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**Research Article**



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**Occurrence of metallic trace elements in the tap water  
due to encrustations inside of individual branch pipes**

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**Abstract**

The tap water may have a quality far removed from that from the distribution service due to direct contamination by metals as well as by those induced by corrosion products. Tap water is the main consumed drinking water in Niamey (Niger), but scientific publications are lacking to document the characterization of the incrustations formed by corrosion. Thus, this work studies the occurrence of metallic trace elements in tap water due to encrustations inside of individual branch pipes. The method consists in taking the deposits formed inside and outside the cast iron and galvanized steel pipes, then the elemental analysis of these deposits is carried out by X-ray fluorescence and X-ray diffraction on powder. The results showed that these incrustations are mainly composed of magnetite ( $\text{Fe}_3\text{O}_4$ ), goethite ( $\text{FeO}(\text{OH})$ ) inside and magnetite ( $\text{Fe}_3\text{O}_4$ ), goethite ( $\text{FeO}(\text{OH})$ ), Rutile ( $\text{TiO}_2$ ) and quartz ( $\text{SiO}_2$ ) outside the pipes. The analysis also showed the presence of Ca, Mg, Fe, Si, Cu, Al, Pb, Zn, Sb, Ti, Mn, Sn etc. These encrustations can then suddenly leach these dissolved or particulate metals into the water in the event of their dissolution or detachment. So this study has evaluated the possible exposure of the population to these metals.

**Keywords:** Metallic trace elements, tap water, encrustations, XRF, XRD, Niamey

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## Introduction

As they are used water pipe and accessories degrade in their natural environment. Thus, depending on the age of the network, the water pressure, its pH and its stagnation time and/or flow, metallic substances migrate into the water depending on the nature of the pipes; The phenomenon of corrosion, especially the internal corrosion of pipes, is the main factor that promotes the dissolution of these substances in water (Gauthier, 1998; Ajuste *et al.*, 2004; DINEPA, 2013).

Corrosion of pipes is then a way of deteriorating its constituent materials following interactions with the surrounding environment. Internal corrosion results in the passage of metallic elements in the water and is the phenomenon explaining the presence of turbid or colored water at the tap. Thus, the occurrence of products (and their derivatives) from pipes and their coatings is most often the factor influencing the health safety of the distributed water (Gauthier, 1998; Euzen, 2005; Proulx *et al.*, 2010; Health Canada, 2017; Health Canada, 2018).

Corrosion products are often found accumulated in suspended particles and deposited as sediments inside the pipes (Lytle and Schock, 2000). The

distributed water then takes on substances that may be responsible for large-scale health effects (Montginoul *et al.*, 2007; Deshommes, 2012; Austruy *et al.*, 2014; INERIS, 2016; Sedki *et al.*, 2018; Barn *et al.*, 2019). In Niamey (Niger) a study conducted by Mijitaba Sahirou *et al.*, (2021) showed that tap water is the main drinking water consumed in this city. It is therefore important, to prevent these risks, to identify the characteristics and mechanisms of accumulation of particulate matter in drinking water distribution networks. In this perspective, this work focused on the characterization of the deposits formed on the surface of the pipes fed by public water supply.

## Materials and Methods

This involves sampling the deposits formed inside the pipes used in the public distribution water pipeline, including cast iron and steel pipes. Then, to perform the elemental analysis of these deposits by X-ray fluorescence (XRF) spectrometry and X-ray diffraction (XRD) on powder.

