Assessment of the Physical and Chemical Potability of Groundwater in Senegal

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Abstract:- Most of the groundwater in Senegal is not recommended directly for consumption. The diagnosis of groundwater shows that more than 80% of the water withdrawn from different areas of Senegal does not respect the WHO recommendation values. Parameters in excess pose serious health risks, their presence may indicate that the groundwater is poor quality and may be indicative of the existence of other problems that may have harmful effects on health. The main objective of this study is therefore to correlate the physical and chemical parameters of groundwater samples with respect to the different sampling areas and to assess their representativeness. To achieve this objective, we used the method of Principal Component Analysis (PCA) and the Hierarchical Ascending Classification (HAC) of the statistical analysis tool (STATISTICA Application) on the results of physical and chemical analyzes in order to better interpret the different parameters.

***Keywords**:- Physical and Chemical Parameters, Groundwater, Chemometrics, Regions, **P**rincipal **C**omponent **A**nalysis (**PCA**), **H**ierarchical **A**scending **C**lassification (**HAC**).*

I. INTRODUCTION

The available natural water reserves are made up of groundwater, stagnant or flowing surface water and seawater **[1]**. Groundwater is all water below the ground surface, in the saturation zone and in direct contact with the ground or subsoil. Underground aquifers mainly contain the freshwater reserve (96%) that can be exploited on land **[2, 3]**. Their pumping is divided into the following uses: 65% for irrigation, 25% for drinking water and 10% for industry.

The geological nature of the terrain has a major influence on the chemical composition of groundwater. At all times, the water is in contact with the ground in which it stagnates or circulates: a balance is established between the composition of the ground and that of the water. The waters circulating in a sandy or granitic subsoil are acidic and have little mineral content. The waters circulating in calcareous soils are calcium bicarbonate and often have a high hardness [**4, 5**]. In the case of karstic waters, however, we can note sudden variations in quality, with the appearance of turbidity and various types of pollution [**6-8**]. These variations are linked to the rainfall and to the runoff entrained without any real filtration in the underground network. Of particular note is good bacteriological purity, low turbidity, constant temperature, chemical composition and the almost general absence of oxygen causing the presence of undesirable reduced elements **[1]**.

Many metamorphic and sedimentary rocks can pollute groundwater. In natural waters, the pollution source may have four different origins [**9, 10**]: rocks that are essentially in carbonate form; accidental pollution; soil drainage; accumulation in the reducing zone of reservoir dams. The release of metals into groundwater does not pose a major risk to human health [**11, 12**], but they can pose problems in drinking water during its slow oxidation and its precipitation in the distribution network. [**13, 14**], summarized these problems as follows: they can give a metallic or bitter taste to the water; under certain conditions, deposits of iron oxide and manganese can occur causing certain inconveniences which are, among other things, stains on the linen, clogging of water softeners, deterioration of water quality due to bacterial development on the chemical medium of manganese oxide [**15**], etc. protection of bacteria against the biocidal effect of chlorine [**16-18**].

Senegal, as part of the achievement of the Millennium Development Goals in terms of access to water and sanitation, has installed many boreholes in rural areas since the 1970s [**19**]. Paradoxically, there are many problems relating to physical and chemical qualities, in particular: high levels of salt, fluorine, iron, manganese; the intrusion of undesirable elements from agricultural (pesticides, nitrates), mining (cyanide, arsenic and mercury) activities; risks of deterioration of the bacteriological quality of water due to lack of treatment, maintenance of hydraulic structures or appropriate sanitation systems, poor water transport and storage practices, unsanitary housing conditions [**20, 21**].

The general objective of this study is to make an inventory of the physical and chemical quality of groundwater in some areas of Senegal. Indeed, the specific objective related to this study is to see the representativeness of the physical and chemical parameters in terms of concentration in the groundwater of Senegal. To achieve this objective, we will apply the method of **P**rincipal **C**omponent **A**nalysis (***PCA***) and the **A**scending **H**ierarchical **C**lassification (***HAC***) of the statistical analysis tool ***STATISTICA*** for the statistical processing of the results of physical and chemical analyses.

