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Assessment of interactions between raw water from the N'Djili river, groundwater and water treated by the Water Distribution Administration in Kinshasa, Democratic Republic of Congo

Innocent MUFUNGIZI[1-2-3-4], Ruben LOOLA[1-3], Jean KABULO[1-3], Ridi DIAKONDUA[1-3], Hubert KAWAYA[1-3], Roda BONGELI[1-3], Jonathan MUSITU[1], Koy KASONGO[1-2], and Aymar AKILIMALI[4-5]

[1]Faculty of Sciences and Technologies, University of Kinshasa, Kinshasa, B.P. 190 Kinshasa XI, RD Congo

[2]Pedo-Geochemistry Laboratory, University of Kinshasa, Kinshasa, B.P. 190 Kinshasa XI, RD Congo

[3]LeGeolog Research Team, Kinshasa, RD Congo

[4]The marine Biological Association (MBA), Plymouth, United Kingdom

[5]Department of research, Medical Research Circle (MedReC), Goma, RD Congo

ABSTRACT: *Background*: Water has an important place in the life of human beings. Regardless of the uses of water, water intended for human consumption must be clean. Despite the fact that the catchments of this water are chemically and microbiologically polluted. The objective of this study is to evaluate the interactions between types of water including that intended for human consumption in the city of Kinshasa.
Methods: Our analytical and experimental study based on laboratory analysis which was carried out over a period of approximately one month (the month of September 2023) while respecting a certain number of steps. This involves geo-environmental investigation, geographic location, collection and analysis of samples as well as interpretation of the results.
Results: After our chemical analyses, we found that the pH of the water is very acidic, the turbidity of the water analyzed is normal, the conductivity is below normal as well as the permanganate index, nitrites and chlorides. Phosphate and nitrates exceed the normal value. Bacteriological analyzes show the development of colonies with the presence of total and fecal coliforms and Escherichia Coli.
Conclusion: The results of the analyzes showed that the water is contaminated and polluted chemically and biologically by chemicals (through the abusive use of chemical fertilizers and pesticides which release nitrogen, phosphorus and chlorine) coming from the activities agricultural and livestock farming.

KEYWORDS: Contamination, Hydrochemistry, REGIDESO, PCA, WIHC.

1 INTRODUCTION

For a long time, water has been of capital importance in the life of human beings [1]. Water serves both as a food, a possibly medicine but also an industrial, energy (to produce electricity) and agricultural raw material, and also a means of transport [2]. Water intended for human consumption is drinking water or water intended for personal hygiene while drinking water is water intended to be ingested by humans [3].

The city of Kinshasa is a large city and the capital of the Democratic Republic of Congo (DR Congo), this city is crossed by the Congo River, one of the great rivers of Africa [4]. The water which is intended for use and consumption by the population of the city of Kinshasa is captured in the part of the watersheds of the rivers as well as from the portion of the Congo River by the water distribution administration (REGIDESO) of the city of Kinshasa [5]. The water of the N'Djili river is polluted during the rainy season by certain anthropogenic activities which take place in the area around the catchment, this water is chemically polluted by sodium, sulfate, chloride and many other chemical elements but also by certain metallic trace elements such as cadmium, lead and arsenic and also microbiologically polluted. This pollution causes a lot of work during the treatment of water by REGIDESO [6].

Groundwater is a source of drinking water in many countries around the world, it is the most abundant source of fresh water available and most of the raw materials extracted on the planet [7,8,9]. Groundwater feeds water sources; this water can contaminate and alter the ecological function of freshwater habitat, which has negative consequences on the ecology of human species [10].

Water which is intended for human consumption must be drinkable therefore must respect biological and chemical conditions and must meet certain requirements such as the hydrogen potential (pH) must be between 6.5-8.5, nitrites <0.2 mg/ l, nitrates <50mg/l, sodium <200mg/l, fluoride <1500µg/l, chloride <250mg/l [11].

This study focuses on the evaluation of interactions between the water of the N'Djili River, groundwater and water treated by REGIDESO. As a result, this study will take into account the impact of anthropogenic activities on water resources in general and on so-called "drinkable" treated water in particular. This study compares the qualitative point of view of the three types of water in order to effectively mitigate the risk of water contamination in the environment and to inform the population about water quality.

2 Methods

This study has a methodology which was carried out by the following steps:

Step-1: Research questions

The first step of the methodology was to ask research questions while specifying them in the literature review.

Step-2: Geo-environmental investigation

Here, the aim is to identify possible sources of contamination and to assess the state of the environment during a period of 3 days, i.e., a period ranging from September 5 to 8, 2023.