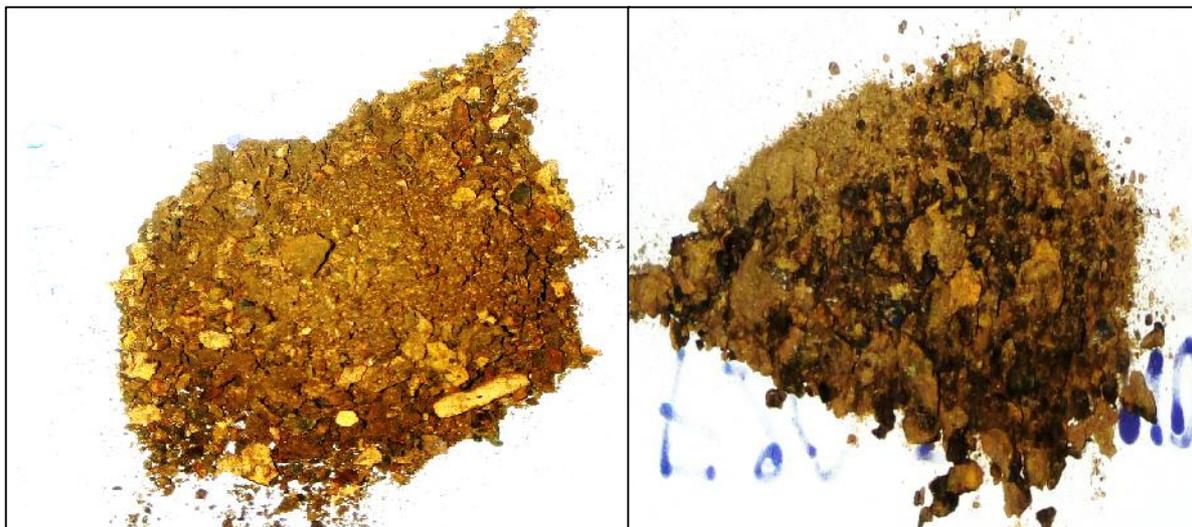
Depending on their use, the nature of the material and that of the surrounding environment (water, soil), plumbing materials are attacked by corrosion. Photo 1 shows an example of pipes damaged by corrosion.



**Photo 1:** Pipe damaged by corrosion: internal view

The encrustations formed inside and outside these pipes were sampled for characterization. The analyzes (XRD and XRF) were carried out at the Central Research Laboratory of Umaru Musa Yar'adua University in Katsina, Nigeria.

The powders used are those of the encrustations formed inside and outside the cast iron and galvanized steel pipes (Photo 2).



**Photo 2:** Deposits formed inside (left) and outside (right) of a cast iron pipe supplied by public water supply in Niamey.

A Thermo fisher Scientific energy dispersive X-ray fluorescence (EDXRF) spectrometer of the model “ARL. QUANT’X. from Thermo fisher Scientific/Switzerland was used for the analysis of sediment deposits due to the corrosion of metal pipes. The diffractometer used is a Thermo scientific diffractometer model: “ARL’XTRA X-ray” with copper anode from Thermo fisher Scientific/Switzerland.

### **X-ray fluorescence analysis**

X-ray fluorescence spectrometry is a qualitative and quantitative analysis technique, which makes it possible to identify and measure most elements, generally from carbon under vacuum or helium. Masses of 2 g of sample were prepared in polypropylene cups (sample holder). The measurement time for each sample was 10 minutes and the medium used was always air.

### **Analysis by X-ray diffraction on powder**

In this study, the mineralogical analysis was carried out on the powders of the encrustations. They are prepared on the one hand on a glass

slide and on the other hand, using the sample preparation block and compressed in the flat sample holder to create a flat and smooth surface, which was then mounted on the sample stage in the XRD cupboard. The samples were analyzed using the reflection scattering stage using the – parameters. The 2 starting position was 4° and ends at 75° for 10 min with a two-step step of 0.026 to 60 seconds per step in order to see the set of potential peaks (Souley Moussa, 2020).

