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Spatio-Temporal Evolution of the Quality of Drinking Water in M'pody, a Village in the District of Anyama (Ivory Coast)

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Abstract: In M'pody village of Anyama district, an epidemic of diarrhoea was detected in January 2020. These cases of diarrhea would be linked, according to the population concerned, to the consumption of water from the improved village hydraulic system (IVH), which has not been maintained for nearly 3 years. The objective is spatio-temporal assessment of the quality of drinking water in M'pody. The methodology consisted in carrying out four campaigns to collect water samples from well, rivers and the single borehole. Classical physico-chemical parameters were determined by electrochemical and spectrophotometric methods. Microbiological analysis was carried out using membrane filtration technique. Results showed that the waters analyzed were weakly mineralized and all contained germs that were indicators of faecal pollution. The parameters implicated in the non-potability of the well, borehole and river water during the four seasons concerned turbidity, pH, nitrite, ammonium, total iron and the following germs: *Escherichia coli*, *Enterococcus*, *Pseudomonas* and sulphite-reducing anaerobes. Furthermore, Kohonen's Self-Organizing Map (SOM) resulted in four classes. Class I is made up of 68.05% of samples in the database. Class II comprises 21.18%, Class III contains 2.77% and class IV represents 7.98% of the samples. To limit water pollution, the following measures should be recommended: isolate the deep aquifers from the superficial aquifers by resistant casing, protect roof from external contributions, install sanitation facilities downstream of wells and boreholes, move waste dumps and latrines away from wells and boreholes.

Keywords: Well, River and Borehole Water, Spatio-Temporal, Quality of Drinking Water, Physicochemical, Microbiological

1. Introduction

Water quality in the world has experienced a significant deterioration in recent years, due to uncontrolled industrial discharges, intensive use of chemical fertilizers in agriculture, and haphazard exploitation of water resources. Consumption of such waters can be harmful to health. According to World Health Organization, approximately 1.1 billion people do not have access to safe drinking water and 2.4 billion do not have access to adequate sanitation. More than 2 million people, mostly children under five years old in developing countries (where hygiene and sanitation measures are inadequate), die each year from diarrheal diseases [36]. Almost 90% of diarrheal diseases worldwide are attributable to poor quality drinking-water and inadequate sewage sanitation [23]. To improve these situations, two conditions are necessary to allow population access to quality drinking-water in sufficient quantity. The supply source must be sustainable on the one hand and the environment maintained in a permanent state of health through an adequate system of water treatment and environmental sanitation on the other hand [26]. Despite existence of improved sources of drinking

water, there is a persistence of waterborne diseases in rural areas due to the consumption of water from either a surface water source (river, pond, marsh) or a traditional well [12, 19]. In Africa, groundwater in urban and rural areas is subject to multiple constraints due to strong population growth and the inadequacy or absence of sanitation [18]. Sewer systems, septic tanks, factory wastewater and solid waste are the main sources of groundwater pollution in urban, peri-urban and rural areas. Agriculture through agricultural inputs, also contributes to degrading the quality of groundwater [10] and watercourses. Demographic growth experienced by Ivory Coast after its independence resulted in an increase in primary needs of population, including access to drinking water for urban and rural populations. This high demographic pressure on natural resources is reflected in an increasingly production of waste of all kinds. Thus, for the past few decades, studies carried out on the water resources of Ivory Coast have reported many sources of pollution in both surface and groundwater in localities of Abidjan, Kossihouen [1, 11], Biankouman [2], Buyo, Daloa [27, 5], N'zianouan [4] and Tortiya [31]. These pollutions were due to heavy metals, nitrogenous derivatives, pesticides and micro-organisms.

