

Physicochemical and Microbiological Evaluation of the Quality of Drinking Water in Cusco (2018-2019)

1Jonny Tello-Yarin, 2Salinova Carrillo Segura, 3Mayra Irina Garcia La Torre, 4Eddy Tello Yarin, 5Maribel Palomino Gamarra, 6Juvenal Perez Huallpa, 7Venancia Ccollatupa Ballon, 8Ruben Ingles Atauchi.

1ORCID 0000-0001-5158-7655

Departamento Académico de Física, Facultad de Ciencias, Universidad Nacional de San Antonio Abad del Cusco, Cusco, Perú

2ORCID 0000-0002-8462-0615

Departamento Académico de Física, Facultad de Ciencias, Universidad Nacional de San Antonio Abad del Cusco, Cusco, Perú

3ORCID 0009-0009-3993-6766

Universidad Nacional de San Antonio Abad del Cusco, Cusco, Perú

4ORCID 0000-0003-3196-0947

Universidad Nacional de San Antonio Abad del Cusco, Cusco, Perú

5ORCID 0000-0002-9951-5551

Universidad Nacional de San Antonio Abad del Cusco, Cusco, Perú

6ORCID 0000-0003-3156-2981

Universidad Nacional de San Antonio Abad del Cusco, Cusco, Perú

7ORCID0000-0001-5169-4258

Universidad Nacional de San Antonio Abad del Cusco, Cusco, Perú

8ORCID 0000-0001-9490-3961

Universidad Nacional de San Antonio Abad del Cusco, Cusco, Perú

Summary

Microbial contamination represents one of the greatest risks to water intended for human consumption. This study evaluated the quality of drinking water in the city of Cusco during 2018 and 2019, with the aim of determining its suitability for consumption, identifying districts with better quality and comparing the measured parameters with the permissible limits established by Supreme Decree No. 031-2010-SA. Drinking water samples were collected in five districts (Cusco, Santiago, Wanchaq, San Sebastián and San Jerónimo), which were analyzed in accredited laboratories through physicochemical and microbiological tests. During 2018, the results showed traces of coliforms in the district of Cusco (0.1×10^2 cfu/ml in December), while in 2019 concentrations above the permissible limits of sulfates, carbonates and hardness were detected in several districts. These findings underscore the need for constant monitoring to ensure the quality of drinking water in the region.

Keywords: drinking water, water quality, permissible limits, microbial contamination, physicochemical analysis.

1. Introduction

Access to safe and quality drinking water is a fundamental right and an indispensable requirement to guarantee public health and the well-being of communities. However, increasing pressure on water resources due to population growth, uncontrolled urbanization and human-intensive activities have jeopardized the quality of water intended for human consumption. In this context, the city of Cusco, with a growing population of 1,331,800 inhabitants according to the latest CPI report (2017), faces serious challenges related to the supply and quality of drinking water. The lack of constant and effective monitoring of the physicochemical and microbiological parameters of drinking water can lead to serious health risks for the population, including gastrointestinal diseases, which occupy the second place in incidence in this region.

The quality of drinking water not only directly influences the health of communities, but also impacts other aspects such as labor productivity, school attendance, and the costs associated with health care. In Cusco, infectious diseases related to the

consumption of unsafe water represent a challenge that not only affects the most vulnerable sectors, but also puts pressure on public and family budgets. This scenario shows the urgent need to evaluate the quality of drinking water and ensure compliance with the standards established by the Ministry of Health's water quality regulations for human consumption (DS No. 031-2010-SA). This regulation establishes permissible limits that must be strictly respected to avoid health risks and guarantee access to a vital resource in optimal conditions.

From a technical perspective, water quality is defined based on physical, chemical, microbiological, toxicological and radioactive parameters, according to the guidelines of the World Health Organization (WHO). In particular, the presence of microbial contaminants, such as fecal coliforms, *Escherichia coli* and *Salmonella*, is one of the main indicators of contamination and poses a direct threat to human health. On the other hand, physicochemical parameters such as turbidity, pH, hardness and the presence of sulfates and carbonates are also essential to determine the suitability of water for human consumption. The evaluation of these parameters not only allows the identification of sources of contamination, but also prioritizes corrective actions to guarantee the quality of water in the communities.

This research focuses on the physicochemical and microbiological evaluation of drinking water in five districts of the city of Cusco (Cusco, Santiago, Wanchaq, San Sebastián and San Jerónimo) during the years 2018 and 2019. This study seeks to answer the general question: What quality of drinking water is available in the city of Cusco during the period analyzed? In addition, it addresses specific issues such as identifying districts with better drinking water service and determining whether the parameters assessed meet the established permissible limits.

The purpose of this research is to generate accurate and up-to-date information that allows the competent authorities to implement effective monitoring and control strategies. It also seeks to raise awareness among the population about the importance of drinking water consumption and promote sustainable management of water resources. The detailed evaluation of physicochemical and microbiological parameters will not only identify possible risks, but also strengthen decision-making based on scientific evidence.

In this sense, the study is based on the hypothesis that the quality of drinking water in the city of Cusco complies with the permissible limits established by Supreme Decree No. 031-2010-SA, although with certain variations in specific parameters depending on the districts and the period analyzed. Confirming or refuting this hypothesis is essential to guide public policies that guarantee equitable and safe access to drinking water, especially in a context where climate change and human activities increasingly threaten the sustainability of water resources.

In conclusion, this research not only aims to contribute to scientific knowledge about the quality of drinking water in Cusco, but also to provide a solid basis for the design of policies and programs that strengthen water infrastructure and promote the well-being of communities. Drinking water is not only a basic resource, but an essential pillar for sustainable development and the improvement of people's quality of life.

