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Research Article

Assessment of the Suitability of the N'ZI River Water (Côte d'Ivoire) for Biological and Drinking Water Use

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Abstract

The evaluation of the suitability of N'Zi River water (Côte d'Ivoire) for biological functions, potable use, and livestock watering across the N'ZI watershed provided an integrated basis for evaluating the river's overall water quality. The objective of this study was to determine the river's fitness for biological processes and potable water use. To this end, sampling was conducted at five sites with a total of 20 samples collected during the dry season and the rainy season. The characterization of water quality was evaluated based on ten (10) alterations. These include organic and oxidizable matter, nitrogenous matter excluding nitrates, nitrates, phosphorous matter, suspended particles, acidification, temperature, mineralization, color, and mineral micropollutants in raw water. Following the determination of the mean concentrations for the measured parameters, the quality indices of the ten (10) alterations were computed using a framework derived from the Water Quality Index (WQI) concept. This procedure enables the application of the SEQ-Water method to evaluate the suitability of N'ZI River water. The results reveal that water temperature and electrical conductivity reflect a low mineralization of N'ZI River water, corroborated by the observed dissolved oxygen concentrations. In contrast, turbidity and suspended solids (SS) exhibit considerable spatial and temporal variability. Nutrient concentrations including nitrate, nitrite, phosphate, and ammonium remain consistently low relative to international water quality standards, indicating limited anthropogenic nutrient input. The organic composition shows significant variation related to anthropogenic activities. As for heavy metals, they exceed the standard. The metals are of poor to very poor quality. The waters are of good to very good quality regarding nitrogenous matter excluding nitrate, nitrates, mineralization, and mineral micropollutants at all sample collection sites. The classification according to the alteration indicates that the waters of the N'ZI river are generally of good to moderate quality for its suitability for biology, for drinking water use, and very conducive to watering.

Keywords

Water Suitability for Biology, Drinking Water Use, Physicochemical Quality, SEQ-Eau Method, N'ZI River, Côte-d'Ivoire

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1. Introduction

The health of ecosystems, human beings, health or socio-economic progress, as well as poverty reduction, require water for their proper functioning [1]. This water must be in good condition and available for each component, which is one of the goals the United Nations set in 2015 to ensure its availability, sustainable management, and sanitation by 2030 [2, 3]. However, there is generally a globally negative degradation of the quality of river water, mostly attributed to environmental changes (natural and anthropogenic factors) that affect water resources [4]. In particular, in Côte d'Ivoire and mainly in the N'ZI watershed, the project of the Authority for the Development of the Bandama Valley (AVB) in the years 1969-1980 significantly affected the river systems in the area [5-7]. Indeed, this area, whose main activity is agriculture, has seen a decline in its production due to land degradation and a decrease in vegetation cover. Nowadays, the practice of gold panning, food crops, and market gardening is multiplying across all localities, attracting a growing mass of the population, which are respectively the main causes of these degradations. Due to the lack of water caused by changes in rainfall patterns and a decrease in flow rates of about 50% revealed in the works of [5, 8], all activities are being carried out at the expense of the N'ZI river, which harms its physicochemical quality observable to the naked eye. The socio-economic growth of the area requires a comprehensive assessment of the water quality of the N'ZI river, which is the main source of water supply. This study aims to evaluate the suitability of the water for different uses, namely biological use and drinking water use.

2. Materials and Methods

2.1. Presentation of the Study Area and Sampling Points

The N'ZI watershed, a sub-catchment of the Bandama River, is located between 3°49′ and 5°22′ W longitudes and 6°00′ and 9°26′ N latitudes (Figure 1). Covering an area of 3,576.4 km², it accounts for approximately 10.88% of Côte d'Ivoire's total land area. The river network extends over a total length of 725 km, forming a significant component of the regional drainage system [5, 9]. The N'ZI River originates in the northern Ferkessédougou region at an elevation of 400 m and confluences with the Bandama River at Tiassalé. It represents the principal fluvial network within the study area, predominantly oriented along a north-south trajectory. The drainage network displays a decreasing density gradient from south to north, ranging from 0.74 to 0.54 km/km². Its chief tributary, the Kan River, joins the N'ZI approximately 5 km downstream of Dimbokro. Additional significant tributaries comprise [5, 9]. The N'ZI watershed experiences monthly rainfall ranging from approximately 2 mm to 225 mm, with an annual monthly mean of 88.93 mm. The study area generally exhibits two distinct rainy seasons. Mean annual precipitation varies between 912 mm and 1,338 mm, yielding a mean value of 1,084 mm.

