International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-7, Issue-8, August 2021
ISSN: 2395-3470
www.ijseas.com

Water Quality Index of the REGIDESO Networks in Butembo city, Democratic Republic of the Congo.

Phalek Kasereka Katswangene[1*], Réné Woto Oleko[2], Zoé-Arthur Malumba Kazadi[2]

[1]Faculty of Agriculture, Adventist University of Lukanga, Butembo, Democratic Republic of the Congo
[2]Department of Biotechnology, Faculty of Sciences, University of Kisangani, Kisangani, Democratic Republic of the Congo
Email: *kphalek@gmail.com, *Telephone: +243 998384613*

Abstract

This study consists in determining of the water quality index (WQI) taken from two REGIDESO water supply networks in the city of Butembo (DR Congo) according to the CCME (1). Doing so, a sample of water was collected monthly from each of the eight sites of withdrawal pinpointed on these networks. Microbiological and physicochemical analysis yielded data on 26 parameters of water quality. During six months of study, there was no collection site providing treated water that always complied with the WHO microbiological guidelines. The physicochemical parameters that have presented a general average higher than the maximum admissible values are: Iron (0.529>0.3 mg/L), Nitrate (56.1146>50 mg/L), pH (6.0708<6.5 - 8.5), and turbidity (7.6542>5 NTU). Thus, the microbial load, the water temperature (21.2917>20°C), the high turbidity and the considerable Nitrate concentration were observed as the main problems of the analysed water. Finally, the categorisation of sampling sites was carried out using the CCME water quality index (WQI) with reference to the WHO guidelines. After calculation, the results indicate that the treated water at the outlet of Makamba network and that of Kanyangoko were of *good* quality (respectively with WQI: 67.64 and 81.66). However, after combining the water from these networks, the WQI had fallen into the category of *mediocre* quality (i.e. WQI: 62.16) just after mixing their water, before returning to its *good* quality (*i.e.* WQI: 74.65 around the middle of the network then at 70.09 towards its end). Finally, mean significant differences have been observed between the WQI and the nature of the samples of water, the type of network and the majority of microorganisms indicating faecal pollution of the water.

Keywords: Microbiological analysis, physicochemical analysis, Water quality, Water quality Index, water supply network, REGIDESO.

Résumé

Cette étude consiste à déterminer l'indice de la qualité de l'eau prélevée sur les deux réseaux de distribution de la REGIDESO de la ville de Butembo (RD Congo) selon le CCME (1). Pour ce faire, un échantillon d'eau était collecté mensuellement sur chacun de huit sites de prélèvement repérés sur ces réseaux. L'analyse microbiologique et physicochimique a permis d'obtenir des données sur 26 paramètres de qualité de l'eau. Durant six mois d'étude, il n'y a pas eu de site de prélèvement fournissant de l'eau traitée toujours conforme aux directives de microbiologique de l'OMS. Les paramètres physicochimiques ayant présenté une moyenne générale supérieure aux valeurs maximales admissibles sont : ammonium (0.2767 > 0.05 mg /L), fer (0.529 > 0.3 mg/l), nitrate (56.1146 >50 mg /L), pH (6.0708<6.5 – 8.5), et turbidité (7.6542>5 NTU). Ainsi, la charge microbienne, la température de l'eau (21.2917>20 °C), la turbidité élevée et la teneur considérable des nitrates ont été observées comme principaux problèmes de l'eau analysée. Enfin, la catégorisation des sites de prélèvement a été réalisée en utilisant l'indice de qualité de l'eau du CCME (IQE) en référence aux directives de l'OMS. Après calcul, les résultats indiquent que l'eau traitée à la sortie du réseau de Makamba et celle de Kanyangoko étaient de qualité *moyenne* (respectivement avec IQE : 67.64 et 81.66). Mais, après fusion d'eau de ces réseaux, l'IQE était tombé dans la catégorie de qualité *médiocre* (soit IQE : 62.16) juste après mélange de leurs eaux, avant de revenir à sa qualité *moyenne* (soit IQE : 74.65 vers milieu du réseau puis à 70.09 vers son extrémité). Enfin, des différences des moyennes significatives ont été observées entre l'IQE et la nature des échantillons d'eau, le type de réseau et la majorité des microorganismes indicateurs de la pollution fécale de l'eau.

***Mots-clés* :** *Analyse microbiologique, Analyse physicochimique, Qualité de l'eau, Indice de la qualité de l'eau, réseau d'adduction, REGIDESO.*

Introduction

It is known that changes in quality of water characteristics are due not only to anthropic factors, but also to combined natural processes. Hydrologic conditions, topography, lithology, climate, precipitations, hygienic conditions at level of catchment stations, tectonic movements, edaphic factors, erosion, etc. constitute a combination having an environmental influence on the quality of water (2). The geologic constructions in place, the degree of confinement of the water-tables and the stay time of water in these geologic constructions represent the main natural factors that explain the chemical variability of underground water (3).

Moreover, from catchment station to the consumer's tap, the water distribution network should not be considered as an inert scheme, but as a real reactor in which innumerable physicochemical and biological interactions occur (Levi, 1995). (4). This can entail the risks of alteration of the quality of water during transport and storage in comparison to the water produced in the processing plant (4).

With nearly a million inhabitants, the city of Butembo knows some particular disastrous facts. It knows insecurity in and in its surroundings, high rural exodus and birth rate. This demographic stress is the basis of strong urbanisation which has resulted in a new land use with consequences on the urban landscape. There is thus a large deficit in drinking water supply mainly during dry seasons (5).

As in most cities of the DRC, REGIDESO has the monopoly of drinking water distribution. However, the REGIDESO water treatment stations of Butembo do not fulfil the required standards because of their deficient filtration system on rapid sand, which has remained rudimentary. This leads to the production of gloomy and coloured water, which makes most of the inhabitants of Butembo consider it unfit for human consumption and push them go to other water points, with all the foreseeable health risks (6).