Step-3: Geographic location

All the sampling points were identified while plotting them on a topographical background during the period from September 11 to 14, 2023. We used as equipment for this phase: A Garmin 60 brand Global Positioning System, a high-quality camera Canon brand and an Android version Smartphone.

Step-4: Collecting all samples

We carried out a sampling campaign to collect the samples which we sent to the laboratory for analyzes during the date of September 16, 2023.

The choice of water sampling points was made as follows:

- For raw water from the N'Djili River, three samples were taken. The first was taken upstream of the REGIDESO catchment on the N'Djili river, in the municipality of Matete, the second at the catchment in the municipality of Limete and the third downstream of the catchment in the municipality of Masina;
- For groundwater, two springs and a borehole were sampled respectively in the municipalities of Masina and N'Djili;
- For water treated by REGIDESO, three samples were taken in the municipalities of Matete, Limete and Masina.

To access the sampling points, we crossed the N'Djili river by canoe. 1 liter plastic bottles were used for sampling water intended for physicochemical analyzes and glass bottles for water intended for bacteriological analyzes while using markers to label said samples. The water intended for bacteriological analyzes was collected in sterile glass bottles as mentioned above, and in an aseptic manner. For storage and transport, equipment containing a cooling system was used to limit the interactions of the samples with the ambient air. Fig. 1 shows the sampling map where all the sampling points are represented.

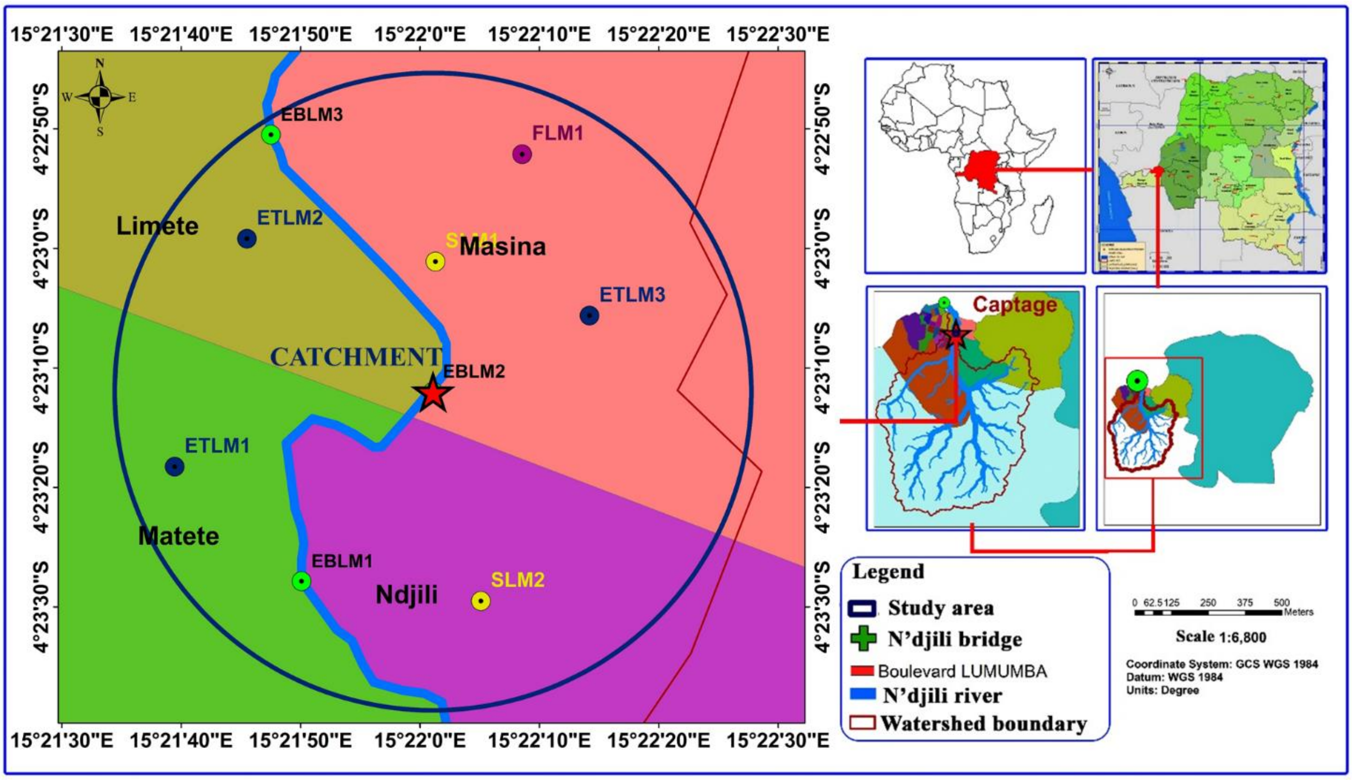

Fig. 1. Map representing the points where sampling was carried out. EBLM1, 2 and 3 represent the river water samples; ETLM1, 2 and 3 represent the water samples treated by the Water Distribution Authority; FLM and SLM1,2 represent groundwater samples