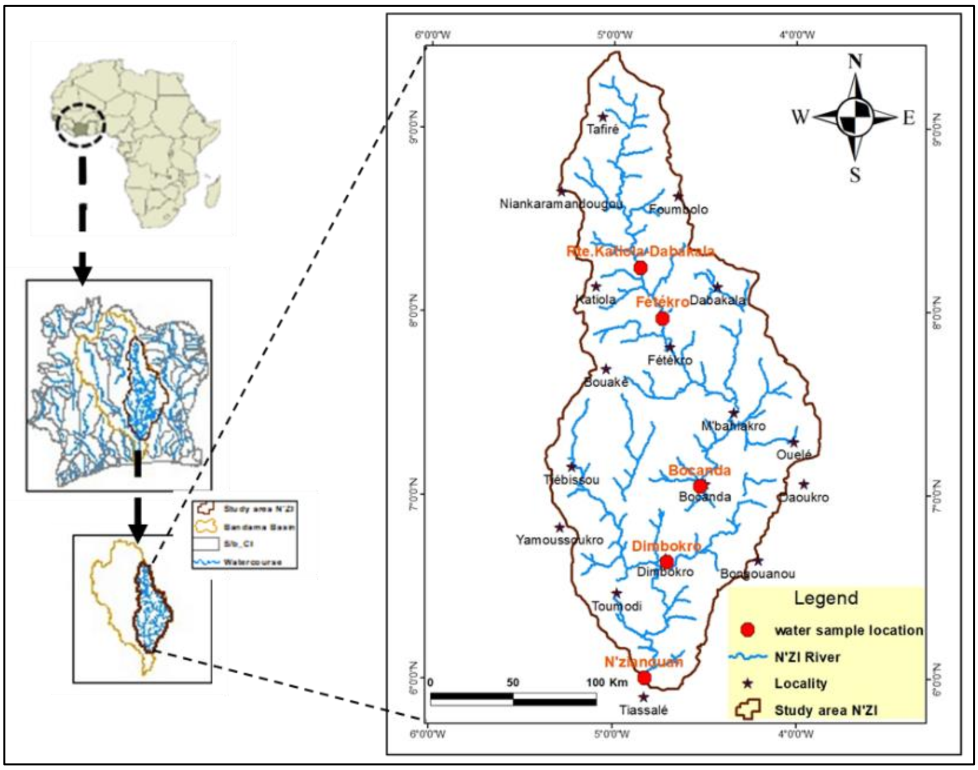

Figure 1. Geographic Location and Surface Water Sampling Sites Within the N'ZI Watershed [5].

The primary livelihood of communities residing in the N'ZI watershed is agriculture, as reported in several studies [7, 9]. Following the decline in cocoa and coffee production due to environmental and climatic changes, local populations have shifted to alternative income sources, including food crops, cotton, cashew, sugarcane, and rubber. These activities rely on the resources of the N'ZI River and frequently involve the use of fertilizers and pesticides. [10-12]. These crops are predominantly established on wetlands, modified or pristine, in the vicinity of N'ZI River tributaries and channels, which can be a source of pollution for this river. In a way, this watercourse is the city's wastewater reservoir, as well as a discharge point for domestic, black and agricultural wastewater [11].

2.2. Data

Grab water samples were collected from the N'ZI River at the sites of N'zianouan, Dimbokro, Bocanda, Fetekro, and Katiola-Dabakala (Figure 1) during both dry and wet seasons, resulting in a total of 20 raw water samples. The samples were collected in 1,000 mL polyethylene bottles, pre-rinsed with river water from the respective sites to avoid contamination. Following collection, the samples were maintained at 4°C in a cooler with dry ice during transport to the laboratory, ensuring compliance with AFNOR (French Association for Standardization) protocols for subsequent physicochemical and microbiological analyses. [13-15]. Samples were taken two at each measurement site. For the analysis of the main major elements, one sample was amended with a drop of concentrated hydrochloric acid. The other sample, raw water, was preserved without the addition of acid, to measure other parameters.

2.3. Methods

Reconnaissance trips were made to the study area to collect many field and raw water samples during the rainy and dry seasons. The water quality assessment system (SEQ-Eau) method (watercourses) is used to assess overall water quality and express its suitability for different uses in the basin, using the quality index determined through mathematical formulation. These methods offer precise results and help to provide essential corrections according to the recommended use [16, 17]. This method adopted in the 2000s, the Water Framework Directive (WFD) aimed to preserve water quality by restoring good ecological status, in order to facilitate the characterization of water resources. The SEQ-Eau watercourse reference system is used to assess the various components (alterations), the impact of quality on natural uses and anthropogenic services, and the impact of water quality on the environment. The fifty different components are nitrogenous matter, nitrates, acidification, organic and oxidizable matter, nitrogenous matter excluding nitrates, phosphorus matter, suspended particles, temperature, color mineralization, mineral micropollutants in raw water, etc. Each is described by several parameters, around 156 in all [18, 19]. For each alteration, the impact assessment is based on two aspects: the physico-chemical quality of the water and its suitability for use and biology. The classification is based on the measurements giving the worst water quality in the time series, provided that this is observed in at least 10% of the measurements (90 quantile rule). The advantage of using SEQ-Eau is that it can be used by a wide range of users, providing them with the basic information they need to help them make a decision [20] on whether to invest in the area.

2.3.1. Intake Water Sampling

The water collection points are depicted in Figure 1. Selection of the five (5) sites was based on the study area's sub-basins. Water samples were gathered manually, following the standardized protocol by AFNOR and Loire-Brittany Water Agency since 2006 [13-15]. Water samples are collected periodically (January-April and June-September), using the linear judgment method and a suitable container. Water samples were obtained at designated points, approximately 30 cm below the surface, and at selected seasonal intervals. Collection sites were strategically chosen based on flow characteristics, current direction, and water depth. Samples were stored in 1 L polyethylene bottles, pre-conditioned with site water, and transported on ice to the laboratory for subsequent physicochemical and microbiological analyses.

2.3.2. Determination of Parameters Measurements

Temperature, pH, electrical conductivity, dissolved oxygen, and turbidity were measured directly in the N'ZI River using a HANA multi-parameter instrument. Suspended solids (SS) were determined through glass fiber membrane filtration (Whatman), in accordance with AFNOR NFT90-105 standards. [21, 22]. The organic pollution parameters analyzed are five-day biochemical oxygen demand (BOD5), measured using the oxitop isotope method, which relies on pressure measurement Within a closed system, microorganisms utilize the available oxygen in the medium. COD was assessed via colorimetric titration, based on the reduction of potassium dichromate. Ammonium (NH_4^+) was quantified by spectrophotometry, nitrite (NO_2^-) and nitrate (NO_3^-) were analyzed using a HACH photometer, and phosphate was determined spectrophotometrically following NF T 90–923 standards. Organic matter (OM) was calculated for each sample through the relationship between BOD_5, COD, and OM [5, 23]. The study assessed chemical pollution parameters comprising toxic elements (mercury, lead, cyanide, cadmium, arsenic), potentially hazardous metals (chromium, nickel), and other metals of interest (Al, Cu, Fe, Mn, Mg, K, Zn). Analysis of major elements was performed using ICP, with total concentrations determined after mineralization and argon plasma atomic emission spectrometric measurement [24, 25]. These different concentrations are analyzed at the Laboratory of Industrial Processes, Synthesis, Environment and New Energies (LAPISEN) at IN-PHB, Yamoussoukro (Côte-d'Ivoire).

