Indian Journal of Advances in Chemical Science

Article

Improvement of Physicochemical and Bacteriological Parameters of a Lake Water using Sand as Filter

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ABSTRACT

This study was initiated with the aim of helping the rural population to easily make raw surface water potable for their well-being. For this purpose, a manual prototype including a sand filtration process was tested. Moreover, the tests were conducted during dry and rainy seasons and repeated 2 years. First, principal component analysis analysis showed that turbidity, conductivity and temperature were more important in dry than rainy seasons. Second, chemical oxygen demand (COD), nitrate and phosphate were abundant in rainy periods. When 14 m^3 of water passed through the filter, 8 m^3 (57.14%) had a final turbidity drop from 0.12 to 0.6 nephelometric turbidity unit. Also, 96.74, 98.32, 64.15, 9.92, 80 and 75% abatement rates, respectively, for COD, turbidity, nitrate, temperature, calcium carbonate and Mg^{2+} were observed. Similarly, 90.86, 91.66 and 9.53, respectively, for conductivity, Ca^{2+} and pH improvement rates were obtained. In addition, aerobic mesophilic germs, *Escherichia coli* and *streptococci* reduction rates, whose were respectively 94.03, 100 and 95.65% proved that the prototype including a sand filtration process was an alternative to improve the lake water quality.

Key words: *Escherichia coli*, Filter, Prototype, Sand, Water.

1. INTRODUCTION

Access to safe drinking water for human being and livestocks is one of the world's persistent crises [1]. This crisis, which is in a processing full resolution in America and Europe, continues to rage in Asia and Africa, and more specifically in Ivory Coast. Unsafe water consumption was responsible for 17,000 people in Asia in 2013 [1]. Moreover, water contamination with agrochemicals causes 20,000 deaths each year in developing countries [2]. Similarly, the consumption of unsafe water is responsible for 57,000 people deaths per year linked to hepatitis C and 500,000–700,000 people are reported to be suffering from cholera [3]. An estimated 22 million people are believed to have contracted disease, which has killed 216,000 mostly school-age children and young adults [1,2,4].

Because drinking water systems are expensive, they are not available in many rural areas in Cote d'Ivoire. Governments try to solve these problems through manual water pumps installations in villages. Unfortunately, these pumps often dry up at times or are unable to supply drinking water to the entire population. Thus, populations are often forced to turn to surface water such as lakes and running rivers whose are never safe without prior treatments. Likewise, Dougba village (6° 38' 52.17'' N; 5° 07' 45.78'' W) has one manual hydraulic pump. So, to meet their water needs, people resort to a lake water.

To solve surface water quality matters, many methods such as membranes, ozonation and activated carbon are used. Despite 83% nitrate removal with activated carbon [3], 65.5% turbidity and 71% chemical oxygen demand (COD) [5] achievements, activated carbon production requires time and a traditional or modern furnace. In fact, their acquisition requires economic funds [5]. In addition, carbon production could lead to the carbon dioxide production and the disappearance of certain plant species for the coal production. Warned by this situation, a simple and manual column including a sand filtration process was made in order to bring back potable water at a lower cost. The accessed hypothesis assumed that "associating different grain size of some clean sand in a column could purify surface water."

2. MATERIALS AND METHODS

2.1. Sampling

The lake water, the filtration system and the laboratory equipment were the main materials used in this work. At the beginning, lake water samples were taken at 2 day intervals for a year to determine the physicochemical characteristics. For this issue, the samples were analysed at INP-HB laboratory of industrial processes, synthesis, environment and new energies. Apart from temperature, turbidity and pH which were measured *in situ*. These analyses were carried out with equipment recorded on Table 1. Following, filtrated water samples were collected and analysed to assess the treatment system efficiency.

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ISSN NO: 2320-0898 (p); 2320-0928 (e)
DOI: 10.22607/IJACS.2022.1001003

Received: 26th July 2021;
Revised: 12th October 2021;
Accepted: 12th January 2022

2.2. Sand Collection and its Cleaning

The sand was collected at the graduate school of agriculture at National Polytechnic Institute Félix Houphouët Boigny (INP-HB). Initially, the sand was collected by avoiding large particles and organic matter. Second, it was washed with tap water to remove organic matter and other impurities. Then, the sand was soaked in hydrogen peroxide with a pH = 1.38. After 24 h, again it was washed until reaching a close pH value to 7 before being dried in an oven at 105°C for 24 h. Thereafter, the sand was sieved with 2 laboratory sieves to obtain fine and coarse sand.

