Determination of Four (4) Trace Metal Elements in Regideso and Well Water in Bunia Town (DRC)

[1*] Fred KAMARA KARAMAGI

[1]Faculty of Science, Department of Chemistry, University of Burundi, P.O Box 2700 Bujumbura, Burundi

*Corresponding Author

DOI: https://doi.org/10.51584/IJRIAS.2025.10100000146

Received: 09 October 2025; Accepted: 16 October 2025; Published: 18 November 2025

ABSTRACT

The water pipe materials used by Regideso may alter the quality of the water supplied. The overpopulation of displaced persons' sites has led to a disorder within these sites, manifested by the pollution of drinking water. The aim of this study is to determine the content of four trace metal elements. Field parameters such as temperature, pH, conductivity, salinity and TDS were analyzed using the PCST Tespr-35 Multiparameter Water Proof Photometer, and the TMEs (Cr, Cu, Ag and Ni) were analysed using the HANNA HI83300 Series Multiparameter Photometer. For physico-chemical parameters values, with the exception of pH (7.4 and 7.21) and temperature (24.52 and 23.4^{0}C), the results show higher concentrations of salinity (182.6 and 30.58 ppm), TDS (272.8 and 37.525 ppm) and conductivity (384.6 and 53.34 µs/cm) in well water than in Regideso water. However, these parameters remain within the norm. The following TMEs values were obtained from Regideso and well water: Chromium with mean concentrations of 0.0436 and 0.0482 mg/L, Copper with mean values of 0.1 and 0.124 mg/L, Silver with mean concentrations of 0.0064 and 0.0326 mg/L, and Nickel with mean values of 0.0566 and 0.0656 mg/L. Generally, the concentrations of trace metal elements remain within the norm, such as [Copper <0.28 mg/L, Silver <0.056 mg/L and Chromium <0.064 mg/L], yet the concentration of [Nickel <0.082 mg/L] appears very high in these different waters. Above all, there is a high concentration of the metal Silver in the well water. Hence the contribution of these pollutants to the pollution of ground water, which undergoes no prior treatment before use.

Keywords- Determination, Trace metal elements (TMEs), Regideso, Wells waters, Bunia

INTRODUCTION

The water distributed by Regideso and well water are the main sources of drinking water for the city of Bunia following the disruption of part of the Ngongo water source when it was attacked by militiamen. This city is the site of intense human activity due to growing demographic change characterized by significant rural exodus following security issues in rural areas on the one hand, and the development of various activities leading to the discharge of various types of pollutants on the other, which have disrupted the natural functioning of ecosystems (Kayalato et al., 2014; OCHA, 2023; Onivogui et al., 2013).

Inter-ethnic violence in Ituri has forced several thousand people to flee their homes, mainly in the territories of Djugu, Irumu, and Mahagi, bringing the total number of internally displaced persons in the province to 1.2 million, according to OCHA. Of these, 227,000 live in 87 sites managed by UNHCR and IOM, while the majority are staying with host families in communities that already have limited resources. The overcrowding of displacement sites has resulted in disorder, as evidenced by the pollution of drinking water (OCHA, 2023; UNHCR DRC, 2019).

It is a fact that trace metal elements are present in soils in several fractions of the solid phase and can be measured by selective sequential dissolution (Ahoussi et al., 2012; Gove et al., 2001).

The increase in the flow of these trace metals into the soil is due to intense human activity at residential sites. This includes industrial and municipal effluents and domestic and hospital activities. These activities have a significant impact on the quality of groundwater and surface water. Today, the poor management of these sites is causing public health and land use planning problems. The numerous small-scale industrial units, particularly dyeing workshops, located within the catchment area protection zones are potential sources of pollution (Onivogui et al., 2013; Tessier et al., 1979).

Regideso's water pipes are made of materials that affect the quality of the water. The most concerning of these is lead. It is an established fact that these were widely used in public connections and private indoor plumbing. They release lead into the water, affecting the nervous system of the population when found in excessive doses (Balloy Mwanza et al., 2019; Veena et al., 1997).

We know that physicochemical analyses of certain parameters carried out by predecessors like TSANDIA, MERUMBE, and GAKERI show that the water from these sources is definitely substandard (Balloy Mwanza et al., 2019; Dégbey et al., 2008).

Therefore, the main question that prompted us to conduct this study was whether the water supplied by Regideso and from wells in the city of Bunia contains trace amounts of metals and, if so, what the levels would be.