2.3.3. Assessment of Water Quality in the N'ZI River

The SEQ-Eau method (Water Quality Assessment System) was used to assess the water quality of the N'ZI river. SEQ-Eau is a modernized and comprehensive tool for assessing the water quality of rivers. The first version of SEQ-Eau was developed in 1999, followed in 2003 by version 2 [26, 27]. It is used to assess the state of the N'ZI river water for biological, drinking water and watering uses. Water quality was characterized by ten (10) alterations. These were: organic and oxidizable matter (MOOX), nitrogenous matter excluding nitrates (AZOT), nitrates (NITR), phosphorus matter (PHOS), particles in suspension (PAES), acidification (ACID), temperature (TEMP), mineralization (MINI), color (COUL) and mineral micropollutants in raw water (MPMI). Calculations are made by cross-referencing several physico-chemical parameters that make up the impairment indicators. The suitability (water quality) is described for each of the impairments, using 5 quality classes ranging from blue for the best, to red for the worst, i.e. an index varying continuously from 0 (the worst) to 100 (the best) (Figure 2). Each suitability class is defined with threshold grids for each parameter of each alteration, in accordance with European and French regulatory standards [26, 28-31]. The quality index enables us to judge changes in water quality within a given class, without even changing class. It takes into account the values of different water parameters and their specific importance for the use in question. The quality index is calculated on the basis of the parameters defined and grouped into 10 alterations (Figure 2). The index is calculated using a system based on the notion of the water quality index (WQI), according to mathematical models that take into account the quality class limits of each alteration, including the application of the downgrading parameter rule (the water suitability index is the lowest between the quality indices of the parameters making up the alteration is calculated). It has been the subject of several successful studies around the world [32-34]. The water quality index (WQI) is expressed by the following equation:

$$WQI = I_i + \left[\frac{(I_s - I_i)}{(b_s - b_i)}\right] \times (b_s - p_a)$$

With,

WQI: water quality index of the parameter analyzed, characterizing the alteration of the water.

Ii: subscript indicating the lower value

Is: subscript indicating the upper value

bi: minimum bound

bs: maximum bound

pa: parameter under analysis.

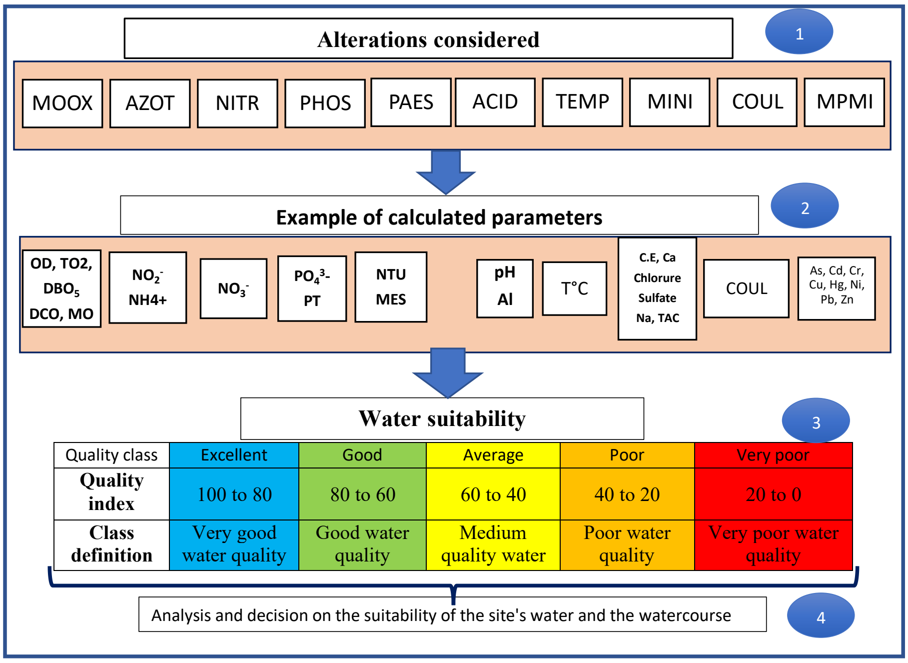

Figure 2. Flow Chart Summarizing Water Quality Assessment in the N'ZI River.

The classification of the N'ZI river waters is therefore in line with the SEQ Eau system, based on the WQI in compliance with the EU Water Framework Directive [26, 35]. The modular graded system adopts a five-class breakdown of water status, as shown in Figure 2. In fact, the concentrations of the various parameters are already determined in the laboratory by the alterations taken into account (1). The averages of the parameters attributed to each element constituting the alteration have been calculated (2). The average concentration of the various samples at each known site is integrated into equation 1, which determines the WQI of the N'ZI river water. This value (WQI) is used in comparison with the quality index defined according to SEQ-Eau (3). This allows us to identify the water quality class for each quality and alteration class, leading to a decision on the suitability of the water at each measurement site (4) or for the river as a whole (Figure 2).