2. General objective

To determine the physicochemical and microbiological quality of drinking water in the districts of Cusco during 2018 and 2019, evaluating its compliance with the permissible limits established by national regulations.

3. Methodology

Drinking water was collected in five districts of the city of Cusco (Cusco, Santiago, Wanchaq, San Sebastián and San Jerónimo) and the addresses were randomly chosen. Subsequently, the samples were taken to the accredited laboratories (Chemical Analysis Service of the UNSAAC, LAB BIOTEC, Microlab) for their corresponding analysis (microbiological and physicochemical analysis), where the regulation of the quality of water for human consumption of the Ministry of Health (DS No. 031 -2010-MINSA) was taken as a reference for the permissible limits.

3.1 Research design

A non-experimental, descriptive and explanatory design was adopted. No variables were deliberately manipulated; instead, the samples were observed and analyzed in their natural context to assess quality parameters.

3.2 Sampling

Drinking water samples were collected from five districts of the city of Cusco (Cusco, Santiago, Wanchaq, San Sebastián and San Jerónimo) during the years 2018 and 2019. The samples were selected in an intentional non-probabilistic manner, in order to adequately represent the water quality in each district.

3.3 Data collection techniques

- Observation was used to record parameters of interest.
- A desk analysis was conducted using national standards, such as Supreme Decree No. 031-2010-SA, as a reference for permissible limits.

3.4 Analysis of samples

The collected samples were subjected to physicochemical and microbiological analysis in accredited laboratories (Chemical Analysis Service of the UNSAAC, LAB BIOTEC and Microlab). The parameters evaluated included turbidity, pH, hardness, chlorides, sulfates, total dissolved solids, and the presence of fecal coliforms, among others.

3.5 Data processing and analysis

The results obtained from the analyses were consolidated in an Excel database to facilitate the comparison and evaluation of the measured parameters against the permissible limits established by the regulations.

3.6 Normative references

The permissible limits established by Supreme Decree No. 031-2010-SA of the Ministry of Health of Peru were taken as a reference, as well as international parameters proposed by the World Health Organization (WHO).

4. Results

	DISTRICT CUSCO	DISTRICT SAN JERÓNIMO	DISTRICT SANTIAGO	DISTRICT WANCHAQ	DISTRICT SAN SEBASTIÁN
Turbidity NTU	1,22	0,90	0,68	1,13	1,41
PH	7,61	7,67	7,63	7,62	7,62
C.E. $\mu\text{S}/\text{cm}$	402,75	978,50	794,50	814,50	972,75
Hardness ppm CaCO ₃	260,72	545,10	453,13	474,88	539,96
Calcium ppm	75,24	166,65	158,46	144,97	152,02
Magnesium ppm	17,14	28,05	22,66	26,34	24,04
PPM chlorides	31,10	126,50	100,85	95,22	116,83
Sulfates ppm	111,35	278,78	214,35	223,15	276,44
Baking soda ppm	158,45	308,18	249,50	212,65	220,78
Carbonates ppm	0	0	0	0	0
Iron ppm	0,103	0,17	0,14	0,14	0,17
S. Total soluble ppm	457,10	1034,55	858,16	816,00	1033,43

Table 1: Average physicochemical parameters for the different districts of the city of Cusco-2018

Source: Own elaboration

In 2018, the physicochemical quality of drinking water in the districts of Cusco showed general compliance with the permissible limits established by national regulations, except in San Jerónimo, where sulfate levels (278.78 ppm) exceeded the permitted limit of 250 ppm. Parameters such as turbidity, pH, electrical conductivity, chlorides, iron and total dissolved solids remained within acceptable ranges, although San Jerónimo presented values close to the limit in hardness (545.10 ppm) and dissolved solids (1034.55 ppm). These variations reflect local differences in mineral composition and possible geological influences, highlighting the need for constant monitoring and specific actions to ensure water quality in this district. In general, drinking

water was suitable for human consumption in all the districts evaluated, with the exception of the aforementioned parameters in San Jerónimo.

	DISTRICT CUSCO	DISTRICT SAN JERÓNIMO	DISTRICT SANTIAGO	DISTRICT WANCHAQ	DISTRICT SAN SEBASTIÁN
Viable mesolic bacteria (CFU/mL)	negative	Negative	Negative	negative	Negative
Total coliforms	NMP9/100mL	NMP9/100mL	Negative	NMP9/100mL	Negative
Fecal coliforms (CFU/mL)	0.1 X 10 ²	Negative	Negative	Negative	Negative
Thermotolerant coliforms (CFU/mL)	0.1 X 10 ²	Negative	Negative	Negative	Negative
Escherichia coli (CFU/mL)	Positive	Negative	Negative	Negative	Negative
Shigella (CFU/mL)	Negative	Negative	Negative	Negative	Negative
Salmonella (CFU/mL)	Negative	Negative	Negative	Negative	Negative
Microscopic algae	Not observed	Not observed	Not observed	Not observed	Not observed
Free-living protozoa	Not observed	Not observed	Not observed	Not observed	Not observed
, Inorganic detritus	Regular quantity	Scarce quantity	Scarce quantity	Scarce quantity	Scarce quantity

Table 2: Average of microbiological and microscopic parameters for the different districts of the city of Cusco-2018
Source: Own elaboration

In 2018, microbiological and microscopic analyses of drinking water in the districts of Cusco showed mostly positive results, with the absence of pathogenic bacteria such as *Shigella*, *Salmonella* and fecal coliforms in all districts, except in Cusco, where thermo-tolerant and fecal coliforms (0.1×10^2 cfu/ml) were detected in December, along with the presence of *Escherichia coli*. In addition, no microscopic algae or free-living protozoa were observed in any samples, and inorganic debris was recorded in scarce or regular amounts depending on the district. These results suggest that, although the microbiological quality of the water was adequate in most cases, the presence of microorganisms in Cusco represents a potential risk that requires immediate attention, highlighting the need to strengthen the treatment processes in that district.

