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Evaluation of the physicochemical properties and heavy metals contamination level of fish farms waters from Soubré (Côte d'Ivoire)

Sanou Ali[1,2,3*], Ouattara Leygnima Yaya[1], Amon Nina Lydie[4], Sanou Issiaka[5], Amadou Kiari Mahamane Nassirou[1], Traoré Sékou[1], Yao Kouassi Benjamin[1]**

[1]Laboratoire des Procédés Industriels, de Synthèses, de l'Environnement et des Energies Nouvelles (LAPISEN), Institut National Polytechnique Félix Houphouët-Boigny (INP-HB), BP 1313 Yamoussoukro, Côte d'Ivoire
[2]Laboratoire de Thermodynamique ; Traitement et Sciences des Surfaces et Interfaces ; Ingénierie et Physicochimie des Procédés et de Mécanique des Matériaux (L2-TSIPM), Institut National Polytechnique Félix Houphouët-Boigny (INP-HB), BP 1093 Yamoussoukro, Côte d'Ivoire
[3]Laboratoire des Sciences Physiques Fondamentales et Appliquées (LSPFA), Ecole Normale Supérieure (ENS), 08 BP 10 Abidjan, Côte d'Ivoire
[4]Département de l'Environnement et de la Santé, Institut Pasteur de Côte d'Ivoire (IPCI), 01 BP 490 Abidjan 01, Côte d'Ivoire
[5]Laboratoire de Chimie et Energies Renouvelables (LaCER), Université Nazi BONI, Bobo-Dioulasso, B.P. 1091 Bobo 01, Burkina Faso
**Corresponding author, Email address: ali.sanou@inphb.ci / sanouali2007@yahoo.fr*
***Corresponding author: sanoussiaka@yahoo.fr*

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Abstract: The present study was carried out with the aim of evaluating the physicochemical quality and the level of metallic contamination of the waters of three fish farms in Soubré in Ivory Coast. Water samples were taken from ponds on the said farms for analysis. Some parameters were measured in situ while others were determined in the laboratory using standard analysis methods. The values of temperature, hydrogen potential, dissolved oxygen, redox potential, suspended solids, turbidity, sulfate ions, chlorides and total organic carbon are respectively between 28.86±1.15 - 30.05±1.01°C; 6.68±0.57 - 8.31±0.84; 1.42±0.43 - 3.74±1.01 mg/L; 140.67±13.09 - 179.07±6.11 mV; 23.09±5.31 - 30.87±1.61 mg/L; 4.71±0.015 - 29.33±0.058 NTU; 19.81±0.01 - 140.15±2.68 mg/L; 0.65±0.05 - 0.75±0.05 mg/L and 5.80 - 15.77 mg/L. Concentrations of ammonium, nitrate, nitrite, total nitrogen, phosphate and chlorophyll-a in farm waters ranged from 4.18±0.18 to 12.30±0.20 mg/L, respectively. ; 0.49±0.00 to 0.83±0.03 mg/L; 0.11±0.00 to 0.19±0.01 mg/L; 1.01±0.01 to 3.75±0.06 mg/L; 0.07±0.00 to 0.15±0.00 mg/L and from 10.07±1.67 to 19.17±1.05 µg/L. Copper, manganese, lead and cadmium were not detected in the waters while the iron and zinc contents were respectively between 0.329±0.177 - 1.977±0.054 mg/L and 0.044±0.025 - 0.094± 0.002 mg/L. Comparative analysis of these values to the standards recommended for freshwater aquaculture revealed that most parameters are suitable for fish farming. However, ammonium, sulfate, dissolved oxygen and zinc recorded concentrations that did not comply with standard values which were respectively < 2.3 mg/L; < 50 mg/L; 3 - 4 mg/L; 0.005 mg/L. This situation can lead to eutrophication of ponds, stress of fish due to lack of oxygen and an alteration of certain metabolisms in fish raised in these ponds if measures are not taken.

1. Introduction

Aquaculture is the farming of aquatic organisms such as fish, shrimp, molluscs and aquatic plants related directly or indirectly to human consumption. It is growing in many countries around the world and aims to promote aquaculture production in order to meet the growing demand for aquatic products (Abboud *et al*., 2015). Aquaculture plays an increasingly essential role in sustainable food production (FAO, 2014; Hambly *et al*., 2015). In recent decades, aquaculture has experienced tremendous growth around the world. Indeed, global aquaculture production increased from less than one million tonnes in the early 1950s to more than 50 million tonnes in 2012 (Mook *et al*., 2012). Additionally, aquaculture accounts for approximately 50% of fish consumed and is one of the fastest growing food sectors with a growth rate of approximately 6.2% in 2011 (Eltholth *et al*., 2018).

In Africa, aquaculture is an essential element of food self-sufficiency policies. The development of animal production activity in aquatic environments could make it possible to cover immense needs for animal proteins (Agadjihouede *et al*., 2011). In low-and middle-income countries, such as Côte d'Ivoire, most farmed fish (> 80%) are produced in freshwater by small producers (Eltholth *et al*., 2018; Hastein *et al*., 2006).

Water quality is a crucial factor in aquaculture systems (Putra *et al*., 2020). Adverse changes in water quality of aquatic ecosystems are reflected in the structure of the biotic community (Niyoyitungiye *et al*., 2019). It is evident from previous research on the effects of water pollution and fish farming, that water pollution plays a key role in reducing and damaging the culture by causing diseases reducing efficient metabolism (Liaqat *et al*., 2017). The chemical and physical characteristics of water are well known to control life in aquatic habitats (Sheekh *et al*., 2018). Furthermore, metal ions can be incorporated into food chains and concentrated in aquatic organisms to a level that affects their physiological state (Soltan *et al*., 2016). Indeed, it is known that these heavy metal ions have harmful effects on the human and animal health, and on the environment (Fort *et al*., 2024; Sanou et al., 2024).