In order to determine the water quality, scientists assess different microbiological and physicochemical parameters. Thus, germs numbers are usually sought as indicators of faecal contamination. It is for example numbering Total Coliforms include genera that originate in feces (Fecal Coliforms e.g. *Escherichia*) as well as genera not of fecal origin (non-Fecal Coliforms e.g. *Enterobacter, Klebsiella, Citrobacter*). However, total coliforms are an indicator of fecal contamination and subsequently of *Escherichia coli*. That is why for safe drinking water, WHO standard requires zero coliforms per 100 ml of water sample. In addition, *E. coli* is known to be an indicator of faecal pollution and sign of water treatment failure process (7).

Regarding the physicochemical and aesthetic parameters, a relationship can be found between human health and those parameters: electrical conductivity, turbidity level, colors in water, hardness, concentration of chlorides, sulfate, nitrate, iron-laden waters, fluorides, etc. Thus, in so far as pH affects the various processes in water treatment that contribute to the removal of viruses, bacteria and other harmful organisms, it can be claimed that pH has an indirect effect on human health. WHO recommended guideline value for pH is 6.5 - 8.5 (7).

Secondly, the electrical conductivity of water is used as indirect measure of ionic activity of dissolved mineral salts. This parameter depends on concentration of ions, their nature and temperature of measurement (7).

Moreover, higher turbidity level (>5 NTU/l) in drinking water may develop gastrointestinal diseases, because contaminants like viruses or bacteria can become attached to the suspended solids. The true colors in water may be due to suspended material, dissolved mineral salts such as ferric hydroxide and manganese, and dissolved organic substances such as humic acids, corrosive material, colored industrial waste or other substances from anthropogenic sources. Color can also indicate the presence of certain runoff or discharges into the water. These colored impurities undermine aesthetic value of drinking water. WHO (1996) recommended level is 15 TCU above which consumer complaints start arising because of unacceptable appearance (7).

Concerning chemical parameters, hard water has high mineral contents. It primarily contains excessive calcium and magnesium metal cations, and sometimes other dissolved compounds such as bicarbonates and sulfates. Water becomes hard during its movement through soil and rock; it dissolves small amounts of these naturally occurring minerals and carries them into the groundwater. A number of studies in various parts of the world have demonstrated that there is high statistically significant negative association between water hardness and cardiovascular disease (7).

Furthermore, surface water normally has low concentration of chlorides as compared to groundwater. Chloride is a chemical the human body needs for metabolism (the process of turning food into energy). It also helps keep the body's acid-base balance. The amount of chloride in the blood is carefully controlled by the kidneys. Chloride ions have important physiological roles. Most sulfate compounds originate from the oxidation of sulfite ores, the presence of shales, and the existence of industrial wastes. Sulfate is one of the major dissolved constituents in rain, but one of the least toxic anions. As early as 1940, it was recognized that consuming waters with high nitrate levels contributed to methemoglobinemia ("blue baby" syndrome). This condition, usually in infants, impairs the ability of blood to carry oxygen. Nitrate toxicities in humans occur through enterohepatic metabolism of nitrates to ammonia, with nitrite being an intermediate (7).

Regarding trace elements, iron in water occurs in the ferrous and ferric forms. The solubility in natural waters is dependent upon the pH and the oxidation-reduction potential. In reducing conditions; iron exists in the ferrous state. On exposure to air oxidized to the ferric form and with water hydrolyzes to in- soluble hydrated ferric oxide that makes iron-laden waters objectionable. As concentrations increase visible orange/brown staining appears and any increase in concentrations may create conditions where complex insoluble oxides, hydroxides and carbonates of iron start precipitating out producing a semi-gelatinous and dense flock carpeting the riverbed. Such conditions are very deleterious to most organisms and can cause serious damage in a river system. Iron in water can cause staining of laundry and porcelain, deposit a slimy coating on the piping. WHO (1996) have recommended the guideline value for iron in drinking water as 0.3 mg/l (7).

Traces of fluorides occurrence are widespread in waters and higher concentrations are often associated with groundwater sources in areas where fluoride- bearing minerals are common. Edmunds and Smedley (1996) have found high fluoride concentrations in groundwater. British Geological Survey (2003) has found that a minor concentration of fluoride in drinking water is beneficial due to having significant mitigating effect against dental cavities. Peterson and Lennon (2004) also reported that mild concentration of fluoride reduces tooth decay and cavities in both children and adults (7).

In order to carry out a global judgement on the quality of the water in a milieu over a given period, strategies of water quality control must be set up. These strategies must take into account the cost and the relevance of the parameters of quality to be analysed and sorted among the most illustrative of the degree of water pollution. The calculation of the quality index should then reveal the effect of the weight of each variable (parameter of pollution) whose values express the degree of pollution (8).

Several modern techniques such as the water quality index have been developed (Bharti & Katyal, 2011). (2). The use of the of Water Quality Index (WQI) as developed by the Canadian Council of the Ministry of the Environment (1) seems to be more and more implemented until today as a very important tool in the assessment of the quality of water and is the most accepted in many countries of the world (7). This index is a mathematical tool that permits to summarise into a single number a very large amount of data about the quality of water in a more comprehensive way (8). Its interest is that it actually makes it possible to transmit information concerning the quality of water to the public in general (8), to the distributors of water, to managers and to regulators (2). It can be used as an important parameter to manage a source of water (Parmar K., Parmar V., 2010) (2), and give an idea on the evolution or the tendency of the quality of water in a given period (Panduranga & Hosmani, 2009). (2). However, its weakness is that it does not provide any information on the origins and reasons for this variability (9).

The target of this study is to contribute to a better understanding of the spatiotemporal variability of the quality of the water provided by REGIDESO in the city of Butembo by using the water quality index according to the CCME and thus have an idea on the evolution of water quality even after the combination of the water supply networks. It also aims at establishing likely relationships between the study variables.

Material and methods

Located in the Northeast of North-Kivu province, in the Eastern part of the DRC, the town of Butembo is large of 190.34 km². Its geographical coordinates are: 0°08′00 ″ North latitude, 29°17′00″ East longitude and average altitude: 1800 m. Its relief consists of many hills and valleys with small streams. It knows a moderate equatorial climate impacted by mountains, of the type *Afa* according to Köppen (10), characterized by the alternation of a short dry season from December to February, followed by a short rainy season from March to the end-May, before a short dry season from June to July. Then a short rain season occurs from August to September before the big wet season from October to November (5). The annual average temperature is of 19.7 ° C recorded in 2017 with a minimum of 14.2 ° C and a maximum of 28.6 ° C (11) with a yearly rainfall of 1382 ± 153 mm (10). Moreover, the climate remains constantly annual and knows very little noticeable disturbance but the length of the rainy season is shortening, undermining urban agriculture production and therefore food security (10).

