Journal of Materials and Environmental Science
ISSN : 2028-2508
e-ISSN : 2737-890X
CODEN : JMESCN

J. Mater. Environ. Sci., 2022, Volume 13, Issue 08, Page 914-927

http://www.jmaterenvironsci.com

Characterization and physicochemical monitoring of water in the Niger River along the city of Niamey in Niger

S. I. Soumaïla[1]*, M. M. Adamou[1], M. B. Mouhamadou[2]**

[1]*Department of Rural Engineering, Water and Forestry, Faculty of Agronomy, Abdou Moumouni University of Niamey, P.M.B.10 960, Niger*
[2]*Department of Biotechnology, Institute of Radioisotopes, Abdou Moumouni University of Niamey, P.M.B.10 960, Niger*
**Corresponding author, Email address: siddo855@gmail.com*
***Corresponding author, Email address: moustapha_@yahoo.com*

Received 27 July 2022,
Revised 15 Aug 2022,
Accepted 16 Aug 2022

Keywords
- ✓ *Niger River,*
- ✓ *Niamey,*
- ✓ *physico-chemical parameters,*
- ✓ *pollution*

siddo855@gmail.com
Phone: +227 99565514
moustapha_@yahoo.com
Phone: +227 96884232

Abstract
Already impacted by the phenomenon of silting, the impacts of agricultural and industrial activities carried out along the Niger River constitute serious threats to the sustainability of the ecosystem services of the Niger River. This study monitors the physico-chemical quality of the river water. Samples were taken during the rainy season, cold dry season and dry season at three points along the river respectively at the entrance, in the center and at the exit of Niamey. A total of 22 physico-chemical elements were analyzed in the laboratory. The results show that the turbidity varies from 20.75 to 1513.17 NTU; SS from 21.5 to 1136.4 mg/l; the pH from 6.97 to 7.59; electrical conductivity from 48.13 to 94.83 µS/cm; MO from 3.04 to 7.63 mg/l; nitrate from 0.15 to 1.48 mg/l; nitrite from 0.01 to 0.6 mg/l and fluorides from 0.7 to 0.87 mg/l. As for mineral trace elements (ETM), their content is 0.02 to 0.03 mg/l; from 0.41 to 6.89 mg/l and from 0.02 to 0.08 mg/l respectively for copper, iron and aluminium. Water quality varies more between seasons than along the stretch of the river in the city of Niamey. And the discharges from the city do not seem to have a significant influence on the physico-chemical quality of the water in the Niger River. However, it is necessary to set up a permanent monitoring system for the quality of the water in the river.

1. Introduction

Water, both useful and irreplaceable, is the essence of life. It is a vector of biodiversity [1]. However, climate change and anthropogenic activities lead to major alterations in the hydrological cycle, the degradation of water quality has then become a crucial global issue for the sustainable development of human beings [2]. All over the world, the pressure on water resources is on the rise, mainly due to the increasing demand [3] and the deterioration of its quality [4]. This strong pressure exerted by anthropogenic activity [5] poses a threat to public health, wildlife species as well as sources of income [6]. In developing countries, 80 to 90% of wastewater and about 70% of household and industrial waste are discharged untreated into surface water [6]. However, it is clear and undeniable that there can be no sustainable development without the control of water resources, particularly for arid and semi-arid countries ([7]; [8]; [9]) where drought has been almost persistent since the 1960s [10] and causes more damage by affecting more people than any other type of disaster [11]. In addition, the industries have very diverse productions and reject several types of wastewater, the volume and degree of contamination of which are highly variable [12]. As a result, the problem of water use and management is acute for many countries [13] and the contradictions that run through the relationship of human beings to water – between vital uses and garbage uses – are far from being overcome [14]. The Niger River is the only permanent watercourse in Niger and serves as the exclusive source for the drinking water supply of Niamey, the capital. It is the main recipient of domestic and industrial wastewater discharges from the city of Niamey [15]. including sludge from drinking water treatment at the Goudel plant. However, in a hydro-fluvial system, the properties that emerge at higher levels integrate the result of phenomena that occur at lower levels [16]. Water poisoning has indirect deleterious effects on human beings by destroying their food reservoirs [14]. Therefore, monitoring the status of rivers has become an increasing necessity [17] to ensure sustainable access to water for all forms of use. So the identification of the main sources and the impact of the current overall water quality is important to improve the accuracy and relevance of water quality management, which will have a significant impact on the quality the aquatic environment and the ecological system [18]. This study aims to (1) establish the current state of the physicochemical quality of the water of the Niger River in Niamey; (2) characterize the seasonal changes in this quality according to various sampling points and (3) explore the links of environmental and anthropogenic factors with the variation of certain chemical elements.

2. Materials and methods

2.1. Presentation of the study area

The Niger River with a maximum flow of 2,340 m3/s, crosses the city of Niamey over a length of more than 15 km. In recent years, it has experienced a disturbance in its diet due to the phenomena of silting, sedimentation and water erosion [19]. Nevertheless, the Niger River in Niamey is marked by two distinct periods of high water [20] (figure 1): a first rise in the water level at the start of the rainy season in June-July, reaching its maximum in August-September and called " local flood", or " red flood " resulting from the flows of the tributaries of the right bank upstream of Niamey (Gorouol, Dargol, Sirba) and a second rise in water due to the contribution of the flows from the upper basin of the Niger River and called " Malian flood" or " Guinean flood" reaching its maximum in December and January. It is also necessary to note the weight of urban runoff water which is drained towards the Niger River. The supply of drinking water to the inhabitants is ensured by the "Société d'exploitation des Eaux du Niger (SEEN)" through the pumping and treatment stations of Goudel and Yantala which take water from the Niger River.

The study area mainly concerns the city of Niamey (figure 2). It is located in the Sahelo-Sudanian zone characterized by a short rainy season (June to September) and a long dry season (October to May), and experiences 2 main types of winds: the hot and dry harmattan which blows from the North- East during the dry season and the monsoon, cool and wet which blows from the West during the rainy season. The annual rainfall has generally varied from 500 to 750 mm with a very exceptional extreme of more than 800 mm in 1998. It is concentrated from June to September. It should be noted that rainfall can be very variable in space and time. The water of these rains flow towards the Niger River. In addition to these, the river receives inputs due to industrial discharges as well as those from certain hospitals and hotels, and gray water from the city.