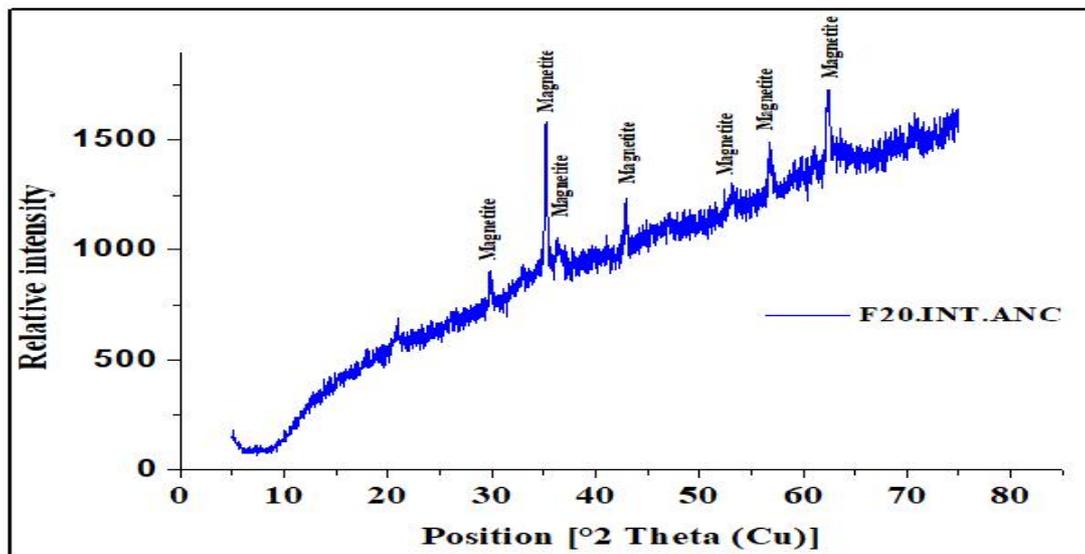
## **Results and Discussion**

### **Elemental composition of the incrustations formed inside the pipes**

The results of the mineralogical analyzes carried out on the incrustations formed inside a galvanized steel pipe and a cast iron pipe fed by public water supply by X-ray diffraction are given by the figures below (Figure 1 to Figure 8). After indexing the set of peaks by the COD database (Crystallography Open Database), these figures show the observations described in the following paragraphs.

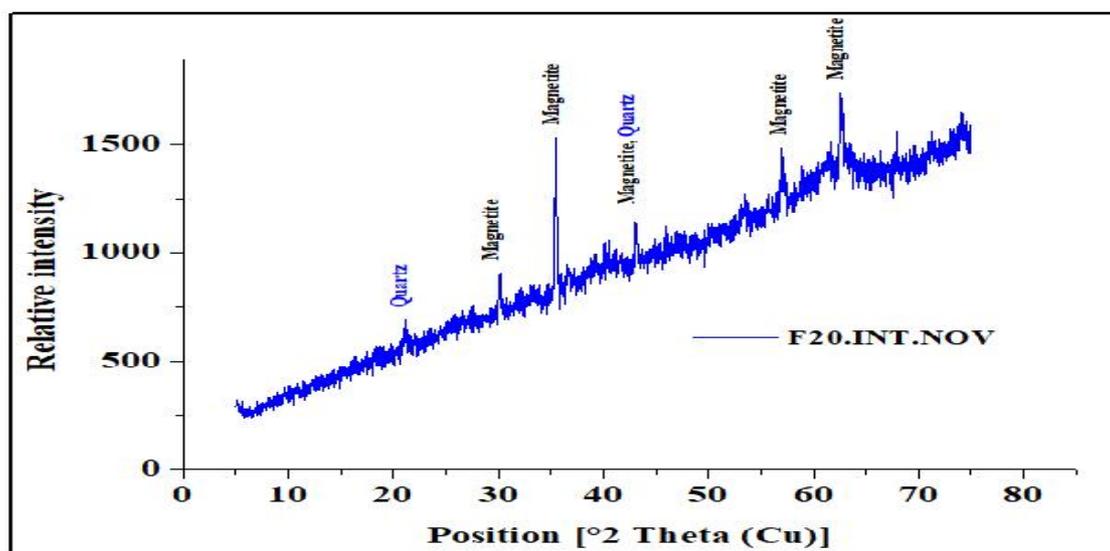
Figures 1 and 2 show the diffractograms of the encrustations formed inside a galvanized steel pipe and a cast iron pipe fed by public mains water. The samples are essentially composed of magnetite ( $\text{Fe}_3\text{O}_4$  or  $\text{FeO}\cdot\text{Fe}_2\text{O}_3$ ). Quartz ( $\text{SiO}_2$ ) is

also present in small quantities inside the cast iron pipe (Figure 2). Characteristic peaks of magnetite formed within the 2 ( $^\circ$ ) in the galvanized steel pipe have been identified (COD reference file: 96-901-3534).



**Figure 1:** Diffractogram of incrustations formed inside a galvanized steel pipe.

The characteristic magnetite and quartz peaks formed within the cast iron pipe were identified at 2 ( $^\circ$ ).



**Figure 2:** Diffractogram of incrustations formed inside a cast iron pipe

Elemental analysis by XRF confirms the results obtained by XRD and shows that these samples essentially contain iron at 45.178% and 44.489% respectively for the encrustations inside the galvanized steel pipe and the cast iron pipe (Figures 3 and 4). The same analysis revealed the presence of traces of Zn, Cu, Pb, Ca, Mg, Al, Si, Mn etc. Thus, these metallic elements can be

found in the distributed water in the event of dissolution of these deposits following a variation in the quality of the water supply, in particular a drop in pH, prolonged stagnation of the water, a hydraulic disturbance or in case of detachment of these deposits. This can suddenly increase the concentration of these metallic elements in the water at the tap outlet (Gérard, 2015).

