



# Trace Metal Content in Drinking Water and Its Effect on Rabbit Growth in the Mining Hinterland of Lubumbashi

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## Abstract

Thirty samples of drinking water were collected from springs used by rabbit farmers near mining sites in Lubumbashi, in order to assess the impact of trace metals on rabbit growth. Chemical analyses were performed using atomic absorption spectrometry (AAS) in the Agro-Pedological Laboratory of the Faculty of Agronomic Sciences. The descriptive and analytical results of the water samples showed high Cd and Co content of the order of (0.04 mg/l of Cd and 3.27 mg/l of Co) in river water, (0.20 mg/l Cd and 4.22 mg/l Co) in stagnant rain-water and low content of the order of (0.00 mg/l Cd and 0.01 mg/l Co) in tap water and an acidic pH (5.6) was shown in drinking water. No significant difference in weight gain was observed between the treatment groups of (928.6667 ± 1060 T0), (922.6667 ± 1012 T1) and (988.6667 ± 1045 T2), P-value of 0.8741, with the higher mortality rate at T2 at the expense of the others. Therefore, rabbit breeders living around the mining sites of Lubumbashi use water of poor chemical quality, which does not meet the standard recommended for watering animals by the national agency for food, environmental and occupational health and safety (ANSES), which is in the order of (0.01 mg/l Cd and 1.0 mg/l Co and 6 mg/l Cu).

## Subject Areas

Environmental Sciences

## Keywords

Water, Trace Metal, Contamination, Pollution, Performance, Lubumbashi

## 1. Introduction

The domestic rabbit (*Oryctolagus the Rabbit (Cuniculus)*) is a farm animal valued for its many advantages, both zootechnical and nutritional. Its meat, with its undeniable dietary qualities, is particularly rich in protein and vitamins, while being low in fat and cholesterol. These characteristics make it a recommended food for the prevention of cardiovascular diseases [1]. In addition to its nutritional qualities, the rabbit is distinguished by its docility, high prolificacy, and high productivity, thus offering interesting potential for food self-sufficiency for families [2].

However, in certain areas, particularly those with high mining activity, biosecurity is a major challenge for livestock systems. Animals there are often watered with water from natural sources whose chemical quality is uncertain. Previous work has shown that the presence of pollutants, even in trace amounts, in natural waters can have harmful effects on ecosystems and living organisms [3].

In hydrometallurgical plants and smelters, the extraction and processing of copper and cobalt are frequently accompanied by discharges of by-products containing zinc, lead, arsenic, cadmium, and various sulfur compounds [4]. These discharges contaminate the air, water, and soil, and can also compromise the zootechnical performance of exposed animals [5].

The city of Lubumbashi, the economic heart of Haut-Katanga province, is particularly affected by this phenomenon. Industrial and artisanal mining there generates significant environmental pollution, exposing animals to serious health risks because it disrupts the delicate balance between livestock feed and environmental conditions. Contaminated environments often contribute to a rapid accumulation of toxic residues in animal products, thus affecting their food safety, nutritional quality, and market value. Environmental pollutants are the main causes of communicable and non-communicable diseases (NCDs), which negatively impact livestock management and meat production [6] [7]. According to [8], soils along the Lubumbashi River have copper (1200 ppm), cobalt (1600 ppm), and manganese (1200 ppm) levels far exceeding the French NFU 44-041 standards. In addition, the water used for irrigation contains significant concentrations of trace metal elements (Trace Metal), including 0.00063 mg/l of Cu, 0.000225 mg/l of Co, 796.5 mg/l of Fe, 504 mg/l of Mn, 0.513 mg/l of Cd and 0.36 mg/l of Pb.

Water is an essential input in animal feed, playing a crucial role in digestion, metabolism, and growth. Excessive trace metals in drinking water could cause chronic toxic effects, impair livestock performance, and compromise the sanitary quality of the meat produced.

However, few studies have focused on the joint assessment of water chemical quality and its direct effects on rabbit growth in this specific context. This scientific gap makes it difficult to implement biosecurity strategies adapted to the realities of mining areas in Lubumbashi.

Rabbit farming is playing an increasingly important role in diversifying animal protein sources in many countries, including the Democratic Republic of the Congo. However, the productivity of this type of farming is highly dependent on the qual-

ity of inputs, particularly drinking water, which plays a crucial role in the animals' metabolism and growth.