2.1.1. Choice of measuring points

Samples were taken at three points located along the Niger River in and around the city of Niamey (Figure 2):

- Tondi kwarey (Tk), located upstream of the city of Niamey in an area free of any industrial activity;

- Goudel threshold (Go), immediately downstream (150 m) of the Goudel drinking water production plant and only receives discharges from this plant;
- Liboré (Li), last district on the Niger River exit from Niamey. Zone located downstream of the city of Niamey and therefore receives discharges from industries and the said city.

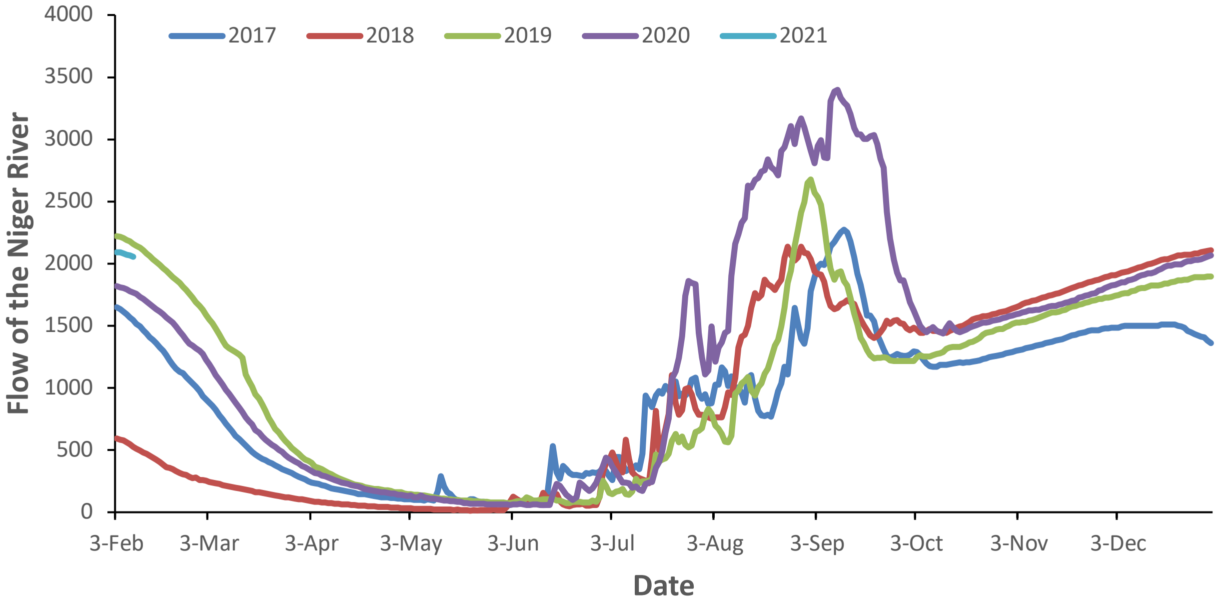

Figure 1: Variation in the level of the Niger River in Niamey

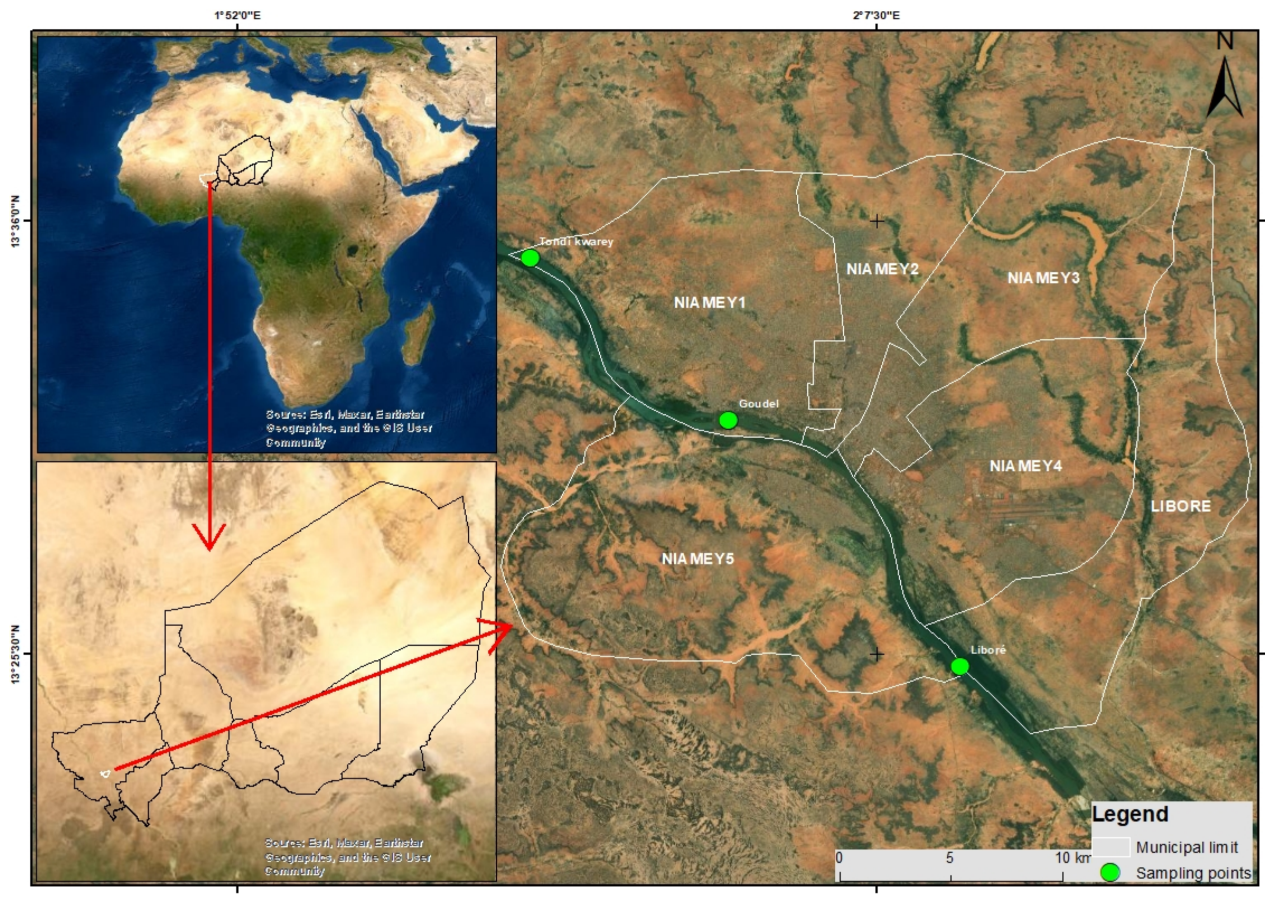

Figure 2: Sample Collection Points

2.2. Sampling techniques and frequency

The samples are collected in 1000 ml polyethylene bottles and kept cool in a cooler at around 4°C until they are admitted to the laboratory [21], where physicochemical analyzes are systematically launched. The elements analyzed are: i) for the physical parameters: turbidity, pH, conductivity, hardness; ii) for the major ions of the chemical parameters: chloride, nitrate and sulphate for the anions and calcium, potassium and magnesium for the cations and iii) for the other elements and some heavy metals: the Complete Alkalimetric Title (TAC), Suspended Solids (SS), Dissolved Solids (TDS), Oxidized Fraction of Organic Matter (MO), Nitrite, Copper, Iron, Sulphide, Manganese, Fluoride, L aluminum and arsenic. The samples are taken every 10 days of the year 2022 for 2 months of each hydrological season of the Niger River [15]: rainy season (SP), cold dry season (SSF) and hot dry season (SSC). A total of 54 samples (i.e. 18 per sampling point) were taken following the recommendations required according to [12] and [22].

2.3. Measuring tools

The measurement tools for determining the physicochemical parameters are: the HACH digital titrimetry, the HACH DR/6000 spectrophotometer and the JENWAY PFP 7 flame photometer.

2.4. Methodological approaches

2.4.1. In the laboratory

The different analytical techniques for chemical parameters are as follows:

- **Volumetry:** The chemical parameters determined are: Calcium, Magnesium (EDTA test), Bicarbonates (sulfuric acid test), and Chloride (silver nitrate test).
- **Spectrophotometry:** The parameters determined by this technique are Nitrites, Nitrates, Iron, Sulphates, Copper, Arsenic.
- **Flame photometry:** For this technique, the apparatus used is the flame photometer allowing the determination of Sodium and Potassium.

2.4.2. Data processing

- **Hardness**

The dissolution of calcium and magnesium cations characterizes the hardness of water. It is usually expressed in milligrams of calcium carbonate per litre. It essentially influences the state of pipes and heating appliances, and the washing of clothes. Within the framework of this study, it is evaluated from the average of the various values of Ca and Mg acquired. It is measured by the hydrometric title which is expressed in mg/l of $CaCO_3$, in mg / l of Mg or Ca. The hydrometric title can also be expressed in French degrees (°F) and is obtained from the following formula:

$$(°\text{dh}) = Ca^{2+}\frac{CaCO3}{Ca} + Mg^{2+}\frac{\text{CaCO3}}{Mg}\,(\text{mg or ppm}) \text{ or } (°\text{dh}) = 2.5Ca + 4.16Mg$$