Anyama Council, like other council of Abidjan, uses deep aquifer as drinking water supply. In rural areas, localities exploit groundwater through wells and springs. Access to sanitation services being non-existent, evacuation of wastewater and excreta from these villages is carried out for the most part by traditional latrines. This constitutes a microbiological risk of contamination of the groundwater, making this groundwater vulnerable to pollution. In Ivory Coast and in M'pody, a village located at about sixty kilometers from the town of Anyama, a diarrhea epidemy was detected in January 2020 affecting 69 people, mainly children aged 0 to 5 years. These cases of diarrhea would be linked according to the population concerned, to the consumption of water from the improved village hydraulic system (IVH) that has not been maintained for almost 3 years [15]. The fear would therefore be that these populations would turn away from this water in favor of other sources of water mainly represented by wells. This study was therefore carried out to control the quality of the main sources of drinking water in M'pody. This work aimed to make a spatio-temporal assessment of physicochemical and microbiological quality of drinking water in M'pody.
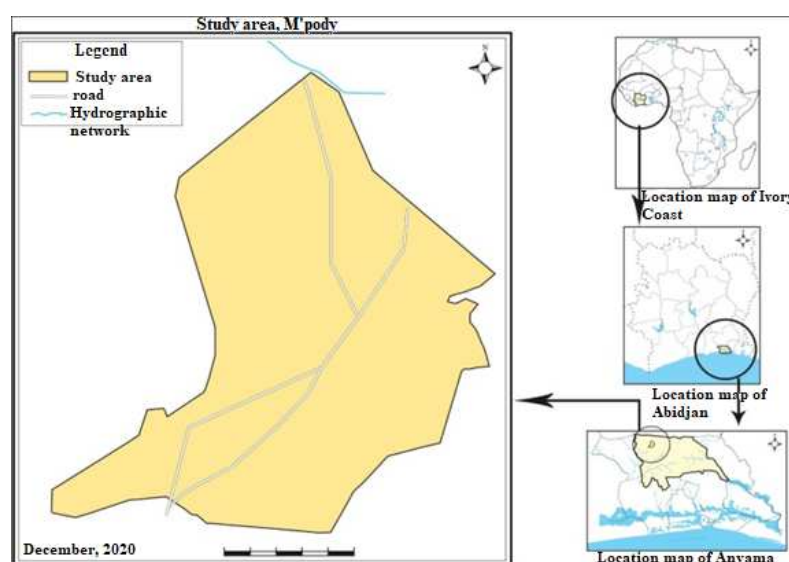

Figure 1. *Presentation of the study area.*

2. Materials and Methods

2.1. Materials

2.1.1. Presentation of the Study Area

M'pody is a locality which belongs to the sub-division of Anyama located in the south of Ivory Coast. Anyama covers an area of 114 km^2 and its population is estimated at 148,962 inhabitants [29].

M'pody village UTM coordinates are 30N03 north latitude and 0616 west longitude. It is located 30 km beeline from the coast of the Gulf of Guinea, northeast of Abidjan, in the evergreen forest zone belonging to the Guinean domain. Natural vegetation has given way to intense agriculture. The highly developed culture of oil palms and rubber trees leads to maximum degradation of the natural environment. Average annual rainfall varies between 1,600 and 2,500 mm. The village has 2,731 inhabitants. Inhabitants of the village of M'pody obtain their water from wells and improved village hydraulics (HVA) [15].

2.1.2. Equipment

Main measuring equipment consists of a Palintest photometer (Great Britain), a pH meter, a conductivity meter, a turbidity meter for physico-chemical parameters and a membrane filtration device for bacteriological parameters.

2.1.3. Sampling

Water sampling was carried out from the 72 (seventy-two)

wells, one (1) borehole and two (2) rivers into the village during four campaigns (long dry season, long rainy season, short dry season, short rainy season). Samples were taken in 1000 ml polyethylene containers for physico-chemical parameters and 500 ml containers for microbiological parameters.

2.1.4. Reagents

All reagents used were of analytical quality. Reagents used to measure chemical parameters were PALINTEST brand (Great Britain). Rapid' E. coli 2 Agar, BEA (Bile Esculin Azide) agar and TSN (Tryptone Sulfite Neomycin) agar from BIORAD were used for the enumeration of faecal markers.

2.2. Methods

2.2.1. Collection, Transport and Storage of Samples

Samples were collected according to Jean Rodier's recommendations (2016) [30]. Samples were stored in a cool box at a temperature between 4°C and 8°C, protected from light and transported to the laboratory, respecting the cold chain by means of ice packs.

2.2.2. Physico-Chemical Analyses

Physico-chemical parameters were determined by the following methods:

1. pH is measured with a HACH type digital laboratory pH meter equipped with a combined electrode (Bioblock Scientific) [28].
2. Conductivity is measured using a HACH [35].
3. Turbidity is determined using HACH nephelometry [34].
4. Titrimetry was used for the determination of organic materials [35].
5. Mineral salts and color were determined through colorimetry using a Palintest 7100 SE photometer with pre-programmed filters and calibration curves, using operational wavelengths between 410 nm and 640 nm

and following manufacturer procedures. The mineral salts tested were nitrite, nitrate, fluoride, iron, manganese, total alkalinity contents (TAC), total hydrotimetric degree (THD), ammonium, sodium, magnesium, calcium, sulphate, potassium, bicarbonate, zinc.