Recent studies carried out in Ivorian fish farms have indicated the non-compliance of certain water quality parameters and the presence of heavy metals in the water, sediments and muscles of farmed tilapia (Coulibaly *et al*., 2019; Sanou *et al*., 2020; Sanou *et al*., 2021a; 2021b; Sanou *et al*, 2022a; 2022b). However, there is no data on the physicochemical quality and the level of metal contamination of water from farms in the study area. It is therefore necessary to pay particular attention to the health state of farms in the area for sustainable management of these farms and for the preservation of the health of the populations consuming these farmed fish.

In this study, the levels of physicochemical parameters and heavy metals in the waters of three fish farms were determined, with the aim of evaluating the environmental quality of the farms. The values obtained were compared to the standard recommended for evaluating the water quality of fish farms intended for fish production. In addition, a bibliometric analysis was carried out to highlight the need for such a study.

2. Bibliometric review on metal contamination in fish farms

Bibliometric analysis offers a quantitative means of managing the evolution of the literature on a given theme (Zupic and Cater, 2015). Bibliometric analysis has already been used by several authors in many scientific and engineering disciplines with the aim of evaluating scientific production and research trends (Akossi *et al*., 2023; Mesdaghinia *et al*., 2015; Ouattara *et al*., 2020; Tchuifon *et al*., 2024; Yandza Ikahaud and El Haddad, 2021). Indeed, this new scientific approach is increasingly used and recommended before undertaking work on a given theme (Koné, 2018; Ouattara *et al*., 2020).

In this study, we analyzed the evolution of scientific production, the distribution of publications by types of publications and research trends according to fields of study. This bibliometric analysis was carried out on January 17, 2020, with the *SciFinder* internet platform. For us, it was a matter of taking stock of the various works carried out on metal contamination on fish farms. In total, 226 publications met the selection criteria. The selected publications were then analyzed based on the above-mentioned article characteristics. This allowed us to assess the scientific interest in the topic.

2.1 Number of publications per year

Figure 1 shows the evolution of the number of publications on metal contamination of fish farms per year. Work on metal contamination in fish farms began in 1986 with a single publication. However, it was from 1990 onwards that scientific interest in this theme really became evident, with continued enthusiasm over the years reaching a first peak in 2010 with 18 publications. The bibliometric results indicate that from 2010 to 2019 the number of articles did not change significantly. From 1986 to 2019, 226 works were published with an annual average of 6.64 publications. The publications dealing with the theme over the study period have a percentage of writings of 71.68% published between 2010 and 2019 with an average of 16.2 publications per year over the last ten years. However, over the last 5 years, an average of 15.8 publications per year appeared with two peaks reached in 2015 and 2016 with 18 publications.

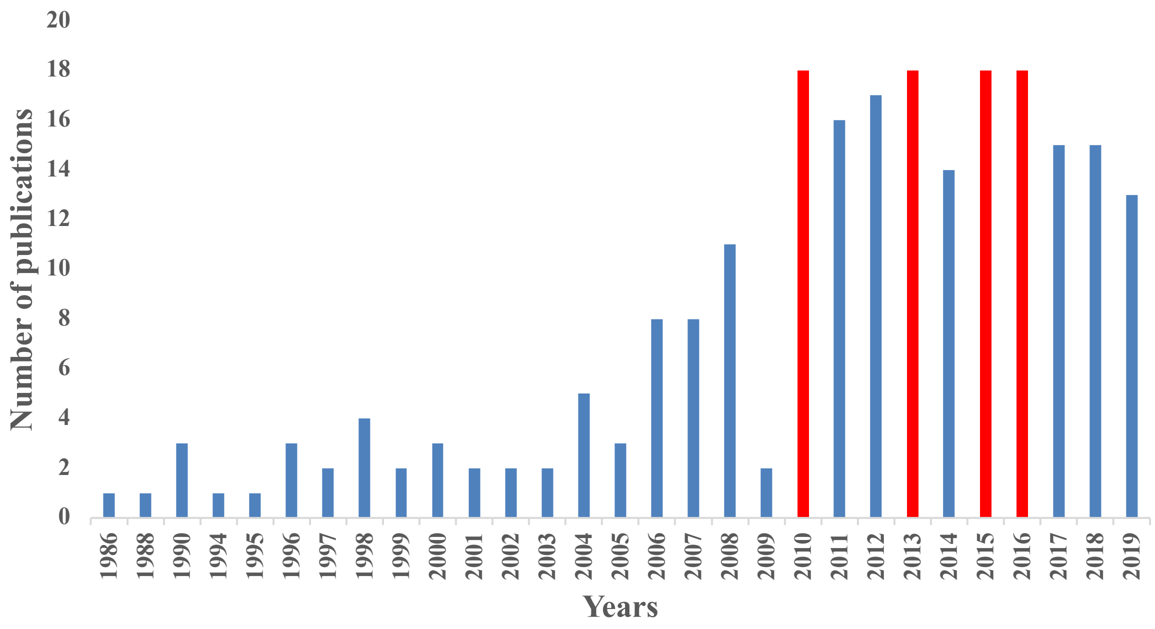

Figure 1. Number of publications per year on metal contamination in fish farms

The increasingly growing interest in studying the presence of heavy metals on fish farms is probably due to the fact that aquatic systems are among the environments most subject to metal contamination (Kouakou, 2017). In addition, fish represents in many developing countries a very important source of protein of good food quality and a moderate price (Ipunga *et al*., 2015) and fish farming is an alternative to the shortage of fishery products. Therefore, any contamination of farmed fish above required standards could be a public health risk (Karim *et al*., 2019). Several studies have shown the presence of heavy metals in the aquaculture environment due, among other things, to anthropogenic activities and fish feed (Karikari *et al*., 2020; Karim *et al*., 2016; Sanou *et al*., 2021a). Consequently, the theme studied is current and of interest to researchers.