where 1°F is equivalent to 10 mg of $CaCO_3$. The classification is then established as follows: Very soft water: (° dh) < 3°F; Fresh water: 3°F < (° dh) <15°F; Hard water: 15°F < (° dh) <35°F and Very hard water: (° dh) <35°F

- **Global data**

The data collected was compiled and analyzed statistically. The statistical analysis of these data was carried out using two software: GenStat for the comparison of means by the Newman-Keuls test at the

5% threshold and R for the study of correlations by Factorial Correspondence Analysis (FCA) in order to highlight the evolution of the water quality according to the seasons but also the sampling points.

3. Results

3.1. Physical Parameters

Table 1 presents the results of the physical parameters of the Niger River water in the rainy season, in the cold dry season and in the hot dry season at the sampling points of Tondi Kwarey, Goudel and Liboré sills.

- **Turbidity and suspended solids**

In the dry season, whether cold or hot, the river water is relatively clear as evidenced by the average turbidity values at the three sampling points which are respectively 25.5 ± 4.20; 26.43 ± 3.63 and 27.23 ± 3.44 NTU for the cold season and 20.75 ±5.94; 27.43 ±19.42 and 38.03 ±14.06 for the hot season in Tondi Kwarey, Goudel and Liboré against very high turbidity values in the rainy season (Table 1). These vary from 1513.17a ±456.96 at Tondi Kwarey, 1355.75a ±638.62 at Goudel to 1143.25a ±496.11 NTU at Liboré. The turbidity value generally increased from upstream to downstream of the city according to the monitoring points in the dry season and vice versa in the rainy season. This rule of variation is respected with regard to variations in suspended matter content except for the cold dry season where the trend is reversed.

- **Conductivity**

The conductivity of the river water varies from place to place and according to the time of year. Indeed, during the dry season, the conductivity values vary from 50.53a±4.68 at Tondi kwarey; 50.83a ± 4.24 at Goudel to 53.03b ± 4.23 at Liboré in the cold dry season. These values increase in the hot dry season and reach 83.36a ± 6.36 at Tondi kwarey; 83.27a ± 6.53 in Goudel and 94.83b ± 10.80 in Liboré. This increase in conductivity could be due to the high evaporation in hot periods linked to the intensification of heat. During the rainy season, the conductivities drop, becoming below and close to those recorded in the cold dry season, this is probably due to the rainfall inputs playing a dilution effect on the water of the river. This implies that the water coming from the upper basin of the Niger River (November, December and January) have an effect on the initial conductivity of the water of the Niger River. The progressive evolution of the conductivities from upstream to downstream demonstrates the water is loaded with dissolved minerals during its transport according to the external contributions.

- **pH**

The pH values recorded at the sampling points depending on the year are neutral to slightly basic pH. Between the rainy season and the hot dry season, the alkalinity of the river water is just multiplied by 5. Neutral values are observed during the rainy season and are similar from upstream to downstream (7.06a ± 0.23 in Tondi Kwarey; 7.01a ± 0.24 in Goudel and 6.97a ± 0.3 in Liboré). These values hardly vary from one point to another in the dry season, especially the hot one (Table 1).