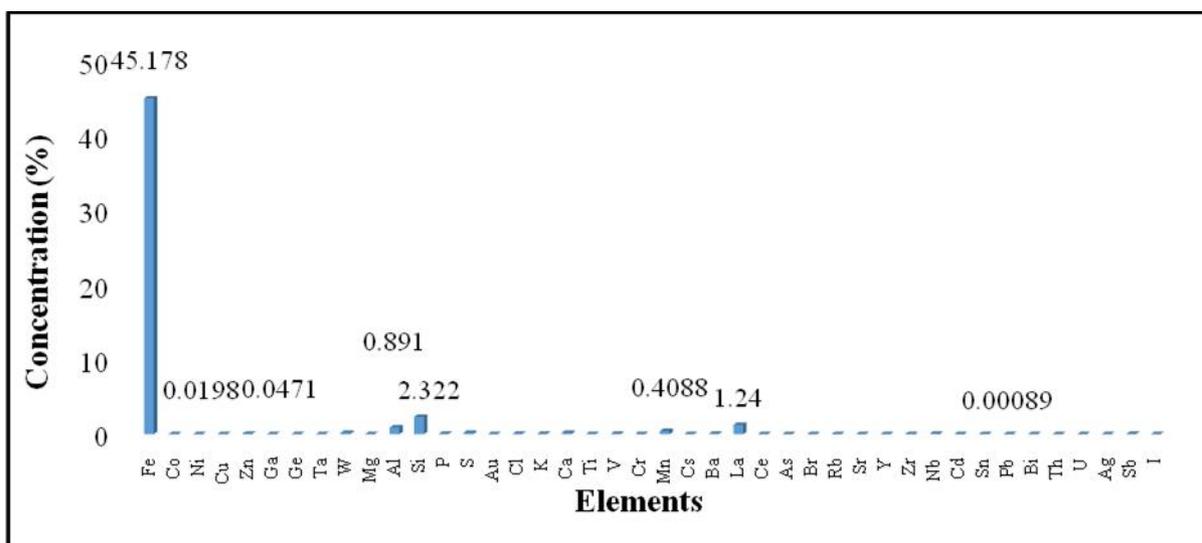


Figure 3: Percentage of elements present in incrustations formed inside a galvanized steel pipe.

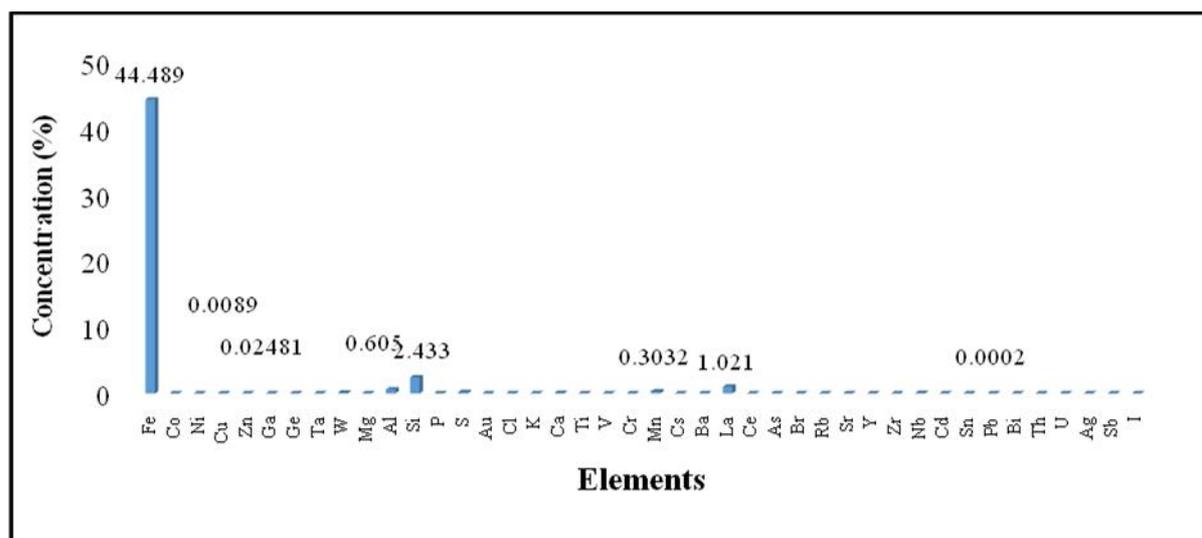


Figure 4: Percentage of elements present in incrustations formed inside a cast iron pipe.