Furthermore, since those responsible for these water sources do not carry out this analysis, the population believes that they are not affected by these pollutants because their effects are felt in the long term (Dahmana et al., 2018; Onivogui et al., 2013).

Our study is crucial. It is vital that the population is informed about the dangers posed by these pollutants. This research will therefore enable the population of the city of Bunia to become aware of this permanent risk or danger, which they continue to ignore.

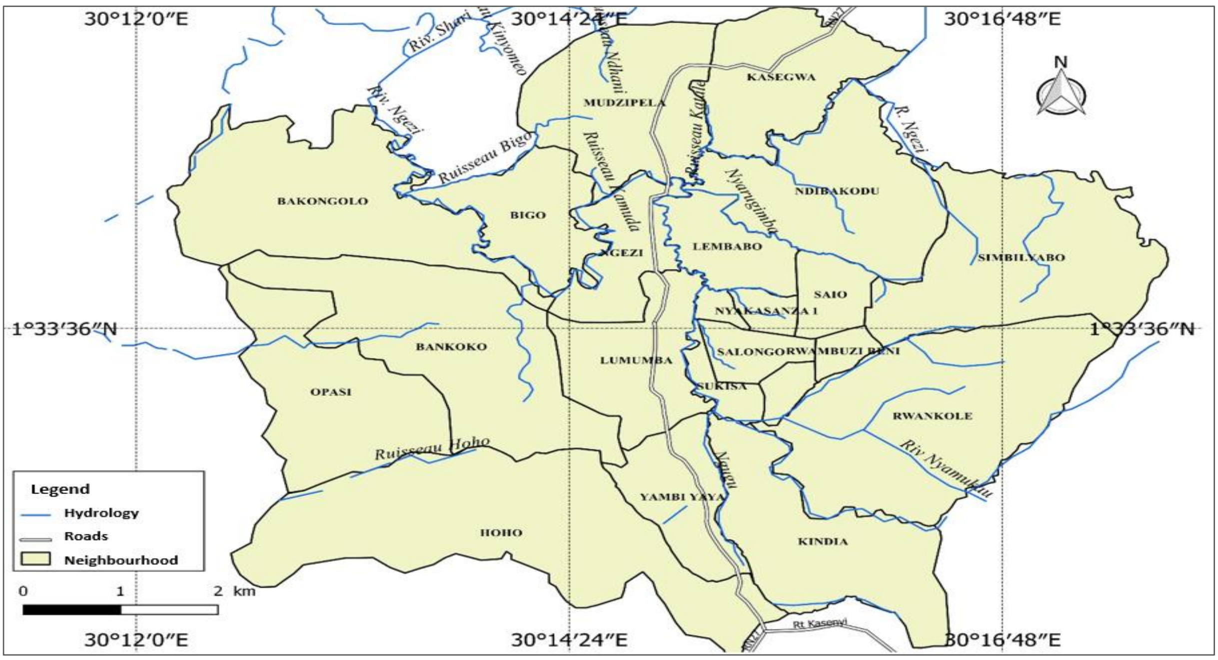
This study will definitively identify the trace metal elements in the water of Regideso and the city of Bunia's wells.

MATERIALS AND METHODS

Study Area

The city of Bunia is located in the Democratic Republic of Congo, in the Ituri province, in the northeast of the country, at 1° 33' 52" East and 30° 14' 24" Northern latitudes. The average altitude is 1,250 m and the rainfall is 1,000 to 1,200 mm/year. The surface area of the island is precisely 830 km², as illustrated in Figure 1 below.

Fig. 1. Map of Bunia city showing its waterways and Neighbourhoods (Source: QGIS, 2020).



ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue X October 2025

Location and Description of Sampling Sites

The following locations were targeted for sampling to perform these analyses:

- **For Regideso**:
  - Treatment plant (Saïo Neighbourhood): where two samples were taken, one for treated water (site 1) and the other for raw water (site 2).
  - In Simbilyabo Neighbourhood: one sample was taken (site 3).
  - In the Nyakasanza Neighbourhood near the Amuda Garage: one sample (site 4).
  - In town (Lumumba Neighbourhood): one sample (site 5).

- **For well water**:
  - Kigonze displacement site (site 6).
  - ISP/Bunia displaced persons site (site 7).
  - HGR/Bunia displaced persons site (site 8).
  - Mr. Richard Lombu's well in HGR/Bunia (site 9).
  - Mr. Shako's well near Radio Candip (site 10).