We hypothesize that water consumption from mining areas would present high concentrations of trace metals and lead to a significant decrease in rabbit growth performance compared to those drinking water of controlled quality. It is in this context that this study was initiated with the objective of contributing to the evaluation of trace metal content in drinking water and its effects on rabbit growth in the mining hinterland of Lubumbashi.

## 2. Materials and Methods

### 2.1. Environment

This study was conducted in the city of Lubumbashi, located between longitude 11°28' East and latitude 11°39' Southeast. It currently comprises 42 neighborhoods distributed across 7 communes, including the communes of Lubumbashi, Kampemba, Rwashi, Kenya, Annexe, Katuba, and Kamalondo [9]. Lubumbashi is the capital of the Haut-Katanga province and is known for its copper and cobalt mining, which dates back to the early 19th century. Founded in 1910 by the Belgians as Elisabethville (named after Elisabeth of Bavaria, who became Queen of Belgium), it was renamed Lubumbashi in 1965 [10]. The name "Lubumbashi" means clay soil in the local Bemba language. This work was carried out specifically in the livestock building of the Faculty of Agronomic Sciences during the dry season. The geographical map of the livestock building is illustrated in **Figure 1**.



**Figure 1.** Photo of the building's geographical map (Google) Earth 2025.

### Water Sampling at the Lubumbashi Mining Site

Thirty samples of drinking water were collected from two sites located in the mining hinterland of Lubumbashi, a region heavily impacted by extractive activity and

the presence of anthropogenic contaminants. These samples were selected based on their proximity to mining or industrial activity areas, as well as their frequent use as watering sources by local livestock farmers.

The first type of water, representing treatment T1, was collected from the Lubumbashi River, downstream from the Gécamines facilities. This waterway, regularly exposed to industrial and domestic wastewater, constitutes an aquatic environment with a high pollution load, particularly in trace metals, especially during the dry season when leaching is amplified. These sites were chosen for their proximity to areas at risk of contamination by trace metals, including lead (Pb), cadmium (Cd), copper (Cu), cobalt, and zinc (Zn), etc.

The second type of water, corresponding to treatment T2, was collected in Kipushi from a rainwater stagnation area located near the KICO mining company. This water, resulting from runoff during the rainy season, stagnates in low-lying, undrained areas and is often used for watering livestock. Contact with soils contaminated by mining waste significantly increases the risk of metal pollution.

Finally, the third type of water, used as a control treatment (T0), comes from the tap water of the Faculty of Agronomic Sciences at the University of Lubumbashi, supplied by Regideso. Although this water meets drinking water standards, some studies point out that the age of the networks or interruptions in treatment can lead to occasional fluctuations in quality.

Water sampling was carried out during the dry season in April 2025. This season is crucial because runoff facilitates the mobilization and transport of contaminants from mining soils to surface or stagnant water sources. Water samples were collected uniformly using sterilized 600 ml bottles, previously rinsed with distilled water, and then stored at 4 °C in an insulated cooler. Sampling was conducted at 10:00 AM to avoid post-collection contamination. Analysis of the collected water samples allows for the evaluation of their quality for watering and highlights potential toxic risks to animal health [11]. The physicochemical parameters analyzed included pH, temperature, electrical conductivity, and trace metal elements (TMEs), including Pb, Cd, Cu, Zn, Fe, Mn, etc. Trace element concentrations were determined by atomic absorption spectrometry (AAS) at the soil science laboratory of the Faculty of Agronomic Sciences. The instruments were calibrated with certified standards, and measurements were repeated to ensure the reliability of the results. The values obtained were compared to the thresholds recommended by the WHO, FAO, and ANSES.

## 2.2. Analytical Method

### 2.2.1. Evaluation of the Content of Trace Metal Elements in Drinking Water Used by Livestock Farmers Living near Mining Sites

Trace element extraction was carried out at the soil science laboratory of the Faculty of Agronomic Sciences, and the interpretation of the results was performed at the Polytechnic Laboratory. Water samples underwent simple acid digestion for the analysis of drinking and wastewater: a 10 ml volume of each previously acidified water sample was placed in a test tube, to which 0.5 ml of ultrapure nitric acid

(residual trace element concentration < 10 ppm) was added. The test tubes were then placed in a heating block at 105°C under a fume hood for 2 hours to reach boiling. Once cooled, the test tubes were diluted to 10 ml with IASTM-type ultrapure water and then stored at 4°C pending analysis [12]. Laboratory analyses were carried out solely on trace metal elements using the flameless Atomic Absorption Spectrometry method according to standard NF T90-112 [13].