2.2.3. Microbiological Analysis

Microbiological analyses were used to identify and enumerate total coliforms (TC), thermotolerant coliforms (TTC), *Escherichia coli* (*E. coli*), *Enterococcus faecalis (E. faecalis), Pseudomonas spp*. These microorganisms were identified and enumerated by filtering homogeneous aliquots of 100 ml and 50 cl (sulphite-reducing anaerobes) onto a membrane with 0.45 µm pore diameter. Membranes were then placed on selective culture media for 24 hours at 37°C in a thermostatic oven. The following media were used: BEA (Bile Esculin Azide) agar (a selective medium used for the isolation and enumeration of enterococci by the conventional plate count method) for faecal Streptococci, Rapid'E. coli 2 Agar (culture medium for the identification of *E. coli*) for total coliforms, TSN (Tryptone Sulfite Neomycin) agar for *Clostridium* sulfitoreductans and pseudosel or ketrimide medium for *Pseudomonas*.

2.2.4. Data Processing

Descriptive analysis (means, medians, minimum, maximum and standard deviation) and multivariate analysis were performed using the 300 samples, 15 physico-chemical variables and 6 microbiological variables. Percentages determination was carried out using EXCEL 2010 software. Kohonen map's classification was obtained using R software.

3. Results

Results of physico-chemical and bacteriological analyses of well water, river and borehole water are given in Table 1.

Table 1. Results of physico-chemical and bacteriological analyses of well water (n=288), river (n=8) and borehole water (n=4).

Parameters	Well water (n=288)±	River (n=8)±	borehole water (n=4)±	WHO/Ivory Coast standard
Turbidity	17,57±16,20	24,23±11,66	9,28±8,20	≤4 UNT*
Conductivity	157,84±154,20	37,04±10,86	196,08±24,44	100-1000 µS/cm
Colour	28,03±15,56	55±22,20	26,25±9,46	15 VCU
pH	5,13±0,56	6,76±0,42	6,80±0,46	6,5-8,5
Temperature	27,80±1,39	27,78±1,77	27,38±2,27	25°C
Chlorine residual	0,31±1,32	-	-	0 mg/L
Organic matter	4,70±2,79	15,09±7,47	6,46±1,99	≤ 5 mg/L
Nitrates	13,67±13,58	5,38±5,48	2,02±3,21	≤ 50 mg/L
Nitrites	0,08±0,21	0,06±0,04	0,08±0,05	≤ 0.1 mg/L
Ammonium	0,36±0,74	0,46±0,47	0,84±1,37	≤ 1.5 mg/L
Total iron	0,55±1,38	1,57±1,49	1,60±1,39	≤ 0.3 mg/L
TAC	74,07±52,94	114,38±79,71	0,21±0,07	500
DHT	24,73±26,70	28,13±49,71	201,25±117,50	
Magnesium	7,98±9,08	9,88±4,42	62,50±22,55	≤ 50 mg/L
Manganese	0,01±0,01	0,02±0,01	6,25±1,89	≤ 0.1 mg/L
Phosphate	0,11±0,17	0,64±0,20	0,03±0,00	≤ 0.5 mg/L
Chloride	18,18±13,11	12,68±2,42	0,42±0,16	≤ 200 mg/L
Sulphate	10,68±13,38	9,38±7,76	16,98±8,07	≤ 250 mg/ L
Sodium	6,86±6,45	4,48±2,50	6,00±5,89	≤ 150 mg/L
Potassium	5,44±5,66	6,69±5,96	2,78±1,66	≤ 12 mg/L

Parameters	Well water (n=288)±	River (n=8)±	borehole water (n=4)±	WHO/Ivory Coast standard
Sodium chloride	25,11±16,51	17,15±4,12	7,68±4,00	≤ 500 mg/L
Calcium	14,97±16,29	9,25±11,16	19,75±8,41	
Carbonate	47,31±29,80	38,75±10,61	92,50±105,32	≤ 250 mg/L
Bicarbonate	90,71±56,53	66,25±13,30	163,75±158,19	
CT	2240,23±5110,60	2534,5±2202,12	13,75±21,36	0 CFU/100 ml
CTh	947,85±2076,18	982,63±1280,13	1,75±2,06	0 CFU/100 ml
E. coli	947,85±2076,18	982,63±1280,13	1,75±2,06	0 CFU/100 ml
E. faecalis	936,08±2172,21	1719±1539,02	15,00±30,00	0 CFU/100 ml
ASR	0,85±2,29	2,125±3,64	7,50±15,00	0 CFU/20 ml
Pseudomonas spp	23,95±106,21	11±15,27	0,00±0,00	0 CFU/100 ml