II. MATERIALS AND METHODS

A. *Study Area*

The samples were taken in the Dakar, Thiès, Louga, Matam, Kaolack, Tambacounda and Ziguinchor regions. To identify the samples, a number has been assigned to each bottle. The sampling equipment was given special attention. Thus, we used new polyethylene bottles. Before going to the field, the bottles are first washed with tap water, then with 10% nitric acid and finally rinsed thoroughly with distilled water. In the field before filling the bottles, as a safety measure, they are washed three (03) times with the water to be analyzed, then filled to the brim. The samples taken, carefully labeled and stored at 4 °C in coolers, are transported to the quality control analysis laboratory.

B. *Methodologies and Equipment Used for the Assays*

Two physical and chemical parameters (pH, electrical conductivity) were measured in-situ, immediately after sample collection. pH is measured in the field using a Radiometer Analytical pHM201 portable pH meter and in the laboratory using a Hanna pH209 laboratory pH meter. Conductivity is measured in the field using a Hanna brand portable conductivity meter. The turbidity is measured using a turbidimeter, turbidity meterWAg-WT 3020. Its unit is the NTU (Nephelometric Turbidity Unit). Sulfate and nitrate ions are determined by spectrophotometry or colorimetry using a Hach Lange DR 3800 spectrophotometer. Chloride ions are determined by the Mohr method. Calcium and magnesium ions are determined by complexometry using EDTA (ethylenediaminetetraacetic acid). Iron and manganese were measured in the laboratory by colorimetry with a DR 2010/Hach type molecular absorption spectrophotometer.

C. *Statistical Analysis*

In this work we used the ***STATISTICA*** software as a data processing tool which could allow us in certain cases to better analyze the results and understand the basic sample matrix **[22-24]**. The technique of chemometrics makes it possible to correlate several variables in order to better understand the influence of several phenomena or constituents in diverse and varied samples in a space of reduced dimensions. There are several techniques used in chemometrics, including:

- **P**rincipal **C**omponent **A**nalysis (**PCA**) which is a multidimensional descriptive method of a set of data. ***PCA*** is a statistical method that reduces a large initial number of more or less correlated variables to a small number of variables called factors or principal components, so that the observed variance is maximum **[25-27]**. These factors, not correlated with each other, are linear combinations of the initial variables.
- The principle of **H**ierarchical **A**scending **C**lassification (**HAC**) consists in creating a new partition of all the data by aggregating the two closest elements according to a distance chosen a priori **[28, 29]**. The hierarchical classifications determine a notion of paternity which results in a dendrogram indicating for each level, the grouping carried out.

The combined use of **P**rincipal **C**omponent **A**nalysis (***PCA***) and **A**scending **H**ierarchical **C**lassification (***HAC***) is a powerful tool for analyzing physical and chemical parameters of mineral elements [30]. Data analysis focused on 10 parameters or variables: conductivity, pH, turbidity, Ca^{2+}, Mg^{2+}, NO_3^-, NO_2^-, Cl^-, SO_4^{2-}, Mn^{2+} and total iron (Fe^{2+} and Fe^{3+}). Indeed, the ***PCA*** is only valid when the studied factorial plans give more than 70% of information. The correlation between two elements is good, if it is close to 1. Correlation coefficients greater than 0.7 are thus considered significant, while those between 0.5 and 0.7 are considered less significant. In the case of the ***CAH***, the euclidean distance was employed as a ***similarity/dissimilarity*** measure, while the Ward aggregation method was employed to link the bundles. A combination of euclidean distance as a measure of similarity and Ward's method as a method of aggregation has been observed as the best combination leading to optimal results in HAC **[31, 32]**. The mathematical basis of the method is based on the calculation of the Euclidean distance between individuals or observations in an n-dimensional space. First, the data must be normalized by calculating their means using the formula:

$$\boldsymbol{K_{ij} = \frac{X_{ij} - X}{S_{iC}}}$$

where $\boldsymbol{K_{ij}}$ is the normal value of $\boldsymbol{X_{ij}}$ for the **i**th variable of the **j**th individual, **X** is the mean of the **i**th variable and $\boldsymbol{S_{iC}}$ the standard deviation.