PARAMETER	WANCHAQ	CUSCO	SN. SEBASTIAN	SANTIAGO	SN. JEROME
Turbidity NTU	1.13	1.96	2.19	2.41	2.55
PH	8.17	8.25	8.50	8.25	8.45
Electrical Conductivity μ S/cm	837.00	248.00	856.00	860.00	825.00
Hardness ppm CaCO ₃	540.00	163.7	522.00	527.00	495.00
Calcium ppm	167.20	50.16	167.20	163.40	152.00

Magnesium ppm	27.60	8.28	21.62	25.30	24.84
PPM chlorides	36.90	10.30	43.90	41.20	39.10
Sulfates ppm	392.50	91.40	396.10	406.20	388.60
Baking soda ppm	169.40	72.10	177.50	180.90	163.20
Carbonates ppm	0.00	0.36	2.32	0.50	2.16
Iron ppm	0.174	0.069	0.18	0.18	0.162
S. Total soluble ppm	878.9	282.609	891.70	896.30	858.20

Table 3: Average physicochemical parameters for the different districts of the city of Cusco-2019
Source: Own elaboration

In 2019, the physicochemical parameters of drinking water in the districts of Cusco showed general compliance with the established permissible limits, except for sulfate levels, which exceeded the permitted limit of 250 ppm in all districts, with particularly high values in Santiago (406.20 ppm) and San Sebastián (396.10 ppm). In addition, hardness was high in Wanchaq (540 ppm) and San Sebastián (522 ppm), approaching the limit of 500 ppm. The pH varied between 8.17 and 8.50, within the acceptable range, while the total dissolved solids, although they met the limit of 1000 ppm, presented high values in Santiago (896.30 ppm) and Wanchaq (878.9 ppm). These results highlight a general increase in physicochemical values compared to 2018, suggesting the influence of local factors and underscoring the need for continuous monitoring and treatment, especially in districts with critical levels of sulfates and hardness.

	DISTRICT CUSCO	DISTRICT SAN JERÓNIMO	DISTRICT SANTIAGO	DISTRICT WANCHAQ	DISTRICT SAN SEBASTIÁN
Viable mesolic bacteria (cfu/mL)	Negative	Negative	Negative	Negative	Negative
Total coliforms	Negative	Negative	Negative	Negative	Negative
Fecal coliforms (cfu/mL)	Negative	Negative	Negative	Negative	Negative
Thermotolerant coliforms (cfu/mL)	Negative	Negative	Negative	Negative	Negative
Escherichia coli (cfu/mL)	Negative	Negative	Negative	Negative	Negative
Shigella (cfu/mL)	Negative	Negative	Negative	Negative	Negative
Salmonella (cfu/mL)	Negative	Negative	Negative	Negative	Negative
Microscopic algae	Not observed	Not observed	Not observed	Not observed	Not observed
Free-living protozoa	Not observed	Not observed	Not observed	Not observed	Not observed
, Inorganic detritus	Not observed	Not observed	Not observed	Not observed	Not observed

Table 4: Average of microbiological and microscopic parameters for the different districts of the city of Cusco-2019
Source: Own elaboration

In 2019, the microbiological and microscopic results of drinking water in the districts of Cusco indicated an adequate sanitary quality, since no pathogenic bacteria such as *Escherichia coli*, *Shigella* or *Salmonella* were detected, nor total, fecal or thermo-tolerant coliforms in any of the samples analyzed. In addition, no microscopic algae or free-living protozoa were observed in the evaluated districts. These findings reflect an improvement compared to 2018, particularly in the district of Cusco, where microorganisms had previously been recorded. The absence of microbiological contaminants suggests that water treatment and distribution processes were effective during this period, ensuring a safe supply for human consumption. However, it is necessary to maintain constant monitoring to ensure the sustainability of these results.

	YEAR 2018	YEAR 2019	Permissible limit DS No. 031-2010-SA (*WHO-2006)
Turbidity NTU	1,07	1.65	5
PH	7,63	8.3	6,5 – 8,5
C.E. μ S/cm	792,60	725.2	1500
Hardness ppm CaCO ₃	454.76	449.54	500
Calcium ppm	139,47	140	60 -200 (*)
Magnesium ppm	23,65	24.53	20 – 30 (*)
PPM chlorides	94,10	26.28	250
Sulfates ppm	220,81	334.96	250
Baking soda ppm	229,91	152.62	200
Carbonates ppm	0	1.07	0
Iron ppm	0,14	0.15	0,3
S. Total soluble ppm	839,85	761.54	1000

Table 5: Average physicochemical parameters for the city of Cusco - years 2018 and 2019
Source: Own elaboration

The comparison of the physicochemical parameters of drinking water between 2018 and 2019 in the city of Cusco shows significant variations, although in general they remained within the permissible limits established by national regulations. In 2019, there was an increase in parameters such as turbidity (1.65 NTU vs. 1.07 NTU in 2018) and sulfates (334.96 ppm vs. 220.81 ppm in 2018), with the latter exceeding the allowable limit of 250 ppm. Likewise, the average pH increased slightly, reaching values closer to the upper limit allowed (8.3 compared to 7.63 in 2018). Although total dissolved solids and hardness decreased slightly on average, some districts continued to show values close to permissible limits, reflecting local differences in water quality. These results suggest that, despite mostly complying with the standards, certain critical parameters, such as sulfates, require specific attention to prevent health risks and ensure the sustainability of water quality in the region.