STEP-5: LABORATORY ANALYZES

The collected samples were analyzed in the central REGIDESO laboratories in Kinshasa (from September 16, 2023). For the physical and chemical part, we analyzed the following parameters: Hydrogen potential (pH), Temperature, Turbidity, Conductivity, Hardness, Color, Permanganate Index (Oxidizable Matter), Rate Dissolved Solids, Phosphates, Nitrites, Silica, Iron, Chlorides, and Nitrates. For bacteriological parameters, we analyzed total coliforms, fecal coliforms and Escherichia coli. For these analyses, we used the operating mode of the REGIDESO central laboratory specified in the documents of the Water and Laboratory Quality Department based on ISO standards. We had access to the following equipment: The water bath, the hot plate, the distiller, the magnetic stirrer, the desiccator, the refrigerator, The spectrophotometer, the pH meter, the conductivity meter, the turbidimeter, the wash bottles, the ramp of filtration, the gas bottle, the incubator, the colony count, the oven and the petri dishes containing the culture media.

STEP-6: DATA PROCESSING, ANALYSIS AND INTERPRETATION

For the processing or statistical analysis of the data, we used Excel 2021 with the XL STAT software component for the correlation circle of the physicochemical parameters analyzed, the observation of individual-individual and individual-variable links (Biplot) and R Studio Software version 3.5.3 for the matrix of correlation coefficients between the physicochemical parameters of the water analyzed.

3 RESULTS AND DISCUSSION

Concerning the laboratory analyzes carried out in this study, we have presented the results of the physical and chemical analyzes in table 1.

Table 1. Results of all physical and chemical parameters analyze

PARAMETERS	EB1	EB2	EB3	ET1	ET2	ET3	F	S1	S2
Ph	6.78	6.82	6.8	6.55	6,77	6,87	4.18	5.56	4.31
Turbidity (NTU)	31.2	27.3	30.2	3.7	3.5	5.6	15.3	2.8	1.2
Conductivitéy (µS/cm)	45.98	42.62	51.87	52.95	57.91	51.52	591.67	941.29	874.42
Total dissolved solids (mg/L)	24.5	22.4	26.7	27.5	30.1	26.6	306	475	447
Temperature (°C)	27.5	27.5	26.3	26.5	26.6	26.4	26.6	26.4	26.1
Color (UPt /Co)	78.5	68.5	75.5	2	4	10	26	3.5	0.5
Organic material (mg/L)	11.6	7.2	12.4	0.8	0.6	1.4	4.4	1.6	1.2
Hardness (THt)	3.8	3.8	3.2	2.2	1.8	3.6	8.4	19	9
Phosphate (mg/L)	0.038	0.064	0.094	0.031	0.054	0.045	0.077	0.025	0.035
Chloride (mg/L)	45.44	22.72	31.24	26.98	32.66	34.08	46.86	92.3	82.36
Nitrites (mg/L)	0.027	0.033	0.026	0.019	0.032	0.013	0.032	0.068	0.017
Iron (mg/L)	1.13	1.31	1.46	0.27	0.2	0.24	0.61	0.07	0.1
Silice (mg/L)	-	-	-	-	-	-	0.199	0.625	-
Nitrate (mg/L)	6.4	6.8	7.2	12.9	9	5.5	**298**	**426**	**228.6**

We have the following results: the pH of the water analyzed fluctuates between 4.18 and 6.87. It is very acidic for spring and borehole water which displays results at the lower limit according to the standard which is 6.5, but for treated water intended for consumption and human use must respect the international standard which is between 6.5 and 9.5 according to the requirements of the European Union [12]. The turbidity of the water after the analysis is between 1.2 and 31.2 (fig. 2a). The standard set by the World Health Organization is 1 Nephelometric Turbidity Unit (NTU), so not all samples analyzed meets the World Health Organization turbidity standard. As the turbidity of the water in the region is high, REGIDESO tolerates turbidity which varies up to 5 NTU. The transition from 31.2 NTU for raw water to 3.5 NTU for treated water occurs during the treatment of water intended for human consumption [13,6].