2.3. Culture Media Preparation

Lake water or filtrated water samples to be analyzed were sown in mass or by incorporation. This method involves inoculating Petrie dishes with 1 mL of well-shaken sample. The media were solidified in the Petrie dishes and incubated in an oven at 37°C for 24 h for aerobic mesophilic germ (AMG) and Staphylococci, and 44°C for 48 h for *Escherichia coli*. Culture media were prepared as described in Table 2.

2.4. Capture Method and Well Operation

Figure 1 displays the raw water load system. First, a 3 m deep well (4) was made at 8 m from the lake (1). A polyvinyl chloride pipe (2) buried in the portion of land (3) and equipped with a filter (2) let the lake water to be captured. Then, a locally manufactured mechanical pump (8), manually operated, discharged the water through another polyvinyl chloride pipe (5). For a good protection of the captured water, the well was hermetically sealed by a concrete slab (6). Finally, an 80 cm high polyvinyl chloride filter (9) with 3 superimposed sand layers was associated at the system exit to filter the water. After passing through the three sand layers, the filtrated water was collected at point 10. The sand used is composed of three types of diameters. firstly, the particles whose diameter varies between 0.5 and 1 mm constituted the 15 cm layer. Second, those whose diameter is between 0.25 and 0.5 mm constituted the second layer (20), and finally, the particles whose diameter is less than 0.25 mm constituted the last layer (10 cm).

3. RESULTS AND DISCUSSION

3.1. Physicochemical Quality of Raw Lake Water

The comparison of the averages of the physicochemical parameters of the lake water with those of the WHO standard is shown in Table 3. Considering the dry period with a significant difference ($P < 0.0001$), nitrate, temperature, and phosphate comply with the WHO standard. Indeed, the averages obtained are lower than the standard values. As for COD, turbidity, and conductivity, the mean values obtained with a significant difference ($P = 0.0001$) do not comply with the WHO standard. During the rainy period, nitrate, COD, and turbidity with a significant difference ($P < 0.0001$) are out of the standard. Apart from these three parameters, the others respect the WHO standards.

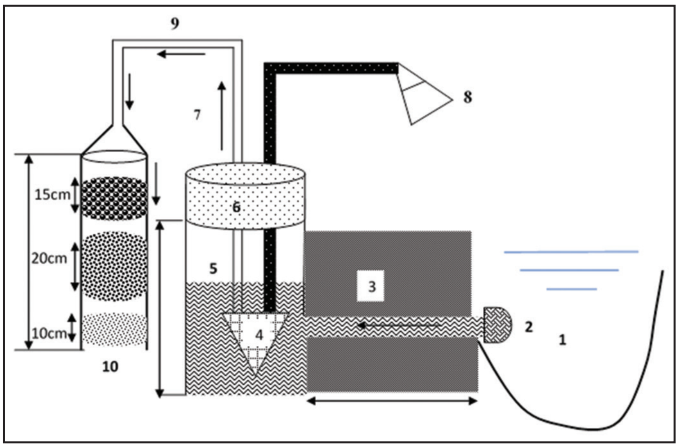

Figure 1: Lake water catchment system.

Table 1: Laboratory equipments.

Designation	Marque	Origins	Utilisation
Conductivity meter	HANNA	Portugal	Conductivity, pH measurement
pH-meter	HANNA	Romania	pH determination
Spectrophotometer	JASCO UV VISIBLE	Japan	Reading of the concentration of the parameters sought in the laboratory (NO^{3}–; COD)
pH meter	WTW	Germany	Turbidity measurement
Sand bath	GERHARDT BONN	Germany	Evaporation
Oven	MEMMERT	Germany	Drying of coal after washing
Prolabo sieve	(AFNOR 05028282)	France	Sieving coal and sand
COD meter			Preparation of samples for COD

COD: Chemical oxygen demand

Table 2: Equipment used for bacteria analysis.

Designation	Enumerated germs	Incubation time	Staining of culture medium	Sterilization time and temperature
Baird parker	Staphylococci	37°C during 24 h	Yellow orange	15 min at 121°C
PCA	Aerobic mesophilic germs	37°C during 24 h	yellow	15 min at 121°C
Bile Lactose agar with purple and red crystal	*E. coli*	44°C during 48 heures	Red	15 min at 121°C
Buffered pectonone water)	Used for dilutions		Colorles	15 min at 121°C

PCA: Principal component analysis, *E. coli: Escherichia coli*

Table 3: Lake physicochemical states.