The procedure adopted gives equal weight to each variable. Thus, the similarity measure is simply the distance defined in a Euclidean space. The distance between two individuals (**j, k**) is given by the following relation:

$$\boldsymbol{d_{ij} = \left[\sum_{i=1}^{n} (K_{ik} - K_{jk})\right]}$$

Where $\boldsymbol{K_{ik}}$ represents the **K**th variable measured on object **i**, and $\boldsymbol{K_{jk}}$the **K**th variable measured on object **j**. The result is given in the form of a vertical dendrogram which classifies the observations or variables by groups or sub-groups having the same weight or the same characteristics.

III. RESULTS AND DISCUSSIONS

Physical and chemical characterization (**Table 1**) based on in situ measurements (pH, electrical conductivity, turbidity) and laboratory assay of major components and metallic trace elements (chloride Cl^-, sulphates SO_4^{2-}, nitrates NO_3^- , nitrites NO_2^-, calcium Ca^{2+}, magnesium Mg^{2+}, sodium Na^+, total iron (Fe^{2+} and Fe^{3+}), manganese Mg^{2+}, etc.) is made in seven (7) regions of Senegal.

Table 1: Characterization of borehole water in some areas of Senegal

Study area	***Conductivity µs/cm***	***pH***	***Turbidity NTU***	***Cl^- °F***	***SO_4^{2-} mg/L***	***Ca^{2+} °F***	***Mg^{2+} °F***	***NO_3^- mg/L***	***NO_2^- mg/L***	***Total iron mg/L***	***Mn^{2+} mg/L***
Dakar	713,60^{a,b}	7,14^{b,c}	6,80^{b}	4,40^{a}	15,02^{a}	21,20^{b}	7,66^{a}	1,61^{a}	0,07^{a}	1,42^{b,c}	0,07^{a}
Thies	797,55^{a,b}	7,19^{c}	2,77^{a}	10,64^{a,b}	0,00^{a}	16,85^{a,b}	9,34^{a}	1,31^{a}	0,08^{a}	0,29^{a}	0,11^{b}
Louga	1122^{a,b}	7,66^{d}	7,02^{a,b}	3,00^{a,b}	280,00^{c}	13,60^{a,b}	8,40^{a}	0,80^{a,b}	0,13^{a}	0,47^{a,b}	0,132^{a}
Saint Louis	161,05^{a,c}	6,62^{a}	2,27^{a,b}	1,70^{a,b}	0,00^{a}	6,65^{a,b}	3,50^{a}	0,00^{a,b}	0,05^{a}	2,40^{c}	0,1^{a}
Kaolack	242^{a,c}	6,76^{a,b}	25,80^{c}	2,00^{a,b}	12,00^{a}	3,80^{a,b}	4,80^{a}	2,80^{a,b}	0,10^{a}	1,94^{b,c}	0,1^{b}
Tambacounda	211,50^{b,c}	7,16^{b,c}	1,45^{a,b}	2,50^{a,b}	2,50^{a}	5,15^{a}	4,15^{a}	1,40^{a,b}	0,09^{a}	0,11^{a}	0,08^{a}
Ziguinchor	1166,33^{b}	6,66^{a}	1,46^{a}	24,78^{b}	122,33^{b}	7,60^{a,b}	10,21^{a}	11,88^{b}	0,12^{a}	0,16^{a}	0,12^{a}

A. *Principal Component Analysis (PCA) in groundwater*

The results of the ***PCA*** were exploited by analysis of the correlation matrix and projection of different groundwaters in the factorial plan F_1-F_2.

B. *Analysis of the correlation matrix*

The analysis of the correlation matrix between parameters in groundwater is reported in ***table 2***.