The majority presence of iron in these sediments is due to the corrosion of the pipes. When the dissolved oxygen concentration is above 7 mg.L<sup>-1</sup>, pipe corrosion results in:

oxidation of metallic iron at the anodes:  $Fe \rightarrow Fe^{2+} + 2e^{-}$

reduction of oxygen at the cathodes:  $\frac{1}{2}O_2 + H_2O + 2e^{-} \rightarrow 2OH^{-}$

Iron(II) oxidizes to iron(III) at a rate that varies with pH (6.5 < pH < 7) when the water is oxygenated (dissolved O<sub>2</sub> 7 mg.L<sup>-1</sup>). Thus, the distributed water has a red color due to the precipitation of ferric hydroxide particles in colloidal suspensions not deposited on the walls. In addition, water that is not very oxygenated and aggressive risks taking on a rusty color on contact with the free air during withdrawal, which is the result of oxidation of ferrous iron ions to ferric iron (Blindû, 2004).

When oxygen is consumed by corrosion reactions and biological coatings, corrosion results in:

at the anodes by the oxidation of iron:  $Fe \rightarrow Fe^{2+} + 2e^{-}$

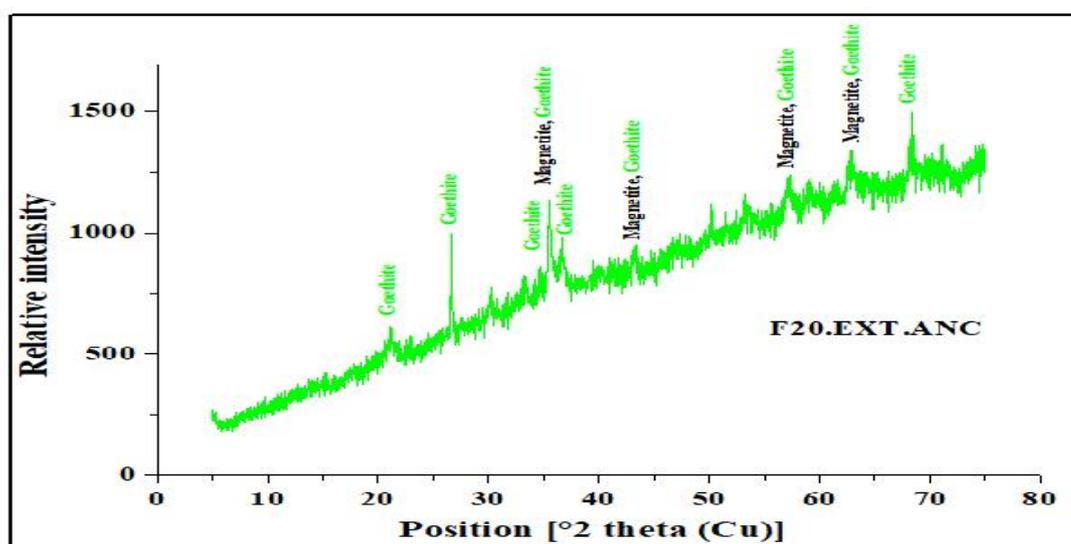
to cathodes by reduction of water:  $2H_2O + 2e^{-} \rightarrow 2OH^{-} + H_2$

Thus, the corrosion will be less intense and will tend to stop. Water loaded with iron(II) is clear on withdrawal but turns red on contact with free air due to the oxidation of Fe<sup>2+</sup> to Fe<sup>3+</sup> and precipitation of ferric hydroxide (Blindû, 2004; Zhang *et al.*, 2014).