### **2.2.2. Evaluation of the Effects of Trace Metal Elements Contained in Water on the Growth Performance of Rabbits**

To determine if the treatment had an effect on the rabbits, the following growth parameters were recorded: Weight, daily feed intake, water intake index, and average daily gain (ADG). Mortality and feed distribution were monitored daily, and feed intake was measured. Growth was assessed weekly.

### **2.2.3. Evaluation of the Level of Accumulation of Trace Metals in the Urine and Feces of Rabbits**

All samples were analyzed in the Agro-Pedological Laboratory of the Faculty of Agronomic Sciences for the extraction phase, and the reading was carried out at the OCC. Urine samples underwent simple acid digestion for urine analysis. A 10 ml volume of each previously acidified water sample was placed in a test tube, to which 0.5 ml of ultrapure nitric acid (residual concentration of trace elements < 10 mg/liter) was added. The test tubes were then placed in a heating block at 105°C under a fume hood for 2 hours without reaching boiling. Once cooled, the test tubes were diluted to 10 ml with IASTM-type ultrapure water and then stored at 4°C pending analysis [14]. At the OCC, laboratory analyses focused solely on trace metallic elements (P, K, Ca, Mg, Na, Cl, Al, Fe, Mn, Zn, Cu, Co, Ni, Cr and Cd) using atomic absorption spectrometry (AAS) according to the NF T90-112 standard [15].

Inspired by the method of [16], a 1000 g sample of feces, previously dried at 15°C, was placed in a porcelain crucible and pre-calcined on a hot plate or in a muffle furnace at 200°C until mineralization. The complete samples (ash detached from the crucible wall and of a uniform white or gray color) were calcined by mineralization for one hour. Upon removal from the muffle furnace, the samples were cooled on a heat-resistant surface, protected from dust and drafts. The ash was then quantitatively transferred to a 100 ml beaker using 10 ml of HNO<sub>3</sub>. The beaker was placed on a glass rod, then in the beaker (resting in the notch of the spout), and covered with a watch glass. The ash was monitored and digested by gently boiling on a hot plate for 30 minutes. Care was taken to ensure that evaporation did not exceed 5 ml. The solution was filtered while still warm into a 50 ml volumetric flask. The watch glass was rinsed, and the filter rod and hot-water beaker were recovered from the filter. The filtrate was cooled, and the flask was filled to the mark with water. Finally, it was sealed with a wax-coated stopper. This extract was used to determine the following elements: Fe, Mn, Zn, Cu, Co, Ni, Cr, and Cd.

## 2.3. Experimental Method

### Experimental Setup

Thirty-six one-month-old male rabbits of a local breed were placed in a completely randomized controlled trial with three treatments and three replicates. Four rabbits were housed per cage. The animals were fed a pelleted feed produced on-site by the company, with *ad libitum* feeding. Water distribution was rationalized, with 0.6 ml per cage per day. The experimental water samples were selected based on spot samples reported to be contaminated with high levels of trace metals. Therefore, water was collected only once in the field and stored in four 20-liter containers in a refrigerator at a base temperature of 4°C for 35 days. The water containers were shaken at each daily feeding. Animals exposed to this water exhibited clinical signs such as leg weakness, paralysis, decreased locomotor activity, and skin chlorosis, which led to the death of some rabbits.

During the experiment, a device based on a black bag was installed under the hutch to allow for the collection of urine and feces. A pre-collection period was observed for one week, and the actual collection was carried out over four weeks to obtain composite samples for each treatment (T0 tap water, T1 river water, and T2 stagnant rainwater). The feces were dried in the shade for four days, and the urine was kept in the refrigerator at a base temperature of 4°C. These samples were then sent to and analyzed at the Agro-Pedological Laboratory of the Faculty of Agronomic Sciences (see **Table 1**).