Collection of samples

All samples were taken at the beginning of October, specifically on the afternoon of 5 October 2020, for Regideso and well water.

Half-litre polyethylene bottles were used, washed and rinsed with demineralised water beforehand. The samples were taken by submerging the bottle in the water to a depth of approximately 25 cm. The water samples were collected in bottles and stored before being transported to the laboratory (Onivogui et al., 2013).

Population under study

The study population consists of Regideso water supplies and wells, among which five taps were distributed for Regideso and five different wells, with three (3) wells for displaced persons sites and two (2) others in the neighbourhood. These samples cover the neighbourhoods of Saïo, Simbilyabo, Nyakasanza, Lumumba, Mudzipela, Bigo, and Kolomani in the city of Bunia.

Statistical data processing

The use of a nonparametric statistical test made it possible to evaluate the average between the values obtained. A nonparametric test is a test based on the study of the ranks of observations that do not make any particular assumptions about the shape of the original distribution (nonparametric). The use of the F_R and T_d tests based on the distribution range was useful for this purpose (Skoog et al., 2002; Conover, 1999).

Past and Excel 2013 software were used for the rapid statistical processing of this data. Then, OriginPro 2015 was used to plot the graphs presented in this paper.

Methods

After collecting the samples, certain parameters were analyzed in the field, namely: temperature, pH, conductivity, salinity, and TDS, to ensure that there were no fluctuations in these values following their transport from the sampling site to the laboratory. The PCST Tespr-35 Multiparameter Waterproof Photometer was used to determine these values.

The HANNA HI83300 Series multiparameter photometer (Fig.2) was used to measure trace metal elements. Ten samples were taken, five from Regideso and five from different wells in the city of Bunia. These samples were transported to the OCC (Office Congolais de Contrôle)/Bunia laboratory for analysis. The samples were then analyzed in accordance with the methodology specified by HANNA Instrument (Hanna Instruments, 2019).

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue X October 2025

Fig.2. HANNA HI83300 Series Multi-Parameter Photometer.

RESULTS

Physico-chemical parameters

Tables 1, 2 and Figure 3 present the results of the analysis of the physico-chemical parameters of well water and Regideso water.

Table 1. Values of in situ physico-chemical parameters at Regideso sites.

Sites	pH	Temperature (^{0}C)	Conductivity(µS/Cm)	TDS (ppm)	Salinity(ppm)
1	6.9	23	55	39.1	31.3
2	5.9	22.8	41.4	29.3	25.5
3	7.65	25.3	57.3	40.6	32.6
4	7.84	22.9	55	39	31.1
5	7.75	23	58	41.2	32.4
Mean	7.21	23.4	53.34	37.525	30.58

Table 1 shows that the values of the physicochemical parameters (pH, temperature, conductivity, TDS, and salinity) are lower in Regideso waters. Site (5) has high conductivity, TDS, and salinity values, while site (2) has low values. The variations in pH and temperature are negligible.

Table 2. Values of in situ physico-chemical parameters of well water.

Sites	pH	Temperature (^{0}C)	Conductivity (µS/Cm)	TDS (ppm)	Salinity (ppm)
6	7.43	24.7	435	308	206
7	7.45	24.2	268	190	127
8	7.44	25.4	256	182	122
9	7.50	24	490	348	233

10	7.20	24.3	474	336	225
Mean	7.4	24.52	384.6	272.8	182.6

Table 2 shows that the values of the physicochemical parameters (pH, temperature, conductivity, TDS, and salinity) are all high in well water. At site (10), conductivity, TDS, and salinity are higher than at all other sites. However, pH and temperature show slight variations.

Fig.3. Physicochemical parameters of Regideso and well water from Bunia.

