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Evaluation of the Physicochemical Quality of Water from the Nyamukau Stream in the Town of Bunia (Ituri/DRC)

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ABSTRACT

Water is an essential resource for humans, animal and plant species, and an essential solvent for economic activities. To this end, a study was conducted in the Nyamukau stream in the urban area of Bunia in Ituri Province (Democratic Republic of Congo) between February and March 2024. The aim was to assess the water quality of this stream using physicochemical parameters (temperature, pH, dissolved oxygen, turbidity, salinity, and conductivity) collected in situ at various stations, including the source, the environment, and the mouth. The physicochemical characterization of these waters revealed that the temperature was 24.16±0.84 °C, the slightly alkaline pH was 7.29±0.09, the dissolved oxygen content was 8.04±0.60 mg/L, the turbidity was 13.16±0.30 NTU, the salinity was 21.14±1.55 mg/L and the conductivity was 95.38±2.88 µS/cm. The measured temperature, pH and dissolved oxygen values provide an ideal environment for the multiplication of microorganisms. Overall, the recorded physicochemical parameter values reveal that the Nyamukau waters are of poor quality compared to the standards of Rodier *et al*. (2009) and WHO (2000).

I. Introduction

Most of the Earth's surface waters are made up of marine waters, with the remaining 2% comprising inland waters (rivers, lakes, ponds, etc.). These waters are of great importance to human activities in terms of their various uses. Examples include domestic activities (consumption and recreation, agricultural and fishing activities, and industrial activities). Their irreplaceable economic value is justified by the fact that these inland aquatic environments provide a variety of goods and services to humans (Gleick 1993; Côtenza *et al*., 1997). Drinking water is probably the most valuable commodity because it is a scarce and vital resource. Water is also used for agricultural irrigation, energy production, and industry (Gleick, op. cit.).

Many populations live around inland waters because of their activities. Therefore, they have a duty to ensure their management and sustainability. It can be seen that freshwater resources are exhaustible considering the current population explosion. However, human activities are one of the major causes of stress in aquatic ecosystems (Vasquez and Favila 1998; Dokulil *et al*., 2000; Tazi *et al*., 2001).

Rivers are highly diverse and productive ecosystems, contributing to economic growth, food security, and human well-being. According to the World Wide Fund for Nature (WWF), an estimated 2 billion people depend directly on rivers for their drinking water, and 500 million people (about one in 14 people on Earth) live in deltas fed by river sediment. Meanwhile, rivers provide some of the world's most productive fisheries and livelihoods for 60 million people, 55% of whom are women. At least 12 million tons of freshwater fish are caught annually (about 12% of the total global catch), enough to provide protein for at least 160 million people, yet very few decision-makers fully appreciate the value of freshwater fish. This is due to a lack of understanding of the extent to which this supports low-income communities or stimulates economies. (https://www.unep.org/fr/actualites-et-recits/recit/quatre-raisons-de-proteger-nos-fleuves-et-nos-rivieres consulted on 09/04/2023 at 10:06).

However, point and diffuse pollution as well as the modification of its physicochemical characteristics are essentially responsible for the degradation of the "water" resource (Malmqvist and Rundle, 2002). Disturbances caused by humans have a very strong impact on aquatic biodiversity (Sweeney *et al*., 2004). In fact, autoecological processes are mainly responsible for the distribution of organisms colonizing aquatic environments (Vannote *et al*., 1980; Dolédec *et al*., 1999). Induced more or less directly by human activities, changes in communities can also come directly from the introductions and/or disappearance of species (Malmqvist and Rundle op.cit; Bollache *et al*., 2004). Apart from ethical and aesthetic considerations, it is the structure and functioning of the ecosystems themselves that are jeopardized, with the consequence of both quantitative and qualitative degradation of the goods and services provided. Thus, throughout the world, there are many bodies of water irreversibly damaged by pollution and/or eutrophication and those located near large human agglomerations are the most vulnerable (Zohary*et al*., 1996). It is unanimously known that phosphorus plays a major role in the eutrophication process (Lacaze, 1996).

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According to the United Nations Environment Programme (UNEP), about one-third of rivers in Latin America, Africa, and Asia suffer from severe pathogenic pollution, which can cause disease and is attributed to untreated sewage discharge, agricultural pesticide runoff, and industrial pollution; severe organic pollution is found in about one-seventh of all rivers; and severe and moderate salinity pollution in about one-tenth of all rivers. This widespread pollution jeopardizes human health, the freshwater fishing industry (threatening food security and livelihoods), and the use of river and stream water for irrigation, industry, and recreation. This pollution also ends up in the ocean, where it has other harmful effects. (https://wedocs.unep.org/bitstream/handle/20.500.11822/39607/Freshwater_Strategic_Priorities.pdf accessed 04/09/2023 at 10:16).