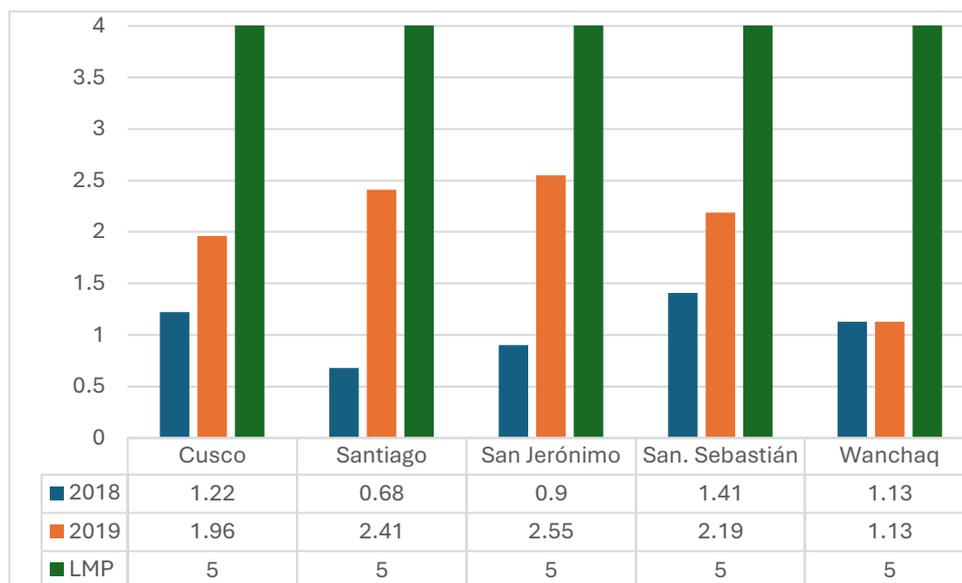


Figure 1. Turbidity (in NTU) of drinking water for the five districts in the years 2018 – 2019
LMP: maximum permissible limit (5pH)

Source: Own elaboration

Figure 1 shows that drinking water turbidity levels in the districts of Cusco remained below the maximum permissible limit of 5 NTU during 2018 and 2019, with an overall increase in 2019, with San Jerónimo (2.55 NTU) and San Sebastián (2.19 NTU) standing out as the districts with the highest values. Although levels remain within the allowable range, this increase could reflect local variations or deficiencies in water treatment, highlighting the need for continuous monitoring to ensure water quality.

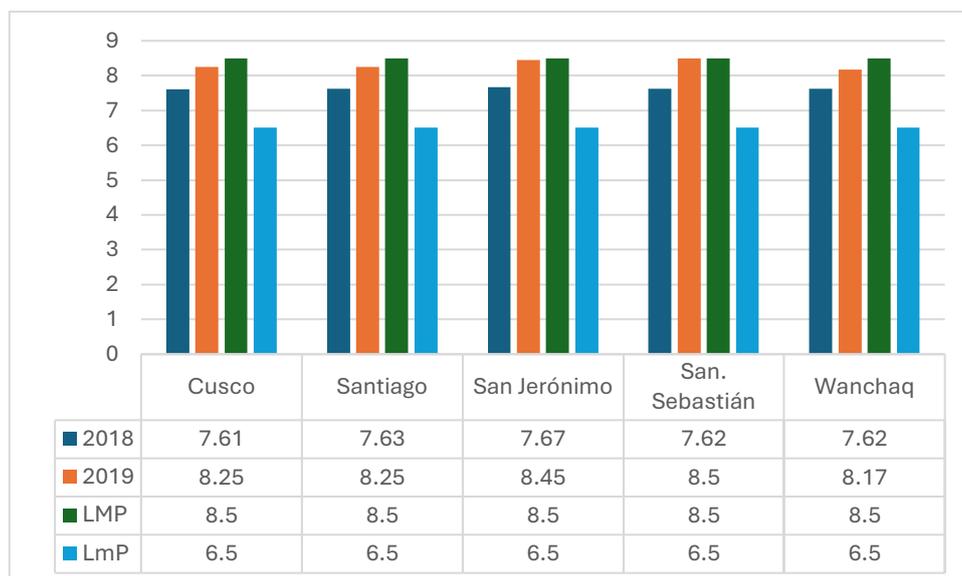


Figure 2. Degree of acidity (pH) of drinking water for the five districts in the years 2018 - 2019
(LMP: maximum permissible limit (8.5pH) - LmP: minimum permissible limit (6.5pH))

Source: Own elaboration

Figure 2 shows the pH values of drinking water in the districts of Cusco during 2018 and 2019, which remained within the permissible range of 6.5 to 8.5. In 2019, slight increases were observed compared to 2018, with values closer to the upper limit, with San Sebastián (8.50) and Santiago (8.45) standing out. These results indicate a drinking water with a neutral to slightly alkaline character, suitable for human consumption, although the increase in 2019 suggests the need for monitoring to prevent possible deviations outside the permitted range.