Variables	Dry season (October to February)		Rainy season (March to September)		OMS
	Means	Std. deviation	Mean	Std. deviation	Theoretical mean
NO_3^- (mg/L)	17.322	6.308	109.752	11.939	≤50
DCO (mg/L)	116.186	24.646	300.343	73.480	<30
Turbidity	7.7985	2.899	6.835	1.616	<1
pH	6.447	0.158	8.979	13.789	6.5–8.5
PO_4^{3-} (mg/L)	0.0105	0.002	0.04	2.108E-17	<0,4
Temperature (°C)	28.1275	0.415	26.645	0.278	<30
Conductivity (µs/cm)	157.99	27.302	220.964	16.073	200–1000
Ca^{2+} (mg/L)	6.282	0.656	6.642	0.785	-
Mg^{2+} (mg/L)	0.162	0.044	0.242	0.044	-
Hardness (mg/L)	6.444	0.651	6.885	0.791	
$CaCO_3$ (mg/L)	0.583	0.119	0.863	0.112	-

$CaCO_3$: Calcium carbonate

3.2. Statistical Analysis of the Data

3.2.1. Principal component analysis (PCA)

The raw water of the lake contains several physicochemical parameters. These can have influences on each other. A PCA yielded Figure 2 and Table 4. In this study, as in [6] a correlation is significant when it is greater than 0.70. Three main components (F1, F2, and F3) with eigenvalues greater than 1 express 79.37% of the total variance. With a percentage of 53.21 %, the main component (F1) is significantly correlated with NO_3^- (r = 0.967), COD (r = 0.90), PO_4^{3-} (0.95), Mg^{2+} (0.75), conductivity (0.84) and calcium carbonate ($CaCO_3$) (r = 0.81). However, it is negatively correlated with temperature. With the exception of temperature (r = –0.91), NO_3^-, COD, PO_4^{3-}, Mg^{2+}, conductivity, and $CaCO_3$ are the physicochemical parameters influenced by the rainy season. Furthermore, hardness (r = 0.86) and pH (r = 0.754) are strongly correlated with the components F2 and F3 whose total variances are 17.05% and 9.11%, respectively. This influence of the rainy season on parameters such as nitrate (NO_3^-), COD, phosphate (PO_4^{3-}) corroborates with the study [7]. In addition, they obtained COD values ranging from 118 ± 31.7280 mg/l to 235 ± 96.1578 mg/l for the dry and wet season, respectively. They also stated that this increase in COD influences nitrification, hence the high nitrate concentration observed [8]. Similarly, increases of 86.4% and 88% in phosphorus related to runoff reported, respectively, by [9,10] explain the slight increase in orthophosphates in wet periods in Lake Dougba.

3.2.2. Correlation Matrix of Physicochemical Parameters

The Pearson correlation matrix (Table 3) is obtained by evaluating the influence of physicochemical parameters (NO_3, COD, Turbidity, pH, PO_4^{3-}, T, Cond, Ca^{2+}, Mg^{2+}, hardness, and $CaCO_3$) on each other. Thus, with regard to correlations, several interactions exist between these physicochemical parameters. Indeed, hardness and calcium are strongly linked with a significant correlation (r = 0.99). This corroborates with the statement of [11] that hard water is rich in calcium. Furthermore, COD, and PO_4^{3-} are related to nitrate with significant correlations (r = 0.89 and r = 0.97, respectively). Contrary to the positive interactions between some parameters, others such as temperature have no influence on nitrate and COD. Correlations of r = –0.91 and r = –0.78 are obtained, respectively, between temperature and nitrate and between temperature and COD. However, temperature and conductivity are positively correlated (r = 0.74). This link between the two parameters was found by [7]. Furthermore, these authors showed that an increase in temperature leads to an increase in conductivity linked to a concentration of the cations responsible for it.

Table 4: Distribution of eigenvalue, total variance, and correlation between physicochemical parameters.

Variables	(F1)	(F2)	(F3)
NO_3^-	0.97	–0.08	0.04
COD	0.90	0.005	0.08
Turbidité	–0.18	0.38	0.53
pH	0.19	0.25	0.75
PO_4^{3-}	0.95	–0.16	0.03
T°C	–0.91	0.02	–0.09
Cond	0.84	–0.25	–0.07
Ca^{2+}	0.40	0.88	–0.24
Mg^{2+}	0.75	–0.13	0.10
Hardness	0.45	0.86	–0.23
$CaCO_3$	0.81	–0.20	–0.10
Dry season	–0.96	0.15	–0.01
Rainy season	0.96	–0.15	0.01
Value propre	5.85	1.87	1.002
Total variance %	53.21	17.05	9.11
Cumulative variance %	53.21	70.25	79.37