However, water can become polluted and affect consumers' health. Water resource pollution is characterized by the presence of microorganisms, chemicals, or even industrial waste. It can affect rivers, water tables, brackish water, but also rainwater, dew, snow, and polar ice (https://www.cieau.com/connaitre-leau/la-pollution-de-leau/pollution-ressource-eau accessed 04/09/2023 at 10:22). Water pollution can take various forms, including chemical, but also bacteriological or thermal; the waters or bodies of water concerned can be fresh, brackish, or salty, underground or surface. It can even involve rain or dew, snow, or polar ice. For public health purposes, it is important to have safe and readily available water for drinking, domestic use, food production, and recreation. Improved water supply and sanitation, as well as better water resource management, can promote economic growth and contribute significantly to poverty reduction.

Contaminated water and poor sanitation lead to the transmission of diseases such as cholera, diarrhea, dysentery, hepatitis A, typhoid fever, and polio. Inadequate, absent, or poorly managed water and sanitation services expose those affected to preventable health risks. This is particularly true in healthcare facilities, where patients and staff are at additional risk of infection and disease when water, sanitation, and hygiene services are lacking. Globally, 15% of patients contract an infection during their hospital stay, with this proportion being much higher in low-income countries.

This waterway pollution phenomenon does not spare the DRC's waterways in general, and those in the Bunia region in particular. In view of the above, it is appropriate to conduct a study on the physicochemical and microbiological quality of the waters of the Nyamukau River which will be the subject of this study.

II. Materials and Methods

2.1. Setting

This investigation will take place in the city of Bunia, where the Nyamukau stream is located. Bunia is a city and the capital of Ituri Province in the Democratic Republic of Congo (DRC). It is located in the northeast of the country near Lake Albert, on the border with Uganda. It is subdivided into 24 neighborhoods, organized into three communes.

Its geographic coordinates are as follows:

• latitude: 29°52' E
• longitude: 120°27' N
• average altitude: 1250 m
• Rainfall: 1000 to 1200 mm/year
• Its surface area is: 830 km²

The city of Bunia has a humid tropical climate with two seasons. The rainy season begins in March and ends in September. The dry season, on the other hand, begins in December and lasts until February. Its temperature ranges from 20°C to 33°C.

The city is crossed by three rivers, including the Nyamukau River, which separates the city from part of the north-south side and flows into the Ngezi Stream, which in turn separates the city from the other Mudzipela district located to the northwest and also flows into Shari, the largest, about three kilometers from the city. The city is also equipped with several rivers. (https://www.google.com/maps/place/Bunia accessed on 03/23/2025 at 2:13 PM) (Figure 1).

2.2. Methodology

2.2.1. Materials and Analysis Method

Water samples will be collected from both streams, at the source, midstream, and mouth, in four replicates. Physicochemical parameters were measured in situ in the waters of Nyamukau Stream at the source, midstream, and mouth. These included temperature, conductivity, pH, dissolved oxygen, and turbidity using an EXTECH DO700 multi-parameter meter.

The geographic coordinates of each station are:

- Source :
• latitude: 1°31’54.62’’ N
• longitude: 30°17’39.97’’ E
• altitude: 1342.2 m

-Medium :
• latitude: 1°33’9.55’’ N
• longitude: 30°15’5.55’’ E
• altitude: 1269.9 m

- Mouth:
• latitude: 1°34’39.10’’ N
• longitude: 30°15’1.41’’ E
• altitude: 1231.5 m.

III. Data Processing

The physicochemical parameters measured in the Nyamukau waters at the source, in the middle, and at the mouth will be presented using histograms and subjected to the ANOVA test to detect any differences between days and stations using PAST 4.03 software.

3.1. Physicochemical Parameters

3.1.1. Temperature

The results obtained are such that, with regard to temperature, the Nyamukau waters recorded temperatures ranging from 23.43 to 25.08°C (an average of 24.16±0.84 °C). It ranged from 21.71 to 24.50 °C (an average of 23.43 ± 1.21 °C) at the source. In the middle, the recorded values range between 22.54 and 28.10 °C (an average of 23.49±2.22 °C). The values observed at the mouth are between 23.13 and 25.47 °C (an average of 23.96±1.10 °C). The waters of the mouth display relatively high temperatures compared to the other stations following their exposure to the sun while those of the middle are relatively less raised because of the plant cover of this station (figure 3).