2.2 Number of publications by publication types

The researchers used several types of documents to popularize the results of their different work. However, bibliometric analysis reveals that the most used channels are journal with 47% of publications followed by online files (18%), articles (12%) and journal articles (12%) (**Figure 2**). It should be noted that the journal designates a set of articles which appear in the same volume; while the journal article is a chapter of the journal, and an article is a publication that appears alone individually without being in a set of other articles in a journal (Koné, 2018). The number of patents filed for this theme is 8 with 2% of all publications. It should be noted that five bibliographic reviews (1%) were carried out on the theme. The presence of a bibliographic review among the publications could justify the desire of researchers to make summaries at given times to see what has been done and to propose new avenues of investigation.

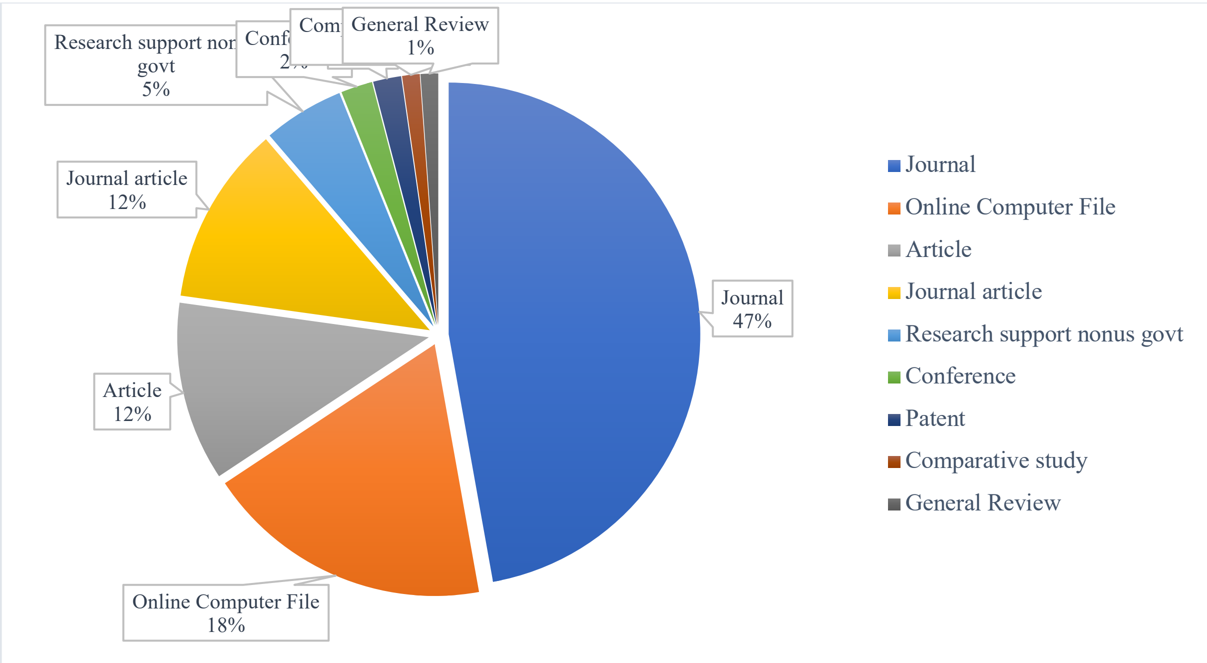

Figure 2. Number of publications per year on metal contamination in fish farms

2.3 Number of publications by field of study

Bibliometric analysis makes it possible to identify the sub-domains of the research theme (Zupic and Cater, 2015). **Figure 3** shows the distribution of work on metal contamination of fish farms in the different fields of study. The evaluation of the distribution indicates that the fields of "water" (58; 25.66%), "chemistry of human and animal nutrition" (51; 22.56%), "toxicology" (41; 18.14%) and "waste treatment and disposal" (10; 4.42%) are the four most productive areas on the theme. This diversity of scientific community could reflect the interest given to the theme.