As far as administration is concerned, Butembo has four municipalities whose appellations and approximate surfaces are as follows: Bulengera (55.18 km^2), Kimemi (42.25 km^2), Mususa (40.30 km^2) and Vulamba (52.61 km^2). (5, 11, 12).

In order to provide Butembo population with sufficient drinking water, REGIDESO nowadays has only two networks, taking, each of them, surface water from the municipality of Vulamba. There is the network of "Kanyangoko" built in colonial times, then erected the network of "Makamba" in 1990, capturing water from the Makamba River whose processing plant is located at Vulindi, on the road to Butuhe. Moreover, in order to meet the needs in water of the ever-growing population, the two water supply networks are combined at the level of the SONAS agency, in the municipality of Bulengera. Unfortunately, despite this effort, the centre of REGIDESO only serves 15-16% of the inhabitants of Butembo. This corresponds to a daily production varying between 4320 to 4800 m^3 for the plant of Makamba and 600 to 700 m^3 for the plant of Kanyangoko, i.e. a total average production of 4920 to 5500 m^3. This volume corresponds to a daily average of 5 to 5.5 L of water per person compared to a minimum of 100 L required per inhabitant (Gadelle, 1995). (13)

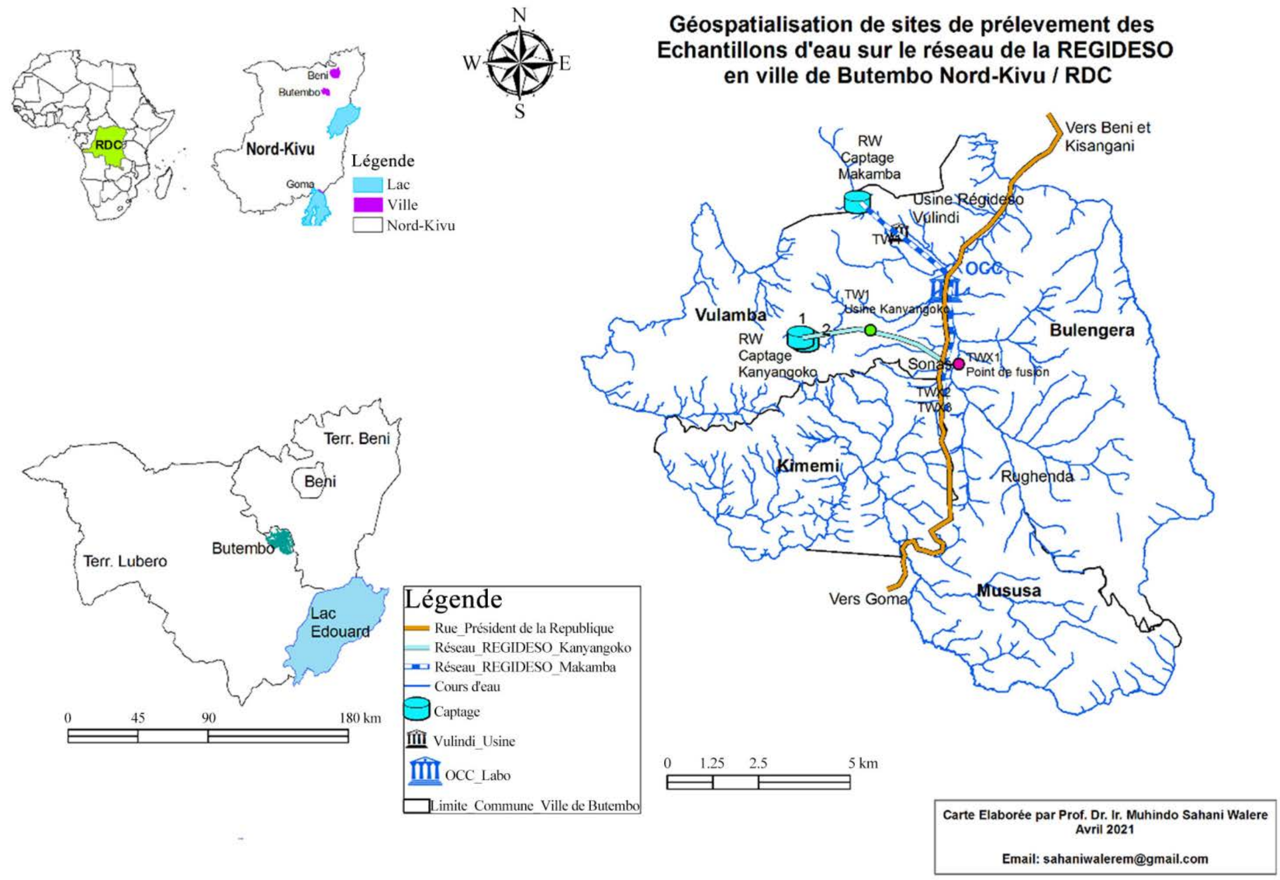


Figure 1. Localisation of water sampling sites in the city of Butembo.

This is a descriptive and longitudinal study in a spatiotemporal approach (13). The population is made up of two REGIDESO conveyance grids in the city of Butembo: Makamba and Kanyangoko. The size of our sample is made up of eight sampling sites pinpointed on these networks. Therefore, 48 samples were taken and analysed from January to June 2019. Thus, it was the sampling point located at the (pool) collection station from which the raw water (*RW*) comes, that is to say before any treatment or disinfection with Chlorine. Then, at the outlet of the processing plant or upstream of the network (*TW1*) and towards the middle of the network (*TW2*). (9). In addition, samples taken after mixing water from these two networks were: *TWx1* for the sample from the station located just after combination of the networks, *TWx2* for the site located in the middle of the network after combination and *TWx3* for the sample located towards the end of that network. Thus, we had constituted a representative sample using the non-random sampling technique by convenience (15).