For the entire river and at the different stations, the temperatures recorded are lower but acceptable compared to international standards for surface water, i.e. 25 °C maximum (Rodier *et al*., 2009). It corresponds to the ambient temperature, conducive to the development of aquatic pathogens. The results of this work are in agreement with those obtained by Ibolobolo *et al*. (2024) who found an average temperature of 25 °C (23-29 °C) and the Sawula rivers showed a significant temperature variation due to the absence of plant cover. The waters of the Isalowe stream in the Yangambi Biosphere Reserve showed similar temperatures ranging from 23.95 to 25.95 °C (an average of 24.00 ± 1.15 °C) (Lokele *et al*., 2024). Compared to the results found by Wognin *et al*. (2024) in the waters of the Bandama River (Ivory Coast), the recorded temperatures vary between 27.85 and 32.2 °C. These values are higher than those of this study and water that is too hot can promote the proliferation of bacteria (WHO, 2000). In a temperate climate, temperatures ranging from 10 to 22 °C (an average of 16 °C) were recorded in the waters of the Oued Boubhir watershed (Imarazene, 2024). These results are lower than those of this work due to the difference in climatic conditions.

3.1.2. Hydrogen Potential: pH

Regarding pH, the values obtained reveal that Nyamukau's waters are around neutral and slightly basic, with values ranging from 7.19 to 7.36 (an average of 7.29±0.09). It varies between 7.07 and 7.33 at the source (an average of 7.19±0.12). In the middle, the recorded values range between 7.27 and 7.33 (with an average of 7.31±0.03). At the mouth, it varies from 6.67 to 7.67 (an average of 7.36±0.47) (Figure 4).

The pH of the samples obtained are mostly within the range recommended by the WHO (6.5 < pH < 9.0) (WHO, 2000). The pH values obtained in the entire river and its various stations are within the standards required for the majority of surface waters (7 < pH < 8) (C.I.E., 2005). Higher pH values were recorded in the waters of six rivers surrounding the city of Mbujimayi, including the Bipemba River (7.65 ± 0.35), Kanshi (7.85 ± 0.49), Lubilanji (7.7 ± 0.42), Lukelenge (7.95 ± 0.21), Muya (7.85 ± 0.35) and Nzaba (8.05 ± 0.35) (Tshiminyi *et al*. 2017). On the other hand, the waters of the Isalowe stream are acidic compared to those of Nyamukau (i.e. 5.53±0.37) (Lokele *et al*., 2024). Average pH values similar to those of this study, ranging from 6.38 to 7.34, were recorded in the Bandama stream in Ivory Coast (Wognin *et al*., 2024). Imarazene (2024) found pH values higher than those recorded in Nyamukau ranging from 7.19 to 8.56 (an average of 8.12±0.45). The waters of the Luvushi River displayed lower pH values than those obtained in Nyamukau (i.e. 5.13±0.06) indicating acidic waters in surface and groundwater consumed by the rural population of Matende, Lukamba sector in the Democratic Republic of Congo. The same is true of the Sawula River (4.5±0.16), Saint André (4.02±0.04) and Lubwe (4.19±0.25) in the same region (Ibolobolo et al., 2024). Other studies show similar pH values in rivers of Kongo Central with lower values (Vuni *et al*., 2024).

3.1.3. Dissolved Oxygen

Regarding dissolved oxygen, the values obtained in Nyamukau waters range from 7.98 to 8.04 mg/L (an average of 8.04±0.60 mg/L). At the source, oxygen saturation ranges from 7.38 to 8.23 mg/L (an average of 7.98±0.40 mg/L). At the median level, oxygen saturation values range from 7.79 to 8.17 mg/L (an average of 8.06±0.18 mg/L). The oxygen saturation level recorded at the mouth ranges from 7.46 to 8.36 mg/L (an average of 8.09±0.42 mg/L) (Figure 5).

Exposure to mixing winds explains these differences observed at the station level. The values obtained are within the standards recommended by Rodier*et al*. (2009) (i.e. 9 mg/L) but lower than the WHO standards (2000) (i.e. < 6.5 mg/L). The same is true at the different stations. A lower average content (5.28±0.75 mg/L) than that obtained in the waters of Nyamukau was recorded in the waters of the Isalowe stream in the Yangambi region by Lokele *et al*. (2024). Wognin *et al*. (2024) obtained dissolved oxygen contents lower than those recorded in the waters of Nyamukau (i.e. 1.4 to 7.03 mg/L). Values lower than those obtained in this work ranging from 5.52 to 6.89 mg/L were obtained in the Assif Hallil rivers and its tributaries, Assif Illilthen, Assif Tirourda, Assif Iferhounene, Assif Hallil and Oued Boubhir in Algeria (Imarazene, 2024). In the waters of Oued Mchera (Bouregreg Basin, Morocco) the much lower contents were recorded with concentrations ranging from 3.13 to 3.06 mg/L (Habchaoui, 2024). The waters of the Luvushi, Sawula, Lubwe and Saint André rivers have average contents varying between 3.5 and 3.55 mg/L in the locality of Matende, Lukamba in the DRC (Ibolobolo *et al*., 2024). The observed differences are due to factors such as temperature and turbidity that differ from the locations of the investigations of the above-mentioned cases.