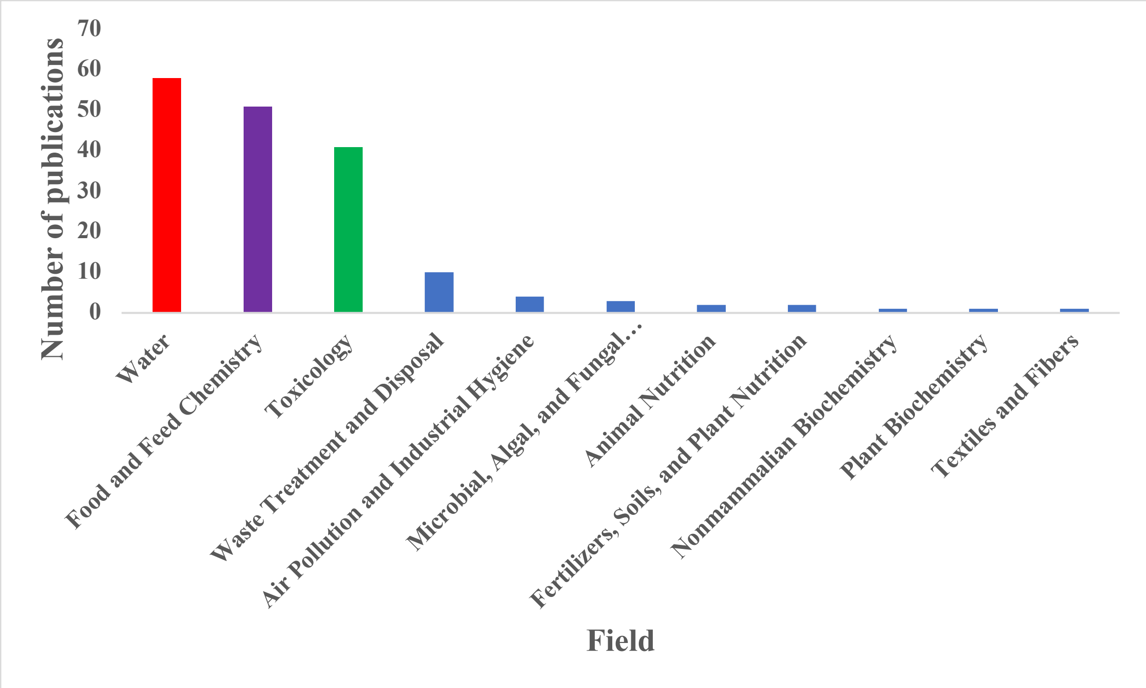

Figure 3. Number of publications by field of study

Bibliometric analysis allowed us to study the research trend by analyzing the distribution of publications, publication types and research areas. The results indicated that the theme of the study, mainly related to heavy metals, is a subject of growing scientific interest in view of the increase in the number of publications over the years. This reflects a need for more in-depth exploration of the theme; all of which justifies this study.

3. Materials and methods

3.1 Presentation of the study area

The present study was carried out on three fish farms in ponds (Three (3) ponds were sampled in each fish farm.) in Soubré in the Nawa region in the southwest of Côte d'Ivoire (**Figure 4**). The sampling stations are tilapia breeding ponds Oreochromis niloticus. The contact details of the aquaculture farms are recorded in **Table 1**.

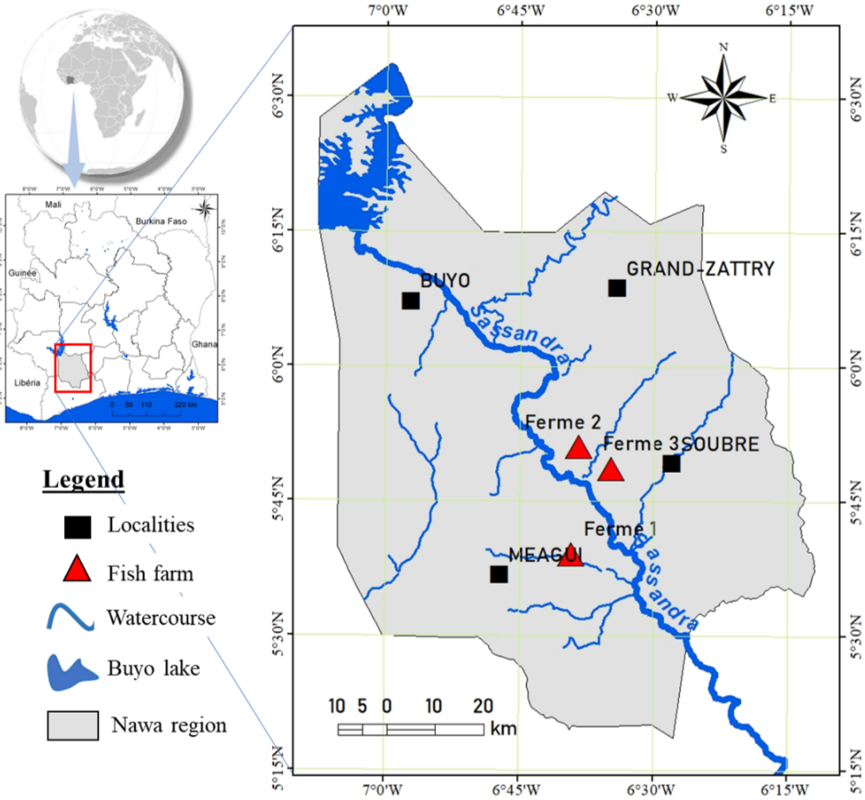

Figure 4. Map of the study area showing the sampling sites

Table 1. References and geographical coordinates of the sampling sites

Fish farms	Locality	Geographical coordinates		
		Latitude (°)	Longitude (°)	Altitude (m)
Farm 1	Gnipi 2	5°39'4.87188'' N	6°39'12.51612'' W	114
Farm 2	Sayo	5°51'3.15108'' N	6°38'22.66368'' W	156
Farm 3	Djidibo	5°49'15.75588'' N	6°34'43.04388'' W	190

3.2 Collection and storage of water samples

The water samples were taken during a sampling campaign in August 2021 in the different fish farms. The water was collected using polyethylene bottles. Each bottle is rinsed three times with farm water before being introduced to the desired depth. Once the bottle is filled, it is removed from the water and closed immediately. The bottles were indelibly labeled according to the numbers of the different fish farms. The water samples are then stored in coolers containing cooling packs to keep them at a low temperature of 4°C to avoid any degradation before their analysis in the laboratory (AFNOR, 1997). The analysis was carried out on 21 parameters (physicochemical, nutrients and heavy metals).

3.3 Determination of parameters

Water temperature (T), hydrogen potential (pH), dissolved oxygen (DO), oxidation-reduction potential (ORP) and turbidity (Turb) were determined in situ using of a portable multi-parameter type HANNA HI 9829. Suspended solids (MES) were determined according to the method described by Aminot and Chaussepied (Aminot and Chaussepied, 1983). Total nitrogen (NT) and total organic carbon (TOC) were determined using an ANALYTIKJENA multi N/C 3100 brand TOC meter. Determination of the sulfate ion content (SO_4^{2-}) of the different samples was carried out by the spectrophotometric method at the wavelength of 650 nm according to the NF T90-009 standard while the chloride ions (Cl^-) were analyzed by titrimetry according to the NF T90-014 standard. The concentrations of nutrient salts and chlorophyll-a were determined using a UV 2700 Molecular Absorption Spectrometer. Nitrates (NO_3^-), nitrites (NO_2^-) and ammonium (NH_4^+) are determined by colorimetric determination according to the method of Koroleff (Koroleff, 1976) and orthophosphate (PO_4^{3-}) is determined according to the method of Murphy and Riley (Murphy and Riley, 1962). Phosphates, nitrites, nitrates and ammonium were measured at wavelengths of 885 nm, 543 nm, 415 nm and 630 nm, respectively. Chlorophyll-a (Chl-a) values were determined by extraction in 10 mL of 97% ethanol followed by reading with an absorption spectrophotometer at 665 nm and 750 nm according to the method of Lorenzen (Lorenzen, 1967). The determination of heavy metals (Cadmium: Cd, Lead: Pb, Copper: Cu, Zinc: Zn, Iron: Fe, Manganese: Mn) was carried out after digestion of the water samples with concentrated HNO3 using the spectrophotometer atomic absorption (AAS model GBC PAL 3000 AUTO SAMPLER) with Air-acetylene (APHA, 1998).