**Table 1.** The content of trace elements in food.

TME	Ag mg/l	Cu mg/l	Co mg/l	Cd mg/l	Mn mg/l	Mg mg/l	Ca mg/l	Al mg/l	Zn mg/l	Ni mg/l	Fe mg/l	Pb mg/l	As mg/l
<b>Content</b>	0.253	7.09	1.202	<0.001	143.9	2940	9312.2	99.05	183.9	<0.001	1901.1	0.06	0.088

## 2.4. Statistical Analysis

For this study, before any statistical analysis, the normality of the data was verified using the Shapiro-Wilk test. If the data were normal, a one-way ANOVA was applied to compare the means from the different rivers. If the data were not normal, a transformation was applied before the ANOVA using the *Bestnormalize* package in R 4.01. For all ANOVAs, the significance level was set at 5%. A post-hoc test, also known as the smallest difference test, was performed. The weight growth data were subjected to a one-way ANOVA. classification using R software version 4.03, the classification criterion being the type of water

## 3. Results

### 3.1. Evaluation of the Content of Trace Metal Elements in Drinking Water Used by Livestock Farmers Living near Mining Sites

The results show an acidic pH with sodium chloride ion levels exceeding the ANSES standard recommended for animal drinking water quality in the well, the Lubumbashi River, and the stagnant water. Furthermore, our selection was based on spot

samples that showed high levels of cadmium (Cd), lead (Pb), and cobalt (Co) exceeding the standard, such as E14 (stagnant rainwater) and E23 (Lubumbashi River). These results are illustrated in **Table 2**.

**Table 2.** Variation of trace metal elements according to water sources.

TME	Sources						ANSES (2010)
	Drilling	Well	Faucet	River	Stagnant Rain	PV	
Temperature	26.000 ± 1.414 <sup>ab</sup>	26.909 ± 0.883 <sup>ab</sup>	27.500 ± 0.577 <sup>a</sup>	27.833 ± 0.289 <sup>a</sup>	25.92 ± 0.607 <sup>b</sup>	0.002	<b>18 - 31</b>
pH	6.3200 ± 0.2970 <sup>ab</sup>	5.8427 ± 0.5631 <sup>b</sup>	6.6143 ± 0.1776 <sup>a</sup>	5.7067 ± 0.5216 <sup>ab</sup>	4.6514 ± 0.4205 <sup>c</sup>	0.000	<b>6 - 9</b>
THIS	1140.0 ± 28.3 <sup>a</sup>	1222.9 ± 115.1 <sup>a</sup>	1130.4 ± 17.5 <sup>a</sup>	1131.0 ± 21.7 <sup>a</sup>	1121.4 ± 24.4 <sup>a</sup>	0.046	<b>200 - 1100</b>
Cl	26.850 ± 4.455 <sup>a</sup>	29.436 ± 3.588 <sup>a</sup>	31.133 ± 0.907 <sup>a</sup>	31.133 ± 0.907 <sup>a</sup>	26.071 ± 1.494 <sup>a</sup>	0.041	<b>2.85</b>
SO <sub>4</sub>	300.24 ± 30.94 <sup>ab</sup>	320.51 ± 30.92 <sup>b</sup>	146.73 ± 12.40 <sup>c</sup>	324.46 ± 155.13 <sup>ab</sup>	396.37 ± 44.30 <sup>a</sup>	0.000	<b>375</b>
N/A	21.500 ± 4.950 <sup>ab</sup>	28.091 ± 3.448 <sup>a</sup>	22.57 ± 5.682 <sup>b</sup>	18.000 ± 1.000 <sup>b</sup>	29.000 ± 2.309 <sup>a</sup>	0.001	<b>2.5</b>
Mn	0.0550 ± 0.0636 <sup>bc</sup>	0.0664 ± 0.0665 <sup>c</sup>	0.0429 ± 0.0399 <sup>c</sup>	0.3300 ± 0.2623 <sup>ab</sup>	0.4757 ± 0.1664 <sup>a</sup>	0.000	<b>25</b>
Al	0.10000 ± 0.01414 <sup>b</sup>	0.03182 ± 0.03842 <sup>ab</sup>	0.02000 ± 0.03559 <sup>b</sup>	0.14333 ± 0.14978 <sup>ab</sup>	0.24429 ± 0.10907 <sup>a</sup>	0.000	<b>3.5</b>
Ar	0.01000 ± 0.00000 <sup>b</sup>	0.00636 ± 0.00505 <sup>ab</sup>	0.00286 ± 0.00488 <sup>b</sup>	0.07000 ± 0.11269 <sup>ab</sup>	0.07429 ± 0.05381 <sup>a</sup>	0.008	<b>0.06</b>
Zn	1.675 ± 1.082 <sup>ab</sup>	0.517 ± 0.370 <sup>b</sup>	0.341 ± 0.381 <sup>b</sup>	1.980 ± 1.524 <sup>ab</sup>	2.463 ± 2.091 <sup>a</sup>	0.009	<b>25</b>
Great!	0.03000 ± 0.02828 <sup>ab</sup>	0.01273 ± 0.00905 <sup>b</sup>	0.00429 ± 0.00787 <sup>b</sup>	0.02000 ± 0.01732 <sup>b</sup>	0.06286 ± 0.03039 <sup>a</sup>	0.000	<b>1</b>
Pb	0.05000 ± 0.007071 <sup>ab</sup>	0.006364 ± 0.006742 <sup>b</sup>	0.000000 ± 0.000000 <sup>b</sup>	0.030000 ± 0.000000 <sup>ab</sup>	0.020000 ± 0.011547 <sup>a</sup>	0.001	<b>0.1</b>
Chr	0.03000 ± 0.01414 <sup>bc</sup>	0.01727 ± 0.00647 <sup>c</sup>	0.00429 ± 0.00787 <sup>c</sup>	0.05333 ± 0.01155 <sup>b</sup>	0.08286 ± 0.01799 <sup>a</sup>	0.000	<b>2.5</b>
CD	0.01 ± 0.014 <sup>ab</sup>	0.001 ± 0.004 <sup>b</sup>	0.00 ± 0.00 <sup>b</sup>	0.0461 ± 0.01 <sup>ab</sup>	0.200 ± 0.01 <sup>a</sup>	0.000	<b>0.01</b>
Co	1.7200 ± 0.6788 <sup>bc</sup>	0.8218 ± 0.5448 <sup>bc</sup>	0.0014 ± 0.3143 <sup>c</sup>	3.2733 ± 2.0740 <sup>ab</sup>	4.2214 ± 0.9744 <sup>a</sup>	0.000	<b>1</b>
Cu	0.6700 ± 0.7778 <sup>b</sup>	0.7791 ± 0.5039 <sup>b</sup>	0.5900 ± 0.3662 <sup>b</sup>	3.0033 ± 1.5172 <sup>a</sup>	3.2314 ± 0.9792 <sup>a</sup>	0.000	<b>6</b>