3. Results and Discussion

3.1. Classification of N'ZI River Water Based on Alteration

The assessment results of the alteration levels of the various water quality parameters for the N'ZI River are presented in Tables 3 and 4, in appendix, corresponding respectively to the classes of biological suitability and drinking water usability.

3.1.1. Organic and Oxidizable Matter Alterations (MOOX))

The parameters tested include dissolved oxygen (DO), oxygen saturation rate (O_2S), chemical oxygen demand (COD), biochemical oxygen demand over five days (BOD_5), organic carbon (OC), and ammonium (NH_4^+). This alteration assessment was applied to determine both the biological suitability class and the drinking water use class. The results presented in Tables 1 and 2 indicate that the waters of the N'ZI River are generally rich in organic matter and oxidizable materials (MOOX). Across all sampling sites, these parameters vary from medium-quality to very poor-quality water. However, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), and chemical oxygen demand (COD) show variations ranging from medium to very good quality at the N'zianouan and Fetekro stations. The waters are rich in organic matter at sampling points located downstream from uncontrolled waste disposal sites (Dimbokro, N'zianouan, Fetekro), agricultural areas, or zones influenced by significant pastoral activity. The results reveal that the N'ZI River water exhibits suitability indices ranging from 0 to 86, corresponding to very poor to very good quality water for the studied alteration parameters. This indicates that the river water is relatively close to its natural state, being rich in organic matter and low in oxygen [26, 36]. Such water conditions reflect low biodiversity of aquatic organisms and require treatments ranging from simple to complex depending on the site and intended use.

3.1.2. Alteration by Nitrates (NITR)

The results of the NITR alteration assessment show a suitability index ranging from 80 to 90 for biological use, drinking water production, and livestock watering across all sampling sites (Tables 3 and 4, in appendix). The river water shows no evidence of nitrate pollution for any of the evaluated uses. However, nitrate concentrations may still pose a potential issue for drinking water production if they exceed the standard limit prescribed by the World Health Organization [42]. This observation remains relevant even though several sampling points are located within or near urban areas or are used as livestock watering points (Figure 3). Overall, the N'ZI River exhibits very good water quality at all monitored sites with respect to nitrate content. Nitrates represent the main nitrogen form found in natural waters and are generally associated with human activities. The presence of nitrates in surface waters may be attributed either to agricultural inputs through leaching of nitrate-based fertilizers or to the oxidation of ammonium into nitrate originating from domestic effluents and animal waste carried by runoff in areas characterized by significant pastoral activity [43].

3.1.3. Alteration by Nitrogenous Compounds Other Than Nitrates (AZOT)

The results of the AZOT alteration assessment show suitability indices ranging from 0 to 100 for biological use and livestock watering across all sampling sites (Tables 1 and 2). For the biological evaluation, the parameters considered were nitrite (NO_2^-) and ammonium (NH_4^+), which varied respectively from 100 to 50 and below 0 across all sites. These results indicate very good to moderate water quality with respect to nitrite, but very poor quality for ammonium. Regarding livestock watering, the water quality ranged from very good to good, with suitability indices between 82 and 70. According to the Surface Water Quality Classification Grid for nitrogenous compounds excluding nitrates, surface water from the N'ZI River can be classified as very good to moderate quality, except for ammonium, which shows signs of localized degradation. Overall, all river stations exhibited suitability indices between 70% and 90%, indicating that the natural state of the water is largely preserved and that nitrogenous pollution, other than nitrates, has limited impact on overall water quality.

3.1.4. Alteration by Phosphorus Compounds (PHOS)

The N'ZI River is not significantly affected by phosphate (PO_4^{3-}) or total phosphorus pollution. However, all sampling sites are frequently used by local populations for laundry and dishwashing activities, which may involve the use of phosphate-based detergents (Figure 3). Consequently, the river may be subject to localized (point-source) pollution from domestic wastewater discharges, as well as diffuse pollution originating from septic systems. These findings are consistent with the observations reported by [11, 33, 38], who highlighted the influence of domestic and household practices on phosphate enrichment in surface waters in similar hydrographic contexts.