Monthly, physicochemical and microbiological analyses of 26 parameters of the quality of water (16) of these water samples were then carried out in the field or in the laboratory of the "Office Congolais du Contrôle (OCC)" in Butembo.

Seven types of indicatory microorganisms of the faecal pollution and of the efficacy of water treatment have been counted monthly. They are indicatory germs of faecal pollution determined during our investigations, including germs that can be revived at 22 ° C and at 37 °C, the total coliforms and thermo-tolerant (faeces) coliforms and *Escherichia coli*, the streptococci faeces (Enterococci) and the *Salmonella-Shigella*. These germs were isolated by incorporation on agar-agar in boxes of Petri after incubation at 22°C, or at 37°C. Other bio-indicators were isolated and then counted on gelled and/or selective media by the technique of filtration or membrane incorporation and incubation varied between 37° and 44.5 °C during 24 hours depending on the types of germs counted (17, 18).

Concerning the physicochemical analyses, 19 parameters were determined. They are: Ammonia, Ammonium, Nitrous Nitrogen, Nitric Nitrogen, free Chlorine (active residual), Chlorides, electrical conductivity, colour, free Copper, total Copper, total hardness, Iron, Fluorine, Manganese, Nitrates, pH, Sulphate, temperature and turbidity of water. Given the instability of certain parameters over time, it was compulsory for us to measure *in situ* such the concentration of residual active chlorine using a conventional colorimeter, the temperature of the samples of water using a thermometer, the turbidity using the classic turbidity meter, and pH and electrical conductivity using a Hanna multi-pH and conductivity meter. For other twelve chemical parameters, measurements were made using a multi-parameter, a Palintest 7100 brand Photometer (16). The remaining chemical parameters were determined in the laboratory after taking samples of water (19) using reagents and the Palintest 7100 Photometer (16).

The CCME (1) WQI was used to calculate and interpret the level of the quality of water. This CCME index (1.0) is based on a combination of the following three factors: the number of variables not meeting targets (*Scope*), the frequency with which the targets are not met (*frequency*) and the difference between non-conform measures and the corresponding objectives (*amplitude*). Thus, the different factors were combined to produce a single value (between 0 and 100) that describes the quality of the water (CCME, 2001). Indeed, the Scope (*F1*) or the percentage of variables of which at least one measurement does not meet the corresponding objective during the study period (failed variables), the frequency (*F2*) or the percentage of analytic results not in accordance with the objectives (failed results) and the amplitude (*F3*) the difference between the non-conforming analytic results and the objectives to which they relate are determined by the following formulas:

$$F_1 = \frac{Number\ of\ failed\ Variables}{Total\ number\ of\ variables} x100$$

$$F_2 = \frac{Number\ of\ failed\ results}{Total\ number\ of\ results} x100$$

The amplitude by which an individual concentration is greater than the goal (or less, when that goal is a minimum) is called the "excursion ". When the analytic result should not exceed the target, the excursion was expressed as follows:

$$Excursion = \frac{failed\ test\ value}{objective\ j} x\ 100$$

In cases where the analytic result should not be lower than the target, the excursion was formulated as follows:

$$Excursion\ i = \frac{objective\ j}{failed\ test\ value} x\ 100$$

To calculate the global degree of non-compliance, we were summing up the excursion of the individual results and then divide this sum by the total number of individual results (whether they met the objectives or not). This variable is the *normalised sum of excursions* (or *nse*) and is represented as follows:

$$nse = \frac{\sum_{i=1}^{n} Excursion\ i}{total\ number\ of\ tests}$$

We then calculated the term *F3* using an asymptotic function that brings the normalised sum of the excursion (*nse*) within a range of values from 0 to 100.

$$F_3 = \frac{nse}{0.01\ nse + 0.01}$$

The combination of F1, F2 and F3 has permitted us to determine the Quality Water Index of the CCME (CCME WQI) according to the formula below:

$$CCME\ WQI = 100 - (\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1{,}732})$$

Once the value the WQI of the CCME was determined, it could be classified into one of the five categories of quality of water detailed in the following chart (1).

Table 1.

Categorisation of IWQ according to CCME (2001)

Rank	WQI value	Description
Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment conditions very close to natural or pristine levels.
Very Good	89-94	Water quality is protected with a slight presence of threat or impairment conditions close to natural or pristine levels.
Good	80-88	Water quality is protected with only a minor degree of threat or impairment, conditions rarely depart from natural or desirable levels.
Fair	65-79	Water quality is usually protected but occasionally threatened or impaired conditions, sometimes depart from natural or desirable levels.
Marginal	45-64	Water quality is frequently threatened or impaired, conditions often depart from natural or desirable levels.
Poor	0-44	Water quality is almost always threatened or impaired, conditions usually depart from natural or desirable levels.

In order to compare the data on the factors of quality degradation and those of the spatiotemporal variability of eight deduction sites, the calculation of the quality of water Index has been used. Finally, for the interpretation of the data of analysis, the search for likely relationships between these factors and the quality of water Index of various origins and natures has been carried out using the 20.0 version of SPSS software for the test *ANOVA-1* and Pearson's *r* correlation test (20).

Results and discussion

Physicochemical and bacteriological parameters of the water studied

Among the 48 samples of water analysed at the water sampling sites, 12 come from the network of Makamba (cf. Table 2), 18 from the network of Kanyangoko and 18 others come from water after the two networks combination. All the general averages of the bio-indicators were not in accordance with the WHO guidelines. These results do not go in the same way as those of Kazadi (21), in his study on the quality and management of drinking water in the Kisangani region (DRC), who concluded that water from the REGIDESO is more drinkable than that of the various sources but its installations make a sector to be improved to comply with the WHO guidelines. In addition, among the 19 physicochemical parameters, five had presented a general average far from the maximum admissible values are (19, 22): Iron (0.529> 0.3 mg/L), Nitrate (56.1146>50 mg/L), pH (6.0708<6.5 - 8.5), water temperature (21.2917> 20 C) and turbidity (7.6542> 5 NTU).

Table 2.