The conductivity values vary between 42.62 micro siemens/centimeter (µS/cm) for the raw water of the N'Djili River and 941.26 µS/cm for source number 2. The standard of the World Organization of Health being 1200 µS/cm for water intended for human consumption, all the waters analyzed have conductivity values lower than that of the required standard and certain authors [14,6] have found conductivity values ranging respectively from 68 to 1143 µS/cm for groundwater and an average of 21.48 µS/cm for the water of the N'Djili river.

Thus, for the results of the analyzes on the levels of dissolved solids, the results vary between 22.4 milligrams per liter (mg/L) (for the water of the N'Djili river) and 447 mg/L (for the water from source number 2). While the guide or reference value according to the World Health Organization is 600 mg/L, which implies that the water analyzed has Total Dissolved Solids (TDS) values lower than the limit set by the recommended standard. The authors *Chouafa et al*. found an average value for the level of dissolved solids of 429 mg/L in the water analyzed in their study published in 2012 [15].

The temperature values vary between 23.5 and 27.5° Celsius (°C) respectively in the waters of the N'Djili river and that of source number 2. The guide value of the water temperature intended for human use according to the World Health Organization being 25°C temperature, but given that the study area is located in a tropical climate, this temperature is permitted as long as it is below 30°C. Other works published respectively in 2018 and 2020 present temperature values with an average of 20.24 and 22.49 °C [16,17].

The measured color values of the analyzed water types vary between 0.5 and 78.5 Units of the true color using cobalt II chlorides as standard solution (UPt /Co) (fig. 2b). The raw waters of the N'Djili River have the highest values well beyond the guideline value but the lowest value is that of the water from the second source. Treated water, spring water and borehole water have values lower than the standard which is 15 UPt /Co [11].

The results of the analysis of the permanganate index show values which vary between 0.4 and 12.4 mg/L while the lowest values are those of the first two samples of treated water while the highest are those of the raw waters of the N'Djili river. The results of water analyzed from the N'Djili River prove contamination in oxidizable organic and inorganic materials, the level of oxidizable materials is respectively 11.6, 7.2, and 12.4 mg/L while the threshold is 2 milligrams of carbon dioxide. Oxygen per liter (mgO_2/L). Some literature shows dissolved oxygen values varying between 3.97 and 4.98 mg/L in groundwater [18,19], and the author *Bwira* in *2017* found the value average of oxidizable materials in water samples from the N'Djili River of 14.45 mg/L [6].

The hardness values of the treated water vary between 1.8 and 19 Hydrotimetric Title (THt). The groundwater has high values (respectively 8.4; 19 and 9 THt) and the lowest value is that of the water treated at source number 3. The hardness of the water analyzed is lower than the guide value or the value of reference which is 100 THt. *Nzomba* in *2023* showed in the results of his study an average hardness value of 12.4 for groundwater [14].

The phosphate values in the water analyzed do not exceed the standard which is 2 mg/L. The highest value is 0.094 mg/L (for river water) and the lowest is 0.025 mg/L (for spring water). The authors (*Emillie et al.*), in their study published in 2008, found phosphate values of 1.2 mg/L, which is pollution of cultivated land by wastewater [20].

The results of the water analysis show that the chloride values are between 22.72 and 92.3 mg/l. In comparison with the reference value which is 250 mg/L, we see that the water analyzed presents values lower than the standard. The concentrations of chlorides and phosphates in the water analyzed can be explained by the use of insecticides in agricultural areas, even if they do not exceed the reference values proposed by the *World Health Organization in 2016* [21].

In the waters analyzed, the nitrite values vary between 0.013 and 0.068 mg/L respectively for the first sample of water from the river and the first sample of water from the source. The World Health Organization and other literature show that the reference value is 0.2 mg/L, which indicates that the values of the waters analyzed in our study are lower than the reference standard [11].

The iron values in the water analyzed vary between 0.07 and 1.46 mg/L (fig. 2c) respectively for the first sample of spring water and the third sample of water from the N'Djili River. We note that the raw waters of the N'Djili River, the waters treated by REGIDESO and the drilling waters present values greater than or equal to those of the World Health Organization standard as well as for other authors (literature). Only spring waters show values lower than the reference value. The values measured for nitrates in the water analyzed vary between 5.5 and 426 mg/L (fig. 2d). Boreholes and springs have the highest values (borehole: 298 mg/L, first spring water sample: 426 mg/L and second spring water sample: 228.6 mg/L) well exceeding the guide value which is 50 mg/L and the lowest value is that of the third sample of treated water, i.e., 5.5 mg/L. Some literature shows nitrate values respectively of 35 mg/L for the average in groundwater, 80.09 and 97.58 mg/L for the maximums in the dry and rainy seasons [22,23].