### Elemental composition of encrustations formed on the exterior of pipes

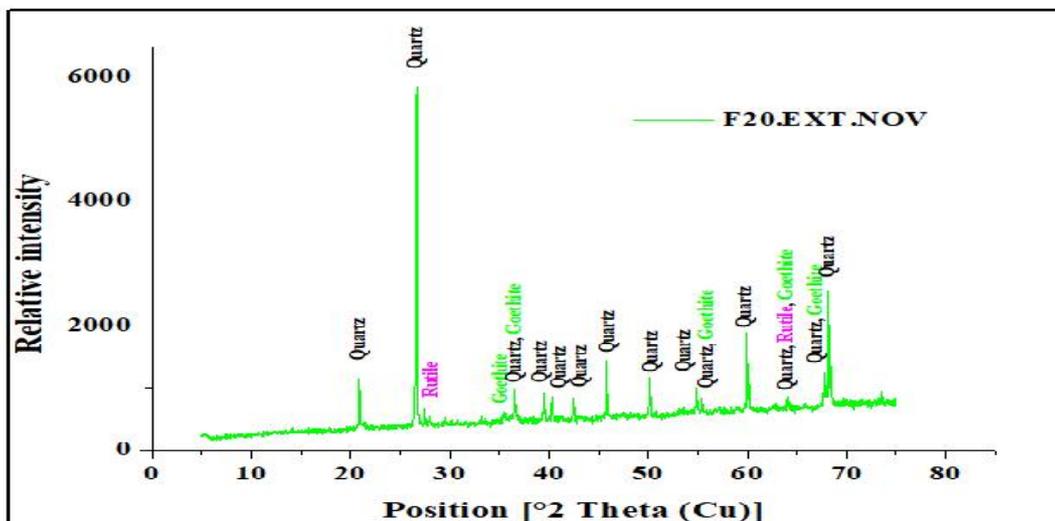
Figures 5 and 6 show the Diffractograms of the encrustations formed on the outside of a galvanized steel pipe and a cast iron pipe fed by public mains water. The samples are essentially composed of magnetite (Fe<sub>3</sub>O<sub>4</sub> or FeO.Fe<sub>2</sub>O<sub>3</sub>) and in small quantities of goethite, FeO(OH). Quartz (SiO<sub>4</sub>) and Rutile TiO<sub>2</sub> are also present in small quantities outside the cast iron pipe.

The characteristic peaks of magnetite and goethite formed on the exterior of the 2 (°) galvanized steel pipe were identified.



**Figure 5:** Diffractogram of encrustations formed on the outside of a galvanized steel pipe

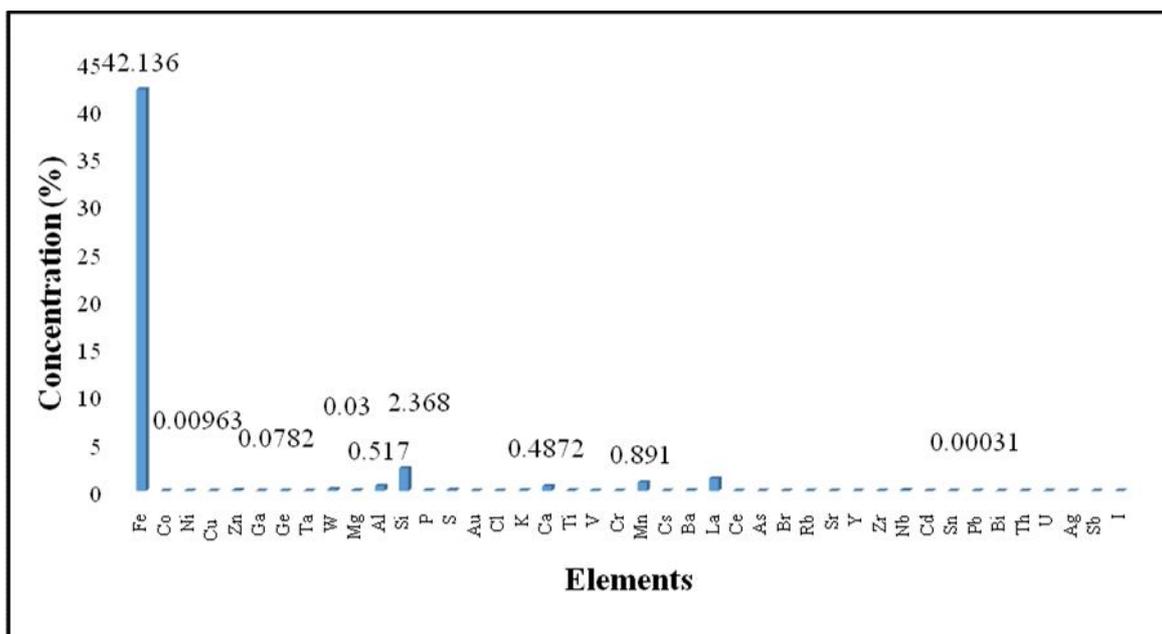
Characteristic peaks of goethite, quartz and rutile formed outside the cast iron pipe at 2 (°) have been identified.