Average of values of parameters of water quality by water network

Network		RESIDESO Makamba			REGIDESO Kanyangoko			REGIDESO merged networks			Total		
Parameter	MAV	M	N	SD	M	N	SD	M	N	SD	M	N	SD
Number of revivable Germs at 22 ° C *	<100/mL	414.1	12	708.9	280.2	18	615.0	29.1	18	63.5	219.5	48	530.0
Number of revivable Germs at 37 ° C *	< 10/mL	677.2	12	1123.7	198.6	18	417.0	38.4	18	66.1	258.1	48	651.7
Number of total Coliforms *	0 in 95 % analyses	622.1	12	881.3	321.3	18	687.3	28.9	18	64.4	286.9	48	639.3
Number of Thermo-tolerant Coliforms *	0/100 mL	190.9	12	311.9	82.8	18	145.8	1.6	18	3.6	79.4	48	189.6
Number of *E. coli* *	0/100 mL	389.3	12	764.7	85.2	18	167.7	2.5	18	6.4	130.2	48	413.8
Number of Enterococci	0/100 mL	92.2	12	173.1	12.0	18	47.0	0.3	18	1.0	27.6	48	96.2
Number of *Salmonella-Shigella*	0/100 mL	231.9	12	579.4	54.6	18	120.4	0.6	18	1.6	78.7	48	303.9
Ammonia	0.2 mg/L	0.4	12	0.9	0.1	18	0.2	0.1	18	0.2	0.2	48	0.5
Ammonium	0.5 mg /L	0.4	12	1.0	0.1	18	0.2	0.2	18	0.3	0.2	48	0.5
Nitrous nitrogen	10 mg/L	8.2	12	10.8	5.2	18	2.9	6.8	18	6.0	6.6	48	6.7
Nitric nitrogen	15 mg/L	10.3	12	10.2	12.9	18	8.4	15.8	18	14.6	13.3	48	11.4
Active residual chlorine	5 mg/l	0.2	12	0.3	0.2	18	0.2	0.2	18	0.2	0.2	48	0.2
Chloride	250 mg/L	5.2	12	7.2	5.1	18	5.1	7.7	18	10.2	6.1	48	7.8
Electrical conductivity	10^3µs/cm	45.4	12	15.0	63.9	18	20.0	55.6	18	9.8	56.1	48	16.9
Colour	15mg Pt/L	12.5	12	11.0	7.5	18	17.4	12.8	18	16.6	10.7	48	15.6
Free copper	2 mg/L	0.0	12	0.1	0.1	18	0.1	0.1	18	0.1	0.1	48	0.1
Total copper	2 mg/L	0.1	12	0.1	0.2	18	0.3	0.1	18	0.1	0.1	48	0.2
Total hardness	200 mg/l	21.7	12	15.6	23.8	18	11.5	27.8	18	14.2	24.8	48	13.5
Iron*	0.3 mg/l	0.3	12	0.2	0.9	18	1.1	0.4	18	0.4	0.5	48	0.8
Fluorine	1.5 mg/L	0.4	12	0.2	0.8	18	1.4	0.4	18	0.2	0.6	48	0.9
Manganese	0.5 mg/L	0.0	12	0.0	0.1	18	0.1	0.1	18	0.2	0.0	48	0.1
Nitrate*	50 mg /L	44.6	12	43.3	52.7	18	32.2	67.2	18	62.0	56.1	48	47.9
pH *	6.5 – 8.5	6.1	12	0.3	6.0	18	0.6	6.1	18	0.3	6.1	48	0.5
Sulphate	250 mg/L	7.3	12	5.0	6.6	18	6.0	11.7	18	11.5	8.7	48	8.5
Water temperature*	8-15 °C	20.5	12	2.3	21.0	18	2.0	22.2	18	1.0	21.3	48	1.9
Turbidity *	5 N.T.U.	9.0	12	3.1	8.4	18	5.2	6.0	18	2.3	7.7	48	4.0

Notes: *M = Mean, MAV: maximum average value complied with WHO guidelines or EU standards, N = number, SD = standard deviation. * = Average deviated from the maximum admissible value.*

Water Quality Index (WQI) by sampling station

Table 3 below is a summary of the calculations for the determination of the WQI according to CCME/Canada (1). After calculating the three combined factors (F1 = Scope, F2 = Frequency and F3 = Amplitude), the WQI has been obtained. And from the value of the obtained WQI, the categorisation of the quality of our eight sampling sites was carried out.

Table 3.

Calculation of the Water Quality Index (IQW) per sampling station

Sampling station	**F1**	**F2**	***SCE***	**nse**	**F3**	**WQI**	**Quality**
RW Makamba	50	36.904	11615.15721	69.1378	98.5742	**32.72**	***Bad***
TW1 Makamba	35.7142	14.285	115.6	0.68811	40.76	**67.64**	***Fair***
RW Kanyangoko	33.3333	36.309	51.6831	30.76	96.8517	**33.66**	***Bad***
TW1 Kanyangoko	28.5714	12.5	10.7869	0.06420	6.03399	**81.66**	***Good***
TW2 Kanyangoko	39.2857	16.074	46.5192673	0.27690	21.6853	**72.48**	***Fair***
TWx1.Makamba*Kanyangoko	46.42857	21.428	116.7	0.69465	40.9909	**62.16**	***Fair***
TWx2 Makamba*Kanyango	32.1428	16.071	54.64	25.2139	25.2139	**74.65**	***Fair***
TWx3Makamba*Kanyangoko	42.8571	20.238	44.1594898	0.26285	20.814	**70.09**	***Fair***