COD: Chemical oxygen demand, $CaCO_3$: Calcium carbonate

3.2.3. Seasonal Influence on Physical and Chemical Parameters

Figure 3 shows the statistical analysis of the season influence. The analysis shows that COD, nitrate, phosphate, $CaCO_3$ and magnesium are influenced by rainfall. They are more abundant in the lake during wet periods. The presence of these parameters in the lake water would be linked to their input by runoff water. Indeed, some researchers such as [12] have observed that nitrates contained in fields are found in the water by the action of runoff water. Furthermore, this abundance of nitrate and COD during the rainy season corroborates the results of several researchers. Indeed, [7] obtained values of 235 ± 96.1578 mg/L versus 118 ± 31.7280 mg/L during the monsoon and post-monsoon seasons respectively. As for [13], they found an increase of 5.12 ± 0.44 mg/L during nitrate rainfall. Contrary to these physicochemical parameters, turbidity, conductivity, and water temperature is rather influenced by the dry period. The highest values of these three parameters are recorded during this period. This finding is corroborated with that of [14] and [15] who obtained a drought elevation of 1.2–2.4 NFU at the level of the Tibetan Lake. With a significant difference ($p = 1.147\ 10^{-8}$) between dry season conductivity and rainy season according to Izonfuo and Bariweni [16] and Gadhia *et al*. [7], the low values during the rainy season would be related to the dilution effect. Indeed, the runoff water will dilute the lake water. Which dilution decreases the concentration of cation responsible for the high concentration. This finding is corroborated with that of [14].

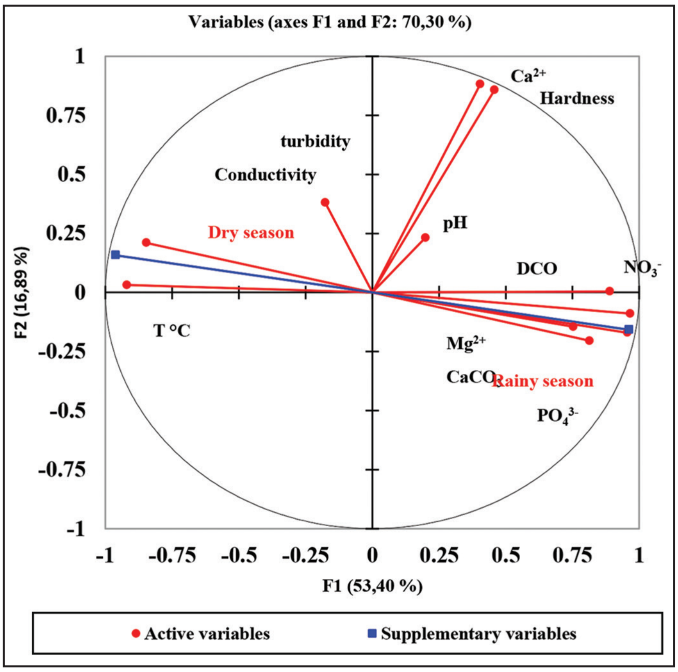

Figure 2: Variable projection diagram.

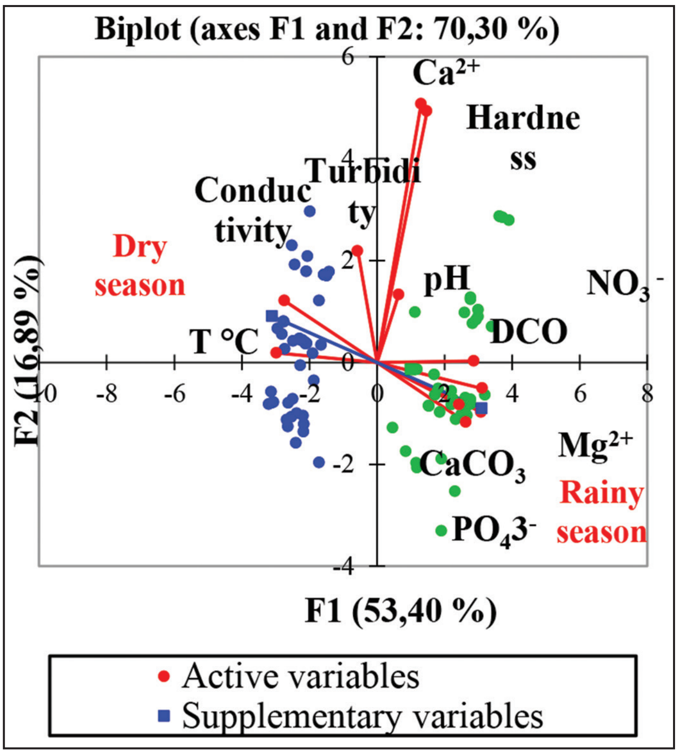

Figure 3: Influence of the season on physicochemical parameters.