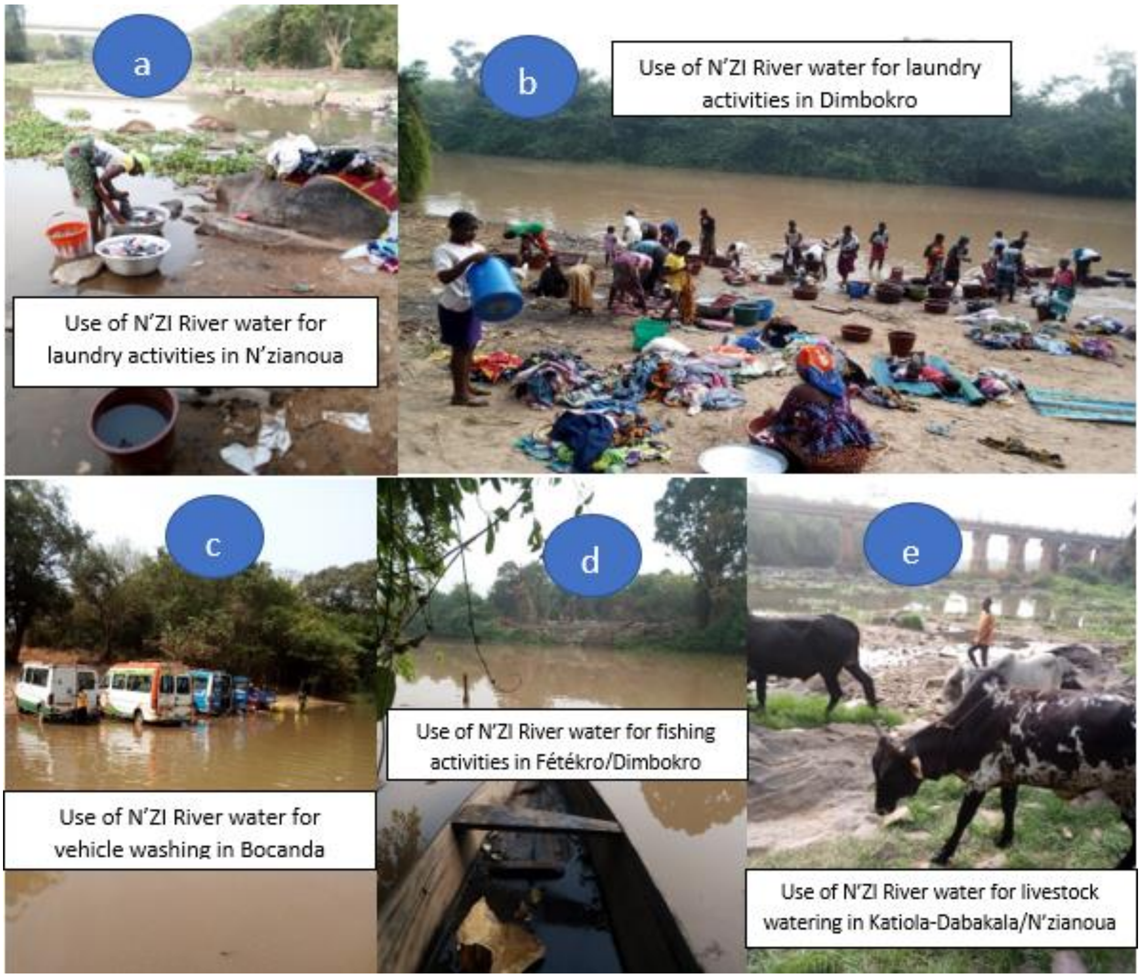

Figure 3. *Illustrative Photographs of Practices Contributing to the Degradation from N'ZI River.*

The water quality of the N'ZI River varies from very good at the N'zianouan and Fetekro stations to good at the Katiola-D. station, but shows very poor quality with respect to total phosphorus. This indicates that the river has been subjected to anthropogenic pressure, resulting in a deviation from its reference ecological state [22, 23, 39]. However, the river still maintains good ecological functionality and provides the physical conditions necessary for the development of diverse aquatic fauna and flora.

3.1.5. Alteration by Suspended Matter (PAES)

The parameters tested include turbidity (NTU) and suspended solids (TSS). These alterations were evaluated for both the biological suitability class and the drinking water use class. According to the Surface Water Quality Classification Grid, NTU and TSS concentrations in the N'ZI River indicate good quality for drinking water production, but very poor quality for biological use (Tables 3 and 4, in appendix). The overall water quality shows signs of degradation and a significant deviation from the reference ecological state, mainly due to human interventions such as hydraulic infrastructure development, as highlighted in the biological assessment. This condition can be associated with high water turbidity, particularly during flood events or at the beginning of low-flow periods [33, 38]. Furthermore, this alteration is strongly influenced by natural factors, including highly erodible soils at the onset of the rainy season and rugged terrain, where runoff promotes soil erosion and contributes various pollutants to the river system [9, 44].

3.1.6. Alteration by Mineralization (MINI)

The parameters tested include calcium (Ca^{2+}), chloride (Cl^-), sulfate (SO_4^{2-}), sodium (Na^+), magnesium (Mg^{2+}), and total alkalinity (TAC) for the biological suitability and drinking water use classes. For livestock watering, the parameters considered were Ca^{2+}, Na^+, and SO_4^{2-}. The results of the suitability classification for biological use, drinking water production, and livestock watering indicate that the N'ZI River water generally ranges from very good to moderate quality, except for sulfate and TAC, which show moderate to poor water quality at certain sites, as well as excess sodium concentrations that affect biological suitability. These variations reflect a slight alteration in the river's salinity, which may be associated with environmental transformations occurring within the watershed. Similar observations have been reported in previous studies on the N'ZI watershed [5-7].

3.1.7. Alteration by Acidification (ACID)

The parameters considered were pH and aluminum (Al) for biological suitability, and pH alone for drinking water use. The results indicate good water quality at the N'zianouan–Dimbokro stations and moderate quality from Bocanda to Katiola-D., with quality indices ranging from 61 to 65 and 59 to 57, respectively. This corresponds to water requiring simple to conventional treatment for drinking purposes (Table 4). For biological suitability, the quality indices ranged from 53 to 61 for pH and 80 to 70 for Al, reflecting good to moderate water quality (Table 3). The water at Dimbokro shows an absence of sensitive microorganisms, while other sampling sites exhibit an absence of several aquatic microorganisms, suggesting conditions that may affect biological diversity. Acidic water can disrupt aquatic life, and this characteristic confirms the natural state of the N'ZI River, which contains high levels of organic matter. This observation is consistent with previous studies by [5-7], which emphasized that rural wetland areas in the region are largely covered by dense vegetation, influencing the river's acidity and organic content.

3.1.8. Alteration by Temperature (TEMP)

This parameter was evaluated only for biological suitability. The quality index indicates poor water quality at N'zianouan and moderate quality at the other sampling sites (Table 3). These results suggest a decline in fish populations in the N'ZI River, likely due to elevated water temperatures. Similar observations have been reported by [9, 10, 45], who highlighted a low frequency of fishing activities along the river, associated with a significant decrease in water flow and changes in rainfall and environmental regimes. These factors collectively contribute to thermal alteration and affect the ecological balance of the N'ZI River.