3.1.4. Turbidity

Turbidity values recorded for the entire river range from 12.98 to 13.50 NTU (an average of 13.16±0.30 NTU). At the source stations, turbidity values range from 10.13 to 18.97 NTU (an average of 13.50±3.82 NTU). In the middle, values for this parameter range from 11.30 to 14.53 NTU (an average of 13.00±1.76 NTU). At the mouth, values for this variable range from 10.07 to 18.30 NTU (an average of 12.98±3.71 NTU) (Figure 6).

Turbidity values are very high compared to international standards (< 5 NTU) in the waters of all stations. Water turbidity should not exceed more than 5.0 NTU. Natural turbidity when it is low (< 5 NTU) (WHO, 2000). Nevertheless, Nyamukau waters can be classified as slightly turbid and acceptable for certain uses but may necessarily undergo treatment (5 > NTU > 30). Ibolobolo *et al*. (2024) found turbidity values lower than those observed in Nyamukau waters in the waters of the Luvushi (i.e. 3.89 NTU), Sawula (i.e. 2.93 NTU), Saint André (i.e. 4.6 NTU) and Lubwe (i.e. 3.6 NTU) rivers. These values reveal clear waters (NTU < 5) unlike those of Nyamukau. In the waters of the Thuenge River east of the city of Kinshasa (DRC), turbidity values ranging from 8.09 to 19.98 NTU were recorded, higher than those of the Nyamukau waters (Sifaet al., 2024). This is also the case with the waters of the Assif Hallil and its tributaries (0.42 NTU), Assif Illilthen (0.49 NTU), Assif Tirourda (2.19 NTU), Assif Iferhounene (0.46 NTU), Assif Hallil (0.81 NTU) and Oued Boubhir (1.31 NTU) rivers in Algeria (Imarazene, 2024). The same observation is made in the waters of Aïn I'kbira, Aïn Saadi and Aïn Toub in Wilaya of Mila in Algeria by Bouguenna and Medjoudj (2024) obtained lower values unlike those recorded in the waters of Nyamukau with values varying between 0.22 and 2.23 NTU. In the waters of Willaya Bordj Bou in Algeria, Rayane and Zohra (2024) found values reaching the values of 41.3 NTU and 50.3 NTU (Case of the Ain Zada dam before treatment) far higher than those obtained in the waters of Nyamukau. The differences observed in the results are due to seasons, climatic differences depending on whether they are tropical and temperate regions (case of Algeria and Morocco) and intertropical climatic variations (case of the rivers in Gungu in Kwilu Province and

Tsuenge in Kinshasa in the DRC). Regions and climatic conditions explain the differences in observed results.

3.1.5. Salinity

Regarding salinity, the values obtained throughout the river range from 19.40 to 22.36 mg/L (an average of 21.14 ± 1.55 mg/L). At the stations, the spring waters recorded values ranging from 19.33 to 22.90 mg/L (an average of 21.68 ± 1.61 mg/L). In the middle, values ranging from 21.77 to 22.90 mg/L (an average of 22.36 ± 0.63 mg/L) were obtained. At the mouth, the values recorded ranged from 11.38 to 22.33 mg/L (an average of 19.40 ± 5.15 mg/L) (Figure 7).

Water is said to be fresh when its salinity is less than 1 g/L (or 1000 mg/L). Fresh water is mostly found on continents. It is estimated that only 2.5% of the water found on Earth is fresh and therefore suitable for consumption (https://www.alloprof.qc.ca/fr/eleves/bv/sciences/la-salinite-de-l-eau-s1342 consulted on 03/17/2025 at 5:10 p.m.). It is called brackish when its salinity is between 1 and 10 grams of salt per liter. These waters are found at the transitions between fresh and salt water (at river mouths, in deltas, etc.). The values obtained in this work are within the norms for fresh water. Bouguenna and Medjoudj (2024) found salinity values varying between 0.1 mg/L and 1.2 mg/L in the waters of Wilaya de Mila, far lower than those of Nyamukau waters. Other values far lower than those obtained in Nyamukau waters (0.2 to 0.4 mg/L) were obtained by Rayane and Zohra (2024) in the waters of the Ain Zada dam before treatment). The results differ from each other by the temperature varying from one region to another and having an effect on the solubilization of salts.

3.1.6. Conductivity

Regarding conductivity, the mineralization level values ranged from 93.18 to 98.64 µS/cm (an average of 95.38±2.88 µS/cm). The station results show that at the source, water conductivity values ranged from 90.03 to 107.07 µS/cm (an average of 98.64±7.00 µS/cm). In the middle waters, conductivity values ranging from 91.27 to 98.43 µS/cm (an average of 93.18±3.51 µS/cm) were recorded. The conductivity values of the waters at the mouth range between 90.30 and 99.80 µS/cm (an average of 94.33±3.97 µS/cm) (figure 8).