Among the physical parameters of the water, only the pH is within the range of the standards recommended by the WHO in 2011 for drinking water. The comparison of the means in the dry season by the Newman keuls test at the 5% threshold only revealed significant differences for the Conductivity ($F< 0.001$) which was greater at the Liboré sampling point. Thus, it can be seen that the quality of water varies greatly depending on the season. In fact, during the rainy season, the water in the river is highly charged, as shown by the high values of turbidity, suspended solids (SS) and oxidizable organic matter (OM). This shows the effects of the discharge from the city of Niamey at the sampling points of Goudel and Liboré, located respectively immediately downstream of the water treatment plant (SEEN) and downstream of the city of Niamey.

Table 1: Variation of the physical parameters of the river water from one point to another and depending on the time of year

Settings	Units	WHO standards, 2011	Rainy season			Cold dry season			Hot dry season		
			Tondi K	Goudel	Liboré	Tondi K	Goudel	Liboré	Tondi K	Goudel	Liboré
Turbidity	NTU	5	1513.17a ±456.96	1355.75a ±638.62	1143.25a ±496.11	25.5y ±4.2	26.43a ±3.63	27.23a ±3.44	20.75a ±5.94	27.43a ±19.42	38.03a ±14.06
Suspended matter	mg/l		1136.4a ± 240.08	1063.7a ± 258.01	960.9a ±308.31	36.66a ± 12.36	36.33a ±12.66	35.16a ± 6.79	21.5a ± 7.77	30.16a ± 23.04	42.83a ± 19.97
pH		6.5-9.2	7.06a ±0.23	7.01a ±0.24	6.97a ±0.3	7.19a ±0.12	7.25b ±0.07	7.17a ±0.09	7.59a ±0.17	7.58a ±0.17	7.57a ±0.3
Conductivity	µS/cm	500-1500	48.59a ±1.56	48.13a ±4.32	56.92a ±11.62	50.53a ±4.68	50.83a ±4.24	53.03b ±4.23	83.36a ±6.36	83.27a ±6.53	94.83b ±10.80

3.2. Chemical parameters

3.2.1. Major ions

As part of this study, seven (7) major elements were assayed. With a value of 20.83 mg/l, the chlorides did not vary from one sampling point to another during the rainy season and during the hot dry season for a value of 18.33 mg/l. These levels varied slightly during the cold dry season, going from 16.66 mg/l in Tondi kwarey to 17.50 mg/l in Goudel and Liboré (table 2).

The nitrate contents are almost nil during the rainy season, less than one mg/l in the cold dry season and a little over one mg/l in the hot dry season for the samples analyzed. The values obtained in the hot dry season are in the same range as those obtained by [23] in 2018 on the Niger River in Niamey, with the same sampling protocols. Bicarbonate is the element with the highest concentration of all the ions measured. It presents a slightly decreasing variation from upstream to downstream.

Sulfate contents are much more observed in Tondi kwarey and Goudel during the rainy season. These are close to zero during the other seasons and whatever the sampling point. Theoretically, the source of sulphate in groundwater could be the oxidation of sedimentary sulphides [24] and in the face of low sulphide concentrations (Table 3), it is quite obvious that the sulphate contents approach zero.

Potassium also recorded almost zero values in the rainy season against values of the order of 1 mg/l in the cold dry season and less than 5 mg/l in the hot dry season for all the measurement points. Calcium contents are higher in the hot dry season than in the rainy and cold dry seasons. As for magnesium, the lowest levels are recorded in the rainy season and the highest in the cold dry season.

All the major ions measured vary very little from one sampling point to another, apart only from magnesium, which saw its value in the rainy season be multiplied by 20 and that of the hot dry season by more than 10 in the dry season. cold. This testifies to new contributions during this period and of different origin from the moment when even the upstream point (which is an agglomeration) observes this variation. Nevertheless, all the values of the various major elements are below the standards set by the WHO for drinking water, whatever the sampling site and the time of year (Table 2). The comparison of the averages of the chemical parameters analyzed by the Newman keuls test at the 5% threshold showed that, for most of them, there is no statistically significant difference between the quality of the water sampled at the level of the three sampling points (Tk, Go and Li).

Table 2: Major ions in the water of the river according to the sampling stations

Settings	Units	WHO standards, 2011	Rainy season			Cold dry season			Hot dry season		
			Tondi K	Goudel	Liboré	Tondi K	Goudel	Liboré	Tondi K	Goudel	Liboré
Chloride	mg/l	250	20.83a ±3.76	20.83a ±3.76	20.83a ±3.76	16.66a ±2.58	17.50a ±4.18	17.5a ±4.18	18.33a ±2.58	18.33a ±2.58	18.33a ±2.58
Nitrate	mg/l	50	0.15 ±0.36	0.00 ±0.00	0.00 ±0.00	0.71 ±0.26	0.68 ±0.27	0.64 ±0.28	0.97 ±0.96	1.11 ±0.94	1.48±1.42
Sulfate	mg/l	500	4.67 ±11.43	2.50 ±6.12	0.00 ±0.00	0.16 ±0.41	0.00 ±0.00	0.00 ±0.00	0.33a ±0.52	0.33a ±0.52	0.16a ±0.41
Bicarbonate	mg/l	200-300	31.84 ±5.61	30.62 ±6.34	30.26 ±6.34	36.97 ±4.76	37.33 ±6.34	37.33 ±5.24	51.97 ±6.47	51.24 ±5.73	53.19 ±7.69
Potassium	mg/l	100	0.53 ±0.82	0.45 ±0.73	0.75 ±0.64	1.56 ±0.24	1.33 ±0.29	1.33 ±0.30	4.30 ±0.59	4.23 ±0.61	4.50±0.80
Calcium	mg/l	200	5.86a ±1.71	6.6a ±1.78	5.4a ±1.65	7.6a ±2.18	5.46b ±2.33	5.46b ±2.11	7.66a ±1.88	6.8a ±1.79	8.40a ±1.64
Magnesium	mg/l	150	3.72a ±1.96	3.60a ±2.16	4.01a ±2.31	66.09a ±99.50	63.74a ±94.58	66.41a ±99.25	4.81a ±1.99	6.05a ±3.61	5.30a ±3.54

Table 3 gives the relative abundance of the different major ions measured according to the season of the year. For the anions the bicarbonate constitutes the dominant ion and whatever the period of the year whereas the nitrate and the sulphate share the last position respectively in the rainy season and dry season. With regard to cations, calcium dominates in the rainy season and hot dry season against a dominance of magnesium in the cold dry season. Potassium is the least dominant for the whole year.