Legend: a, ab, bc and c: This is a method by Tukey that represents the significant differences between metals in water.

### 3.2. Evaluation of the Effects of Trace Metal Elements Contained in Water on the Growth Performance of Rabbits

#### Daily Water Consumption

The statistical analyses presented in **Table 3** show that the average daily consumption of accumulated water per week was significantly different in the fifth week ( $P < 0.02$ ); this result is illustrated in **Table 3**.

#### 3.3. Assessment of Average Daily Weight Gain

The results show that statistical analyses revealed a non-significant difference in average weight gain. The results are illustrated in **Table 4**.

**Table 3.** Weekly water consumption.

Treatment	Weekly Water Consumption				
	Week 1	Week 2	Week 3	Week 4	Week 5
T0	1.0666667 ± 1.10	1.3166667 ± 1.7	1.5333333 ± 2.2	1.500000 ± 1.6	2.2666667 ± 2.5 <sup>a</sup>
T1	0.7600000 ± 0.80	1.290000 ± 1.6	1.3966667 ± 1.5	1.5666667 ± 1.6	1.8666667 ± 2.0 <sup>ab</sup>
T2	0.7633333 ± 0.88	1.1466667 ± 1.3	1.1333333 ± 1.2	1.3666667 ± 1.5	1.600000 ± 2.0 <sup>ab</sup>
P-value	0.1699	0.172	0.3997	0.1631	0.02941 <sup>*</sup>

T0: Tap water; T1: Lubumbashi river water; T2: Stagnant rainwater with a distributed quantity of 6 ml/day/cage. a, ab, bc and c: This is a method by Tukey that represents the significant differences between metals in water. \*: Probability value confirms the significant difference in treatments at Week 5.