3.1. Evolution Over Time of Physico-Chemical and Bacteriological Parameters of M'pody Drinking Water

3.1.1. Evolution of Physico-Chemical Elements Contents Over Time

(i). Turbidity

The turbidity curves for borehole, well and river waters showed the same pattern, with two peaks for well and river waters (Figure 2A). For all three types of water, the maximum peak was observed in the main rainy season and the second peak in the short rainy season. At the wells level, turbidity values ranged from a minimum of 14.12 NTU in the long dry season to a maximum of 20.97 NTU in the long rainy season. At the level of boreholes, turbidity values ranged from 0.51 to 19.8 NTU in the short and long rainy seasons respectively. River water turbidities ranged from 18 to 32.9 NTU in the short and long rainy seasons respectively.

(ii). pH

pH of borehole and well waters showed a decreasing trend during the four seasons but at river level, the curve showed an increasing trend (Figure 2C). In borehole water, the lowest pH value was recorded during the short rainy season (6.13) while the highest value was recorded during the long dry season (7.17). Concerning wells, the lowest pH 4.86 was obtained in the short rainy season while highest value of 5.31 was recorded in the long dry season. pH of rivers samples ranged from 6.46 to 6.96, with the lowest value in the long dry season and the highest in the long-wet season.

(iii). Electrical Conductivity

Electrical conductivity of the borehole, well and river waters showed a similar saw tooth pattern with a peak in the short-dry season for borehole and well waters and two peaks one in the long-dry season and another in the short-dry season for river samples (Figure 2B). The minimum conductivity values obtained for borehole, well and river waters were 168.1 μS/cm, 148.22 μS/cm and 26 μS/cm respectively, corresponding to long dry season for borehole and long rainy season for well and river waters. The maximum values were 223 μS/cm, 178.88 μS/cm and 50.55 μS/cm respectively and were all recorded in the short dry season.

(iv). Nitrate Ion Concentration

Nitrate concentration curves in well waters and river waters showed each, two peaks in long dry season and short rainy season respectively, while those of borehole waters showed a single peak in the short rainy season (Figure 2D). At wells level, nitrate concentration fluctuated between a minimum of 4.14 mg/L in the long rainy season and a maximum of 20.70 mg/L in the short rainy season. In borehole waters, nitrate levels varied from 0.023 mg/L (short dry season) to 6.8 mg/L (short rainy season). Concerning river waters, nitrate values ranged from a low of 0.15 mg/L in the long rainy season to a high of 11.75 mg/L in the long dry season.

(v). Nitrite Ion Concentration

The nitrite concentrations of wells waters showed a decreasing trend with a rise in the short rainy season. In case of borehole water, curves showed an increasing trend with a peak during the short-rainy season. River waters showed a peak in the short-dry season (Figure 2E). The nitrite levels varied between a minimum of 0.02 mg/L in the long-dry season and a maximum of 0.13 mg/L in the short-rainy season in borehole waters. Wells water level in nitrite was ranged from 0.05 mg/L in the short-rainy season to 0.13 mg/L in the long-dry season. In river waters, nitrite values ranged from a low of 0.05 mg/L in the long dry season to a high of 0.09 mg/L in the short dry season.

(vi). Ammonium Ion Concentration

Concentration curve of ammonium in river waters showed a decreasing trend and a rise with two peaks respectively in the long-dry season and the short-dry season, while borehole-water showed an increasing trend with a peak in the short-rainy season. Wells water showed a peak in the short-dry season (Figure 2F). Talking about borehole water, ammonium values ranged from 0.1 mg/L in the short-dry season to 2.9 mg/L in the short dry season. For wells waters, ammonium concentrations ranged from 0.20 mg/L in the long-rainy season to 0.57 mg/L in the short-rainy season. River waters ammonium values ranged from a low of 0.11 mg/L in the long-rainy season to a high of 1.09 mg/L in the long-dry season.