**Figure 6:** Diffractogram of incrustations formed on the outside of a cast iron pipe.

Elemental analysis by XRF presented in Figures 7 and 8 confirms the results obtained by XRD and shows that these samples contain iron at 42.13%

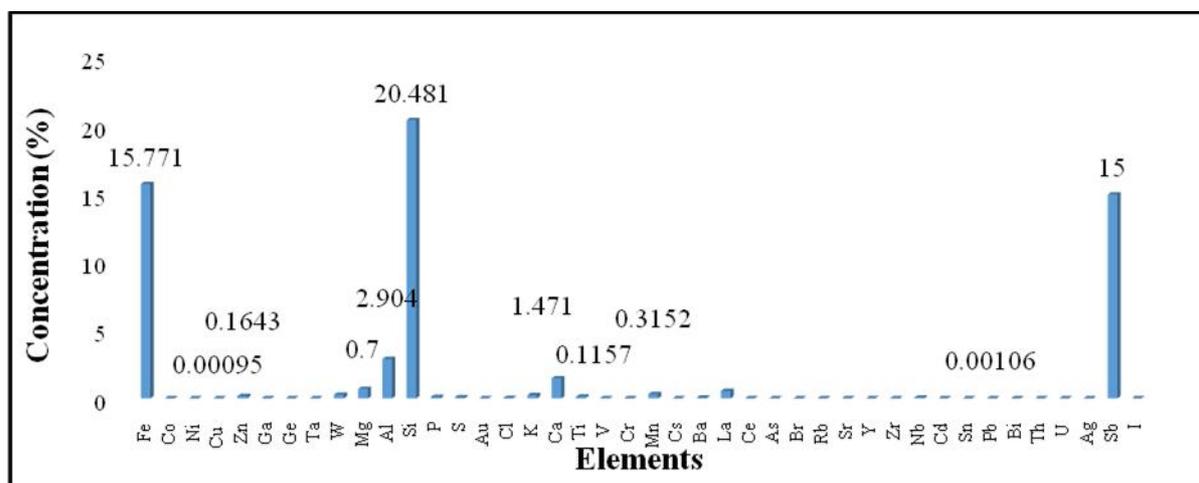
and 15.771% respectively for the encrustations formed on the outside of the pipe in galvanized steel and cast iron pipe.



**Figure 7:** Percentage of elements present in encrustations formed on the exterior of a galvanized steel pipe.

The presence of quartz ( $\text{SiO}_2$ ) and Rutile ( $\text{TiO}_2$ ) is justified by a significant amount of silicon (20.48%) and titanium (0.11%) in the sediment formed outside the cast iron pipe. Antimony is also present in a significant proportion (Figure 8). The presence of these metals would be due mainly to the nature of the ground on which the

pipe is placed. The same analysis revealed the presence of traces of Zn, Cu, Pb, Ca, Mg, Al, Si, Mn etc. In addition, the encrustations formed inside and outside the cast iron pipe contain much more metallic elements than those formed inside and outside the galvanized steel pipe.



**Figure 8:** Percentage of elements present in encrustations formed on the outside of a cast iron pipe.

## Conclusion

The characterization of the encrustations formed inside and outside the individual branch pipes fed by public water supply in Niamey showed that these encrustations are mainly composed of magnetite ( $\text{Fe}_3\text{O}_4$ ), goethite ( $\text{FeO}(\text{OH})$ ) inside and magnetite ( $\text{Fe}_3\text{O}_4$ ), goethite ( $\text{FeO}(\text{OH})$ ), Rutile ( $\text{TiO}_2$ ) and quartz ( $\text{SiO}_2$ ) outside the pipes. The formation of these products is a sign of pipe degradation. Cast iron pipe seems to be more attacked by corrosion and its products than galvanized steel pipe. Elemental analysis of corrosion products showed the presence of Ca, Mg and several metallic trace elements apart from iron and silicon such as Cu, Al, Pb, Zn, Sb, Ti, Mn, Sn etc. These encrustations can then suddenly leach these dissolved or particulate metals into the water in the event of their dissolution or detachment.

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