3.4 Statistical analysis

The values presented for each farm are the averages of the three sampled on that farm. The mean values and standard deviations of each parameter were calculated using STATISTICA software (Version 7.1).

4. Results and Discussion

4.1 Physico-chemical parameters of water

Water quality is one of the main factors that control fish quality, growth and production (El-Nemaki *et al*., 2008). The physicochemical parameters of water play a very important role in the biology and physiology of fish (Soltan *et al*., 2016). **Table 2** presents the mean and standard deviation of the physicochemical parameters in the waters of the three fish farms. The values found in this study were compared to the recommended criteria for good aquaculture productivity.

Table 2. Average values of the physicochemical parameters of the sampled waters

Parameters	**Fish farms**			**Standards values***
	Farm 1	**Farm 2**	**Farm 3**	
T (°C)	30.03±0.64	30.05±1.01	28.86±1.15	**13.5-33 °C (FAO, 1989)**
pH	8.03±0.04	8.31±0.84	6.68±0.57	**6.5-9 (Boyd and Tucker, 1998)**
DO (mg/L)	1.42±0.43	3.74±1.01	2.25±0.85	**> 3 - 4 mg/L (Lloyd, 1992)**
ORP (mV)	153.17±21.76	140.67±13.09	179.07±6.11	**< 320 mV (Li *et al*., 2014)**
SM (mg/L)	30.87±1.61	23.09±5.31	27.43±2.13	**< 80 mg/L (Mélard, 2004)**
Turb (NTU)	4.71±0.015	29.33±0.058	12.40±0.1	**5-30 NTU (Balarin and Hatton, 1979)**
SO_4^{2-} (mg/L)	19.81±0.01	110.32±0.44	140.15±2.68	**< 50 mg/L (Mélard, 2004)**
Cl^- (mg/L)	0.7±0.05	0.65±0.05	0.75±0.05	**< 4 mg/L (Mélard, 2004)**
TOC (mg/L)	10.75	15.77	5.80	–

*Standard values of some physicochemical parameters for freshwater aquaculture

Water temperature (T) is probably the most important variable affecting aquaculture production. It affects the natural productivity of aquatic ecosystems and indirectly or directly affects all other water quality parameters (Boyd and Tucker, 1998). Water temperature is one of the most determining environmental factors for pond dynamics, metabolism and fish growth (Boyd, 1990; Soltan *et al*., 2016). Indeed, each fish species has an ideal temperature range in which it grows quickly (Das *et al*., 2015). The temperature values recorded in the present study ranged from 28.86±1.15 to 30.05±1.01 °C

(**Table 2**). The values found for all stations are consistent with the tolerance range for breeding *Oreochromis niloticus* between 13.5 and 33 °C (FAO, 1989; Sanou, 2018). Therefore, the water temperature of fish farms was favorable for fish farming with good potential for fish production as the optimum temperature range is 25-30 °C (FAO, 2006).

Water pH can also affect fish health. Indeed, pH influences many biological and chemical processes in water (Niyoyitungiye *et al*., 2019). It determines the solubility and biological availability of chemical constituents such as nutrients and heavy metals (Shetaia *et al*., 2020). During this study, pH ranged from 6.68±0.57 to 8.31±0.84. These results indicate alkaline waters in farms 1 and 2; and slightly acidic in farm 3. The higher pH values observed in farms 1 and 2 would be due to the large quantity of nitrogen in these farms compared to farm 3. Indeed, according to Soltan et al., high pH values in ponds are due to higher concentrations of nitrogen and phosphorus (Soltan *et al*., 2016). However, these pH values are within the desirable range for fish production recommended by Boyd and Tucker which oscillates between 6.5 and 9 (Boyd and Tucker, 1998) (**Table 2**). At pH below 6.5, some fish species experience slow growth and at lower pH, the organism's ability to maintain its salt balance is affected (Lloyd, 1992) and reproduction ceases. For pH values less than or equal to 4 and greater than or equal to 11, most species die (Lawson, 1995, Nasri *et al*., 2024).

Dissolved oxygen (DO) is a parameter that is both important for aquatic life and necessary for biochemical oxidations (Mutlu and Kurnaz, 2018). It is one of the most important chemical parameters in aquaculture (Das *et al*., 2015) because it controls fish metabolism (Mélard, 2004). Dissolved oxygen concentrations ranged from 1.42±0.43 to 3.74±1.01 mg/L. The highest oxygen concentration was recorded at Farm 2 while the lowest oxygen concentration was recorded at Farm 1 (**Table 2**). Only farm 2 has a content that complies with the tolerable water quality range for fish farming (3 – 4 mg/L) indicated by Lloyd (Lloyd, 1992). The dissolved oxygen levels observed in farm 1 (1.42±0.43 mg/L) and farm 3 (2.25±0.85 mg/L) are below 3 mg/L value from which respiratory stress occurs in Oreochromis niloticus (Hamouda, 2005). Low dissolved oxygen levels are responsible for fish mortality, directly or indirectly (Das *et al*., 2015). Indeed, these low dissolved oxygen values could lead to the transformation of ammonia into nitrite which is toxic to fish (Putra *et al*., 2020). The low dissolved oxygen content in our study could be due on the one hand to the low quantity of phytoplankton and on the other hand to the high-water temperature. Indeed, the abundance of phytoplankton in the aquatic environment increases photosynthetic activity leading to the production of a large quantity of dissolved oxygen (El-Nemaki *et al*., 2008) and the solubility of oxygen in the water decreases with increasing temperature (Mélard, 2004).