(vii). Iron Ion Concentration

The curves of iron ion concentrations in borehole waters and rivers waters had a similar sawtooth pattern with two peaks in the long-dry season and short-dry season respectively, while the borehole water had a decreasing pattern and stabilized with a peak in the long-dry season (Figure 2G). In the borehole water, iron levels ranged from

0.25 mg/L in the long-dry season to 2.9 mg/L in the short-dry season. In wells waters, iron concentrations ranged from a low of 0.35 mg/L in the short-dry season to a high of 1.11

mg/L in the long-dry season. Concerning rivers waters, iron values ranged from a low level 0.15 mg/L in the long-rainy season to a high level of 2.58 mg/L in the short dry season.
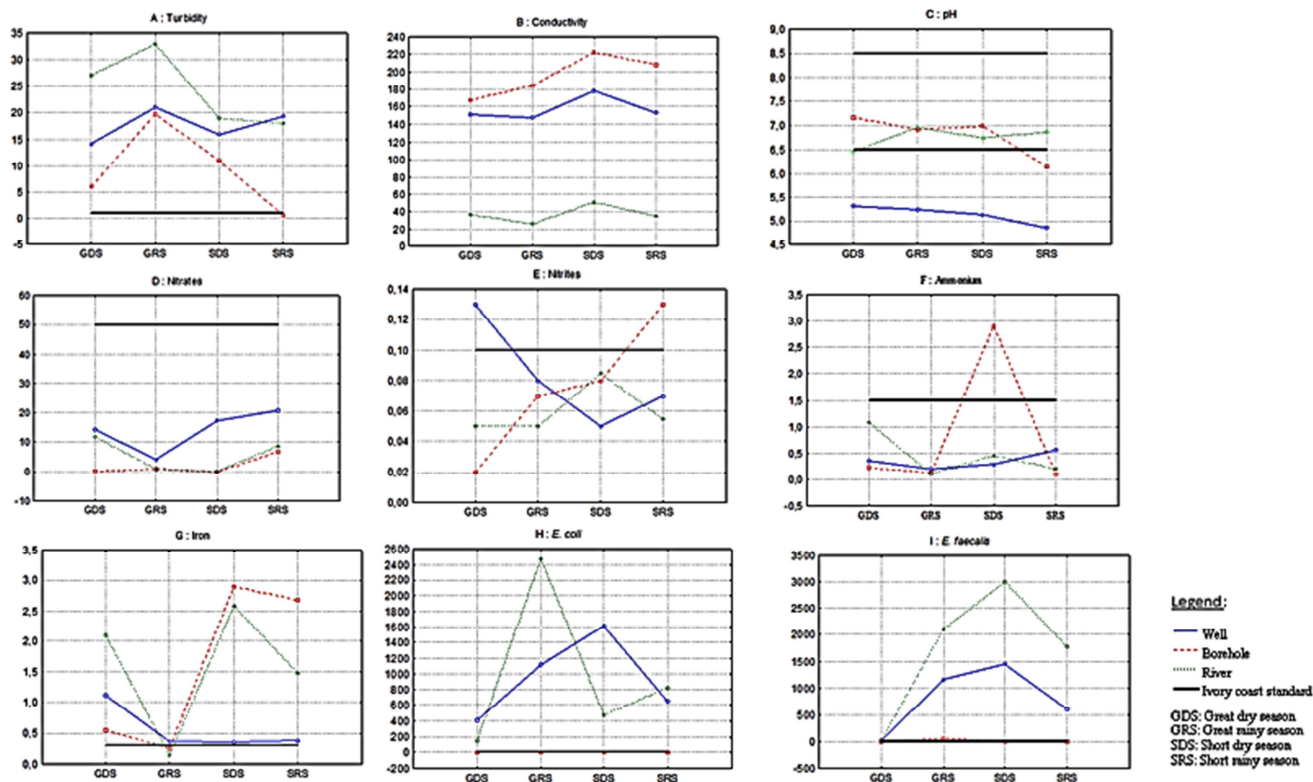

Figure 2. Seasonal evolution of physicochemical et bacteriological parametters in different drinking waters.

3.1.2. Temporal Variation of Bacteriological Parameters in Drinking Water

(i). E. coli Densities

The curve of *E. coli* densities in boreholes waters was constant while rivers waters showed a sawtooth pattern with two peaks in long and short rainy seasons respectively (Figure 2H). In wells waters, *E. coli* densities preented a peak in the short dry season. Boreholes waters showed *E. coli* densities ranged from 0 CFU/ml in the short dry and rainy season to 4 CFU/ml in the long rainy season. From wells waters, *E. coli* densities ranged from 411.75 CFU/ml in the long dry season to 1612.11 CFU/ml in the short dry season. In rivers waters, *E. coli* concentrations ranged from 150.5 CFU/ml in the long dry season to 2475 CFU/ml in the long rainy season.