Table 2: Analysis of the correlation matrix between the physical and chemical analysis

	Cond	***pH***	***Turb***	***Cl^-***	***SO_4^{2-}***	***Ca^{2+}***	***Mg^{2+}***	***NO_3^-***	***NO_2^-***	***Fe^{2+}***	***Mn^{2+}***
Cond	1,00										
pH	0,41	1,00									
Turb	-0,22	0,02	1,00								
Cl-	0,93	0,20	-0,20	1,00							
SO_4^{2-}	0,63	0,46	-0,15	0,44	1,00						
Ca^{2+}	0,29	0,40	0,009	0,14	-0,11	1,00					
Mg^{2+}	0,85	0,44	-0,09	0,78	0,49	0,21	1,00				
NO^{3-}	0,03	-0,46	-0,09	0,05	-0,05	-0,21	-0,13	1,00			
NO^{2-}	-0,03	-0,04	0,07	-0,05	-0,11	0,006	-0,09	0,21	1,00		
Fe^{2+}	-0,19	0,02	0,57	-0,16	-0,22	0,02	0,07	-0,15	-0,20	1,00	
Mn^{2+}	0,49	0,09	0,01	0,57	0,23	-0,11	0,31	0,32	-0,04	0,03	1,00

Examination of the correlation matrix clearly shows that pH and sulphate ions (SO_4^{2-}) have negative correlations with nitrate ions (NO_3^-) and total iron, respectively (-0.46) and (-0.22). This correlation shows an inversely proportional evolution of pH with SO_4^{2-} ions and indicates that groundwater samples have low levels of nitrate ions (NO_3^-) and total iron. The matrix also reveals a good correlation (0.93) between the conductivity of the samples and the chloride ions (Cl^-) which shows that the conductivity is mainly controlled by the Cl^- concentrations. Indeed, the measurement of the electrical conductivity makes it possible to evaluate quickly, but very approximately, the global mineralization of the water and to follow its evolution. The electrical conductivity values obtained vary between 161.5 and 1166.33 µS/cm respectively for the regions of Dakar, Thiès, Louga, Saint Louis, Kaolack, Tambacounda and the lower Casamance area (**Table 2**). The regions of Dakar, Thiès, Louga and lower Casamance have conductivity values higher than the ***WHO*** recommendation which is 300 µS/cm. We can say then, that these regions are highly mineralized. This mineralization could be explained by a surplus of the concentrations of certain metals in the water, because the more the concentration of the latter increases, the more the electrical conductivity increases **[33-35]**.

C. *Spatial groundwater analysis*

The spatial analysis of the different groundwater samples and variables is presented in plan F_1-F_2 (***Figure 1 and 2***).