Table 3: Abundance order of ions

Season	Cations	Anions
Rainy	$Ca2^{+} > Mg2^{+} > K^{+}$	$HCO_3^{-} > Cl^{-} > SO_4^{2-} > NO_3^{-}$
Dry cold	$Mg2^{+} > Ca2^{+} > K^{+}$	$HCO_3^{-} > Cl^{-} > NO_3^{-} > SO_4^{2-}$
Hot dry	$Ca2^{+} > Mg2^{+} > K^{+}$	$HCO_3^{-} > Cl^{-} > NO_3^{-} > SO_4^{2-}$

- **Water hardness**

Table 4 gives the hardness of water and its action on equipment. These waters are soft everywhere during the rainy season and the hot dry season and hard in the cold dry season. They corrode material during the first two periods and have no effect on material in the third period (table 4).

Table 4: Water hardness and its effect on material

Settings	Units	Rainy season			Cold dry season			Hot dry season		
Hardness	mg/l	30.00a ±11.31	31.33a ±11.59	30.00a ± 13.11	289.66a ±411.36	276.0a ±390.07	287.0a ±408.0	39.16a ±7.57	42.0y ±17.98	43.66a ±15.02
Classification		Fresh			Hard			Fresh		
Effects on hardware		Corrosion of material			No effect			Corrosion of material		

3.2.2. Other elements and some heavy metals

Significant statistical differences were highlighted at the level of the oxidizable fraction of the organic matter ($F<0.031$) and of the Total Alcalimetric Title or TAC ($F<0.020$).

The Goudel (Go) sampling point has an average rate of oxidizable organic matter of 7.63 mg/l, statistically higher than that of the Liboré (Li) sampling point located downstream of the city of Niamey (6.52 mg/l). However, this comparison of averages did not reveal a significant difference between the MO values of the control sampling point located upstream of the city of Niamey at Tondi kwarey (7.12 mg/l) and that of Goudel. With regard to the Complete Alkalimetric Title, the Tondi kwarey sampling point recorded a value of 2.617°F which is higher than those of the Goudel and Liboré sampling points

which obtained respective values of 2.517 and 2.483°F (Table 4). It should be noted that rainwater (acid) can contribute to the reduction of the TAC.
In addition, it also appears that the water quality varied slightly between the different sampling points (Tk, Go and Li). Others, on the other hand, vary significantly according to the three sampling points. These are the oxidizable fraction of organic matter ($F<0.001$) and the rate of dissolved substances ($F<0.001$) with the highest levels, respectively 3.38 mg/l for organic matter and 26.48 mg/l for the rate of dissolved substances. These levels are higher at the Liboré sampling point receiving the cumulative discharges from the city of Niamey.
The analytical and comparative study of this season's data has shown that despite these slight variations, certain parameters remain statistically equal with the Newman Keuls test at the 5% threshold depending on the stations. These are iron, sulfide, Complete Alkalimetric Title and hardness.
The analysis of the same parameters according to the seasons highlighted significant to highly significant differences. Thus, the significant differences are observed at the level of parameters such as sulphide and TDS. As for the highly significant differences, they are observed at the level of iron, SS, organic matter, TAC and hardness.
The rate of nitrites is higher during the rainy season (around 0.6 mg/l) compared to the dry season (0.01 mg/l). This rate seems to decrease from upstream to downstream of the sampled points. In any case, it is well below the WHO standard.
Manganese keeps almost the same value (0.004-0.005 mg/l) in the dry season, whether cold or hot. On the other hand, in the rainy season, the levels exceed the WHO standards for all the sampling points and these levels show a downward trend from upstream to downstream (Table 5).

Table 5: Inter-seasonal quality of river water according to sampling stations

Settings	Units	WHO standards, 2011	Rainy season			Cold dry season			Hot dry season		
			Tondi K	Goudel	Liboré	Tondi K	Goudel	Liboré	Tondi K	Goudel	Liboré
Nitrite	mg/l	3	0.60 ±1.35	0.54 ±1.23	0.54 ±1.30	0.17 ±0.35	0.16 ±0.35	0.16 ±0.35	0.01 ±0.01	0.01 ±0.01	0.01 ±0.00
Manganese	mg/l	0.5	1.16	1.04	0.76	0.04 ±0.02	0.04 ±0.03	0.05 ±0.03	0.05 ±0.03	0.05 ±0.03	0.05 ±0.03
Copper	mg/l	2	0.03 ±0.05	0.02 ±0.05	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00
Iron	mg/l	0.3	6.89a ±3.63	6.46a ±2.67	6.12a ±2.09	0.59a ±0.25	0.73a ± 0.16	0.70a ± 0.10	0.42a ±0.12	0.41a ± 0.17	0.64a ± 0.29
Sulfide	mg/l		0.37a ±0.41	0.33a ±0.39	0.31a ±0.35	2.02a ±4.89	4.69a ±11.42	3.52a ± 8.56	0.002 ±0.00	0.004 ± 0.01	0.004 ± 0.01
Fluoride	mg/l	1.5	0.71	0.70	0.87	-	-	-	-	-	-
Aluminum	mg/l	0.2	-	-	-	0.02 ±0.00	0.02 ±0.01	0.02 ±0.00	0.037 ±0.00	0.05 ±0.03	0.08 ±0.10
Arsenic	mg/l	0.01	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00
TAC	°F	-	2.61a ±0.46	2.51b ±0.52	2.48b ±0.52	3.03a ±0.39	3.06a ± 0.52	3.06a ± 0.43	4.26a ±0.53	4.2a ±0.47	4.36a ± 0.63
Suspended matter	mg/l	-	1136.4a ±240.08	1063.7a ±258.01	960.9a ±308.31	36.66a ± 12.36	36.33a ±12.66	35.16a ± 6.79	21.5a ± 7.77	30.16a ±23.04	42.83a ±19.97

The copper concentrations determined are zero in all the samples in the dry season and almost zero in the rainy season. This agrees with the results found by [23] in 2018 where the copper concentrations are less than 0.01 mg/l.
Iron values show elevated concentrations in all samples exceeding WHO recommended standards. These iron contents decrease from the sampling point situated upstream to that situated downstream.

They are much higher in the rainy season. Fluoride could only be determined during the rainy season. During this period, it then presents concentrations below WHO standards and which evolve from upstream to downstream according to the direction of the water flow.