The oxidation-reduction potential (ORP) depends on all the oxidants and reducers present in the system. In the aquatic environment, ORP is strongly linked to temperature, pH, salinity and dissolved oxygen concentrations (Summerfelt *et al*., 2009). The redox potential results recorded in the present work ranged from 140.67±13.09 to 179.07±6.11 mV with the highest average value at farm 3 (**Table 2**). Our values are below those found in the literature by Spiliotopoulou *et al.* (Spiliotopoulou *et al*., 2017) and Saad (Saad, 2019) which are respectively close to 600 mV and between 370 mV and 880 mV. High ORP values could harm fish welfare (Saad, 2019). Studies, in fact, have shown that several hematological parameters of fish were altered by increasing ORP levels (Li *et al*., 2014). Also, according to these authors, alterations in blood glucose and plasma protein concentration indicated that ORP above 300-320 mV began to stress the bass fish. Additionally, short-term exposure to ORP levels around 320-350 mV induces fish mortality. Therefore, it is strongly recommended to keep the ORP level below 320 mV for breeding (Li *et al*., 2014). The values of the present study are therefore favorable to fish farming activity.

Suspended matter (SM) constitutes an indicator of water pollution (Makhoukh *et al*., 2011). High concentrations of suspended solids could harm water quality by affecting light absorption, making waters warmer; thus, decreasing the capacity of water to retain oxygen, essential for aquatic life (Mutlu and Kurnaz, 2018). During the present study, SM values ranged from 23.09±5.31 to 30.87±1.61 mg/L. SM for all study stations complied with the standard norm (< 80 mg/L) adapted to freshwater fish farming recommended by Mélard (Mélard, 2004).

Water turbidity (Turb) is usually caused by suspended soil particles and/or the abundance of plankton (Soltan *et al*., 2016). In aquaculture ponds, turbidity from planktonic organisms is often desirable to some extent, whereas that caused by suspended particles is undesirable (McCombie, 1953). However, excessive turbidity can be harmful in breeding ponds. Indeed, at high concentrations, the gills of fish, especially those of small animals, risk becoming clogged, causing asphyxiation (Mélard, 2004). The turbidity values found in the present study fluctuated between 4.71±0.015 and 29.33±0.058 NTU. These values characterize slightly turbid waters conducive to the development of *Oreochromis niloticus* (Avit *et al*., 2012). Furthermore, the values obtained conform to the standard range (5-30 NTU) suitable for fish farming recommended by Balarin and Hatton (Balarin and Hatton, 1979).

The presence of sulfate ions (SO_4^{2-}) in the aquatic environment is important for improving biological productivity (Tas, 2011). According to Mélard, a sulfate concentration below 50 mg/L is suitable for freshwater fish farming (Mélard, 2004). Kuçuk, set the maximum limit of sulfate in water for aquatic products at 90 mg/L (Kuçuk, 2007). In the present study, sulfate values ranged from 19.81±0.01 to 140.15±2.68 mg/L. Very high concentrations were observed on the farms of Sayo (Farm 2) and Djidibo (Farm 3). These values obtained were higher than the communicated standards and were therefore not suitable for fish farming purposes. However, the values found for the Gnipi 2 farm respected the standard (< 50 mg/L) reported by Mélard (Mélard, 2004), therefore suitable for fish farming.

Chloride (Cl^-) level is an important indicator of water quality (Mutlu and Kurnaz, 2018). Chloride concentration in water is considered one of the most important factors influencing nitrite toxicity to fish (Kroupova *et al*., 2005). The highest average chloride value is observed at farm 3 (0.75±0.05 mg/L) while the lowest concentration is recorded at farm 2 (0.65±0.05 mg/L). L). For all fish farms in the study, the values obtained were lower than the maximum limit (< 4 mg/L) recommended by Mélard and were suitable for fish farming purposes (Mélard, 2004).

Total organic carbon (TOC) is defined as any compound containing carbon atoms except carbon dioxide (CO_2) and related substances such as carbonate, bicarbonate and others (Chou *et al*., 2010). TOC is one of the important parameters to monitor for the efficiency of aquaculture systems (Carstea *et al*., 2016; Spilotopoulou *et al*., 2017) because a high rate could harm the well-being of fish. Indeed, organic carbon is the energy substrate of many microorganisms, and its consumption contributes to the problem of insufficient dissolved oxygen in water bodies which becomes a threat to aquatic life (Mook et al., 2012). In the present study, the TOC values recorded ranged from 5.80 to 15.77 mg/L.

All physicochemical parameters recorded standard deviations lower than the average values at the levels of each fish farm, which suggests the low variability of said parameters (Yao *et al*., 2020) in fish farm ponds.

4.2 Nutrients

Nutrient results in all fish farms are presented in **Table 3**. Nutrients are the major constituents of proteins and occupy a prominent place in aquatic ecosystems. The nutrient content of water has a vital role in regulating the production of planktonic organisms in fish ponds. However, high nutrient levels can be harmful by causing excessive plankton growth, algal blooms, and oxygen depletion (Das *et al*., 2015).