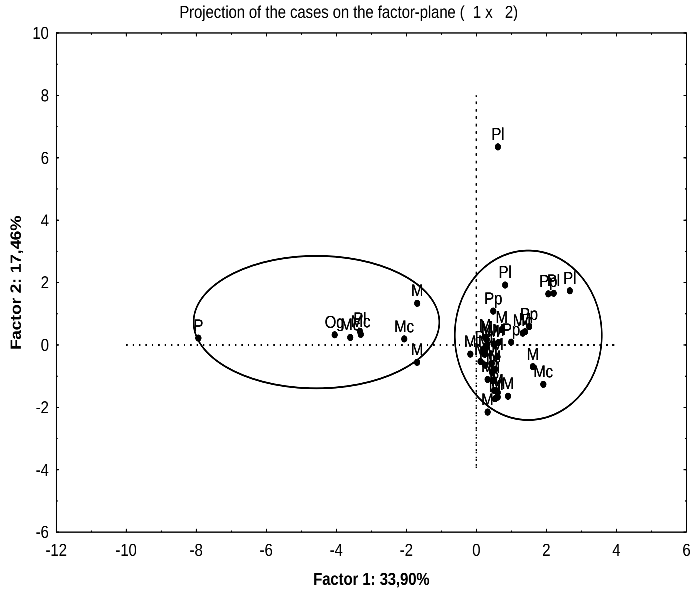

Fig. 1: Spatial groundwater analysis in plane F_1-F_2

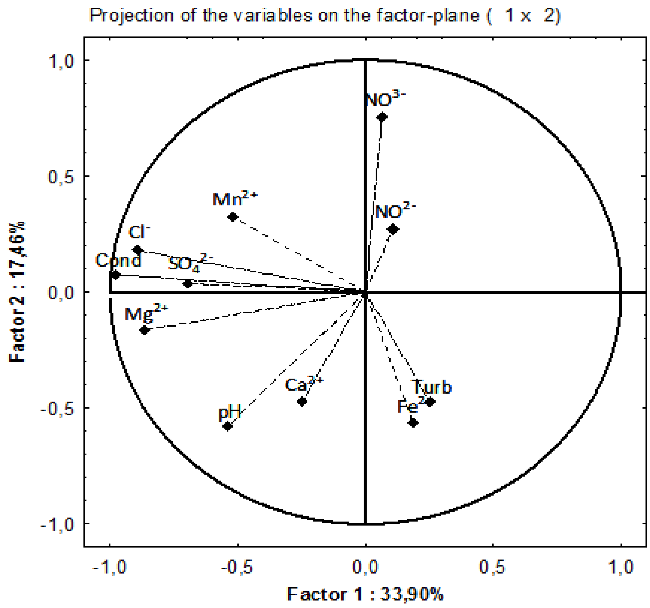

Fig. 2: Spatial analysis of variables in the F_1-F_2 plane

The variables in this plane indicate that the factor 2 is well correlated in its negative part with parameters such as chloride ions (Cl^-), conductivity, sulphate ions (SO_4^{2-}), and magnesium ions (Mg^{2+}) and to a lesser degree with pH, calcium ions (Ca^{2+}) and manganese (Mn^{2+}). However, the calcium is well correlated on the positive part of F_1 as well as the total Iron and the turbidity. All these elements appear in the water after a long time of contact with the source rock. However, these chemical components vary enormously depending on the origin, the type of rock, the aquifer collected, etc. Factorial axis 1 is mainly represented by the relationship between iron (Fe), turbidity, calcium (Ca) and the pH of the medium in opposition to nitrate and nitrite ions (NO_3^- & NO_2^-). Factor 2 can be considered as a high mineralization of the waters.

Indeed, the nitrate levels vary during the study period from 0-11.88 mg. L^{-1} (**Table 1**) in different regions. These values remain below the ***WHO*** guideline value of 50 mg. L^{-1}, with the exception of the sampling site. It is the same observation that is made globally with regard to nitrite ions (NO_2^-). The ***WHO*** recommends a limit value of 50 mg .L^{-1} for water intended for human consumption (NO_3^-) and specifies that account must also be taken of the concentration of nitrites (NO_2^-) so that the sum of the concentration ratios (nitrates/nitrites) in relation to their respective guide values must be less than 1. Biological processes have the advantage of eliminating nitrates, whereas with physical and chemical processes, these are found in discharges **[36]**.

D. Hierarchical Ascending Classification (HAC) of Groundwater

The result of the ascending hierarchical classification on the different groundwater samples is shown in **fig. 3**.