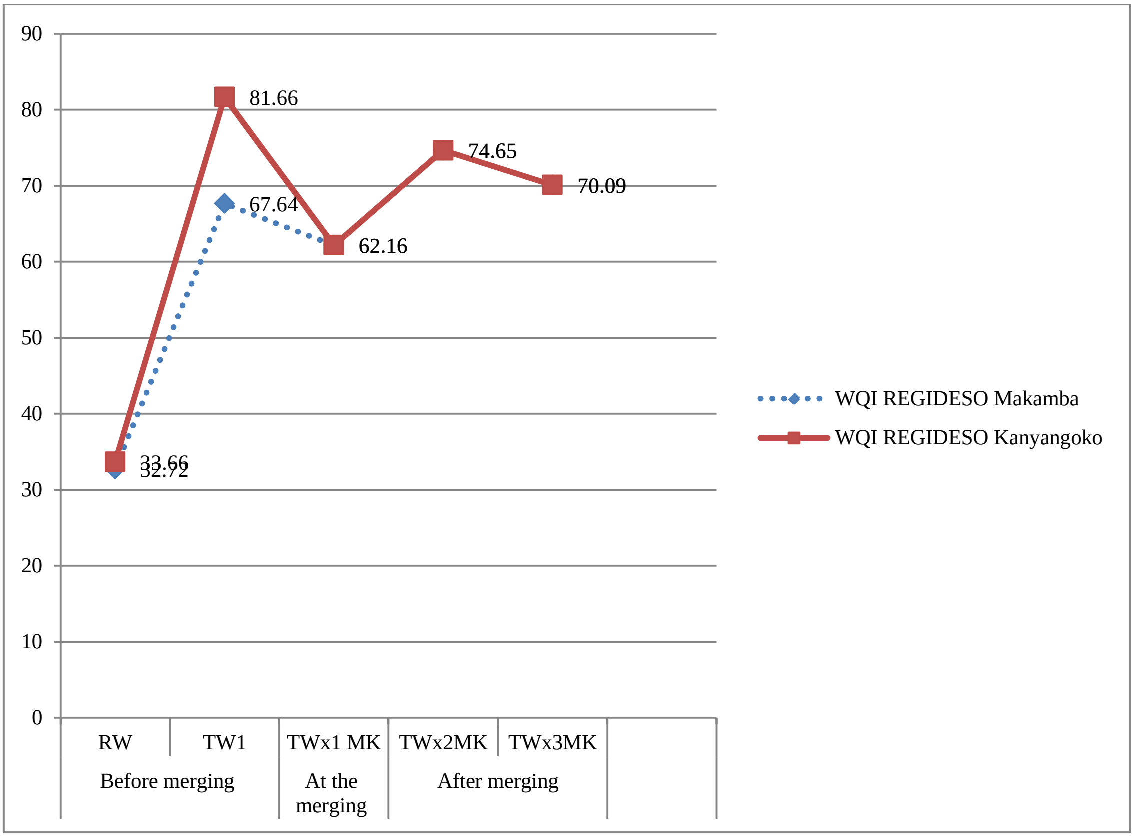
Notes: ***F1*** *= Scope;* ***F2*** *= Frequency;* ***F3*** *= Amplitude;* ***WQI*** *= water quality index;* ***RW*** *= raw water (before any treatment or disinfection);* ***SCE*** *= Sum of excursions;* ***nse*** *= normalized sum of excursions;* ***TW1*** *= water leaving the treatment plant;* ***TW2*** *= water towards the middle of the network;* ***TWx1*** *= Station located just at the crossroads of the REGIDESO Makamba and REGIDESO Kanyangoko networks;* ***TWx2*** *= Station located in the middle of the merged REGIDESO Makamba and REGIDESO Kanyangoko networks;* ***TWx3*** *= Station located towards the end of the merged REGIDESO Makamba and REGIDESO Kanyangoko networks.*

The Table 3 shows that the samples from the raw water were of *poor* quality (WQI = 32.72 for REGIDESO Makamba, 33.66 for REGIDESO Kanyangoko). REGIDESO collects water from two small rivers subject to significant biological pollution in the borders of the municipality of Vulamba. On the other hand, samples from already treated water show the best WQI. Thus, the best WQI is 81.66 for TW1 REGIDESO Kanyangoko, followed by that of TWx2 REGIDESO Makamba with a WQI = 74.65.

Evolution of the WQI after combination of two networks of REGIDESO

Before treated water mixing, the WQIs of TW1 Kanyangoko and Makamba were respectively 81.66 and 67.64. After water combination from these networks, the resulting WQI becomes 62.16. Figure 2 below shows that after mingling the two waters, the quality index obtained does not seem to appear as an average (*i.e.* 74.65) between the quality indexes calculated before mixture, but that it is the flow rate which here seems to be the most determining parameter.

It is observed that the trend curve would more lean towards the WQI of REGIDESO Makamba maybe because it has a higher flow (*i.e.* compared to 180-200 m^3 / hour) than that of Kanyangoko with a lower flow (*i.e.* 25-30 m^3/hour). Further, we notice that the WQI increases significantly: it may be that the higher IQW exerts a stronger influence on the intermediate WQI.



Notes: ***TW1*** *= water leaving the treatment plant;* ***TW2*** *= water towards the middle of the grid;* ***TWx1*** *REG.MK = Station located just at the crossroads of the REGIDESO Makamba and REGIDESO Kanyangoko networks;* ***TWx2*** *REG.MK = Station located in the middle of the REGIDESO Makamba and REGIDESO Kanyangoko combined networks;* ***TWx3*** *REG.MK = Station located towards the end of the combined REGIDESO Makamba and REGIDESO Kanyangoko ns.etworks.*

Fig. 2. Evolution of the WQI after mixing water from two REGIDESO grids.

Additional observations are essential here to better understand this phenomenon. Indeed, the evolution of the WQI is subject to many internal and external factors on the water supply networks: the infrastructure itself, ... so that Blokker *et al*. (23) argue that always providing potable water in distribution networks is very important for public health, but remains a great challenge due to the number and complexity of the physical, chemical and biological processes that lead to the deterioration of the water in the piping.

Mean differences between study variables

With regard to Table 4 below, the ANOVA test does not reveal any statistically significant mean difference between the average numbers of bio-indicators and the months of sample water collection. On the other hand, significant difference are always observed between these numbers and the nature of samples taken, but very often with the type of networks (5/7) as well as that of the samples (6/7).

Table 4.

Mean differences between the numbers of microorganisms and some variables of study.