As far as aluminum is concerned, it was measured only during the dry season where it shows stable levels of 0.02 mg/l in the cold dry season and increasing respectively by 0.037±0.00 at Tondi kwarey; 0.05 ±0.03 at Goudel and 0.08 ±0.10 at Liboré. Arsenic determination tests in the different samples taken did not reveal the presence of arsenic in these water, so the values are all below the arsenic detection threshold.

In general, all the values determined for heavy metals remain below the WHO standards except for manganese, which observes values above the standards set by the WHO in the rainy season, for all the sampling points.

3.2.3. Study of correlations

The Factorial Analysis of Correspondences (AFC) with the R Software on the evolution of the quality of the water of the river at the level of the three (3) sampling stations made it possible to highlight the correlations between the variables and their behavior in according to the seasons (rainy season or SP, cold dry season or SSF and dry season or SS).

Figure 3A shows that the two dimensions (Dim 1 with 51.08% and Dim 2 with 42.92%) are largely sufficient to assess the behavior of the variables. This figure also shows that the Liboré station is the richest in chemical elements but also in suspended solids.

Figure 3B, with representative dimensions (Sun 1=76.88% and Sun 2=23.12%) shows the correlation between seasons and water quality. At this level, there is a very marked correlation of water quality according to the three seasons. In the rainy season, turbidity, suspended solids and iron are the most important elements. In the cold dry season, the water stands out for the abundance of its hardness, its rate of magnesium and sulphide. In the dry season, the Dissolved Solids Rate, conductivity, Complete Alkalimetric Title, calcium, pH, chloride and organic matter are the most important.

Figure 3C with representative dimensions (Sun 1=75.10% and Sun 2= 22.94%) shows the correlation between water quality according to the sampling stations but also the seasons. Thus, during the same season, it is observed that the quality of the water is strongly correlated and that the richness in elements varies mainly according to the seasons as it has been described in the interpretation of FIG. 3B.

4. Discussion

The water quality of the Niger River varies greatly depending on the hydrological seasons.

In the rainy season, the water in the river is highly charged as shown by the high values of turbidity and SS and MO. This is linked to the degradation of surface hydrographic networks in the Sahelian zone [25], where the soils are exposed to the heat of the sun and the driving of the rains. In this region, many soils have lost their humus-rich horizons [26], which results in an increase in OM in surface water. It can be seen that the suspended solids of the water of the river increase during periods of flooding while the EC decreases. Which corroborates the result of [27] who observed that the SS in the water of the Merja Fouarate in Morocco increases during floods and the EC decreases following the dilution effect. In this season, the comparison of the means by the Newman keuls test at the 5% threshold showed that, for most of the parameters considered, there is no statistically significant difference between the quality of the water sampled at the level of the three stations (Tk, Go and Li).

Figure 3: Correlation between variables and sites over time

A: Correlation between variables and sites; B: Correlation between variables and seasons; C: Correlation between variables, seasons and sites; Tk: Tondi Kwarey; GB: Goudel; Li: Libore; SP: rainy season; SSF: cold dry season; SS: dry season; SPTk : rainy season at Tondi kwarey; SPGo : Rainy season in Goudel; SPLi : rainy season in Liboré; SSFTk : cold dry season at Tondi kwarey; SSFGo : cold dry season in Goudel; SSFLi : cold dry season in Liboré; SSTk : dry season at Tondi kwarey; SSGo : dry season in Goudel; SSLi : dry season in Liboré.

These are calcium, chloride, conductivity, iron, SS, magnesium, turbidity, sulphide, TDS, hardness and pH. The statistical differences were highlighted at the level of the MO ($F<0.031$) and the TAC ($F<0.020$). As a result, the oxidizable MO content of the water is higher from upstream to downstream. Compared to TAC, contrary to oxidizable organic matter, its value decreases from upstream to downstream with respective values of 2.61a ± 0.46; 2.51b ± 0.52 and 2.48b ± 0.52°F at the three sampling points. In the cold dry season, the water quality varied slightly between the different sampling points (Tk, Go and Li). The analytical and comparative study of this season's data has shown that despite these slight variations, certain parameters remain statistically equal to the 5% threshold with the Newman keuls test. These are chloride, iron, MES, magnesium, turbidity, sulphide, TAC and hardness. Others, on the other hand, vary significantly depending on the sampling points. These are Calcium ($F<0.007$), conductivity ($F<0.001$), MO ($F<0.001$), TDS ($F<0.001$) and pH ($F<0.023$). Among them, EC (53.03 µS/cm), MO (3.38 mg/l) and TDS (26.48 mg/l) are the most important at the Liboré sampling point. This increase in CE, MO and TDS at the Liboré sampling point would be linked to discharges from the city of Niamey. Anthropogenic inputs of many substances influence concentrations in water and cycles in natural systems [28]. Indeed, in Niamey, a large quantity of wastewater is discharged there with EC varying from 220.7 to 8095 µS/cm for industrial and hospital discharges and from 271.25 to 2018.33 µS/cm for domestic and municipal discharges. As for the TDS discharged in this wastewater, it varies from 140 to 1200 ppm for domestic discharges and from 111.65 to 4070 ppm for industrial and hospital discharges [29].