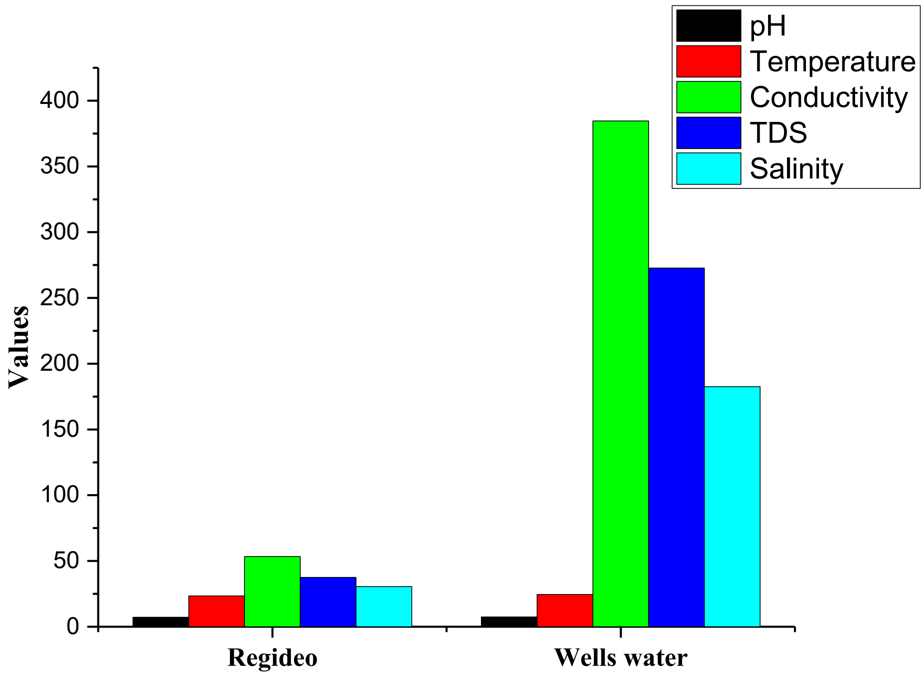


Figure 3 shows that the conductivity, TDS and salinity are all high in well water than Regideso.

Trace Metal Elements (TMEs)

The following tables and figure show the trace metal content in Regideso water and well water.

Table 3. Trace metal content in Regideso water in mg/L

Sites	**The TMEs investigated**			
	Cr	**Cu**	**Ag**	**Ni**
1	0.03	0.15	0.018	0.061
2	0.047	0.05	0.005	0.074
3	0.039	0.09	0	0.037
4	0.064	0.17	0.006	0.049
5	0.038	0.04	0.003	0.062
Mean	0.0436	0.1	0.0064	0.0566

Legend: TMEs = Trace metal elements, Cr = Chromium, Cu = Copper, Ag = Silver, and Ni = Nickel.

Table 3 shows that the concentration of silver is very low or non-existent in Regideso's water.

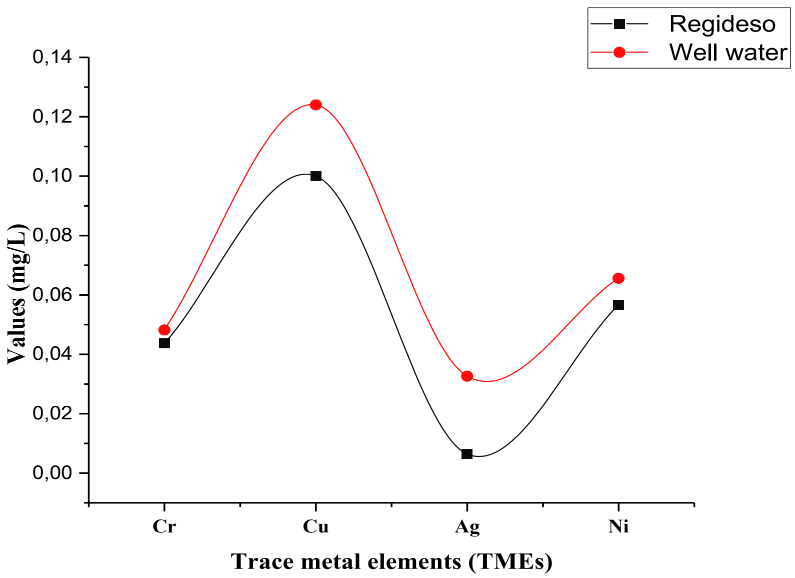
Table 4. Trace metal content in well water in mg/L

Sites	The TMEs investigated			
	Cr	Cu	Ag	Ni
6	0.056	0.11	0.038	0.052
7	0.051	0.06	0.031	0.082
8	0.057	0.05	0.013	0.067
9	0.030	0.28	0.056	0.046
10	0.047	0.12	0.025	0.081
Mean	0.0482	0.124	0.0326	0.0656

Legend: TMEs = Trace metal elements, Cr = Chromium, Cu = Copper, Ag = Silver, and Ni = Nickel.