(ii). Densities of E. faecalis

The curves of wells and rivers water showed the same

pattern with each showing a peak in the short dry season while the borehole water remained constant over the four seasons with a peak in the long rainy season. In the borehole water, *E. faecalis* loads ranged from 0 CFU/ml in the long dry season, the short dry season and the short rainy season to 60 CFU/ml in the long rainy season. For wells waters, *E. faecalis* densities ranged from 17.39 CFU/ml in the long dry season to 1454.35 CFU/ml in the short dry season. *E. faecalis* loads ranged from 6 CFU/ml in the long dry season to 3000 CFU/ml in the short dry season (Figure 2I).

3.1.3. Seasonal Comparison of Physical, Chemical and Bacteriological Parameters in Drinking Water

Out of the 26 parameters analyzed in drinking water from M'pody, only the levels of 5 parameters, namely conductivity, iron, manganese, bicarbonate and total coliforms, showed no significant difference during the four seasons.

Table 2. Significance levels of the evolution of physico-chemical and bacteriological parameters of drinking water according to the four seasons, determined from the Kruskal Wallis test.

p-value	Physico-chemical parameters s	Microbiology parameters
> 0,05	Conductivity, iron, manganese, bicarbonate	CT
0,05 - 0,01	Ammonium, TAC, potassiu	ASR
0,01 - 0,001	Turbidity, colour, carbonate	
< 0,001	pH, Temperature, Chlorine residual, Nitrate, Nitrite, Organic matter, Chloride, DHT, Calcium, Magnesium, Sulphate	*E. coli, E. faecalis, Pseudomonas spp*

3.2. Spatial Evolution of Physico-Chemical and Bacteriological Parameters of Borehole, Well and River Waters During the Four Seasons

A classification of the waters on the Kohonen map has been establish rising four groups of water emerge. Physico-chemical and bacteriological parameters characterizing each group are presented in Figure 3.

The SOM component planes of the dataset allow to distinguish two types of colors, the dark red cells which represent high values while the blue cells represent low values (Figure 4).
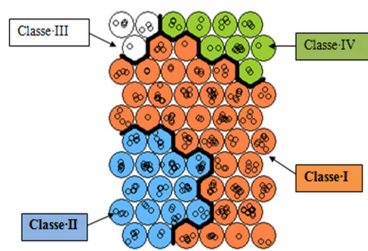

Figure 3. *Distribution of samples on the Kohonen map based on physico-chemical and bacteriological variables.*
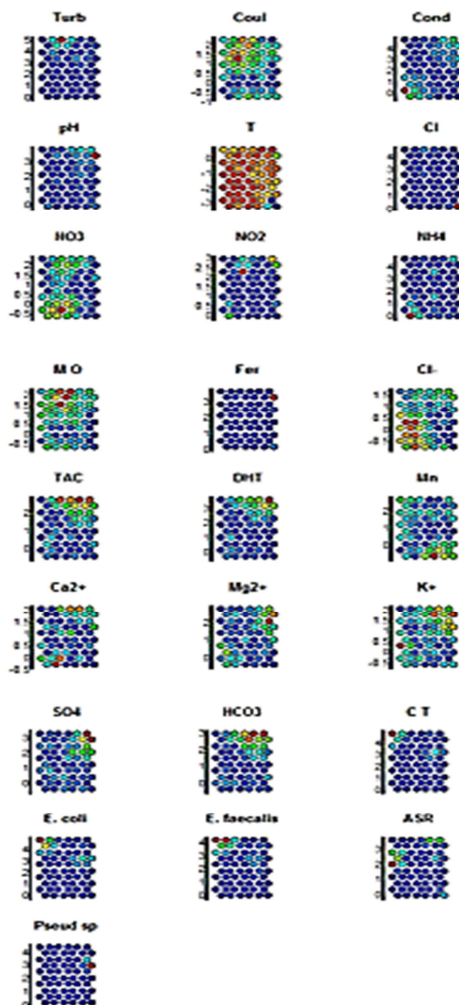

Figure 4. *Gradient of values of physico-chemical and bacteriological parameters on the Kohonen map.*

The first class is made up of the largest number of samples with 196, representing 68.05% of the database. These waters are characterized by high values of residual chlorine (16.2 mg/L). Furthermore, they are richer in NO_2^- (1.65 mg/L), Mn^+ (0.06 mg/L) and color (95 UCV) than the others. There is also a strong presence of *Pseudomonas sp* and ASR in this group (Figure 4).

The second class has 61 samples and represents 21.18% of the total database. It is mainly characterized by high concentrations of chemical elements K^+ (45 mg/l), Cl^- (70 mg/l), Ca^{2+} (104 mg/l), NO^{3-} (73.8 mg/l) and by a very high electrical conductivity (1283 µs/cm).