In the dry season, the water in the Niger River is clearer with a turbidity of around 20.7 NTU at the Liboré station. It is also less loaded with regard to MES. The Goudel point therefore combines the effects of sludge from the production of drinking water and other related residues. As for the Liboré point, in addition to discharges from the Société d'Exploitation des Eaux du Niger, it also receives discharges from other industrial units (SOLANI, ORIBA, NIGER-LAIT, Slaughterhouse, Niamey National Hospital, national de Lamordé) and housework. It can be seen that at this time of year, the river water is more conductive with 83.36 µS/cm, 83.27 µS/cm and 94.83 µS/cm respectively in Tondi Kwarey, Goudel and Liboré. In addition, the pH of the water is on average 7.58 ± 0.17 at the Goudel sampling point, although acidic sludge with an average pH of 5.7 is discharged there. The average pH values recorded in the dry season at the three sampling stations (Tk =7.59; Go=7.58 and Li=7.57) are close to those obtained during this period by [30] (pH=7.04) and [31] (pH=7.8) on the Niger River at Sinder, located in the Tillabéri region (about 150 km upstream from Niamey). The EC contents obtained by [30] and [31] of 64.3 µS/cm and 73.4 µS/cm respectively showed that the EC is higher in Niamey than in upstream areas. The iron (0.67 mg/l), nitrate (2.2 mg/l) and sulphate (2 mg/l) contents obtained by [31] in Sinder show that this water has a similar concentration to that of water from the Niger River in Niamey. However, the contents of calcium (4.4 mg/l), magnesium (2.43 mg/l), potassium (1.8 mg/l), chloride (0.6 mg/l) and nitrite (0.003 mg/ l) in Sinder are lower than those obtained in this study. This shows that the water is richer in these elements downstream of Niamey. The chloride concentration in the water of the Niger River in Niamey is higher than those obtained by [32] N'Diaye and Guindo (1998) in Niono (Niger River in Mali), Lossa (Niger River in Niger), Kaédi (Senegal River), Lai (Logone river) and Shar (Chari river) which are respectively 0.35 mg/l, 0.00 mg/l, 8.5 mg/l, 0.35 mg/l and 0.35 mg/l. The degradation of surface water quality is the result of dissolved matter inputs [33] which can come from industries which are a multifaceted source of environmental pollution [34]. In the dry season, the comparison of the means by the Newman keuls test at the 5% threshold only revealed significant differences for the Conductivity ($F< 0.001$) which was greater at the Li station.

Significant differences are observed in parameters such as calcium, chloride, sulphide and TDS. As for the highly significant differences, they are observed by conductivity, iron, SS, organic matter, magnesium, turbidity, TAC, hardness and pH. Although the Goudel drinking water production plant uses aluminum sulphate for coagulation and flocculation, the pH of the river water immediately upstream of its discharges remains little variable throughout the year (7 .01 to 7.58).
Iron and manganese are heavy metals exceeding WHO standards for drinking water. Heavy metals like iron (Fe) are considered non-carcinogenic at lower concentrations and act as a micronutrient, while at higher concentration they may pose health risks [35]. On the other hand, heavy metals such as arsenic (As) are highly toxic to humans and other organisms ([36]; [37]), it therefore deserves regular monitoring in water for human consumption and at risk of containing them.

Conclusion

It emerges from this study that the quality of the water varies greatly according to the three hydrological seasons. However, this variation is very small from one sampling point to another within the same season. We note that the quality of the water at Goudel is not very different from that of Tondi kwarey, upstream. The water seems to be richer at Liboré where most of the chemical elements analyzed were abundant. The water quality of the Niger River varies significantly according to the hydrological seasons and slightly from one point to another during the same period, although large volumes of waste are discharged into it. Nevertheless, the values obtained for the major ions are below the WHO standards. Concentrations of heavy metals were barely detected at all sampling sites, with some being significantly lower than drinking water standards. This could be due to the high dilution capacity of the river and denotes the high level of its self-purifying power as an ecosystem. Only iron and manganese have their contents exceeding WHO standards. They must therefore be subject to regular monitoring.

References

[1] P. Bartout and L. Touchart, The inventory of French water bodies: a tool for better surface water management. *Annals of Geography,* 3(691) (2013). 266-289.

[2] R. Arafat, J. Ishrat, N. J. Yeasmin, Assessment of physicochemical properties of water and their seasonal variation in an urban river in Bangladesh. *Water Science and Engineering*, 14(2) (2021) 139e148. https://doi.org/10.1016/j.wse.2021.06.006

[3] H.A. Boubakar, Superficial and deep aquifers and urban pollution in Africa: Case of the urban community of Niamey (Niger) (2010). Doctoral thesis presented to obtain the degree of Doctor from Abdou Moumouni University of Niamey, Specialty: Earth Sciences Option: Hydrogeology. 250p.

[4] N. Nouayti, D. Khattach, and M. Hilali, Evaluation of the physico-chemical quality of groundwater in the Jurassic aquifers of the upper Ziz basin (Central High Atlas, Morocco). *J. Mater. About. Sci.* 6(4) (2015) 1068-1081.

[5] A. Adjagodo, DTM Agassounon, N.C. Kelome and R. Lawani, Flows of pollutants linked to anthropogenic activities, risks to surface water resources and the trophic chain throughout the world: bibliographical summary. *Int. J.Biol . Chem. Sci.* 10(3) (2016) 1459-1472.

[6] C. Faye, The challenges of water pollution, a threat to public health: strengths and weaknesses of water laws and policies in Senegal. *Larhyss Journal,* 32 (2017) 107-126.

[7] A. Kettab, Water resources in Algeria: strategies, challenges and vision. *Desalination*. 136 (2001) 25–33.

[8] O. Clus, Radiative condensers of atmospheric water vapor (dew) as an alternative source of fresh water (2007). Thesis to obtain the degree of doctor from the University of Corsica Pascal Paoli, discipline: physics, energy engineering, physical processes [physics]. 236p.

[9] A. Talhaoui, E.H. Abdellah, H. Jaddi, H. Ousmana, I. Manssouri, Calculation of the Water Quality Index (IQE) for the evaluation of the physico-chemical quality of surface water of the Moulouya wadi (NE, Morocco). *European Scientific Journal.* 16(2) (2020) 64-85.

[10] K.E. Kouakou, BTA Goula and I. Savane, Impacts of climate variability on surface water resources in the humid tropical zone: case of the cross-border watershed of Comoé (Côte d'Ivoire - Burkina Faso). *European Journal of Scientific Research,* 16(1) (2007) 31-43.

[11] S. Ardoin-Bardin, Hydro-climatic variability and impacts on the water resources of large hydrographic basins in the Sudano-Sahelian zone. Hydrology (2004). Montpellier II University - Sciences and Techniques of Languedoc. France. 441p.

[12] S. Hébert and S. Légaré, Monitoring the quality of rivers and small watercourses, Quebec, Department for monitoring the state of the environment. Ministry of the Environment, envirodoq no ENV-2001-0141 (2000). report no QE-123. Canada. 24 p.

[13] S. Hazourli, L. Boudiba, M. Ziati, Characterization of wastewater pollution in the industrial zone of El-hadjar, Annaba. *Larhyss Journal,* (6) (2007) 45-55.

[14] S. Paquerot, Environmental crimes: if water pollution kills… unfortunately it pays off! *Criminology,* 49(2) (2016). 215–240.