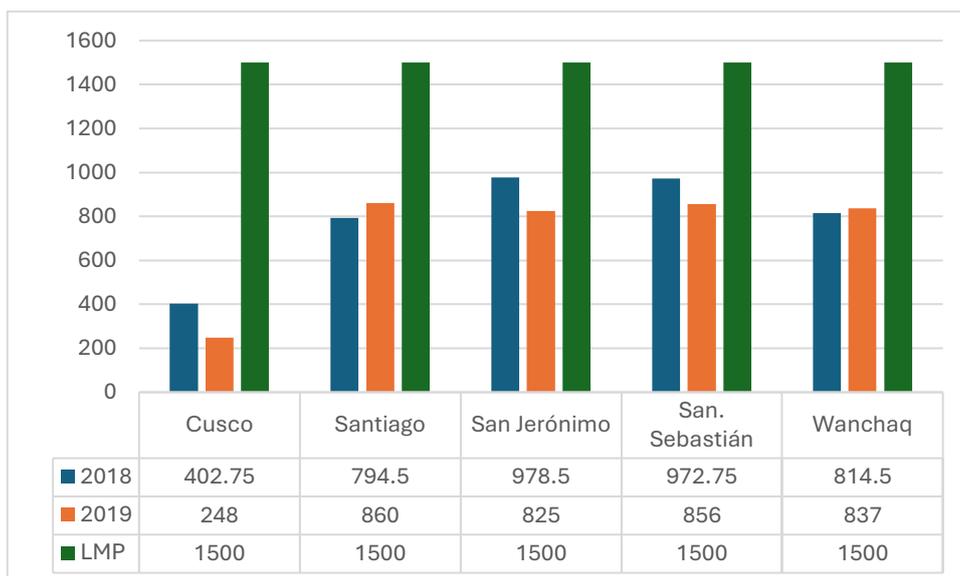


Figure 3. Electrical conductivity (in $\mu\text{S}/\text{cm}$) of drinking water for the five districts in the years 2018 – 2019 (LMP: maximum permissible limit ($1500 \mu\text{S}/\text{cm}$))
Source: Own elaboration

Figure 3 shows the electrical conductivity values of drinking water in the districts of Cusco during 2018 and 2019, which remained below the maximum permissible limit of $1500 \mu\text{S}/\text{cm}$. In both years, San Jerónimo and San Sebastián presented the highest values, although with a slight decrease in 2019. These differences reflect variations in the concentration of dissolved salts, probably related to local geological features. Despite meeting standards, continuous monitoring is necessary to ensure that these levels do not affect the perceived quality of drinking water.

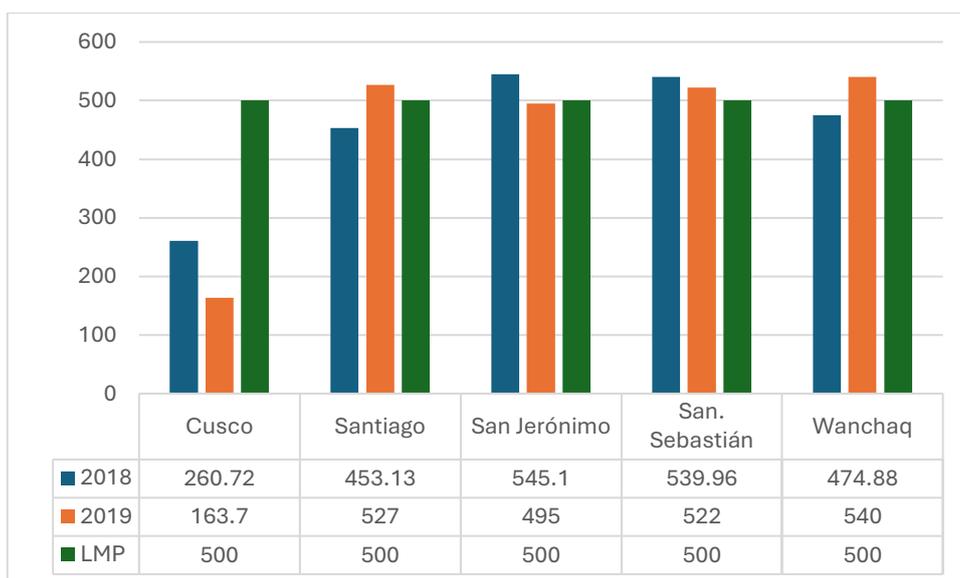


Figure 4. Hardness (in ppm CaCO_3) of drinking water for the five districts in the years 2018 – 2019 (LMP: maximum permissible limit of 500 ppm)
Source: Own elaboration

Figure 4 shows the levels of drinking water hardness in the districts of Cusco during 2018 and 2019, with values that remained within the maximum permissible limit of 500 ppm, except in Wanchaq and San Sebastián in 2019, where 540 ppm and 522 ppm were recorded, respectively. These results indicate an increase in the concentration of calcium and magnesium salts in some districts, which could affect water quality in terms of taste and scale formation. It is recommended to monitor these levels to prevent them from exceeding the permissible limits in a sustained manner.