The third class contains the lowest number of samples (08) and represents 2.77% of the total database. It is mainly characterized by concentrations of TC (72000 CFU/ml), *E. coli* (20000 CFU/ml) and *E. faecalis* (15000 CFU/ml). Finally, the fourth class contains 23 samples and represents 7.98% of the total data. It is characterized by high turbidity and organic substance levels and by chemical element concentrations in total iron (13.2 mg/l), Mg^{2+} (65 mg/l) and SO_3^{2-} (89 mg/l)

4. Discussion

Following an outbreak of diarrhea in the village of M'pody in the greater Abidjan area of Anyama, an assessment of the quality of various water sources was undertaken as part of this study. The water sources consisted of one IVH, 72 wells and two rivers. The assessment included 288 well water samples, 8 river water samples and 4 borehole water samples that were collected during months of February (major dry season), June (major rai ny season), August (minor dry season) and October (minor rainy season) of the year 2020. The study was carried out according to the following points:

1. Seasonal evolution of physico-chemical and bacteriological parameters of the water sources;
2. Spatial evolution of physico-chemical and bacteriological parameters.

4.1. Seasonal Evolution of Physico-Chemical and Bacteriological Parameters

The Kruskal Wallis test was carried out to assess the seasonal variation of the physico-chemical and bacteriological parameters of the drinking water during the four seasons and allowed to distinguish two groups. One group had no significant difference in parameters and was represented by conductivity, total iron, manganese ions, bicarbonate ions and total coliforms for the characterization of the quality of drinking water in the locality studied. *E. coli, E. faecalis,* ASR and *Pseudomonas spp* with a p-value $p < 0.05$.

The determination of minerals in the collected water samples showed very low concentrations of fluoride, calcium, magnesium, sulphate, chloride, phosphate, sodium and zinc over the four seasons and no impact on water quality. Similar results were reported by Mahamane et Guel (2015) in Burkina Faso and Pambou et al. (2022) in Gabon on the major ions

$(Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-)$ in groundwater and surface waters [25, 28]. The levels of trace elements such as iron showed high peaks respectively in wells during long dry season, in rivers during the long and short dry season and in boreholes during the short dry season. These high levels of iron in the groundwater were similar to those obtained by Lanciné et al. 2008 The high iron levels in the groundwater were similar to those observed by Tiassalém a region of southern Côte d'Ivoire, located at about 50 km from the village of M'pody [24]. The high iron content caused a problem of acceptability of the water by the population. Indeed, this element has given the water an unpleasant metallic taste. According to Goné et al. (2005), the high Fe^{2+} and Mn^{2+} levels suggest that the environment is poor in O_2 dissolved [17].

Nitrate levels in wells waters (13.67±13.58 mg/L) were higher than nitrate levels in boreholes waters (5.38±5.48mg/L) and surface waters (2.02±3.21mg/L). Nitrate was final stage of nitrogen oxidation, and was the most highly oxidised form of nitrogen in water. However, the main source of nitrates in wells waters was attributed to human activities. Indeed, their content in wells waters is linked to agricultural activities (fertiliser use), domestic wastewater and animal manure [39]. As the study area is an agricultural area, the presence of nitrates in the water would be due to agricultural activities using chemical fertilizers. Another likely source would be the decomposition of plant organic matter [31]. In addition, the massive input of fertilisers and heavy rainwater drainage have contaminated groundwater by increasing the nitrate content [3, 8]. This vertical infiltration of nitrates was accelerated or delayed by the geological nature of the unsaturated zone. Well water became vulnerable to organic pollutants from domestic activities: latrines, rubbish dumps, sewage infiltration [32]. The shallowness of the wells and the failure to respect the minimum distance between the well and the latrine (15 m according to the WHO) were aggravating factors.

Nitrite levels peaked during the long dry season for well water and during the short rainy season for borehole water. Nitrite was therefore a good indicator of organic contamination of the water. The pollution would probably be linked to the significant infiltration of runoff water during this season, carrying the pollutants to the water table. Our values were lower than those obtained by Gnagne et al. (2013) in Abidjan whose values vary from 0.6 mg/L to 4.8 mg/L [16]. According to these authors, the contamination of water by this nutrient is due to the presence of septic tanks and leaky family latrines near the wells and is favoured by direct infiltration of wastewater into the water table. According to Ohou-Yao et al. (2014), the poor handling of the pitcher, which is usually placed on the ground, is also thought to be the cause of the contamination of water by this nutrient [27].