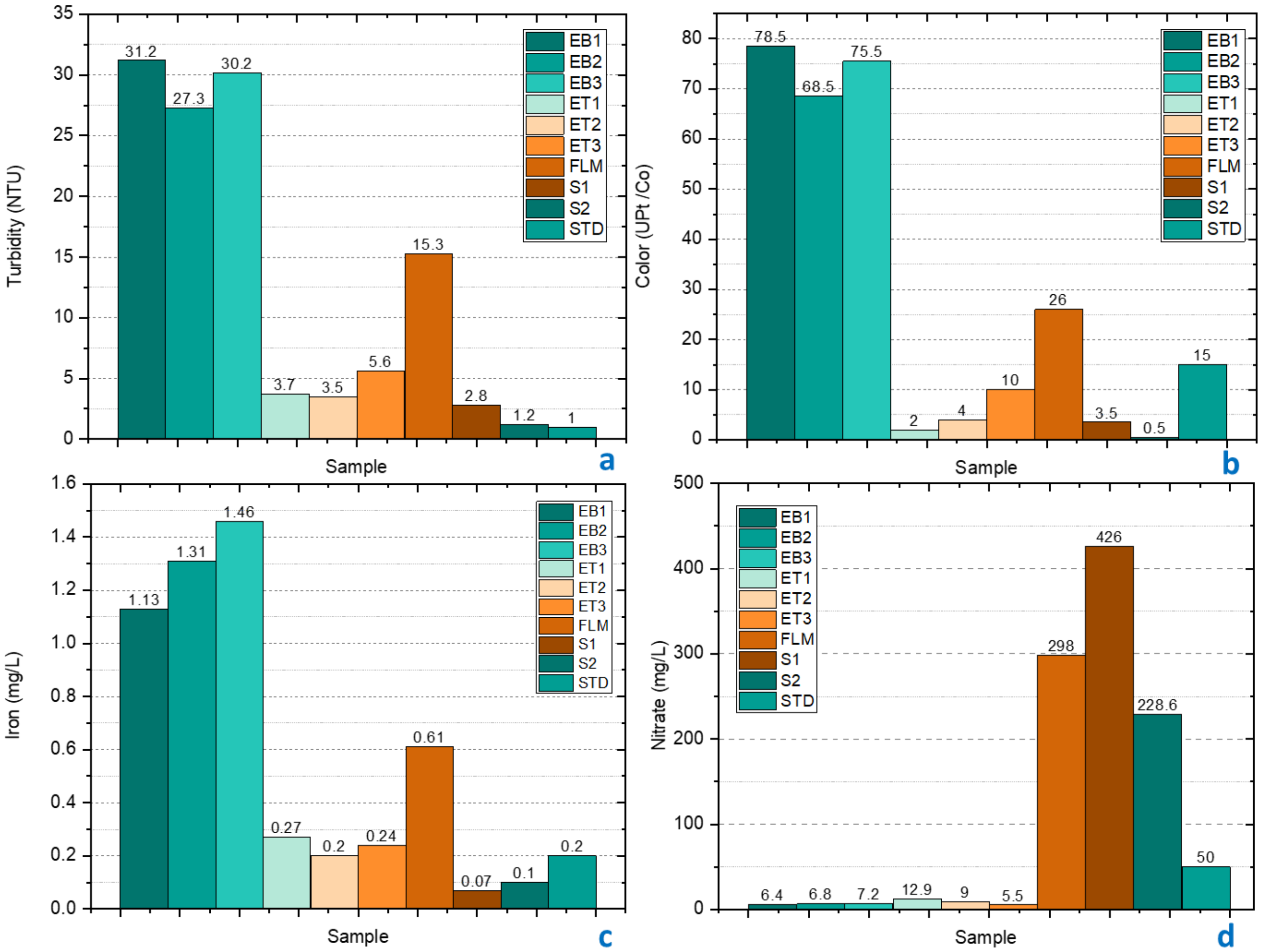

Fig. 2. Variation of element values in the analyzed samples. (a) Turbidity, (b) Color, (c) Iron and (d) Nitrate. STD symbolizes the value guiding the WHO and the European Union

Fig. 3 presents the results concerning the bacteriological analyses, the samples were incubated for 24 hours and we note colonies which developed in the Petri dishes proving the presence of total and fecal coliforms in the raw water taken from the N' river. Djili and in the second spring water sample.