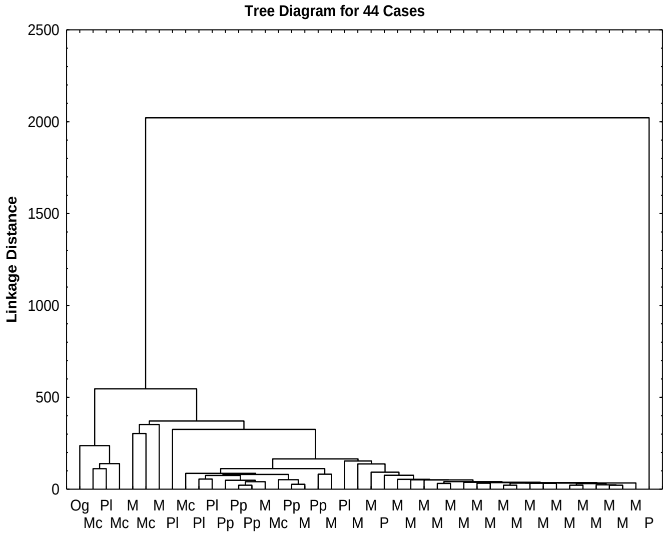

Fig. 3: Dendrogram of various tea leaves

The result of the hierarchical ascending classification on the aquifers captured is presented according to the regions. Based on distances and their position on the dendrogram, distinct classes and subclasses of regions emerge (**Fig. 3**). The subclass defined by regions such as Dakar, Thiès and Louga indicates that these three (3) regions have approximately the same physical and chemical parameters. In the same way, this is what is observed for the regions of Saint Louis and Kaolack as well as the regions of Tambacounda and Ziguinchor. In other words, the examination of **fig. 3**, allows us to say that statistically the regions of Dakar and Thiès present very different physical and chemical results (difference between classes) compared to the regions of Tambacounda and Ziguinchor. Indeed, this could be explained by the fact that geologically these areas do not present the same types of soil.

Indeed, the chemical elements of groundwater from the sampling sites chosen in the Kaolack region, shown in **Table 1**, show a variability of the different analysis parameters. Although we do not have all the chemical data, the literature reveals that this aquifer layer contains excessive fluorine contents of up to 4.75 ppm. This aquifer is made up of predominantly sandy and clayey-sandy formations. Due to its characteristics as an unconfined aquifer, the CT presents a vulnerability profile similar to quaternary formations. The higher fluorine concentrations in the CT cover a very large part of the territory following a central band where the salt contents are higher. These concentrations, as well as the salinity, result from the leaching of solutes over a long period due to the very slow circulation speeds in this part of the basin.

In the Tambacounda region, on the four (4) sampling sites, the analysis of the iron content made it possible to assess the quality of the waters and the level of contamination of the Paleozoic basement of the Tambacounda area. The iron contents are between 0.02 and 0.21 mg. L^{-1}, with an average of 0.115 mg. L^{-1} (**Table 1**). These relatively low levels seem to indicate the absence of sources likely to pollute this iron sheet. In addition, the manganese contents vary from 0.013 to 0.257 mg. L^{-1}, with an average of 0.135 mg. L^{-1}.

IV. CONCLUSION

This study made it possible to determine the physical and chemical parameters of groundwater in some regions of Senegal. The Principal Component Analysis (***PCA***) made it possible to highlight the strong correlation between the parameters and the regions. This work also allowed us to analyze the physicochemical parameters of groundwater used before treatment and, to a lesser extent, used as a source of drinking water, especially in the southern regions of Senegal. This study showed that these groundwaters are not recommended for consumption as drinking water without upstream treatment. The parameters which downgrade this groundwater as drinking water are above all iron, electrical conductivity, turbidity for certain regions of Senegal. The physical and chemical results, presented in our study, show that groundwater has a slightly acidic pH and is highly mineralized. Indeed, the data analysis showed globally that mineralization is essentially controlled by nitrate and nitrite ions (NO_3^- and NO_2^-), chlorides (Cl^-), sulphates (SO_4^{2-}) and iron (total iron). These results confirm the work of **(Gnamba et al., 2016)** who showed that iron is more abundant than manganese in nature because it represents about 5% of the earth's crust while manganese only represents 0.1%. However, these two elements are essential trace elements for organic life. According to this diagnostic study, in Senegalese groundwater, the concentrations usually encountered in iron and manganese are in a ratio of 10 mg of iron for 1 mg of manganese.