3.1.9. Alteration by Color (COUL)

The quality index indicates that the water generally falls within the "good quality" class at all sampling sites, except at Katiola-D, where the water color is classified as poor (Tables 3 and 4; Figure 3). This localized alteration may be associated with suspended particles, organic matter, or human activities observed along the riverbanks.

3.1.10. Alteration by Mineral Micropollutants in Raw Water (MPMI)

This category includes metals and mineral micropollutants detected in the raw water. The results show that parameters such as arsenic (As), cadmium (Cd), mercury (Hg), lead (Pb), and selenium (Se) indicate poor to very poor water quality, while barium (Ba), boron (B), chromium (Cr), copper (Cu), nickel (Ni), and zinc (Zn) reflect very good to moderate quality (Table 4). For biological suitability, the quality index reveals generally poor to moderate water quality across the N'ZI River, except at Bocanda, Fetekro, and Katiola-D., where Cr, Ni, and Zn concentrations correspond to good quality levels. Regarding livestock watering, the quality indices range from 100 to 80 for most parameters, despite excessive Pb concentrations detected in the river water (Table 3). This indicates an overall good suitability class of water for livestock use. The degradation of the N'ZI River water can be attributed to anthropogenic pressures on wetland areas, especially those converted to agricultural lands located along or near the riverbanks, where the use of agrochemical products is common [10]. Moreover, vegetation loss and soil degradation caused by intensive farming and the expansion of artisanal gold mining in the region [4-6, 11, 12] have been reported to increase metal concentrations in aquatic systems, thereby posing environmental and health risks to both humans and aquatic organisms when these elements occur in excess.

3.2. Evolution of the Water Quality Status from N'ZI River

The assessment of the physicochemical quality and heavy metal concentrations from N'ZI River was conducted using the Water Quality Evaluation System (SEQ-Eau). This system enables the evaluation of water quality and its suitability for supporting specific ecological and domestic functions. In this study, the SEQ-Eau method was applied to determine both the biological suitability of the N'ZI River water and its fitness for drinking water production (Tables 1 and 2). This evaluation was carried out through the calculation of water quality classes and quality indices, expressed by the Water Quality Index (WQI).

3.2.1. Water Quality Indices and Biological Suitability Classes at Reference Stations

Table 1 summarizes the state of biological alterations in water at the sampling sites of N'zianouan, Dimbokro, Bocanda, Fetekro, and Katiola-D. The results indicate that, overall, the sampled points exhibit very poor-quality water, with indices falling within the red category, except at N'zianouan, where the water quality index is classified as poor. These poor alteration levels are mainly attributed to anthropogenic pressures exerted on the fluvial network, including domestic discharges, agricultural runoff, and local human activities that disturb the natural ecological balance of the N'ZI River.

Table 1. Biological Suitability of N'ZI River Water at Reference Stations.

	Code		Blue	Green	Yellow	Orange	Red
		Quality class	100-80	80-60	60-40	40-20	20-0
Sites	Alteration parameters	Average concentration (mg/L)					
N'zianouan	MOOX, AZOT, NITR, PHOS, PAES, ACID, TEMP, MINI, COUL, MPMI	18,12				25,20	
Dimbokro	MOOX, AZOT, NITR, PHOS, PAES, ACID, TEMP, MINI, COUL, MPMI	29,1					13,07
Bocanda	MOOX, AZOT, NITR, PHOS, PAES, ACID, TEMP, MINI, COUL, MPMI	38					10,84
Fetekro	MOOX, AZOT, NITR, PHOS, PAES, ACID, TEMP, MINI, COUL, MPMI	39,9					14,33
Katiola.d	MOOX, AZOT, NITR, PHOS, PAES, ACID, TEMP, MINI, COUL, MPMI	38,5					14,61

3.2.2. Water Suitability for Various Uses

The assessment of water suitability focused on two main uses: drinking water production and livestock watering. These evaluations were conducted based on the Water Quality Index (WQI) and the suitability classes established for each parameter.

Drinking Water Production at Reference Stations

The various results regarding the suitability of the N'ZI River water for drinking water production are presented in Table 2. This suitability was evaluated based on seven (7) alteration parameters following the SEQ-Eau methodology: organic and oxidizable matter (MOOX), nitrates (NITR), suspended particles (PAES), acidification (ACID), mineralization (MINI), color (COUL), and mineral micropollutants in raw water (MPMI). As shown in Table 2, most alteration parameters indicate very poor water quality indices, except at the N'zianouan station, where the water exhibits poor quality indices. Overall, these findings suggest that the N'ZI River water requires complex treatment processes to be suitable for drinking water production.

Table 2. Suitability of N'ZI River Water for Drinking Water Production at Reference Stations.

	Code		Blue	Green	Yellow	Orange	Red
		Quality Class	100-80	80-60	60-40	40-20	20-0
Sites	Alteration parameters	Average concentration (mg/L)					
N'zianouan	MOOX, AZOT, NITR, PHOS, PAES, ACID, TEMP, MINI, COUL, MPMI	17,9				24,39	
Dimbokro	MOOX, AZOT, NITR, PHOS, PAES, ACID, TEMP, MINI, COUL, MPMI	37,5					13,08
Bocanda	MOOX, AZOT, NITR, PHOS, PAES, ACID, TEMP, MINI, COUL, MPMI	46,6					10,73
Fetekro	MOOX, AZOT, NITR, PHOS, PAES, ACID, TEMP, MINI, COUL, MPMI	53,1					14,22
Katiola,d	MOOX, AZOT, NITR, PHOS, PAES, ACID, TEMP, MINI, COUL, MPMI	50,9					14,674

