	50	84
	PO_4^{2-}	0.1	0.4	0.2	0.2	3	100
	F -	0.0	0.8	0.2	0.1	1.5	100
	Na^{+}	4.4	691.1	104.3	59.8	150	89
	Ca^{2+}	11.9	218.5	72.1	47.6	100	74
	Mg^{2+}	5.1	178.0	27.7	18.4	50	89
	K^{+}	1.7	18.5	5.3	3.2	12	95
	Fe^{2+}	0.0	0.7	0.2	0.2	0.3	74
Paleocene	HCO_3^-	24.4	2253.8	**427.2**	228.7	250	50
	Cl^-	41.5	2074.0	**396.7**	124.2	250	58
	SO_4^{2-}	1.1	820.8	85.2	2.7	250	92
	NO_3^-	0.4	50.8	15.6	6.4	50	92
	F^-	0.1	1.4	0.3	0.2	1.5	100
	PO_4^{2-}	0.2	0.4	0.3	0.2	3	100
	Na^{+}	3.5	1149.9	191.1	50.5	150	67
	Ca^{2+}	19, 9	258, 3	**106.6**	87.9	100	58
	Mg^{2+}	9, 7	116, 5	38.5	28.5	50	83
	K^{+}	1, 7	23, 4	7.2	4.4	12	83
	Fe^{2+}	0, 1	6, 3	1.2	0.3	0, 3	42

HCO_3^-concentrations vary between 18 and 378 mg L^{-1} (infrabasaltic), 61 and 475.8 mg L^{-1} (Maastrichtian) and 24.4 and 2, 253.8 mg L^{-1} (Paleocene) with average values of 133.8, 216.4 and 477.2 mg L^{-1}, respectively. The Ca^{2+} concentrations in the Paleocene aquifer were between 19.9 and 258.3 mg L^{-1} (mean = 106.6 mg L^{-1}) and the Na^+ and Mg^{2+}concentration in the infrabasaltic aquifer ranged from 23 to 8557.0 mg L^{-1} (mean = 539.36 mg L^{-1}) and from 7 to 479 mg L^{-1} (mean = 60.6 mg L^{-1}), whereby exceeding WHO limits for three elements.

The nitrate contents in groundwater sampled in the area range from 1.2 to 292 mg L^{-1}, 0.9 to 354.2 mg L^{-1} and 0.4 to 50.8 mg L^{-1} for infrabasaltic, Maastrichtian and Paleocene aquifers whereby 88, 84 and 92% of the water samples from these aquifers respectively show nitrate concentrations below WHO threshold for drinking water set to 50 mg L^{-1}.

Fluorine (F^-) concentration values vary between 0 and 0.8 mg L^{-1} and 0.1 and 1.4 mg L^{-1} in the Maastrichtian and Paleocene aquifers, respectively. All water sampled from these two aquifers has fluoride values below WHO threshold.

4. Conclusion

The characterization of the groundwater's supplying water to Dakar city according to the hydrochemical analysis showed, that 80, 75 and 86 % of the groundwater sampled in the infrabasaltic, Maastrichtian and Paleocene aquifers, respectively are suitable for drinking purposes. The pH values of the water samples from the infrabasaltic, Maastrichtian and Paleocene are mostly alkaline. The measured EC values of the infrabasaltic, du Maastrichtian and Paleocene aquifers vary between 365-37, 181.9 µS cm^{-1}, 173-4770 µS cm^{-1} and 366-7040 µS cm^{-1}, respectively. The chemical data analysis on the Maastrichtian aquifer showed that the concentrations of the chemical elements analyzed are generally lower than the WHO drinking water standards in the mean values. The Piper diagram showed the occurrence Cl-Ca-Mg water type in the Infrabasaltic aquifer, while in the Maastrichtian aquifer both HCO_3-Ca-Mg and Cl-Na-K water types occur.

References

[1] Eissa M, De-Dreuzy J, Parker B. (2018). Integrative management of saltwater intrusion in poorly-constrained semiarid coastal aquifer at Ras El-Hekma, Northwestern Coast, Egypt. *Groundwater for Sustainable Development, Volume 6, pp* 57-70. https: //doi. org/10.1016/j. gsd.2017.10.002.

[2] Li P. and Qian H. (2018). Water resources research to support a sustainable China. *International Journal Water Research Development 34 (3): 327-36*. doi: 10.1080/07900627.2018.1452723.