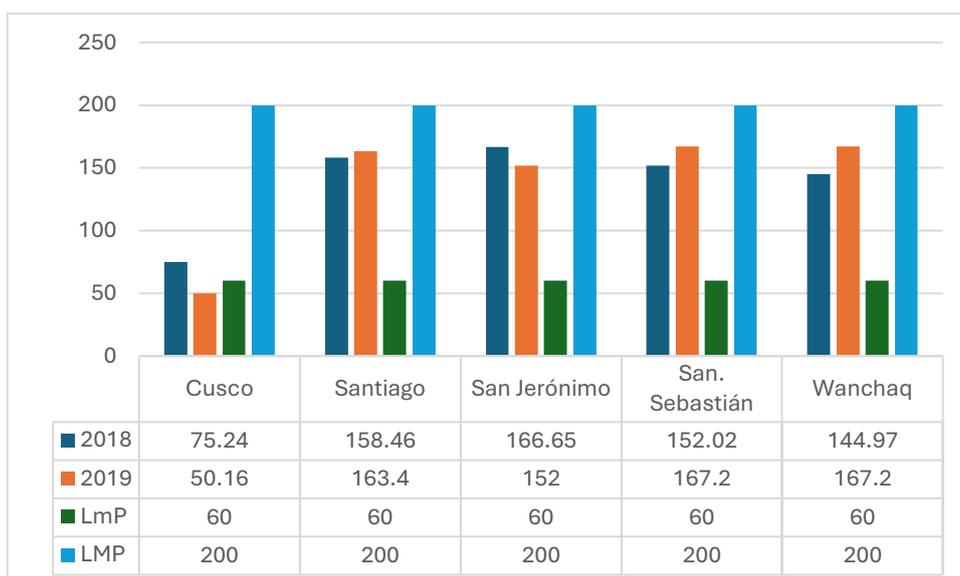


Figure 5. Calcium concentration (in ppm) of drinking water for the five districts in the years 2018 – 2019 (LMP: maximum permissible limit (200ppm) - LmP: minimum permissible limit (60ppm)) (LMP: maximum permissible limit of 500 ppm)

Source: Own elaboration

Figure 5 shows the levels of calcium in the drinking water of the districts of Cusco during 2018 and 2019, which remained within the permissible range of 60 to 200 ppm. In both years, San Jerónimo and San Sebastián presented the highest values, reaching 167.20 ppm in 2019. These levels reflect a significant contribution to water hardness, especially in districts with high values. Although the water is still fit for human consumption, it is essential to monitor this parameter to prevent cumulative effects that may impact perceived water quality.

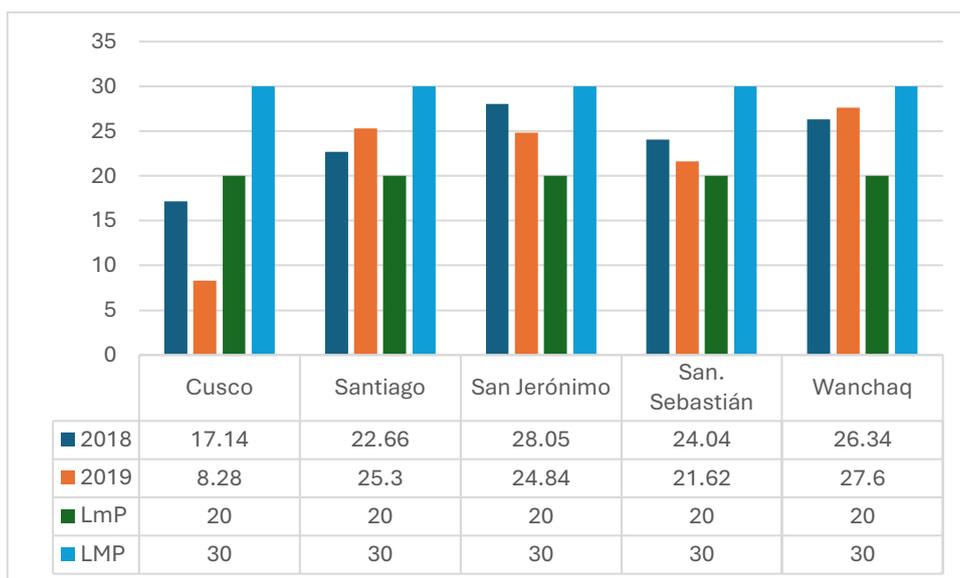


Figure 6. Magnesium concentration (in ppm) of drinking water for the five districts in the years 2018 – 2019 (LmP: minimum permissible limit (20ppm) -LMP: maximum permissible limit (30ppm))

Source: Own elaboration

Figure 6 shows the levels of magnesium in the drinking water of the districts of Cusco during 2018 and 2019, which remained within the permissible range of 20 to 30 ppm established by the WHO. In both years, the highest values were recorded in San Jerónimo and Wanchaq, reaching a maximum of 28.05 ppm in 2018 and 27.60 ppm in 2019. These results reflect a moderate contribution of magnesium to water hardness, without exceeding acceptable limits for human consumption, although its constant monitoring is important to ensure the stability of water quality.

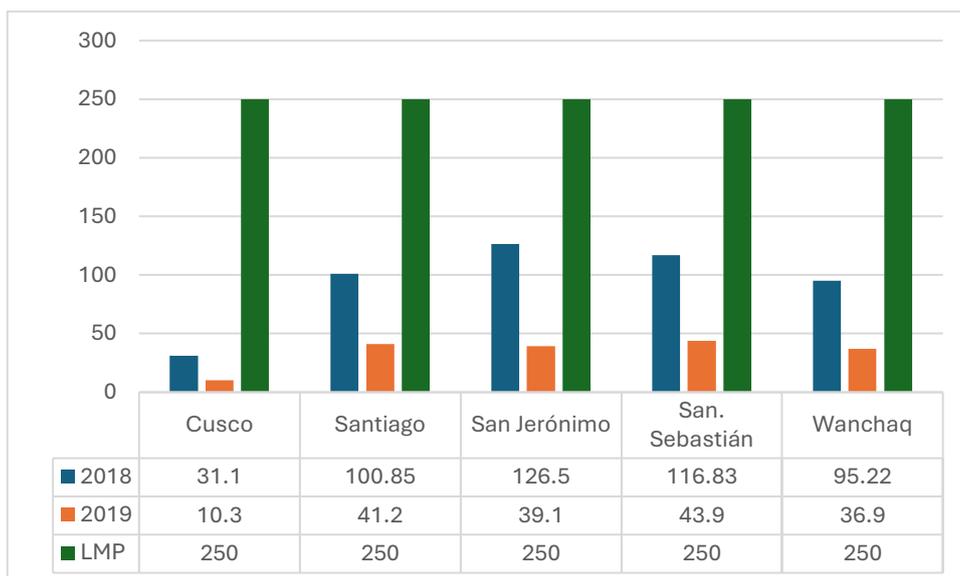


Figure 7. Magnesium concentration (in ppm) of drinking water for the five districts in the years 2018 – 2019 (LmP: minimum permissible limit (20ppm) -LMP: maximum permissible limit (30ppm))
Source: Own elaboration