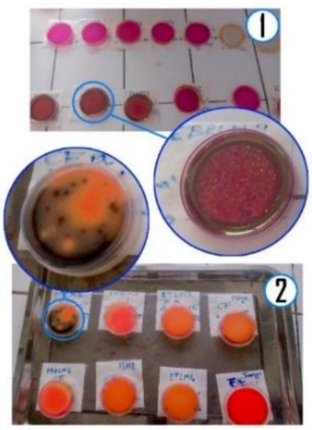

Fig. 3. Samples showing the petri dishes after incubation. We observe the development of colonies. (1): Total coliforms; (2): Fecal coliforms

Table 2 presents the results of the bacteriological analyzes and the results show that there is pollution of the raw waters of the N'Djili river and that of the source. Total and fecal coliforms are indeterminate in the raw waters of the N'Djili River and Escherichia Coli analyzes revealed the presence of the latter. In the water sample from the source, 56 colonies of total coliforms were counted and one colony of fecal coliforms. Following these results, it should be noted that these coliforms come from water contaminated by the feces of warm-blooded animals. In the study area, during the investigations, we realized that these contaminants are generally produced directly by humans and indirectly by livestock activities (beef, pork, poultry, etc.) carried out in the environment. The presence of Escherichia coli constitutes indisputable proof of recent fecal contamination. This micro-organism should be completely absent from drinking water.

Table 2. Results of bacteriological analyzes

Samples	TC	FC	*Escherichia coli*
EBRLM1	Ind	Ind	P
EBRLM2	Ind	Ind	P
EBRLM3	Ind	Ind	P
ETLM1	0	0	A
ETLM2	0	0	A
ETLM3	0	0	A
FLM1	0	0	A
SLM1	0	0	A
SLM2	56	1	A

(TC: represents total coliforms, FC: fecal coliforms, Ind: indeterminate; the number of coliform colonies is so high that it becomes difficult to count them, A: absence of Escherichia coli and P: presence of Escherichia coli).

To analyze the correlation between the measured physical and chemical parameters, the results shown in **Fig. 4,** we used principal component analysis, which is one of the most frequently used multivariate data analysis methods. Since some parameters show the same pattern (conductivity and total dissolved solids), we will forgo the Bartlett spherical test and the Kaiser-Meyer-Olkin sampling precision measure.

	pH	Turb.	Cond.	T.D.S.	Temp.	Color	O.M.	Hardness	Phosphates	Chloride	Nitrites	Iron	Nitrates
pH	1.000												
Turb.	0.358	1.000											
Cond.	-0.851	-0.474	1.000										
T.D.S.	-0.857	-0.472	1.000	1.000									
Temp.	0.041	0.529	0.005	0.005	1.000								
Color	0.401	0.994	-0.476	-0.475	0.547	1.000							
O.M.	0.318	0.966	-0.384	-0.384	0.475	0.969	1.000						
Hardness	-0.584	-0.339	0.893	0.889	0.103	-0.333	-0.260	1.000					
Phosphates	0.058	0.595	-0.327	-0.322	0.300	0.554	0.563	-0.364	1.000				
Chloride	-0.662	-0.436	0.932	0.929	0.074	-0.410	-0.298	0.890	-0.500	1.000			
Nitrites	-0.144	-0.061	0.501	0.494	0.245	-0.056	-0.044	0.777	-0.167	0.523	1.000		
Iron	0.394	0.978	-0.517	-0.515	0.445	0.975	0.936	-0.401	0.676	-0.513	-0.106	1.000	
Nitrates	-0.796	-0.402	0.949	0.948	0.031	-0.424	-0.338	0.942	-0.246	0.854	0.665	-0.460	1.000

Fig. 4. Correlation or covariance matrix. The color range varies from red to blue. The color range going to red represents negative values while that going to blue represents positive values.

Thus, the analysis of the results shows that the correlation/covariance matrix corresponds to the data used for the calculations. This shows that nitrates have a strong correlation with nitrites, hardness, dissolved solids and conductivity while pH, turbidity, temperature, color, oxidizable, phosphates and iron have correlations.

The PCA correlation circle (Fig. 5a) presents the interpretation based on the angles separating either the variables from each other, or the variables with the dimensions of the PCA. Acute angles reflect a positive relationship between variables, right angles separate unrelated variables, and obtuse angles represent negative relationships. Thus, pH, temperature, oxidizable materials, color, iron, phosphates and turbidity are not linked to nitrates, nitrites, chlorides, hardness, conductivity and the rate of dissolved materials.