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REFERENCES

[1]. DEGREMONT, Les eaux eaux potable, 2005.
[2]. L. Rodríguez-Lado, G. Sun, M. Berg, Q. Zhang, H. Xue, Q. Zheng, C.A. Johnson, Groundwater arsenic contamination throughout China, Science 341 (2013) 866-868.
[3]. J. Podgorski, M. Berg, Global threat of arsenic in groundwater, Science 368 (2020) 845-850.
[4]. K. Arumugam, K. Elangovan, Hydrochemical characteristics and groundwater quality assessment in Tirupur region, Coimbatore district, Tamil Nadu, India, Environmental Geology 58 (2009) 1509-1520.
[5]. N. Chandrasekar, S. Selvakumar, Y. Srinivas, J. John Wilson, T. Simon Peter, N. Magesh, Hydrogeochemical assessment of groundwater quality along the coastal aquifers of southern Tamil Nadu, India, Environmental earth sciences 71 (2014) 4739-4750.
[6]. P. Marina, M. Snežana, N. Maja, M. Miroslava, Determination of heavy metal concentration and correlation analysis of turbidity: a case study of the Zlot source (Bor, Serbia), Water, Air, & Soil Pollution 231 (2020) 1-12.
[7]. M. Pešić, S. Milić, M. Nujkić, M. Marić, The impact of climatic parameters on the turbidity and natural organic matter content in drinking water in the City of Bor (Eastern Serbia), Environmental Earth Sciences 79 (2020) 1-13.
[8]. D. Hubelova, J. Mala, A. Kozumplikova, K. Schrimpelova, H. Hornova, P. Janal, Influence of Human Activity on Surface Water Quality in Moravian karst, Polish Journal of Environmental Studies 29 (2020).
[9]. R. Antony, P. Sujith, S.O. Fernandes, P. Verma, V. Khedekar, L. Bharathi, Cobalt immobilization by manganese oxidizing bacteria from the Indian Ridge System, Current microbiology 62 (2011) 840-849.
[10]. A. Matin, F. Rahman, H.Z. Shafi, S.M. Zubair, Scaling of reverse osmosis membranes used in water desalination: Phenomena, impact, and control; future directions, Desalination 455 (2019) 135-157.
[11]. O. Abe, T. Okubo, N. Hayashi, N. Saito, N. Iriguchi, I. Shirouzu, Y. Kojima, T. Masumoto, K. Ohtomo, Y. Sasaki, Temporal changes of the apparent diffusion coefficients of water and metabolites in rats with hemispheric infarction: experimental study of transhemispheric diaschisis in the contralateral hemisphere at 7 tesla, Journal of cerebral blood flow and metabolism : official journal of the International Society of Cerebral Blood Flow and Metabolism, 2000, pp. 726-735.
[12]. A. Tekerlekopoulou, D. Vayenas, Ammonia, iron and manganese removal from potable water using trickling filters, Desalination 210 (2007) 225-235.
[13]. E.D. Stein, M. Mattson, A.E. Fetscher, K.J. Halama, Influence of geologic setting on slope wetland hydrodynamics, Wetlands 24 (2004) 244-260.
[14]. B.R. Pant, Ground water quality in the Kathmandu valley of Nepal, Environmental monitoring and assessment 178 (2011) 477-485.
[15]. O.K. Jean-Eudes, R.F. Avahounlin, C.N. Kélomé, O. Pierre, A.M.H. Adéké, E.W. Vissin, Evaluation of the Physico-Chemical Quality and Potability of Groundwater Consumption in Department of Collines at Benin, Journal of Geoscience and Environment Protection 10 (2022) 29-48.
[16]. S. Phull, A. Newman, J. Lorimer, B. Pollet, T. Mason, The development and evaluation of ultrasound in the biocidal treatment of water, Ultrasonics sonochemistry 4 (1997) 157-164.
[17]. T. Mason, E. Joyce, S. Phull, J. Lorimer, Potential uses of ultrasound in the biological decontamination of water, Ultrasonics sonochemistry 10 (2003) 319-323.
[18]. E. Joyce, S. Phull, J. Lorimer, T. Mason, The development and evaluation of ultrasound for the treatment of bacterial suspensions. A study of frequency, power and sonication time on cultured Bacillus species, Ultrasonics sonochemistry 10 (2003) 315-318.
[19]. **[19]** DGPRE, Étude pour l'élaboration d'une stratégie nationale d'amélioration de la qualité de l'eau potable au Sénégal in: R. diagnostic (Ed.) Étude pour l'élaboration d'une stratégie, Ministère de l'Hydraulique et de la Planification des Ressources en Eau, 2015, pp. 189.
[20]. P. Hounsinou, D. Mama, A. Alassane, M. Boukari, Hydrogeology and Chemistry Synthesis of the deep Boring of the Township of Abomey-Calavi, Benin, Research Journal of Chemical Sciences - ISSN 2231 (2014) 606X.
[21]. F. Zahi, F. Medjani, M. Djidel, A. Drouiche, Groundwater quality and its suitability for different uses in lower Djendjen Watershed, Northest Algeria, Asian Journal of Research in Chemistry 14 (2021) 179-185.
[22]. J.M. Hilbe, STATISTICA 7: an overview, The American Statistician 61 (2007) 91-94.
[23]. [23] S. Sarumathi, N. Shanthi, S. Vidhya, P. Ranjetha, Statistica software: a state of the art review, International Journal of Computer and Information Engineering 9 (2015) 473-480.
[24]. L. Demidova, M. Ivkina, E. Zhdankina, O. Krylova, E. Sofyin, V. Reshetova, N. Stepanov, N. Tyart, Software package statistica and educational process, SHS Web of Conferences, EDP Sciences, 2016, pp. 02011.
[25]. H. Abdi, L.J. Williams, D. Valentin, M. Bennani-Dosse, STATIS and DISTATIS: optimum multitable principal component analysis and three way metric multidimensional scaling, Wiley Interdisciplinary Reviews: Computational Statistics 4 (2012) 124-167.
[26]. A.J. Calder, A.M. Burton, P. Miller, A.W. Young, S. Akamatsu, A principal component analysis of facial expressions, Vision research 41 (2001) 1179-1208.
[27]. L. Rocchi, L. Chiari, A. Cappello, Feature selection of stabilometric parameters based on principal component analysis, Medical and Biological Engineering and Computing 42 (2004) 71-79.