Figure 7 shows the levels of chlorides in the drinking water of the districts of Cusco during 2018 and 2019, which remained below the maximum permissible limit of 250 ppm. In both years, San Jerónimo and San Sebastián registered the highest values, with a maximum of 126.50 ppm in 2018. These levels reflect adequate regulation of the saline content in drinking water, without implying significant health risks, although it is recommended to maintain regular monitoring to ensure its stability.

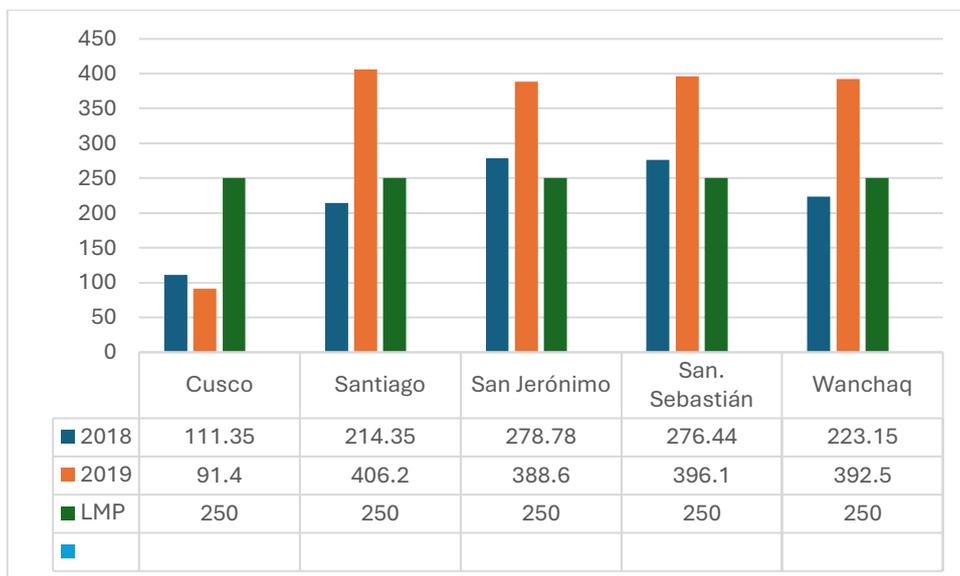


Figure 8. Sulfate concentration (in ppm) of drinking water for the five districts in the years 2018 – 2019
Source: Own elaboration

Figure 8 shows the levels of sulfates in drinking water in the districts of Cusco during 2018 and 2019. In 2019, all districts exceeded the maximum permissible limit of 250 ppm, reaching particularly high values in Santiago (406.20 ppm) and San Sebastián (396.10 ppm). These levels pose a potential risk to water quality and could be related to local geological features or treatment deficiencies. This significant increase highlights the need to implement corrective measures and ongoing monitoring to ensure the safety of drinking water.

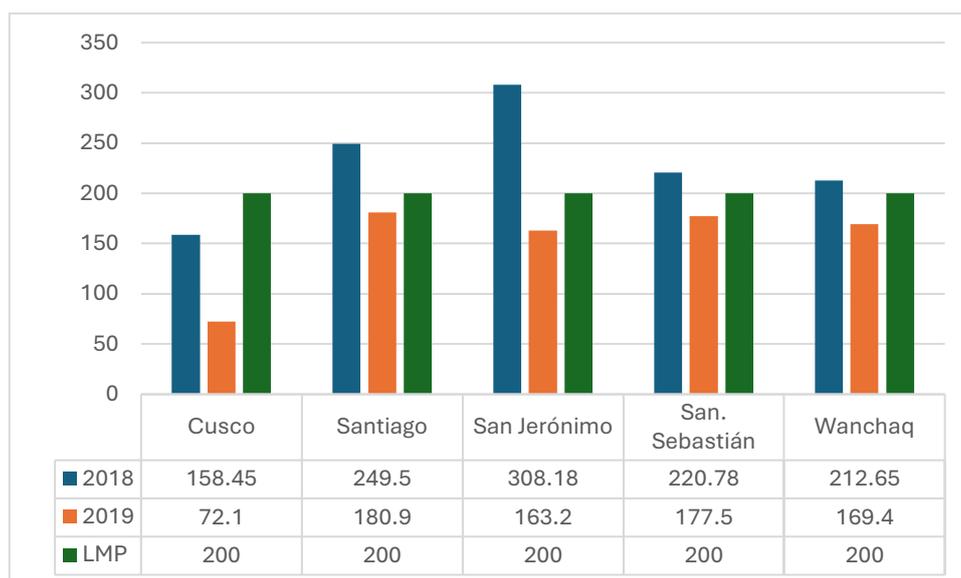


Figure 9. Bicarbonate concentration (in ppm) of drinking water for the five districts in the years 2018 – 2019 (LMP: maximum permissible limit 200ppm)

Source: Own elaboration

Figure 9 shows the levels of bicarbonates in the drinking water of the districts of Cusco during 2018 and 2019. In 2018, all districts presented values within the maximum permissible limit of 200 ppm, but in 2019 significant increases were observed in some districts, such as San Sebastián (177.50 ppm) and Santiago (180.90 ppm), approaching the established limit. Although these values do not yet represent a critical risk, the observed increase suggests the need for constant monitoring to prevent permissible limits from being exceeded and to ensure the stability of water quality.