Table 4 shows that silver concentrations appear to be relatively high in well water. In addition, copper concentrations are high compared to other metals.

Fig.4. Variation of trace metal concentrations in well and Regideso water from Bunia.



As shown in Figure 4, all trace metal elements have higher concentration in well water compared to Regideso water. Furthermore, copper and silver exhibit notably higher levels in well water.

Results of the F_R and T_d statistical analyses

Tables 5 and 6 show the results of the nonparametric statistical tests F_R and T_d based on rank distribution.

Table 5. F_R and T_d test results based on distribution range comparing averages between well water and Regideso.

Parameters	F_R obs.	$F_R$tab.	n	SS	T_d obs.	T_d tab.	n	SS
pH	6.47	3.2	5	S	0.175	0.61	5	NS
Temperature	1.79	3.2	5	NS	0.175	0.61	5	NS
Conductivity	14.096	3.2	5	S	2.64	0.61	5	S
TDS	13.95	3.2	5	S	2.64	0.61	5	S

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue X October 2025

Salinity	15.63	3.2	5	S	2.57	0.61	5	S
Chromium	1.259	3.2	5	NS	0.15	0.61	5	NS
Copper	1.769	3.2	5	NS	0.13	0.61	5	NS
Silver	2.39	3.2	5	NS	0.86	0.61	5	S
Nickel	1.03	3.2	5	NS	0.25	0.61	5	NS

Legend: n=number of samples, SS=statistical significance, S: significance, NS: non-significance.

Table 5 shows that there is a significant difference between the averages of the following physical parameters: conductivity, TDS, and salinity; and, at the level of a single TME, silver, which is more abundant in well water than in Regideso spring water. Furthermore, the F_R test indicates that the accuracies differ in the parameters: pH, conductivity, salinity, and TDS, and elsewhere, it remains the same.

Table 6. T_d test results based on distribution range comparing the averages of the analysed waters to the relevant standard.

Parameters	T_d obs.	$T_d$tab.	n	SS
pH	0.23	0.30	10	NS
Temperature	0.4	0.30	10	S
Chromium	0.12	0.30	10	NS
Copper	7.87	0.30	10	S
Silver	0.17	0.30	10	NS
Nickel	0.91	0.30	10	S

Legend: n=number of samples, SS=statistical significance, S: significance, NS: non-significance.

Table 6 shows that, on the one hand, there is a significant difference between the standard values and the mean values of the following parameters and TMEs: temperature, copper, and nickel; and, on the other hand, there appears to be no significance between pH, chromium, and silver.

DISCUSSION

The results of the physico-chemical analyses (Tables 1 and 2) show the following.

The pH values of the sampled waters are slightly basic at eight sites and slightly acidic at two sites. The figures vary between 5.9 and 7.84, with the maximum value recorded at site (4) and the minimum at site (2). It is clear that they all comply with the WHO standard, which sets pH values between 6.5 and 9.5. However, pH influences most chemical and biological reactions in water, especially when its value is outside this range (Chapman, 1996; Dahmana et al., 2018; WHO, 2017).

It is important to note that temperature variations diminish beyond a depth of 3 metres and that the temperature of groundwater remains constant throughout the year (Petit & Erpicum, 1987). The temperature study showed that the values obtained at the various sites range from 22.8°C to 25.4°C. The highest value was recorded at site (8), while the lowest value was recorded at site (2). It is clear that the values for this parameter at sites (3) and (8) are above 25°C, which is the reference value for drinking water quality (Chapman, 1996). It is clear that these values are consistent with those of our predecessors, which ranged between 23.2^{0}C and 24.60^0 C (Rodier, 2009).

The conductivity values of the 10 sites vary from one site to another. The range is from 41.4 µs/cm to 490 µs/cm, with the maximum recorded at site (9) and the minimum at site (2). The relationship between mineralization and conductivity expressed in µs/cm shows that the well waters studied have high conductivity values ranging from 256 to 490 µs/cm. Regideso waters have an extremely low conductivity of less than 100 µS/cm. The mineralisation of the well water is moderately high compared to the Regideso water, which has very low mineralisation. Conductivity is directly related to the amount of metals and mineral salts in the water; it increases with the amount of conductive elements, particularly metals and mineral ions. The results presented above prove that the longer the stagnation time, the higher the metal content and conductivity (Ghazali & Zaid, 2013; Rodier, 2009).