These results reflect a very low mineralization according to Rodier *et al*. (2009) because it is between 0 and 100 µS/cm while the WHO (2000) recommends conductivity values < 2100 µS/cm. The waters of Nyamukau meet the requirements of two standards. The conductivity results of the waters of Nyamukau are included in those obtained by Sifa *et al*. (2024) (i.e. 83.15-194.5 µS/cm) in the Thuenge River to the east of Kinshasa. Very high and higher values (i.e. 409 to 1397 µS/cm) were recorded in some rivers of the Oued Boubhir sub-catchment (Imarazene, 2024). In the waters of the Oued Mchera (Bouegreg Basin in Morocco) Habchaoui et al. (2024) found values ranging from 923 to 8300 µS/cm, far higher than the conductivity values of Nyamukau waters. However, far lower values were obtained in the waters of the Luvushi (8.14 µS/cm), Sawula (5.33 µS/cm), Saint André (10.07 µS/cm) and Lubwe (7.59 µS/cm) rivers (Ibolobolo *et al*., 2024). Lokele *et al*. (2024) recorded much lower values in the waters of Isalowe Stream in the Yangambi Biosphere Reserve (i.e. 5.53±0.37 µS/cm). The differences in the results obtained in the above-mentioned research with those of Nyamukau waters are explained by the temperature which varies from one region to another depending on the season. In fact, temperature is a physical parameter with a great influence on the mineralization of organic matter and, consequently, on the electrical conductivity of surface waters. Considering the classification of Rojsek (2002), it can be deduced that the waters of Nyamukau are of “excellent quality”.

It should be noted that the Analysis of Variance (ANOVA) test carried out to reveal the difference between the stations and the sampling days did not show any significant difference for the physicochemical parameters such as temperature, pH, turbidity, dissolved oxygen and conductivity between these two variables. However, a significant difference was observed between these two variables regarding salinity between the third and fourth days ($p < 0.05$).

IV. Conclusion

This study focused on determining the water quality of the Nyamukau stream in the town of Bunia, Ituri Province, Democratic Republic of Congo. The measured physicochemical parameters revealed that the water in this stream is not of good quality, deviating from the standards of Rodier *et al*. (2009) and WHO (2000).

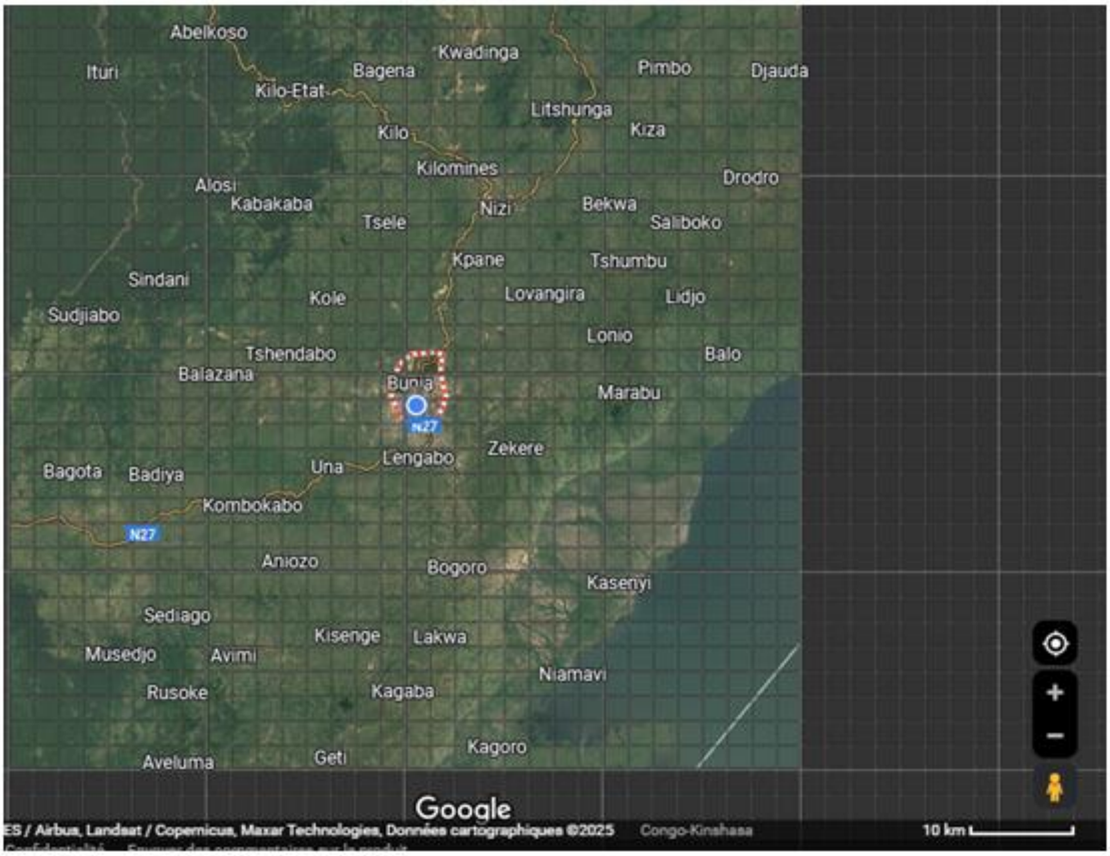

Fig. 1. Map of the city of Bunia (source: https://www.google.com/maps/place/Bunia consulted on 03/23/2025 at 2:13 p.m.).