[15] B. Alhou, Impact of discharges from the city of Niamey (Niger) on the water quality of the Niger River (2007). Thesis, University of Namur & Abdou Moumouni University Niamey, 300p

[16] D. Peyrard, A hydro-biogeochemical model to describe exchanges between surface water and the hyporheic zone of large alluvial plains (2008). Doctoral thesis, Toulouse III-Paul Sabatier University, UFR Life and Earth Sciences, Speciality: hydroecology. France. 277p.

[17] N. Lamhasni, L. Chillasse, H. Abba, S. El Haouat and M. El Madani, Typology of surface water in the Sebou basin by multi-approach: correlation between global biological index of monitoring networks and monitoring (IBG-RCS) and the physicochemical and microbiological approach. *Africa SCIENCE,* 09(2) (2013) 35–49.

[18] X. Hanxiao, G. Qiang, Y. Bin, Analysis and identification of pollution sources of comprehensive river water quality: Evidence from two river basins in China. *Ecological Indicators* 135.108561 (2022). https://doi.org/10.1016/j.ecolind.2022.108561

[19] H.A. Hado, A.M. Moustapha, G. Favreau, K. Hima, I.D. Dano, A.A. Toure and N. Saidou, Monitoring of the Physicochemical and Bacteriological Quality of the Water of the Gounti-Yéna Basin and Assessment of the Impact on the Health of the Populations. *Journal of Environmental Protection*, 13 (2022) 459-489 https://doi.org/10.4236/jep.2022.137030

[20] R. Gallaire, Data on transport in the middle Niger between Kandadji and Niamey. Great Peri-Atlantic River Basins: Congo, Niger, Amazon, edited by JC Olivry and J. Boulègue (1995). 317-332.

[21] D.C. Adjahouinou, B. Yehouenou, MND Liady and E.D. Fiogbe, Bacteriological characterization of raw wastewater from the city of Cotonou (Benin). *Journal of Applied Biosciences* 78 (2014) 6705 – 6713.

[22] J. Rodier, B. Legube, N. Merlet, R. Brunet, J. Mialocq, P. Leroy, M. Houssin, G. Lavison, C. Bechemin, M. Vincent, P. Rebouillon, L. Moulin, P. Chomodé, P. Dujardin, S. Gosselin, R. Seux, F. Al Mardini, Water analysis. 9th fully updated edition (2009). Dunod, Paris. 1579p.

[23] BRLi and Beria, Update of the liquid sanitation and stormwater drainage master plan for the city of Niamey Niger. Mission A Report, Volume 1 (2018) – Main Report. 225 pages.
[24] R.A. Berner, Worldwide sulfur pollution of rivers. *J. Geophys. Res.* 76 (1971) 6597–6600.
[25] J.C. Desconnets, J.D. Taupin, T. Lebel, The role of ponds in the hydrological balance of a Sahelian region. Exchange processes at the Land Surface for a Range of Space and time scales (Proceedings of the Yokohama Symposium, July 1993) IAHS Publ. (1993). No.212. 1993.
[26] R. Eric, The zaï: the work of termites and farmers in the Sudano-Sahelian zone. The Enduring Review. BIMONTHLY TEST NUMBER 1 (2002) 22-26.
[27] H. Nassali, H. Ben Bouih, A. Srhiri and M. Dhahbi, Influence of wastewater discharges on the composition of surface water and superficial sediments of Lake Merja fouarate in Morocco. *Africa science,* 01 (1) (2005) 145-165.
[28] S. Laura, B. Philippe, S. Werner, Chemistry of aquatic environments. 5th edition (2014). Paris, 487p.
[29] A. Naiban, Characteristics of the outlets of wastewater discharge from the city of Niamey to the Niger River. End-of-study dissertation for obtaining the License in agronomic sciences (2018). Faculty of Agronomy of Abdou Moumouni University. 31p.
[30] H.A.H. Habi, Impact of new water treatment technologies on the drinking water supply of island and riverside areas of the Niger River: case of the municipality of Sinder. Thesis presented for obtaining the Master's degree in Prospecting and Management of groundwater Resources (Hydrogeology) (2016). Faculty of Sciences and Techniques of Abdou Moumouni University. Niamey, 59p.
[31] O.D. Ousseini, Study of the physico-chemical and bacteriological quality of the water of the Niger River, treated by the Bio-Sand Filter system and their socio-economic impacts: case of the downstream part of the municipality of Sinder, Tillabéry/Niger. Thesis presented for obtaining the Master's degree in Prospecting and Management of groundwater Resources (Hydrogeology) (2017). Faculty of Science & Technology /Abdou Moumouni University. 57p.
[32] M.K. N'Diaye and D. Guindo, Evolution of irrigated soils in the Niger valley (Mali): sodization and alkalinization under rice cultivation. Soil Study and Management, 5(4) (1998) 269-276.
[33] S. Maïga-Yaleu, H. Yacouba, I. Guiguemde, Hydrochemistry of rainwater and runoff in the Sahelian region. *J. Soc. West -Afr. Chem.* 042 (2016). 16-29.
[34] D. Claude, Pollution of African continental water: acquired experience, current situation and prospects. French institute of scientific research for development in cooperation. Editions de l'ORSTOM (1988). Paris, 513p.
[35] D. Pal, S.K. Maiti, Seasonal variation of heavy metals in water, sediment, and highly consumed cultured fish (Labeo rohita and Labeo bata) and potential health risk assessment in aquaculture pond of the coal city, Dhanbad (India). About. *Sci. Pollute. Res.* 25 (13) (2018) 12464–12480. https://doi.org/10.1007/s11356-018-1424-5
[36] S.K. Malyan, R. Singh, M. Rawat, M. Kumar, A. Pugazhendhi, A. Kumar, V. Kumar, S.S. Kumar, An overview of carcinogenic pollutants in groundwater of India. Biocatalyst. *Agric. Biotechnol.* 21, (2019) 101288, https://doi.org/10.1016/j.bcab.2019.101288
[37] S.K. Malyan, S.S. Kumar, R.K. Fagodiya, P. Ghosh, A. Kumar, R. Singh, L. Singh, Biochar for environmental sustainability in the energy -water- agroecosystem nexus. *Renew. Sustain. Energy Rev.* 149 (2021) 111379 https://doi.org/10.1016/j. rser.2021.111379 .