With regard to ammonium, it is only the borehole that had high values during the short dry season. Ammonium is the product of the final reduction of nitrogenous organic substances and inorganic matter in water and soil. The abnormal concentration of ammonium in the groundwater could be explained by the fact that in the dry season there is a concentration of ions in the sampled water [20]. These results were similar to the work of Kouamé et al, Yao et al and Yapo et al. [22, 37, 38].

Turbidity of well water, borehole water and river water showed peaks during the main rainy season. Turbidity is a measure of the cloudiness of water, i.e. this parameter is an indicator of water transparency. The high turbidity levels could be due to infiltration and percolation of rainwater depending on soil permeability and nature.

The analytical results showed the presence of faecal contamination bacteria in the well, borehole and river water of M'pody. Indeed, the average *E. coli* content was 947.85±2076.18 CFU/mL for the wells, 1.75±2.06 CFU/mL for the borehole and 982.63±1280.13 CFU/mL for the river. For *E. faecalis,* the concentrations in well water, borehole water and river water were 936.08±2172.21 CFU/mL, 15.00±30.00 CFU/mL and 1719±1539.02 CFU/mL respectively. The presence of faecal germs provides information on recent and old faecal contamination, which means that there is a probable risk that pathogenic germs are present in these waters. The locality of M'pody, as in almost all villages in Côte d'Ivoire, lacks an adequate sanitation system. Some houses have no latrines, which means that the population usually has to relieve themselves in the open air. In this locality, rainfall is very abundant with a peak of 1,646.5 mm and run-off water erodes the soil and deposits it in watercourses and other sources. Most houses with latrines have wells nearby, usually within 15m. The growth and abundance of total coliforms show good aeration conditions and water rich in dissolved oxygen. Furthermore, the acidity of the water in the region could favour the proliferation of total coliforms. This hypothesis is supported by the work of Douagui et al. (2012) which revealed a positive correlation between the abundance of total coliforms and the acidity of the pH (average of 5.8) [14]. These results are confirmed by those published by Dakouri Desmos (2021) who reports that the high presence of total coliforms, *Clostridium spp.* and faecal streptococci, indicate a high level of bacterial contamination of faecal origin in the waters of this bay, the degree of pollution of which increases after the rainy season [13].

4.2. Spatial Evolution of Physico-Chemical and Bacteriological Parameters

To assess spatial evolution of physico-chemical and bacteriological parameters of drinking water during the four seasons, Kohonen map was used. Self-organizing maps (SOM) are artificial neural network techniques based on unsupervised learning algorithms [21]. Because of their classification capabilities as well as their visualization performance, they have been successfully used in environmental domains (soil, air, water, etc.). In the locality of M'pody, Kohonen Self-Organising Map (SOM) was used to obtain four classes, Class I contqining 68.05% of samples in the database, Class II contains 21.18% of the samples, Class III contains 2.77% of the samples and class IV represents 7.98% of the samples.

Several authors have used Kohonen map in their studies. This the case of Alvarez-Guerra et al. (2011) who developed a methodology based on the SOM technique for the integration and classification of data on several pollutants measured at monitoring stations according to their indications on air quality in Spain [7]. Tsakovski et al. (2010) used SOM to reveal the main factors controlling runoff water quality in Gdansk (Poland) [33]. Berrada et al. (2016) used SOM and a hierarchical bottom-up classification (SOM-HCA) to detect seasonal variations in heavy metal concentrations in the surface sediments of the Sidi Chahed dam (Morocco) [9].

5. Conclusion

At the end of this study whose objective was the spatio-temporal evaluation of drinking water quality in M'pody. Among the 15 physico-chemical parameters measured in the wells, boreholes and rivers waters during the four seasons, turbidity, pH, nitrite, ammonium and total iron levels were above the standard for drinking water quality. In terms of bacteriological parameters, the wells waters, boreholes waters and rivers waters were contaminated with bacteria indicative of faecal pollution. Kohonen self-organising map (SOM) resulted in four classes. Class I which contains 68.05% of the samples in the database; Class II contains 21.18% of the samples, Class III contains 2.77% of the samples and class IV represents 7.98% of the samples.

There are many undeveloped water points and the high germ density in these waters poses at short-term a major health risk to consumers. To limit water pollution, the following measures should be recommended: isolate the deep water from the surface water by resistant casing, protect the roof from external inputs, install sanitation facilities downstream of wells and boreholes, keep waste deposits and latrines away from wells and boreholes.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgements

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