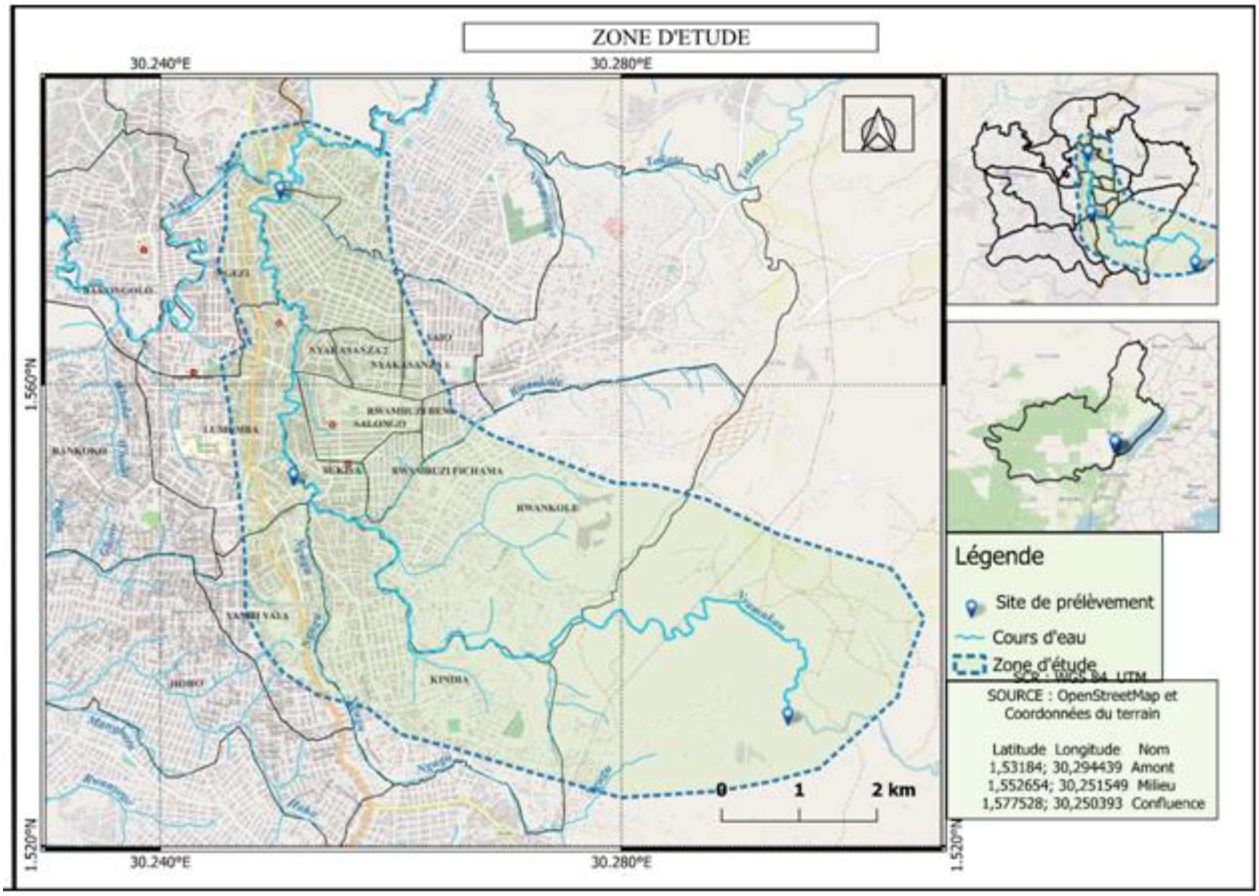

Fig. 2. Map of Nyamukau Stream sampling stations.