Variables	Type of Networks			Months of Sampling			Type of Samples			Nature of samples		
Parameters	*F*	*p*	*VI*	*F*	*p*	*VI*	*F*	*p*	*VI*	*F*	*p*	*VI*
Number of revivable Germs at 22 °C	2.20	*0.12*	NS	0.246	*0.94*	NS	6.78	*0.00*	TS	16.2	*0.0*	VS
Number of revivable Germs at 37 °C	4.04	*0.02*	S	0.30	*0.91*	NS	5.11	*0.00*	TS	12.8	*0.0*	VS
Number of Total Coliforms	3.47	*0.04*	S	0.61	*0.69*	NS	9.34	*0.00*	TS	18.5	*0.0*	VS
Number of Thermo-tolerant Coliforms	4.06	*0.02*	S	0.38	*0.86*	NS	8.08	*0.00*	TS	17.2	*0.0*	VS
Number of *Escherichia coli*	3.70	*0.03*	S	0.70	*0.63*	NS	3.56	*0.01*	TS	9.2	*0.0*	S
Number of Enterococci	4.16	*0.02*	S	0.54	*0.75*	NS	2.81	*0.03*	S	7.4	*0.0*	VS
Number of *Salmonella* & *Shigella*	2.30	*0.11*	NS	0.63	*0.68*	NS	2.15	*0.08*	NS	5.9	*0.0*	VS

Notes*: F = calculated value of ANOVA, p = significance level <0.05; VI = verbal interpretation; S = Significant test (0.01> p <0.05); VS = Very significant test (p <or = 0.01).*

Mean difference between the WQI by sampling station and parameters of water quality

By the ANOVA test, the following Table 5 shows that there is a significant mean difference between the WQI per sampling station and most of the values of the bio-indicators counted. Indeed, the WQI depends significantly on the parameters of water quality: number of germs that can be revived at 22 °C (*F = 4.611; p = 0.001*); number of revivable aerobic germs at 37 °C (*F = 5.189; p = 0.000*); number of total coliforms (*F = 6.642; p = 0.000*); number of thermo-tolerant coliforms (*F = 6.102; p = 0.000*); number of *E. coli* (*F = 3,803; p = 0.003*) and number of enterococci (*F = 3,846; p = .003*). However, no association has been observed between the WQI and the number of *Salmonella* & *Shigella* (*F = 2.071; p = 0.070*). Additional observations would be necessary to better elucidate this phenomenon.

Table 5:

Relationship between the WQI and the microbiologic parameters

Microbiological parameters	*Square of averages*	*F*	*p*	*VI*
Number of revivable Germs at 22 °C	842157.857	4.611	*.001*	VS
Number of revivable Germs at 37 °C	1356983.402	5.189	*.000*	VS
Number of Total Coliforms	1475359.402	6.642	*.000*	VS
Number of Thermo-tolerant Coliforms	124700.083	6.102	*.000*	VS
Number of *Escherichia coli*	459421.369	3.803	*.003*	S
Number of Enterococci	24995.068	3.846	*.003*	S
Number of *Salmonella* & *Shigella*	164933.476	2.071	.070	NS

Notes*: F = calculated value of ANOVA, p = significance level <0.05; VI = verbal interpretation; NS = Test not significant (p> 0.05); S = Significant test (0.01> p <0.05); VS = Very significant test (p <or = 0.01).*

In addition, the ANOVA test, Table 5 below shows that there are significant mean differences between the WQI per sampling station and five physicochemical parameters considered. In fact, there is a mean difference between the WQI and the following parameters of water quality: free residual chlorine (*F = 3.376; p = 0.006*); electrical conductivity (*F = 5.023; p = 0.000*); Iron (*F = 5,320; p = 0,000*); the water temperature (*F = 3.651; p = 0.004*) and the turbidity (*F = 3.130; p = 0.010*). These parameters remain very decisive in the assessment of water quality (18).

Table 5:

Mean differences between the WQI and the physicochemical parameters

Physicochemical Parameters	*Square of averages*	*F*	*p*	*VI*
Ammonia	.255	1.058	.408	NS
Ammonium	.268	.901	.515	NS
Nitrous nitrogen	25.460	.528	.808	NS
Nitric nitrogen	115.386	.863	.544	NS
Active residual chlorine *	.140	3.376	.006	S
Chloride	23.053	.345	.928	NS
Electrical conductivity*	896.354	5.023	.000	VS
Color	348.140	1.545	.180	NS
Free copper	.005	.958	.474	NS
Total copper	.030	.765	.620	NS
Total hardness	82.092	.409	.891	NS
Iron*	1.911	5.320	.000	VS
Fluorine	.817	1.062	.405	NS
Manganese	.029	1.459	.210	NS
Nitrate	3426.068	1.638	.153	NS
pH	.116	.505	.825	NS
Sulphate	131.497	2.124	.063	NS
Water temperature *	9.440	3.651	.004	S
Turbidity*	37.098	3.130	.010	S

Notes: *F = calculated value of ANOVA, p = significance level <0.05; VI = verbal interpretation; NS = Test not significant (p> 0.05); S = Significant test (0.01> p <0.05); VS = Very significant test (p <or = 0.01).*

Conclusion

During six months of study, eight water samples from REGIDESO were analysed monthly at the sampling site or in the laboratory. Globally, the results were as follows: the raw water was of *poor* quality (WQI = 32.72 for REGIDESO Makamba, 33.66 for REGIDESO Kanyangoko). In contrast, samples from previously treated water showed the best WQI. Thus, the best (*good*) WQI was 81.66 for TW1 REGIDESO Kanyangoko, followed by that of TWx2 REGIDESO Makamba with a WQI = 74.65. After water mixture of observed grids, the trend curve of WQI would more lean towards WQI of REGIDESO Makamba, which in fact has a higher flow than that of Kanyangoko with a lower flow. Later on, the opposite is true: the higher flow may have a stronger influence on the intermediate WQI. Additional observations are very important here to better elucidate this phenomenon of water fusion of several networks (24).

Furthermore, with regard to relationships between the numbers of bio-indicators, no statistically significant mean differences was observed with the month chosen for the collection of samples of water. On the other hand, significant l mean difference are always observed between these numbers and the nature of the water, but very often with the type of networks and the type of samples taken. Finally, significant mean differences have been observed between the WQI per sampling station and the following five physicochemical parameters: active residual Chlorine (*F = 3.376; p = 0.006*); electrical conductivity (*F = 5.023; p = 0.000*); Iron (*F = 5,320; p = 0,000*); water temperature (*F = 3.651; p = 0.004*) and turbidity (*F = 3.130; p = 0.010*).