[3] Adimalla N, Li P. (2019). Occurrence, health risks, and geochemical mechanisms of fluoride and nitrate in groundwater of the rock-dominant semi-arid region, Telangana State, India. *Human and Ecological Risk Assessment 25 (1-2), 81-103*. https: //doi. org/ 10.1080/10807039.2018.1480353.

[4] Rosegrant MW, Ringler C, Zhu T. (2009). Water for agriculture: maintaining food security under growing scarcity. *Annual Review of Environment Resources 34 (1), 205-222*. https: //doi. org/10.1146/annur. ev. environ.03030 8.090351.

[5] Isa NM., Aris AZ. andSulaiman, WNAW. (2012). "Extent and severity of groundwater contamination based on hydrochemistry mechanism of sandy tropical coastal aquifer, " *Science of the Total Environment*, vol.438, pp.414-425.

[6] ANSD (2020). Situation économique et sociale du Sénégal. Edition 2017-2018.411 p.

[7] OMS. (1972). Approvisionnement en eau et assainissement de Dakar et ses environs. Etude des eaux souterraines. Nappe des sables quaternaires. Projet Sénégal 3201 (EX 22). Tome II.
[8] GRDR et IFAN. (2014). La dimension locale de la dialectique Migration et développement: monographie de Dakar. Version finale. Rapport. p 16.
[9] Diouf OC, Weihermüller L, Ba K, Faye S. C, Faye S, &Vereecken H. (2016). Estimation of reference evapotranspiration with limited data in Senegal. *Journal of Agriculture and Environment for International Development*-JAEID 110 (1): 117-137. DOI: 10.12895/jaeid.20161.417.
[10] Bellion YJC. (1987). Historique géodynamique post-paléozoïque de l'Afrique de l'ouest d'après l'étude de quelques bassins sédimentaires (Sénégal, Taoudenni, Iullemmeden, Tchad). Thèse de Doctorat des Sciences, Université d'Avignon (Paris, France), 302 p.
[11] Castalain J. (1965). Aperçu stratigraphique et micropaléontologique du bassin du Sénégal. Historique de la découverte paléontologique. In Coll. Int. de micropaléontologie, Dakar et mémoire BRGM n032, p.357-365, 1pl. h. t.
[12] Hebrard L. (1966). Les formations tertiaires et quaternaires de l'isthme de la presqu'ile du Cap-Vert (feuille THIAROYE; SENEGAL). Rapt. Geol. Fac. Sc. Dakar n°.16, 75p.
[13] Martin A. (1970). Les nappes de la presqu'île du Cap-vert: leur utilisation pour l'alimentation en eau de Dakar. *Rapport BRGM, 56 p*.
[14] Miquel G. (2022). La qualité de l'eau et assainissement en France 74 p + annexes; rapport l'OPECST n° 2152.
[15] Todd K. (1980). Hydrologie des eaux souterraines, 2e éd. John Wiley &Fils, New York.
[16] Sawyer GN, &McCartly DL. (1967). Chimie du sanitaire ingénieurs (2e éd. p.518). New York: McGraw Hill.
[17] WHO. (2017). Guidelines for drinking-water quality: Fourth edition Incorporating the First addendum. World Health Organization, Geneva, Switzerland, 541 p.
[18] Saxena VK, Mondal NC, Singh VS. (2004). Evaluation des paramètres hydrogéochimiques pour délimiter les zones d'eau douce dans les aquifères côtiers. J Appl Geochem 6: 245-254.
[19] Mondal NC, Singh VS, Rangarajan R. (2009). Aquifer characteristics and its modeling around an industrial complex, Tuticorin, Tamil Nadu, India: a case study. J Earth SystSci 118 (3): 231-244.
[20] Piper AM. (1944). A graphic procedure in the geochemical interpretation of water-analyses. *Eos, Transactions American Geophysical Union, 25* (6); 914-928.
[21] BatarsehM, ImreizeeqE, TilevS, AlAlaweenM, SuleimanW, AlRemeithiAM, AlTamimiMK, AlAlawnehM. (2021). Assessment of ground water quality for irrigation in the arid regions using irrigation water quality index (IWQI) andGIS-Zoningmaps: Case study from AbuDhabi Emirate, UAE. *Groundw. Sustain. Dev.*2021, *14*, 100611. https: //doi. org/10.1016/j. gsd.2021.100611.