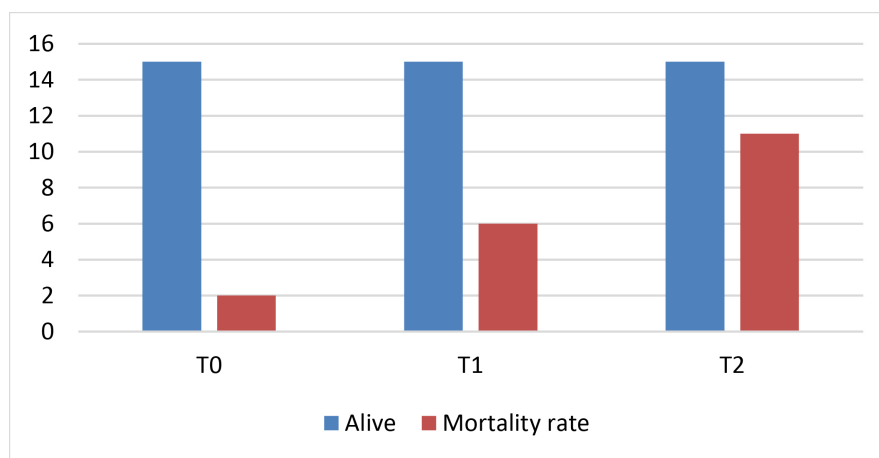
**Table 4.** Assessment of average daily weight gain.

Treatment	Average Weekly Weight Gain				
	Week 1	Week 2	Week 3	Week 4	Week 5
T0	348.3333 ± 399	483.3333 ± 557	650.0000 ± 833	783.6667 ± 1010	928.6667 ± 1060
T1	348.6667 ± 392	454.3333 ± 548	576.3333 ± 619	715.0000 ± 823	922.6667 ± 1012
T2	312.0000 ± 368	428.6667 ± 492	569.0000 ± 691	681.0000 ± 802	983.3333 ± 1020
P-value	0.8269	0.8482	0.6207	0.4402	0.8741

T0: Tap water; T1: River water; T2: Stagnant rainwater with a distributed quantity of 6 liters/day/cage.

### 3.4. Mortality Rate Assessment

**Figure 2** shows that the mortality rate was highest at T2, followed by T1 at the end of T0.

**Figure 2.** Mortality rate.

### 3.5. Evaluation of the Level of Accumulation of Trace Metals in the Urine and Feces of Rabbits

#### 3.5.1. Level of Accumulation in Urine

The result shows that the average value of trace metal elements in rabbit urine was elevated in cobalt, copper, arsenic, zinc, chromium and cadmium compared to the

recommended standard of ANSES (French Agency for Food, Environmental and Occupational Health & Safety) and ATA (Annals of Analytical Toxicology) (**Table 5**).

**Table 5.** Levels of trace elements in rabbit urine.

TME	DS	ANSES standard (2010)
Mn	0.1820 ± 0.2154	<b>0.015 (ATA 2001)</b>
Al	0.0943 ± 0.1152	<b>0.01 (ATA 2001)</b>
Ar	0.02800 ± 0.05041	<b>0.01 (ATA 2001)</b>
Zn	1.154 ± 1.414	<b>0.7 ANSES (2010)</b>
Neither	0.02433 ± 0.02812	<b>0.01 (ATA 2001)</b>
Pb	0.02567 ± 0.03848	<b>0.08 (ATA 2001)</b>
Cr	0.0690 ± 0.0739	<b>0.01 (ATA 2001)</b>
CD	0.1690 ± 0.0872	<b>0.002 ANSES (2010)</b>
Co	3.269 ± 1.088	<b>0.005 ANSES (2010)</b>
Cu	4.08 ± 5.60	<b>0.01 (ATA 2001)</b>

M: Mean; EC: Standard deviation; ANSES: French Agency for Food, Environmental and Occupational Health & Safety; ATA: Analytical Toxicological Annals; TME: Trace Metal Element; Mn: Magnesium; Al: Aluminum; Ar: Arsenic; Zn: Zinc; Ni: Nickel; Pb: Lead; Cr: Chromium; Cd: Cadmium; Co: Cobalt; Cu: Copper; DS: Standard Deviation.

### 3.5.2. Level of Accumulation in Feces

The results showed that the levels of Co, Cu, Ar, Zn, Chr, and Cd were elevated in the feces of rabbits raised in the vicinity of mining sites compared to the recommended standard (ANSES and ATA) (**Table 6**).