Acknowledgments: The authors extend their gratitude to the responsible of the “Office Congolais du Contrôle (OCC”/Butembo); of REGIDESO Butembo; from CAUB, CEPROSSAN and UCG / Butembo laboratories.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Conseil Canadien des Ministres de l'Environnement [CCME]. Recommandations canadiennes pour la qualité des eaux : Indice de qualité des eaux du CCME 1.0 : Manuel de l'utilisateur, dans Recommandations canadiennes pour la qualité de l'environnement, Winnipeg, le Conseil. 1999 ; 6 p.
2. Damo R, Icka P. Evaluation of Water Quality Index for Drinking Water "Fan S. Noli" University of Korca, Agronomy Department, Korca, Albania. Pol.J. Environ. Stud. Vol. 22, No. 4 (2013), 1045-1051.
3. Gouvernement du Québec. Rapport sur l'état de l'eau et des écosystèmes aquatiques au Québec. Québec. 2014. Available from : http://www.mddelcc.gouv.qc.ca/rapportsurleau/Etat-eau-ecosysteme-aquatique-qualite-eau-Quelle-situation_NappeH2OSouterraine.htm [2016 Oct. 25].
4. Gauthier F. Biofilm et qualité de l'eau potable au cours de sa distribution. Mémoire DESS QGE. Université de Picardie – Amiens. 2002 ; 64 p.
5. Sahani M. Le contexte urbain et climatique des risques hydrologiques de la ville de Butembo (Nord-Kivu/RDC). Thèse de doctorat. Collège de doctorat en Géographie. Fac. Sci. Université de Liège. 2012 ; 237 p.
6. Katswangene PK. Contribution à la détermination des bactéries indicatrices de la contamination fécale et efficacité de traitement de l'eau de boisson en ville de Butembo et ses environs (R.D.-Congo). Mémoire de Diplôme d'Etudes Supérieures. Dpt Sci. Biotechnologiques. Fac. Sci. UNIKIS. 2014 ; 121 p.
7. Malik, M.A., Azam, M. and Saboor, A. (2010) *Water Quality Status of Upper KPK and Northern Areas of Pakistan*. Pakistan Council of Research in Water Resources, Water Resources Research Centre, Peshawar Ministry of Science and Technology, Publication No. 142-2010.
8. Sharma D, Kansal A. Water quality analysis of River Yamuna using water quality index in the national capital territory, India in Appl. Water Sci. (2011) 1:147–157 DOI 10.1007/s13201-011-0011-4 (2000–2009). 2011; 11 p.
9. Scheili A. Variabilité spatio-temporelle de la qualité de l'eau potable des petits réseaux : Facteurs explicatifs et développement d'outils de gestion. Thèse de doctorat. Faculté d'aménagement, d'architecture, d'art et de design. Université Laval. 2015 ; 172 p.
10. Sahani M., Moeyersons J., Vandecasteele I., Trefois P. & Ozer P. Evolution des caractéristiques pluviométriques dans la zone urbaine de Butembo (RDC) de 1957 À 2010. Geo-Eco-Trop., 2012, 36: 121-136.
11. Kitakya PA. Interactions entre la gestion foncière et l'économie locale en région de Butembo, Nord-Kivu, République Démocratique du Congo. Thèse de doctorat. Université Catholique de Louvain. 2007 ; 262 p.
12. Rapport annuel de l'administration de Territoire, ville de Butembo, 2018.
13. Emmanuel E. Evaluation des risques sanitaires et ecotoxicologiques liés aux effluents hospitaliers. Institut National des Sciences Appliquées de Lyon. Thèse de doctorat. Lyon, France. 2009 ; 260 p.
14. Delvienne L. Définition des différents types d'études. Available from : http://www.Ebm.ac.be/prostate/typ-etud.html 1999 [2016 Apr. 10/04].
15. Okitolonda WEP. Méthodologie de la recherche. Module 4. Université de Kinshasa. Ecole de Santé Publique. Kinshasa. RDC. 2008 ; 181 p.

16. Palintest. Water Analysis Technologies. Kingsway, Team Valley Gateshead Tyne & Wear NE11 0NS England. 2019. Avalaible from: www.palintest.com
17. Foma, M, Tabu B, Liya SM. Détection et dénombrement des coliformes et streptocoques fécaux dans les eaux de consommation de la ville de Kisangani (République du Zaïre). Tropicultura. 4,2. 1986; p. 49-52.
18. Rodier J, Legube B, Merlet N et coll. L’analyse de l’eau. 9^{e}éd. Dunod. Paris, France. 2009 ; 1526 p.
19. Centre for Affordable Water and Sanitation Technology [CAWST]. Introduction à l’Analyse de Qualité de l’Eau de Boisson. Calgary, Alberta, T2E 8H6, Canada. Disponible sur www.cawst.org. 2013; 197 p.
20. Hair J.F., Black W.C., Babin B.J., Anderson R.E.& Tathan R.L. Mutivariate Data Analysis. 6th ed. Pearson Education International. New Jersey. 2006; p.407-409.
21. Kazadi MZA. Contribution à l’étude de la qualité et de la gestion de l’eau de boisson dans la région de Kisangani. Thèse de doctorat. Faculté des Sciences. Université de Kisangani. Dep. Sciences Biotechnologiques. Kisangani. 2012 ; 145 p.
22. OMS. Directives de qualité pour l’eau de boisson. Recommandations. Troisième Edition. Volume 1. Genève, Suisse. 2004 ; 110 p.
23. Blokker EJM, Furnass RW, Machell J, Mounce RS, Schaap GP, Boxall BJ. Relating Water Quality and Age in Drinking Water Distribution Systems Using Self-Organising Maps. Article. Environments. MDPI. 2016; 17 p.
24. Poitelon JB, Joyeux M, Welté B, Dugu JP, DuBow MS. Le réseau de distribution d’eau potable : un écosystème complexe lié à des enjeux de santé publique. Revue des sciences de l’eau. Volume 24, No. 4, 2011 ; p. 383–418.