The salinity values of the 10 sites range from 25.5 ppm to 233 ppm. The maximum value was recorded at site (9) and the minimum value was recorded at site (2), which is confirmed by the conductivity values found previously. Generally, these salts come mainly from the erosion of lithosphere rocks by runoff and groundwater (Ghazali & Zaid, 2013). The salinity study showed that the values obtained are less than 1 g/L, meaning that all these waters are fresh. Thus, the salinization of well water and Regideso water is mostly due to the dissolution of evaporates and the infiltration of runoff water due to anthropogenic pollution of urban origin, especially for well water. Upon returning to the water table, the salt-laden irrigation water initially encountered the soil or the unsaturated zone (Arques & Béraud, 2000; Bekkoussa et al., 2013).

The TDS values for the 10 sites range from 29.3 ppm to 348 ppm; the maximum value was recorded at site (9) and the minimum value was recorded at site (2), which is further confirmed by the conductivity and salinity values given above. Total dissolved solids (TDS) represent the total concentration of substances dissolved in water. TDS consists of inorganic salts and some organic matter (Ghazali & Zaid, 2013). The most significant influence that dissolved solids have on water quality is the alteration of taste. They sometimes cause scaling in pipes (Lallemand-Barres, 1990). High TDS values have been recorded in well water. This high concentration in well water is due to infiltration caused by rain and runoff at the landfill, the intrusion of groundwater into the landfill, and the moisture content of the waste. Very often, when the waste retention capacity is exceeded, liquid effluents are produced, the composition of which depends on the nature of the household or mixed waste and their interactions. These reactions are harmful insofar as they lead to the solubilization of heavy metals (Iounes et al., 2016).

Examining Tables 3 and 4 reveals the following key points:

It is a fact that well water contains significant amounts of copper compared to Regideso, which is spring water. This is because Regideso undergoes treatment before use. Copper is often present in the resource, but it is generally well removed by clarification, including coagulation. In cases of more significant pollution, particularly in soft water, pre-demineralization (CO_2 + soda or lime) is sufficient to precipitate copper hydroxycarbonate. The high copper concentration in well water is undoubtedly due to a lack of certain preliminary treatments. However, in Regideso water, these pre-treatments are carried out effectively, reducing the heavy metal content (Legube, 2015). The maximum value recorded at site (4) is clearly explained by the presence of a paint factory on the site, which also contains significant quantities of metals. The concentrations are well within the permitted range set by the WHO standard of 2 mg/L and 1 mg/L for the EEC (European Economic Community). From a copper perspective, this water is definitely safe to drink (WHO, 2017; Veena et al., 1997).

The highest concentration was recorded at site (4), where the presence of a paint factory had been reported. Dovonou complained that the drinking water catchment area supplying the city of Cotonou and its surroundings was facing rapid population growth. This rapid population growth, combined with the uncontrolled establishment of dyeing workshops, garages, vehicle washing sites, illegal dumps, and wells turned into illegal garbage dumps, had affected the quality of the shallow aquifer in the south of the Allada plateau (Dovonou et al., 2022; Gove et al., 2001). In addition, chromium is present in small quantities in nature and is concentrated mainly in basic rocks. Unlike siliceous rocks, chromium is a foreign element in water: its presence is linked to discharges from electroplating workshops, which explains the high concentration at site (4) and in well water (Kayalato et al., 2014). However, the average concentration of metal in wells and springs remains below the relevant standard of 0.05 mg/L (WHO, 2017). This is a worrying situation, on the one hand because hexavalent chromium is classified as carcinogenic to humans due to its toxicity, particularly when inhaled. On the other hand, the displacement sites that also contain significant amounts of this metal are very recent. Some were established in 2017, others in 2019 or even 2020, which raises the important question: what will happen in the coming years, given the extent of this contamination, which is thought to be due to intense human activity?(Legube, 2015).

It is clear that the nickel concentration exceeds the WHO permissible value of 0.02 mg/L (WHO, 2017). This result is consistent with that found by Ngaram, who detected high nickel concentrations in the Chari River (Ngaram, 2011). Nickel is an element that increases the risk of respiratory tract cancer through pulmonary inhalation (Legube, 2015). The high concentration of this metal in well and Regideso water poses a permanent threat to the population exposed to it. Lime decarbonation is the most effective treatment for removing these metals from water. The solubility of nickel dihydroxide is only a few µg/L at pH 9 (Legube, 2015). It is essential that well water is adequately treated before use for drinking purposes, as the concentration of these metals is even higher. Nickel is also found in groundwater, but only in small quantities. Its presence in water is clearly linked to human activities, which explains the high concentration everywhere (Ahoussi et al., 2012; Arques & Béraud, 2000). The public authorities must instruct the specialised service to analyse the water before it is used.