[28]. M. Jourlin, J. Breugnot, B. Abdallah, J. Corvo, E. Couka, M. Carre, Image Segmentation in the Field of the Logarithmic Image Processing Model: Special Focus on the Hierarchical Ascendant Classification Techniques, Advances in Imaging and Electron Physics, Elsevier2013, pp. 1-44.

[29]. M. Akil, P. Tittelein, D. Defer, F. Suard, Statistical indicator for the detection of anomalies in gas, electricity and water consumption: Application of smart monitoring for educational buildings, Energy and Buildings 199 (2019) 512-522.

[30]. S.M. Yidana, D. Ophori, B. Banoeng-Yakubo, A multivariate statistical analysis of surface water chemistry data—The Ankobra Basin, Ghana, Journal of Environmental Management 86 (2008) 80-87.

[31]. V. Cloutier, R. Lefebvre, R. Therrien, M.M. Savard, Multivariate statistical analysis of geochemical data as indicative of the hydrogeochemical evolution of groundwater in a sedimentary rock aquifer system, Journal of Hydrology 353 (2008) 294-313.

[32]. J. Walter, R. Chesnaux, V. Cloutier, D. Gaboury, The influence of water/rock− water/clay interactions and mixing in the salinization processes of groundwater, Journal of Hydrology: Regional Studies 13 (2017) 168-188.

[33]. A.A. Mahamane, B. Guel, Caractérisations physico-chimiques des eaux souterraines de la localité de Yamtenga (Burkina Faso), International Journal of Biological and Chemical Sciences 9 (2015) 517-533.

[34]. C. Bakouan, B. Guel, A.-L. Hantson, Caractérisation physico-chimique des eaux des forages des villages de Tanlili et Lilgomdé dans la région Nord du Burkina Faso-Corrélation entre les paramètres physico-chimiques, Afrique Sci 13 (2017) 325-337.

[35]. E. Doboy, S.M. Marthe, K.D. Nathalie, M.W.L. Carelle, D.V. Germain, G. Roger, Physico-Chemical Characterizations of the Water from Three Boreholes in the Town of Massakory (Chad).

[36]. B.L. Jean RODIER, Nicole MERLET et coll., Analyse de l'eau, Dunod, Paris, 2009 (2009) 1579.