4. Discussion

The average concentrations of the alteration parameters analyzed are summarized in Tables 1 and 2. The results indicate that the water suitability classes of the N'ZI River range from poor to very poor quality across most parameters, reflecting an overall very poor biological water quality. According to the SEQ-Eau classification system, this corresponds to low to very low aquatic biodiversity, characterized by the absence of many sensitive organisms or microorganisms when parameter values exceed the prescribed limits. Regarding the suitability of the water for drinking water production, the alteration levels vary from one station to another as well as among the parameters analyzed, revealing a generally poor to very poor water quality. Considering the global water quality, the N'ZI River falls within the very poor suitability class, indicating that it cannot be directly used for drinking water supply without the application of complex treatment processes, as defined by the SEQ-Eau evaluation grid. The high concentrations of certain alteration parameters, such as organic and oxidizable matter, appear to be among the main factors negatively affecting aquatic productivity, along with temperature and other environmental variables [45] (Tohouri et al., 2016). Furthermore, the degradation of water quality reduces dissolved oxygen levels, thereby limiting aquatic life. Similar observations have been reported by [13-15, 18, 19, 21, 36]. These alterations can serve as indicators of pollution or ecosystem imbalance, particularly when productivity declines. In extreme cases, they may lead to eutrophication and potentially irreversible degradation of the aquatic environment. The mean alteration value for acidification was found to be below 5.5 (Tables 1 and 2), which may contribute to metabolic acidosis. Conversely, the pH of the N'ZI River water generally remains below 8.5, indicating a potential risk of metabolic alkalosis in plants [29, 30]. The N'ZI River water is therefore slightly alkaline, rich in calcium and magnesium, and contains significant amounts of bicarbonates and carbonates, reflecting a high alkalinity that enables it to neutralize acids [4, 11]. The current assessment of water pollution was conducted using the Water Quality Evaluation System (SEQ-Eau), which integrates multiple physicochemical parameters grouped into alteration categories. In this study, water suitability was evaluated for biological functions and human uses (i.e., drinking water production). Each alteration was assessed according to five suitability classes, ranging from blue (very good suitability) to red (unsuitable). Each class is defined by threshold values associated with the parameters of each alteration, corresponding to the French and European regulatory standards [26, 37]. The alterations considered in this study that may affect biological balance or water usability include: organic and oxidizable matter (MOOX), nitrogen compounds (AZOT), nitrates (NITR), phosphates (PHOS), suspended particles (PAES), acidification (ACID), temperature (TEMP), mineralization (MINI), color (COUL), and mineral micropollutants in raw water (MPMI). The results obtained are consistent with the water quality index (WQI) classes established by the SEQ-Eau method, which provides a reliable diagnostic tool for evaluating water quality and determining the necessary corrective actions to improve it based on its intended use. The SEQ-Eau method is based on the concept of alteration, where approximately 150 parameters are grouped into 16 categories that indicate specific types of pollution. In the present study, about 50 parameters were used to assess the quality of the N'ZI River water, grouped into 10 alteration categories. Water quality was analyzed according to the intended use, meaning that threshold values for the same parameter may vary depending on the usage (e.g., biological suitability vs. drinking water production). The quality index for each parameter was calculated using four different models, adapted to the specific conditions encountered [26, 40]. The Water Quality Index (WQI) provided accurate and reliable results [33, 41]. The computed WQI values showed variations in alteration intensity from one sampling point to another, depending on the type of water use. The main parameters identified in the natural waters correspond to alterations whose fluctuations are generally related to human activities. Indeed, the presence of MOOX, AZOT, NITR, PHOS, PAES, ACID, TEMP, MINI, COUL, and MPMI in surface waters may result either from agricultural inputs through fertilizer leaching, or from the transformation of ammonium into nitrates derived from domestic discharges or animal waste carried by runoff in areas with significant pastoral activity.

5. Conclusions

This study assessed the suitability of N'ZI River water for biological functions and drinking water production using the SEQ-Eau evaluation system. The mean values of the analyzed parameters and the computed quality indices provided a comprehensive appraisal of the river's potential uses. The physicochemical analyses revealed that the N'ZI River water quality ranges from poor to very poor, regardless of use, from upstream to downstream across all reference stations. The general deterioration of water quality in the study area is primarily attributed to mineral micropollutants, microorganisms, phosphates, and nitrites, which originate from surface runoff and agricultural practices in the surrounding area. Changes in physical indicators, including: temperature (T°C), turbidity (NTU), pH, and electrical conductivity (EC) further indicate Deterioration of water quality. Low temperature variation does not favor a balanced aquatic life, while high turbidity fluctuations are primarily linked to agricultural activities and land exploitation near the river. These conditions maintain a persistent turbidity, which alters the physicochemical quality of the river water. Water from the N'ZI River is predominantly basic, due to reduced CO_2 levels in the water layers, and shows minimal risk of pollution from chlorides, phosphates, nitrites, and nitrates. However, organic pollution indicators (COD and BOD_5) reveal waters ranging from biodegradable to poorly biodegradable. Despite the observed spatial and temporal variations, the river still retains part of its natural character. Nevertheless, its overall quality remains poor to very poor for both biological and drinking water uses. The available data are insufficient to accurately determine the river's self-purification capacity. Therefore, studies are recommended to strengthening the control of action source pollution such as: Limiting gold panning activities; Establishing a water quality monitoring system; Implementing a water quality early warning mechanism to support local governments scientifically. Promoting ecological restoration and sustainable development projects, such as wetland protection and the construction of ecological buffer zones.