The concentration of silver is more than the European Community standard of 0.01 mg/L. The WHO has made it clear that setting a limit value for this substance is not necessary. Regideso's value is below the relevant standard. Protection zones are essential for preserving groundwater quality. The uncontrolled occupation of these areas by the population poses a threat to groundwater quality, as the activities carried out there are potential sources of pollution. Illegal dumps, wastewater production activities and the disposal of solid waste in wells are a major source of heavy metal pollution in the shallow aquifer of the catchment area (Dimon et al., 2014; Dovonou et al., 2022).

CONCLUSION

This study took samples from two types of sites: closed wells and Regideso-captured sources used to develop fountains.

We determined the physico-chemical parameters such as temperature, pH, conductivity, TDS, and salinity in situ. We measured four trace metals in these samples: copper, chromium, nickel and silver.

The results are clear: all the physico-chemical parameters meet acceptable standards, with trace metal concentrations remaining well within the norm (such as copper, silver, and chromium). F_R and T_d test revealed a significant difference in conductivity, TDS, salinity, and in the concentration of silver, which was higher in well water than in Regideso spring water. Moreover, T_d test reveals again a significant difference between the mean values of temperature, copper, and nickel and their corresponding standard values. However, nickel concentrations are clearly very high in these different water sources. The population of Bunia city (DRC) must therefore limit its consumption of well water due to the high concentrations of trace metals.

ACKNOWLEDGEMENTS

We would like to thank the laboratory of the OCC (Office Congolais de Contrôle) in Bunia (DRC), and in particular Mr. KHALID Abdallah, for supervising us in the laboratory during the completion of this work.

Declaration Of Interest

Author declares no conflict of interest.

REFERENCES

1. Ahoussi, K. E., Koffi, Y. B., Loko, S., Kouassi, A. M., Soro, G., & Biemi, J. (2012). Caractérisation des éléments traces métalliques (Mn, Ni, Zn, Cd, Cu, Pb, Cr, Co, Hg, As) dans les eaux superficielles de la commune de Marcory, Abidjan Côte d'Ivoire: Cas du village d'Abia Koumassi. Geo-Eco-Trop, 36, 159-174.
2. Arques, D., & Béraud, J.-F. (2000). Rooted maps on orientable surfaces, Riccati's equation and continued fractions. Discrete mathematics, 215(1-3), 1-12.