However, hardness, calcium, and pH are not influenced by any season. Multiplicity, coupling constants, and assignment in that order.

3.3. Impact of Filtration on Physicochemical Parameters

After filtration, an efficiency to DCO, Turbidity, and Nitrate is related (Table 5). The abatement rates vary from 96.74 to 80.62%, 98.32 to 73.53% 64.15 and 8.29% respectively for DCO, Turbidity, and Nitrate is related. This reduction of these parameters after sand filtration has been proven by several researchers. Indeed, 10 has shown that a layer of sand can reduce the COD by 6%. Hence, in this study, by associating several sand layers, this could explain the importance of the reduction obtained. Contrary to the reduction in the concentration of certain parameters, calcium, conductivity, and pH are improved through an increase. In contrast, by reducing the concentration of certain parameters, calcium, conductivity, and pH are improved through an increase. Improvements of 13.68–90.86 and 23.33–91.66%, respectively, for conductivity and calcium. Furthermore, the increase in the rate of calcium would be linked to the dissolution of $CaCO_3$. Indeed, the $CaCO_3$ may have released its calcium as a result of the chemical reaction indicated by equation 2.

$$\mathrm{Ca}CO_3 + H_2\mathrm{O} + CO_2 \leftrightarrow 2\mathrm{H}CO_3^- + 2Ca^{2+}$$

This improvement in conductivity and calcium was observed by [17] after testing several types of sand filter. However, he noticed that fine sand gives the best results.

3.4. Bacteriological Analysis

AMG, *E. coli,* and streptococci are the bacteria analyzed in Table 6. With regard to the concentration of 201, 27, and 46, respectively, for GAM, *E. coli,* and streptococci, it is impossible to consume lake water without prior treatment in accordance with the WHO standards (2011). The turbidity values of 0.12 nephelometric turbidity unit (NTU) obtained show that sand filtration eliminates the bacteria well [18,19]. Indeed, these authors showed that a reduction in turbidity to less than 0.3 NTU is an indicator of the reduction of certain bacteria such as

Table 5: Removal of physicochemical parameters after filtration.

Parameters	Abatements		Improvement efficient	
	% max	% min	% max	% min
DCO	96.74	80.62	-	-
Tur	98.32	73.53	-	-
Cond	-	-	90.86	13.68
Ca^{2+}	-	-	91.66	23.33
NO_3^-	64.15	8.29		
pH	-	-	4.29	9.53
T	9.92	2.17	-	-
$CaCO_3$	80	2.22	-	-

$CaCO_3$: Calcium carbonate

Table 6: Bacteriological parameters.

Filtered samples	Filtered water	Lake water	% removal	WHO standards
AMG	12	201	94.03	0
E. coli	00	27	100	0
Streptococci	02	46	95.65	1.5

AMG: Aerobic mesophilic germ, *E. coli: Escherichia coli* protozoa (Giardia and Cryptosporidium) and viruses [20]. However, in order to reduce to zero the microorganisms present in the water, it would be interesting to add to the sand filters other things such as inoculum or algae already used by [21]. To optimize the removal of certain physical, chemical, and bacteriological parameters.

4. CONCLUSION

A study of the characteristics of the lake water in the vicinity of Dougba reveals serious risks associated with very high concentrations of certain parameters. Some parameters such as turbidity, COD, and nitrate vary greatly during the rainy season. Overall, the lake water is soft but acidic, especially during the dry season. the different concentrations of certain physicochemical parameters are influenced by the season, which is determined by rainfall. The sand filtration test is a simple and reliable way to reduce pollutants and bacteria. The percentages of abatement 94.03, 100, and 95.65%, respectively, for AMG, *E. coli,* and staphylococci allow concluding that the prototype is reliable and can make the surface water not too loaded with pollutants potable. This technique, which does not require sufficient means, is an alternative for many households in rural areas. Indeed, the sand used is available and does not imply enough means for its use as a filtering material.

5. ACKNOWLEDGMENTS

The authors express their sincere thanks to those who contributed to this study and to the reviewers and editors who helped to improve the quality of the manuscript.

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****Bibliographical Sketch***

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