Abbreviations

Acronym	Meaning
pH	Potential Hydrogen
NTU	Turbidity
WHO	World Health Organization
COD	Chemical Oxygen Demand
BOD_5	Biochemical Oxygen Demand over Five Days
CO_2	Carbon Oxygen
E C.	Electrical Conductivity
TSS	Suspended Solids
Pt/Co	Platin/Color
LAPISEN	Laboratory of Industrial Processes, Synthesis, Environment and New Energies
IN-PHB	Institut National Polytechnique Felix Houphouët-Boigny
MOOX	Organic and Oxidizable Matter
AZOT	Nitrogenous Matter Excluding Nitrates
NITR	Nitrates
PHOS	Phosphorus Matter
PAES	Particles in Suspension
ACID	Acidification
TEMP	Temperature
MINI	Mineralization
COUL	Color
MPMI	Mineral Micropollutants in Raw Water
WQI	Water Quality Index
AFNOR	French Association for Standardization
ICP	Plasma Atomic Emission Spectrometric

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Author Contributions

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Data Availability Statement

All required datasets are provided in the manuscript.

Conflicts of Interest

The authors have no conflicts of interest to disclose.

Appendix

Table 3. *Biological Suitability of N'ZI River Water at Reference Stations.*

sites Alterations	N'zianouan	Dimbokro	Bocanda	Fetekro	Katiola.D
MOOX					
OD	44.20	42.80	57.56	65.72	51.96
TO2	49.27	50.53	54.51	65.27	50.70
DCO	72.26	81.17	54.73	85.76	42.33
DBO5	68.18	30.00	69.09	52.73	-13.64

sites Alterations	N'zianouan	Dimbokro	Bocanda	Fetekro	Katiola.D
MO	25.19	-47.18	-38.51	14.68	-265.50
NH4+	-168.85	-69.39	2.27	-16.37	-190.35
AZOT					
NO2-	80.76	77.07	73.59	74.13	50.54
NH4+	-305.80	-153.55	-43.88	-72.41	-338.69
NITR					
NO3-	82.85	82.88	82.71	81.97	80.03
PHOS					
PO43-	82.84	81.68	85.79	83.47	76.95
PT	-245.11	-380.99	-321.56	-359.89	-250.22
PAES					
NTU	-3.40	-33.84	-304.64	-271.47	-174.61
MES	26.27	-44.25	-159.16	-337.71	-271.33
ACID					
pH	56.7	60.8	57.7	53.2	58.08
Al	79.78	79.91	79.93	79.68	79.85
TEMP					
T°C	31.00	52.50	46.85	53.60	52.10
MINI					
C.E	81.30	76.98	81.53	80.79	82.00
Ca	84.11	84.11	84.11	84.11	84.11
Chlorures	98.80	98.93	98.93	98.80	99.20
Sulfate	65.63	82.68	68.47	55.84	75.74
Na	109.05	109.49	109.63	109.63	109.40
Mg	88.60	88.51	88.53	88.57	88.54
TAC	82.54	60.43	60.43	83.59	83.91
COUL					
Color	77.89	70.40	60.41	70.40	29.41
MPMI					
As	-1298.93	-1322.12	-998.09	-780.06	-1126.58
Cd*	-1342.56	-1098.79	-477.54	-859.45	-891.36
Cr*	55.41	42.87	49.99	66.11	53.48
Cu*	-119.79	-20.19	23.81	-639.91	-93.11
Hg *	-75134.23	-39912.98	-33715.12	-43443.17	-44408.23
Ni*	49.75	47.98	68.21	-561.13	64.75
Pb*	6.92	-17.33	-17.33	-41.57	56.01
Zn*	-128.24	-108.12	-83.65	76.70	-103.40

* (Low hardness)

Table 4. Suitability of N'ZI River Water for Drinking Water Production at Reference Stations.

Sites Alterations	N'zianouan	Dimbokro	Bocanda	Fetekro	Katiola.D
MOOX					
OD	35.25	33.50	51.95	62.15	44.95
TO_2	33.90	35.80	41.77	57.90	36.05
DCO	-7.31	24.13	-69.20	40.32	-112.94
DBO_5	-6.67	-286.67	0.00	-120.00	-606.67
MO	7.19	-65.18	-56.51	-3.32	-283.50
NH_4^+	-453.26	-240.11	-86.57	-126.51	-499.31
NITR					
NO_3^-	82.85	82.88	82.71	81.97	80.03
PAES					
NTU	77.80	76.99	69.84	70.72	73.28
MES	79.48	78.81	77.70	75.99	76.63
ACID					
pH	61.36	64.64	57.70	58.56	58.08
MINI					
C.E	81.30	76.98	81.53	80.79	82.00
Ca	95.02	95.03	95.02	95.03	95.03
Chlorures	79.10	79.20	79.20	79.10	79.40
Sulfate	45.32	32.36	43.16	52.76	37.64
Na	77.63	78.74	79.07	79.07	78.49
Mg	88.60	88.51	88.53	88.57	88.54
TAC	83.49	53.13	53.13	84.93	85.37
COUL					
Color	77.89	70.40	60.41	70.40	29.41
MPMI					
As	-1430.82	-1456.33	-1099.90	-860.06	-1241.24
Ba	216.81	216.60	214.11	211.95	214.58
B	75.48	73.99	72.97	76.15	73.23
Cd	-773.27	-627.05	-254.42	-483.50	-502.64
Cr	55.38	42.85	49.97	66.08	53.45
Cu	78.74	79.75	80.19	73.47	79.01
Hg	-74608.15	-39633.45	-33478.98	-43138.93	-44097.24
Ni	79.14	75.60	115.83	-1135.00	108.95
Pb	3.71	-26.46	-26.46	-56.64	64.82
Se	22.49	22.05	20.70	22.05	21.14
Zn	135.66	138.98	143.01	169.45	139.75

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