**Table 6.** Level of trace elements in rabbit feces.

TME	DS	ANSES standard (2010)
Mn	445.4 ± 480.0	<b>0.015 (ATA 2001)</b>
Al	105.576 ± 3.288	<b>0.01 (ATA 2001)</b>
Ar	3.042 ± 3.288	<b>0.01 (ATA 2001)</b>
Zn	692.3 ± 0.819	<b>0.7 ANSES (2010)</b>
Neither	0.02433 ± 0.02812	<b>0.01 (ATA 2001)</b>
Pb	0.001 ± 0.1152	<b>0.08 (ATA 2001)</b>
Cr	3.042 ± 3.288	<b>0.01 (ATA 2001)</b>
CD	0.001 ± 0.001	<b>0.002 ANSES (2010)</b>
Co	3.257 ± 3.387	<b>0.005 ANSES (2010)</b>
Cu	349.9 ± 399.0	<b>0.01 (ATA 2001)</b>

M: Mean, EC: Standard deviation; ANSES: French Agency for Food, Environmental and Occupational Health & Safety; ATA: Analytical Toxicological Annals; TME: Trace Metal Element; Mn: Magnesium; Al: Aluminum; Ar: Arsenic; Zn: Zinc; Ni: Nickel; Pb: Lead; Cr: Chromium; Cd: Cadmium; Co: Cobalt; Cu: Copper; DS: Standard Deviation.

## 4. Discussion

### 4.1. Evaluation of the Content of Trace Metal Elements in Drinking Water Used by Livestock Farmers Living near Mining Sites

The result shows that the water around the mining sites of Lubumbashi is contaminated with trace metals such as cadmium and cobalt due to their availability and mobility. This result is similar to that obtained by [17], which shows that mining and mineral processing activities, as well as artisanal mining in Katanga, are responsible for the dramatic contamination of surface water, sediments, groundwater, and soils with trace metals, and can also negatively affect the local environment and water resources through freshwater withdrawal and pollution from wastewater discharges from mineral processing plants. The result found by [18] showed very high levels of Cu (1200 ppm), Co (1600 ppm), and Mn (1200 ppm) in the soils along the Lubumbashi River, exceeding the NFU 44-041 standard in force in France. The irrigation water added trace elements to the soils, amounting to approximately 0.00063 mg/l of Cu, 0.000225 mg/l of Co, 796.5 mg/l of Fe, 504 mg/l of Mn, 0.513 mg/l of Cd, and 0.36 mg/l of Pb, which constitutes a significant contribution to the soil.

Chemical analyses of various water sources (wells, rivers, stagnant rainwater, and boreholes) in the vicinity of the mining sites show that they contain high levels of chloride ions in the form of sodium chloride (NaCl). This corroborates the findings of [19] regarding chloride content, which varies between 11.54 and 49.7 mg/l. This high chloride content is attributed to the lack of protection in septic tanks, allowing urine from toilets to flow directly into the water, as well as the dissolution and spreading of salt deposits. The average pH of these different water sources is 5.6, indicating that the water resources in the vicinity of the mining sites are acidic, which is similar to the pH of 5.68 found by [20], which was analyzed in the Lubumbashi river water and the pH of 5.8 analyzed in the water from the Lowowoshi neighborhood wells in Lubumbashi [21] and the samples have acceptable conductivity values of 1160 ms/Cm which is close to the result found and contrary to the only one found by [22].

### 4.2. Evaluation of the Effects of Trace Metal Elements Contained in Water on the Growth Performance of Rabbits

#### 4.2.1. Water Consumption

Rabbits given tap water (T0) consumed more water than those in groups T1 and T2. This decrease can be attributed to the trace element load, which reduces palatability and alters the taste of the water. These results are consistent with those of [23] and [24], who state that contaminated water leads to a significant reduction in water and feed intake. Water is essential for digestion, thermoregulation, and waste elimination. Thus, the decreased water consumption observed in groups T1 and T2 is the first factor explaining the decline in growth performance.

#### 4.2.2. Assessment of Average Daily Weight Gain

In this study, no significant difference was observed between treatments in terms of weight gain, since all rabbits were fed the same type of pelleted food, the same quantity, and had constant access to water. The more a rabbit eats, the greater its weight gain; this result is similar [25]. After weaning, rabbits continue to grow with an increase in their nutritional needs, both in quantity and quality.