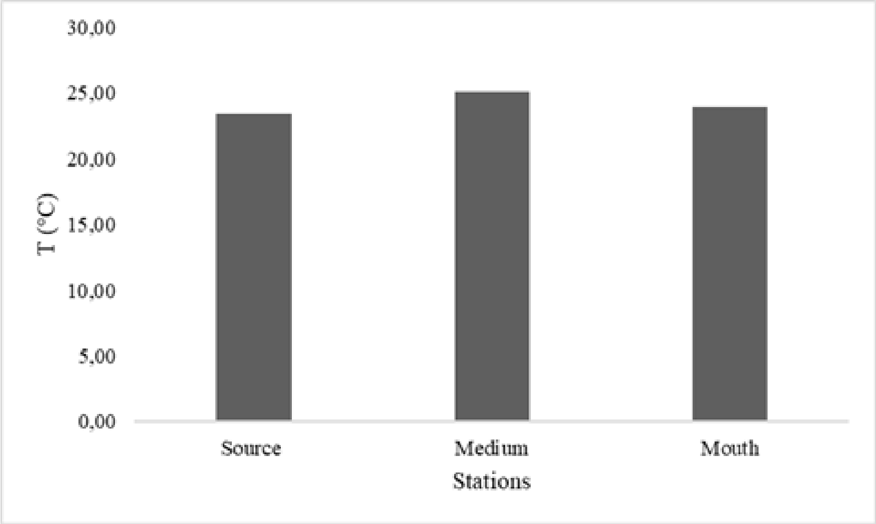

Fig. 3. Nyamukau water temperatures at stations

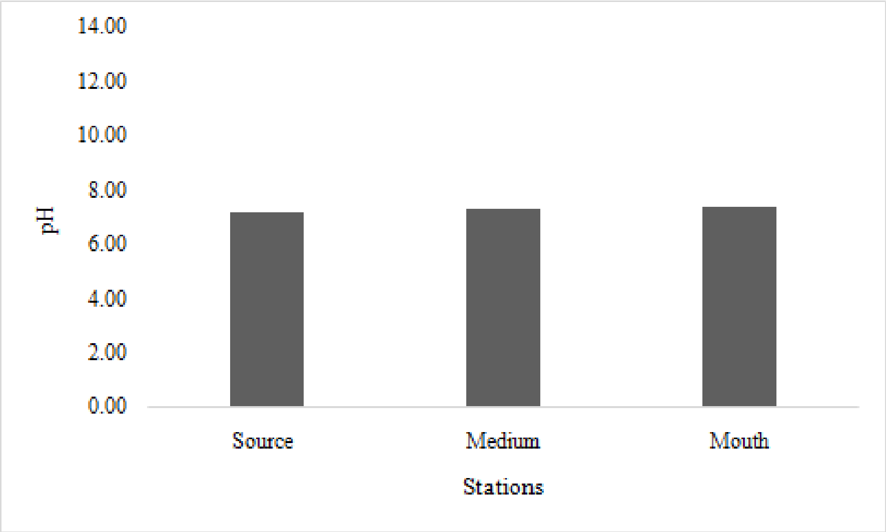

Fig. 4. Nyamukau water pH at stations

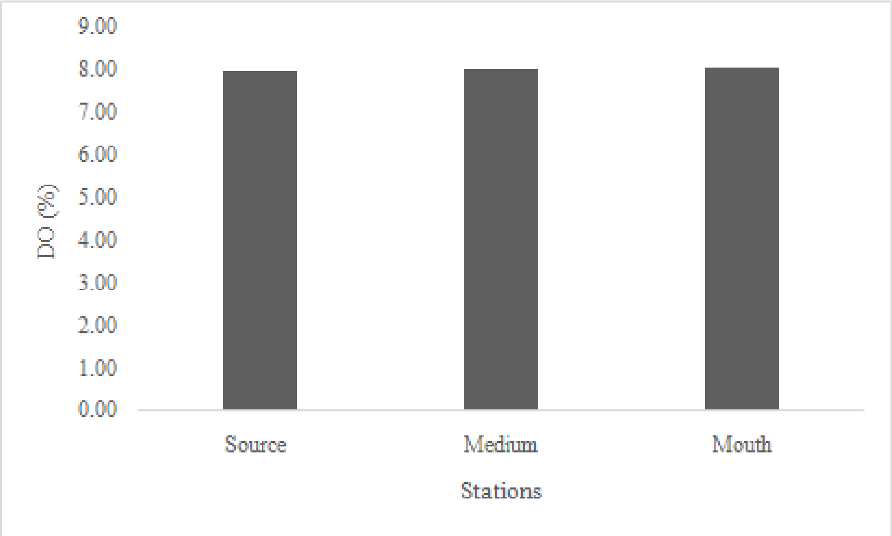

Fig. 5. Nyamukau water dissolved oxygen at stations

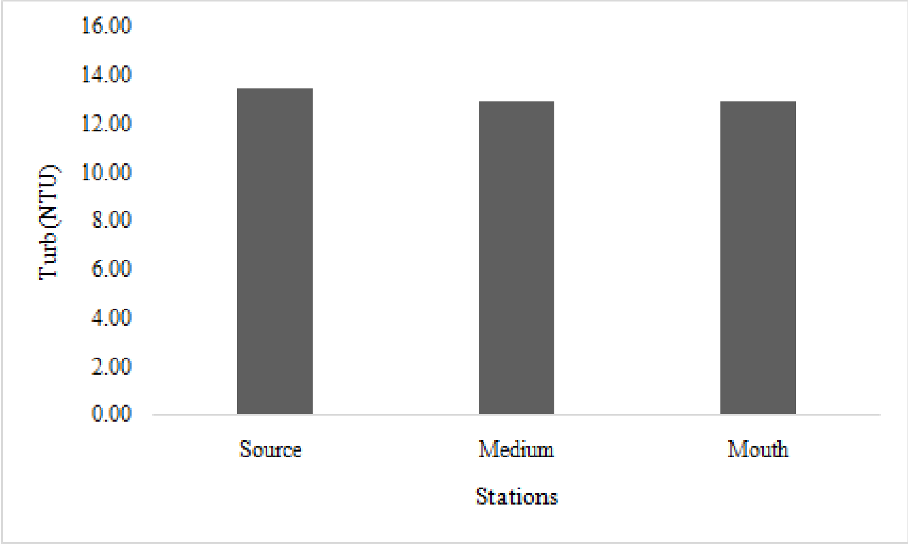