3. Balloy Mwanza, P., Katond, J. P., & Hanocq, P. (2019). Evaluation de la qualité physico chimique et bactériologique des eaux de puits dans le quartier spontané de Luwowoshi (RD Congo). Tropicultura. 37(2), 1-15. https://doi.org/10.25518/2295-8010.627
4. Bekkoussa, B., Jourde, H., Batiot-Guilhe, C., Meddi, M., Khaldi, A., & Azzaz, H. (2013). Origine de la salinité et des principaux éléments majeurs des eaux de la nappe phréatique de la plaine de Ghriss, Nord-Ouest algérien. Hydrological sciences journal, 58(5), 1111-1127.
5. Chapman, D. V. (1996). Water quality assessments : A guide to the use of biota, sediments and water in environmental monitoring. CRC Press.
6. Conover, W.J. (1999). Practical nonparametric statistics (3rd ed.). Wiley. https://doi.org/10.1002/9780470316696
7. Dahmana, A. E., Belhadj, S., & Yahiya-Dahmana, S. (2018). Analyse de la qualité de l'eau suivant les normes de potabilité de quelques sources naturelles dans la commune de Feraoun (Wilaya Bejaia) [Master Thesis]. Université Abderrahmane Mira-Béjaia, Algérie.
8. Dégbey, C., Makoutode, M., Ouendo, E.-M., Fayomi, B., & Brouwer, C. D. (2008). La qualité de l'eau de puits dans la commune d'Abomey-Calavi au Bénin. Environnement, Risques & Santé, 7(4), 279-283. https://doi.org/10.1684/ers.2008.0158
9. Dimon, F., Dovonou, F., Adjahossou, N., Chouti, W., Mama, D., Alassane, A., & Boukari, M. (2014). Caractérisation physico-chimique du lac Ahémé (Sud Bénin) et mise en relief de la pollution des sédiments par le plomb, le zinc et l'arsenic. J. Soc. Ouest-Afr. Chim, 37, 36-42.
10. Dovonou, F. E., Alladassivo, E. M., Koukpo, J. M., Sintondji, L., & Yalo, N. (2022). Evaluation de la qualité physico-chimique et bactériologique de l'eau du lac Azili dans la commune de Zangnanado au centre du Bénin. International Journal of Biological and Chemical Sciences, 16(2), 867-877.
11. Ghazali, D., & Zaid, A. (2013). Etude de la qualité physico-chimique et bactériologique des eaux de la source Ain Salama-Jerri (Région de Meknès-Maroc). LARHYSS Journal P-ISSN 1112-3680/E-ISSN 2521-9782, 12.
12. Gove, L., Cooke, C. M., Nicholson, F. A., & Beck, A. J. (2001). Movement of water and heavy metals (Zn, Cu, Pb and Ni) through sand and sandy loam amended with biosolids under steady-state hydrological conditions. Bioresource Technology, 78(2), 171-179.
13. Hanna Instruments. (2019). Catalogue Photomètre multi paramètre. Parc d'Activités des Tanneries.
14. Iounes, N., Kabriti, M., & El Amrani, S. (2016). Caractérisation physico-chimique et analyse biologique des eaux de surface de l'Oued Daliya, Maroc. Afrique Science, 12(4), 256-270.
15. Kayalato, B., Mbofung, C. M., Tchatchueng, J., & Ahmed, A. (2014). Contribution à l'évaluation de la contamination par les métaux lourds de trois espèces de poissons, des sédiments et des eaux du Lac Tchad. International Journal of Biological and Chemical Sciences, 8(2), 468-480.
16. Lallemand-Barres, A. (1990). Etude documentaire sur la pollution des eaux par les décharges contrôlées de résidus urbains et déchets assimilés (classe II). Orléans: Bureau de recherches géologiques et minières.
17. Legube, B. (2015). Production d'eau potable : Filières et procédés de traitement (2015^{e} éd.). Dunod.
18. Ngaram, N. (2011). Contribution à l'étude analytique des polluants (en particulier de type métaux lourds) dans les eaux du fleuve Chari lors de sa traversée de la ville de N'Djamena [PhD Thesis]. Université Claude Bernard-Lyon I; Université de N'Djaména.
19. OCHA. (2023). Democratic Republic of the Congo (DRC). United Nations Office for the Coordination of Humanitarian Affairs. Retrieved June 23, 2023 from https://www.unocha.org/drc
20. Onivogui, G., Balde, S., Bangoura, K., & Barry, M. K. (2013, septembre 1). Evaluation des risques de pollution en métaux lourds (Hg, Cd, Pb, Co, Ni, Zn) des eaux et des sédiments de l'estuaire du fleuve Konkouré (Rep .de Guinée). Afrique Science: Revue Internationale des Sciences et Technologie, 9(3), 36-44.
21. Petit, F., & Erpicum, M. (1987). Variation de la température des eaux de source et de leurs débits en fonction de leur mode d'alimentation. Exemples pris en Lorraine belge. Bulletin de la Société Géographique de Liège, 22.
22. Rodier, J. (2009). L'analyse de l'eau : Eaux naturelles, eaux résiduaires, eaux de mer (9^{e} éd.). Dunod.
23. Skoog, D., West, D., & Holler, J. (2002). Chimie Analytique (1997^{e} éd., Vol. 1). De Boeck.
24. Tessier, A., Campbell, P. G. C., & Bisson, M. (1979). Sequential extraction procedure for the speciation of particulate trace metals. Analytical Chemistry, 51(7), 844-851. https://doi.org/10.1021/ac50043a017
25. UNHCR DRC. (2019, November 20). Press release: Opening of a new displacement site in Bunia. United Nations High Commissioner for Refugees (UNHCR). https://data.unhcr.org/en/documents/details/72453

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue X October 2025

26. Veena, K. B., Radhakrishnan, C. K., & Chacko, J. (1997). Heavy metal induced biochemical effects in an estuarine teleost. Indian Journal of Marine Sciences, 26(1), 74-78.
27. WHO. (2017). Guidelines for drinking-water quality (4th ed., Vol. 4, incorporating first addendum). World Health Organization.