Following a Principal Component Analysis, it is possible to represent both observations and variables simultaneously in the factor space. The term biplot is reserved for simultaneous representations which respect the fact that the projection of observations onto the variable vectors must be representative of the input data for these same variables. In other words, the points projected onto the variable vector must respect the order and relative distances of the starting data corresponding to the same variable.

Fig. 5b presents the observations and makes it possible to evaluate the links between individuals and the links between individuals and variables.

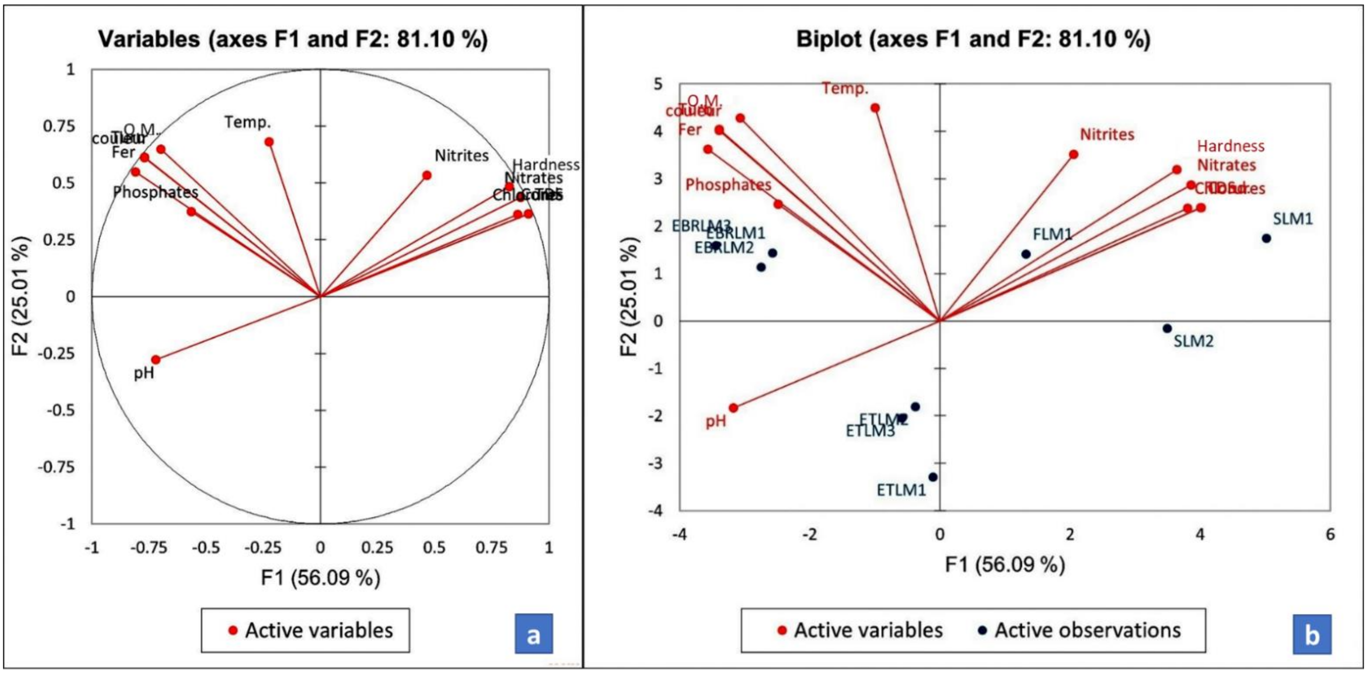

Fig. 5. ***Correlation circle of the physical and chemical parameters analyzed (a), Observation of individual-individual and individual-variable links (Biplot) (b).***

Indeed, during the treatment of water, after injection of aluminum sulfate and filtration on the filter mass (quartz for the case of the N'Djili wastewater treatment plant), it is carried out during the disinfection phase. water an injection of calcium hypochlorite with the chemical formula Ca (ClO) 2 which eliminates pathogenic organisms present in the water. During preparation in water, this intake releases Cl2 which has a bactericidal effect (capacity to destroy germs at a given stage of treatment) and a residual effect (effect of the disinfectant which remains in the water, particularly in the distribution network, and which makes it possible to guarantee the bacteriological quality of the water up to the farthest consumer's tap, we speak of residual chlorine). The diagram presenting the interactions between river water, water treated by the Water Distribution Authority and groundwater is shown in Fig. 6.