The growth curve varies with age because there is no significant difference depending on the water consumption of the kits, which corroborates the result found by [26], stating that water is a factor in maintaining the health of rabbits both during pregnancy and fattening. However, it can also be a source of problems depending on the attention given to it. Rabbits drink a lot of water; when well cared for, rationally and fed a dry diet, they provide an average of 0.2 to 0.3 liters of water per day for a growing rabbit, 0.6 to 0.7 liters for lactating does, and 1 liter for a doe with a litter.

#### 4.2.3. Mortality Rate Assessment

During this trial, the mortality rate was observed from day 14 of the experiment and was higher at T2 and very low in the control treatment (T0). The cause was attributed to the high dose of cobalt (4.22 ml/l) and cadmium (0.04 ml/l) initially reported in stagnant rainwater, exceeding the ANSES (French Agency for Food, Environmental and Occupational Health & Safety) recommended dose of 1 ml/liter of cobalt and 0.01 ml/liter of cadmium, as part of the animal health biosecurity measures. Furthermore, the low mortality rate at T0 was due to the large cage size and the rabbits' sensitivity to cold, as the temperature was controlled to the detriment of the rabbit's natural thermoregulation. This result corroborates the study found by [27] on oral cadmium exposure, which has also been associated with a number of other, less sensitive effects in laboratory animals, including effects on the immune, cardiovascular, and nervous systems. Effects on reproduction and development have been observed in several studies and are summarized in section.

### 4.3. Evaluation of the Level of Accumulation of Trace Metals in the Urine and Feces of Rabbits

The results showed that the urine and feces of rabbits raised near mining sites had higher values of Co, Cd, Cu, Zn, Pb, Cr, and As exceeding the normal dose defined by ANSES and ATA. These results are similar to those found by [28], who showed that the urine of animals and humans living near mining sites in the mining industries of Southeast Katanga had high levels of trace elements, except for Nickel, compared to unpolluted sites (Kamina). Thus, in neighborhoods located less than 3 kilometers from the metallurgical industries (Shamilemba, Pengapenga, and Kawama), the geometric means of urinary concentrations expressed in  $\mu\text{g/g}$  of creatinine were 17.8 (10.9 - 29.0) for As, 0.75 (0.38 - 1.16) for Cd, 15.7 (5.27 - 43.2) for Co, 17.1 (8.44 - 43.2) for Cu, 17 (1.47 - 5.49) for Pb. A significant difference in the level of trace element accumulation in urine and feces was observed between stagnant rainwater, river water, and well water. This agrees with the results of [29]

on water and soil contamination resulting from the deposition of atmospheric particles from various sources. Furthermore, the findings of [30] on leaching by rainwater as it passes through soils or rocks containing cobalt are also responsible for the contamination of resurgent water.

## 5. Conclusions

This work was conducted to contribute to the assessment of the impact of trace metals present in drinking water on rabbit growth, with the aim of proposing safe management of livestock water. To achieve this, 30 drinking water samples were collected from sources used by rabbit farmers living near mining sites in Lubumbashi. Chemical analyses were performed using atomic absorption spectrometry (AAS) in the Agro-Pedological Laboratory of the Faculty of Agronomic Sciences. A completely randomized design of 3 treatments with 3 replicates was used to monitor the growth performance of the animals.

The descriptive and analytical results of the water samples showed high Cd and Co content of the order of (0.04 mg/l of Cd and 3.27 mg/l of Co) in river water, (0.20 mg/l Cd and 4.22 mg/l Co) in stagnant rainwater and low content of the order of (0.00 mg/l Cd and 0.01 mg/l Co) in tap water and an acidic pH (5.6) was shown in two of the above sources.

No significant difference in weight gain was observed between the treatment groups of ( $928.6667 \pm 1060$  T0), ( $922.6667 \pm 1012$  T1), and ( $988.6667 \pm 1045$  T2), with a P-value of 0.8741. The mortality rate was higher in the T2 group compared to the other groups. Urine and feces of rabbits raised near mining sites showed higher doses of cobalt, cadmium, copper, zinc, lead, chromium, and arsenic, exceeding normal levels.

These results confirm that metallic contamination of drinking water in mining areas of Lubumbashi represents a threat to animal productivity, food security and, indirectly, to human health through the food chain.

## Conflicts of Interest

The authors declare no conflicts of interest.

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