Table 3. Average nutrient and chlorophyll-a values of sampled waters

Parameters	Fish farms			Valeurs standards*
	Farm 1	Farm 2	Farm 3	
NH_4^+ (mg/L)	4.18±0.18	12.30±0.20	9.37±0.05	**< 2.3 mg/L (FAO, 1989)**
NO_3^- (mg/L)	0.4873±0.0003	0.83±0.03	0.56±0.03	**1-5 mg/L (Mélard, 2004)**
NO_2^- (mg/L)	0.11±0.01	0.19±0.01	0.13±0.01	**< 0.5 mg/L (Boyd, 1998)**
TN (mg/L)	1.41±0.08	3.75±0.06	1.01±0.01	**0.5 – 4.5 mg/L (Boyd, 1998)**
PO_4^{3-} (mg/L)	0.07±0.01	0.147±0.006	0.11±0.01	**< 0.5 mg/L (Barbe *et al*., 2000)**
Chl-a (µg/L)	19.17±1.05	11.18±1.05	10.07±1.67	**10-200 µg/L (Fereira *et al*., 2011)**

*Standard values of some nutrients for freshwater aquaculture

Nitrogen is a macronutrient essential for the synthesis of amino acids, chlorophyll and hormones. However, nitrogen pollution is known to be a significant environmental problem (Carballeira *et al*., 2019). Standard values of total nitrogen (TN) required for aquatic life should be between 0.5 and 4.5 mg/L (Boyd, 1998). In the present study, TN values ranged from 1.01±0.01 to 3.75±0.06 mg/L. The relatively high nitrogen contents in farm 2 could be due to the incorporation of organic molecules such as amino acids (Hauck, 2010), or to the retention of nitrogen-containing particles in living organisms (Carballeira *et al*., 2019) in the fish farming environment. However, agricultural practices account for more than 50% of the total nitrogen discharged into water sources (Adesakin *et al*., 2020; Dippong *et al*., 2021). For all farms in our study, the values obtained were below the range reported by Boyd and were therefore suitable for growing fish (Boyd, 1998).

In water, nitrogen can be present in the form of ammonia, nitrite and nitrate (Emerenciano *et al*., 2017; Serra *et al*., 2015). Nitrogen sources entering surface waters come from natural, domestic and agricultural resources (Mutlu *et al*., 2013). Organic nitrogen compounds (ammonium, nitrite and nitrate) are nutrients that generate eutrophication and strongly disrupt aquatic ecosystems (Mook *et al*., 2012) because they play an important role in the pollution of surface waters (Bamba *et al*., 2017). However, these nitrogen compounds have been identified as major metabolic products in fish farming (Tilak *et al*., 2007).

Nitrate (NO_3^-) is the end product of nitrogenous organic matter. Its presence in surface waters is an indicator of the pollution of these waters by domestic and industrial wastewater and nitrogen fertilizers (Topal and Topal, 2012). However, nitrate ions rarely accumulate in pond systems (Mélard, 2004). Furthermore, the nitrate ion is the least toxic nitrogenous mineral compound for fish (Mélard, 2004). However, studies conducted on the toxicity of nitrate on aquatic animals indicate that nitrate reacts with hemoglobin causing a shortage of oxygen in their body (methaemoglobin) and leads to their death (Camargo *et al*., 2005). The nitrate content recorded during the study ranged from 0.49±0.00 to 0.83±0.03 mg/L. According to Mélard, a nitrate concentration ranging from 1 to 5 mg/L is suitable for freshwater fish farming (Mélard, 2004). Acu stated that fish mortality begins at doses greater than or equal to 4 mg/L (Acu, 2004). The values obtained in the present study were therefore within the desirable limits recommended by Mélard (Mélard, 2004).

Nitrite (NO_2^-) is an intermediate in the oxidation of ammonium to nitrate (Boyd, 2014; Kroupova *et al*., 2005). This nitrogen compound occasionally accumulates in aquaculture systems (Tilak *et al*., 2007). Nitrite is very toxic to aquatic organisms and poses a potential threat to farmed fish (Tilak *et al*., 2007). Indeed, nitrite is actively absorbed by the gills of fish (Kroupova *et al*., 2005) and passes into the circulatory system (Perrone and Meade, 1977). Exposure to nitrite causes gill damage, edema in the skeletal muscles of fish and also affects respiration (Boyd, 2014). In the present study, the nitrite level varied from 0.11±0.00 and 0.19±0.01 mg/L. Since the range of nitrite in uncontaminated fish waters is < 0.5 mg/L (Boyd, 1998), the average values showed that all farms were unpolluted and can be recommended for fish farming purposes if alone nitrite is considered. It should be noted that high nitrite values could harm fish production by disrupting several physiological functions of fish such as ion regulation, respiratory, cardiovascular, endocrine and excretory processes (Kroupova *et al*., 2005). The toxic effects of nitrite also include the oxidation of hemoglobin to methemoglobin, a form incapable of binding molecular oxygen (Brown and McLey, 1975) thereby compromising oxygen transport in the blood. Fish with high methemoglobin levels may therefore suffer from anoxia (Tomasso, 1981).

Ammonium (NH_4^+) - the ionized form of ammonia - is a non-toxic nutrient for aquatic animals except at very high concentrations (Lawson, 1995 ; Mélard, 2004). This compound therefore does not cause ecological stress on aquatic organisms (El-Sheekh *et al*., 2017). Ammonium concentrations recorded ranged from 4.18±0.18 to 12.30±0.20 mg/L. The results of the present study indicate that ammonium is the dominant form of nitrogen followed by nitrate and nitrite in the waters of all the farms studied. FAO reported that ammonium ion concentration below 2.3 mg/L indicates productive water (FAO, 1989). This means that the ammonium levels of the sampled farms are not suitable for good fish productivity.

Phosphate (PO_4^{3-}) in water resources is a necessary element for aquatic life. It is one of the nutrient minerals affecting the productivity of aquatic life (Mutlu and Kurnaz, 2018). It is a non-toxic nutrient for aquatic organisms (Shetaia *et al*., 2020). During the present study, phosphate concentrations ranged from 0.07±0.00 to 0.15±0.00 mg/L. These results are consistent with the water quality standard required in fish farming recommended by Barbe (Barbe *et al*., 2000). For Ferreira *et al*., an optimal orthophosphate range of 0.01 to 0.20 mg/L is recommended for maximum growth and production of most aquatic species (Ferreira *et al*., 2011).