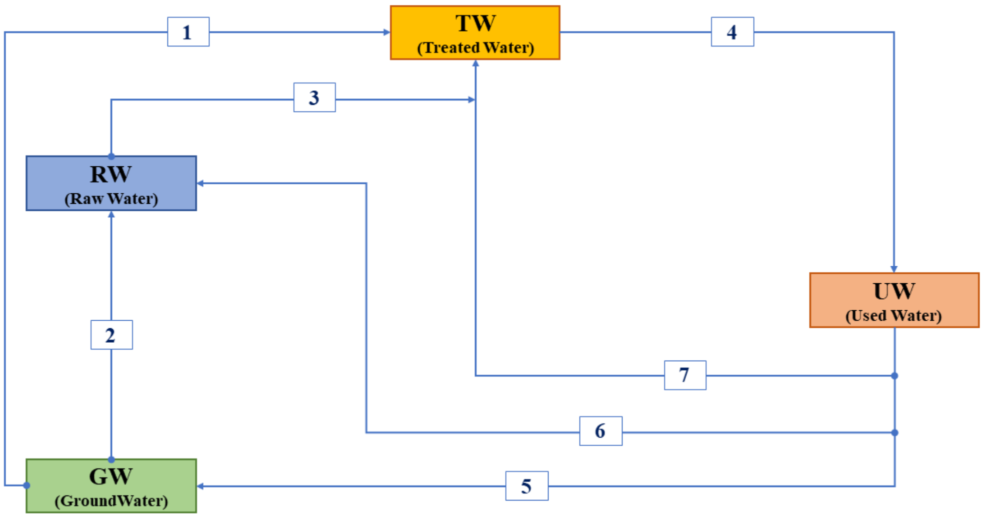

Fig. 6. Interaction diagram between different water qualities: Groundwater loaded with elements such as nitrates contaminates treated water through leaks in water distribution pipes intended for human consumption (1), groundwater flows and feeds the river at resurgence points (2), the raw water from the river is captured for treatment (3), the treated water is used by households and factories where it becomes loaded with certain elements and becomes wastewater (4), this uncanalized wastewater runs off and infiltrates into the ground contaminating the groundwater (5), the canalized and uncanalized wastewater is discharged into the river bringing in the elements which further contaminate it (6), the wastewater household and industrial contaminate treated water through leaks in distribution pipes (7).

4 Conclusion

This study focuses on the evaluation of interactions between raw water from the N'Djili River, groundwater and water treated by REGIDESO in Kinshasa. We know that groundwater contamination is caused by nitrogen, phosphorus and chlorine. Groundwater has very high nitrate levels, groundwater receives nitrate, phosphate and chlorides from agricultural areas where chemical inputs are used to increase agricultural productivity, and from domestic and industrial wastewater. The results of the bacteriological analyzes prove contamination and pollution of water by fecal matter confirmed by the presence of Escherichia Coli. REGIDESO must have an active team of plumbers for the repair of water distribution pipes whenever leaks are observed in areas where groundwater flows to the surface and thus make a water safety plan intended for human consumption.

Declarations

Ethics approval

This study protocol was approved by the ethics committee of the Medical Research Circle research department. An official letter of cooperation was written to the management of the Kinshasa Water Distribution Administration.

Consent for publication

Not applicable.

Availability of data and materials

Not applicable.

Competing interests

The authors declare that there is no conflict of interest.

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AUTHOR CONTRIBUTIONS

Conception: Innocent MUFUNGIZI, ***Design:*** Aymar AKILIMALI, ***Project administration;*** Innocent MUFUNGIZI, ***Supervisor:*** Ruben LOOLA, ***Funding acquisition;*** Aymar AKILIMALI, ***Investigation;*** Innocent MUFUNGIZI and Ruben LOOLA, ***Resources;*** Innocent MUFUNGIZI and Ruben LOOLA, ***Validation;*** Koy KASONGO and Aymar AKILIMALI, ***Visualization;*** Innocent MUFUNGIZI, ***Literature search:*** All authors, ***Collection and assembly of data:*** Innocent MUFUNGIZI, ***Data analysis and interpretation:*** Innocent MUFUNGIZI, Ruben LOOLA and Aymar AKILIMALI, ***Software;*** Innocent MUFUNGIZI, ***Manuscript preparation:*** All authors, ***Manuscript editing:*** All authors, ***Manuscript review:*** All authors, ***Final approval of manuscript***: All Authors.

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