Fig. 6. Nyamukau water turbidity at stations

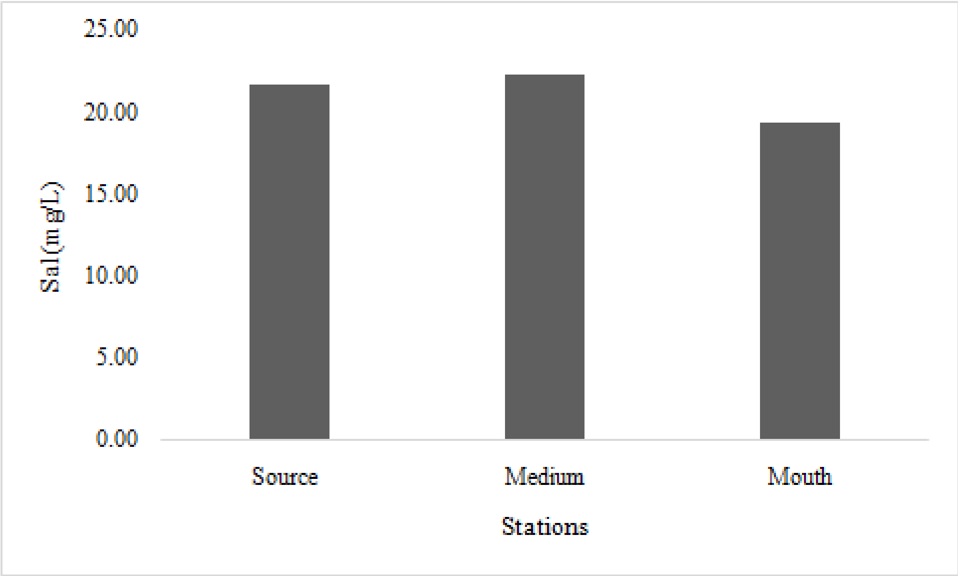

Fig. 7. Nyamukau water salinity at stations

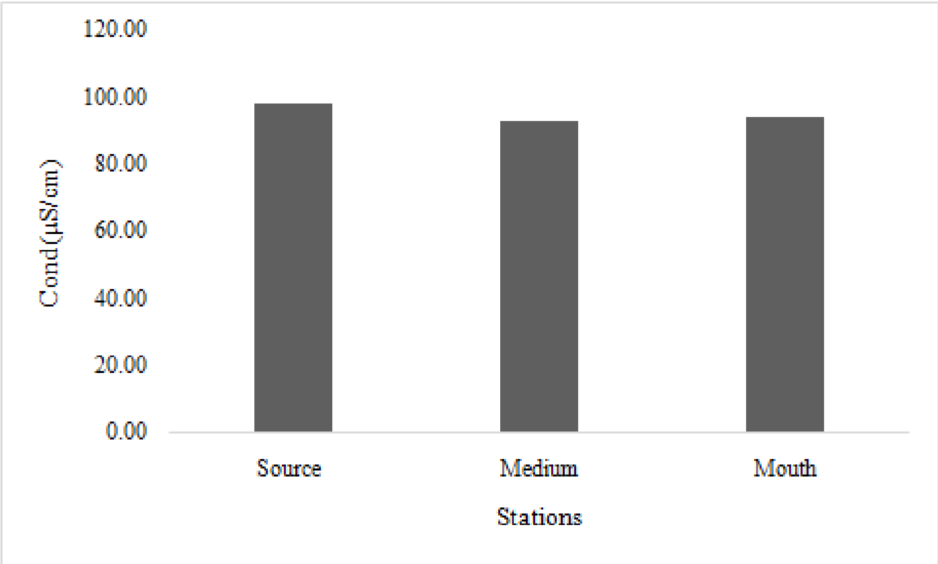

Fig. 8. Nyamukau water conductivity at stations

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