Chlorophyll-a (Chl-a) is the main pigment that gives plants and algae the green color. This pigment allows plants and algae to photosynthesize by using solar energy to convert water and carbon dioxide into oxygen and cellular matter (Niyoyitungiye *et al*., 2019). Chlorophyll-a can be used as an indicator of the pollution level (trophic state) of a water body (Hakanson *et al*., 2007 ; Shetaia *et al*., 2020). According to Fereira et al., the concentration of chlorophyll-a in fish waters should be in the range of 10-200 µg/L to ensure optimal growth and production (Ferreira *et al*., 2011). In the present study, the value of chlorophyll-a ranged from 10.07±1.67 to 19.17±1.05 µg/L. For all fish farms in the study, the values obtained were within the standard.

We also observe a low variability of nutrients and chlorophyll-a in the waters sampled at the three fish farms. Indeed, all standard deviations are lower than the mean values (Yao *et al*., 2020).

4.3 Heavy metals

The concentration values of heavy metals in fish farm waters are presented in **Table 4**. Aquatic environments constitute one of the largest reservoirs of heavy metals (Sanou *et al*., 2020). The analytical concentrations of Cu, Mn, Pb and Cd in all water samples were below the limit of detection (LOD). These observations are similar to those of Karikari *et al*. (Karikari *et al*., 2020). Indeed, during a study in a cage farm on Lake Volta in Ghana, lead, copper, cadmium and selenium were not detected in the water by these authors. Copper is an essential heavy metal and an important constituent of living organisms. Since Cu is an essential component of metabolism, lower Cu levels are an issue of concern

(Karikari *et al.*, 2020). High concentrations of cadmium (Cd), manganese (Mn) and lead (Pb) are considered highly toxic to aquatic life (Koki *et al.*, 2015).

Table 4. Average values of heavy metals in the sampled waters

Parameters	Fish farms			Standards values*
	Farm 1	Farm 2	Farm 3	
Fe	0.329±0.177	1.977±.,054	0.489±0.150	**5–10 mg/L (Mélard, 2004)**
Zn	0.094±0.002	0.045±0.027	0.044±0.025	**0.005 mg/L (Mélard, 2004)**
Cu	< LOD	< LOD	< LOD	**0.03 mg/L (Mélard, 2004)**
Mn	< LOD	< LOD	< LOD	–
Pb	< LOD	< LOD	< LOD	**0.02 mg/L (Mélard, 2004)**
Cd	< LOD	< LOD	< LOD	**0.005 mg/L (Mélard, 2004)**

*Standard values of some nutrients for freshwater aquaculture

Iron and zinc were detected in all waters sampled. Our results on metal concentrations in water show that Fe content was the highest and Zn content was the lowest in water from all fish farms (**Table 4**). The pH of the water, the nature and concentration of organic ligands, the oxidation state and the redox conditions in the environment could influence the solubility of metals (Lalah *et al.*, 2008 ; Coulibaly *et al.*, 2012). Zinc is an essential heavy metal contained in the cells of living organisms as one of the main components of various enzymes. It is involved in many aspects of cellular metabolism (Resma *et al*., 2020). Zn concentrations are between 0.044±0.025 and 0.094±0.002 mg/L. These values are higher than the authorized limit of Zn in water for freshwater aquaculture (0.005 mg/L) recommended by Mélard (Mélard, 2004). These high Zn concentrations could harm fish farming activities. Indeed, according to Kouakou (Kouakou, 2017), heavy metals with high bioavailability could be absorbed by aquatic organisms. Furthermore, in tilapia Oreochromis niloticus, high zinc concentrations impair reproduction and survival (Al-Kahtani, 2009).

Iron is one of the most common metals in nature. Its concentration in fresh water is essentially controlled by flow and redox conditions, the type and quantity of dissolved organic matter and the pH of the water (Abdel-Satar *et al.*, 2017). Iron tends to accumulate in liver tissues due to the liver's physiological role in blood cells and hemoglobin synthesis (El-Moselhy *et al*., 2014). Fe concentrations were between 0.329±0.177 and 1.977±0.054 mg/L. Although this metal has the highest content in farm water, its concentration remains below the recommended standard of between 5 and 10 mg/L (Mélard, 2004). However, the continued exposure of fish to heavy metals in water could harm them, which could accumulate these metals through the phenomenon of bioconcentration (Sanou *et al.*, 2021a). Indeed, fish can accumulate heavy metals in their body by direct absorption of water through the gills (Vilizzi and Tarkan, 2016) which constitute the main route of exchange of metal ions from the water of the made of their very large surface areas which facilitate the rapid diffusion of toxic metals (El-Moselhy *et al*., 2014). Furthermore, studies of histological analysis of liver diseases showed that different liver abnormalities were frequently detected in fish living in metal-contaminated water and fish morbidity evolved with metal contamination of the water (Moiseenko *et al.*, 2018).

Conclusion

The objective of this study was to evaluate the physicochemical and metallic quality of the waters of the ponds of three fish farms. A total of 21 parameters including 9 physicochemical, 6 nutrients and 6 heavy metals were analyzed and compared to the standards recommended for freshwater aquaculture. The results of the comparative analysis indicate that the aquaculture farms have high fish farming potential because the water quality parameters were largely suitable for fish farming. Indeed, 17 parameters (80.95%) namely temperature, pH, redox potential, suspended matter, turbidity, chlorides, total organic carbon, nitrate, nitrite, total nitrogen, phosphate, chlorophyll-a, iron, copper, lead, manganese and cadmium were within the permissible limits for fish farming. However, dissolved oxygen, sulfate ions, ammonium and zinc, representing 19.05% of the parameters analyzed, did not respect the standard values for good fish production. Non-compliant levels of these 4 parameters can affect the production of fish farms by causing damage to fish such as low resistance to diseases, an alteration of the metabolic, physiological and structural system and a reduction in the growth rate in fish. raised in these ponds.

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