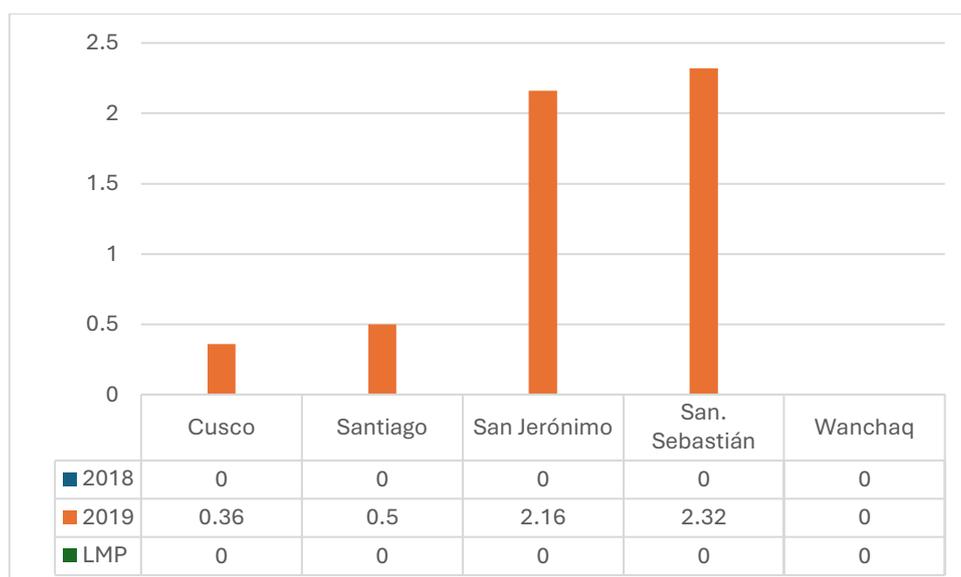


Figure 10. Carbonate concentration (in ppm) of drinking water for the five districts in the years 2018 – 2019 (LMP: maximum permissible limit 0ppm)

Source: Own elaboration

Figure 10 shows the levels of carbonates in the drinking water of the districts of Cusco during 2018 and 2019. In 2018, no carbonates were recorded in any of the districts, but in 2019 low values were observed, although detectable, in some districts, highlighting San Sebastián (2.32 ppm) and San Jerónimo (2.16 ppm). These values, although lower, indicate a slight change in the chemical composition of the water, which could be associated with local factors. Although the permissible limits are not exceeded, it is important to monitor this parameter to ensure stability in water quality.

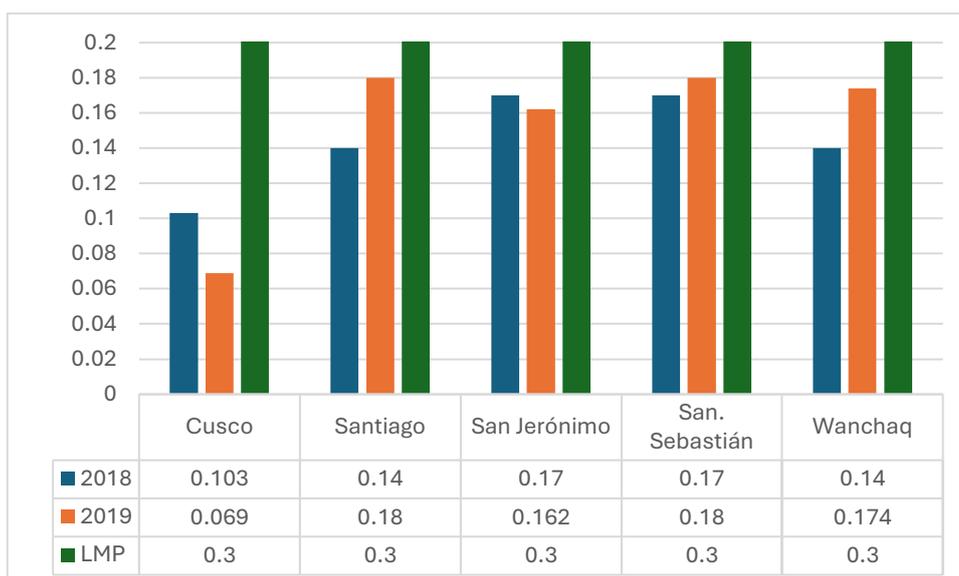


Figure 11. Iron concentration (in ppm) of drinking water for the five districts in the years 2018 – 2019 (LMP: maximum permissible limit 0.3ppm)
Source: Own elaboration

Figure 11 shows the levels of iron in the drinking water of the districts of Cusco during 2018 and 2019, which remained below the maximum permissible limit of 0.3 ppm. The values ranged from 0.069 ppm in Cusco to 0.18 ppm in San Sebastian in 2019. These results indicate a low concentration of iron in drinking water, which is favorable to avoid problems with taste, color or formation of residues in the pipes. Despite safe values, continuous monitoring is recommended to prevent fluctuations that may compromise water quality.

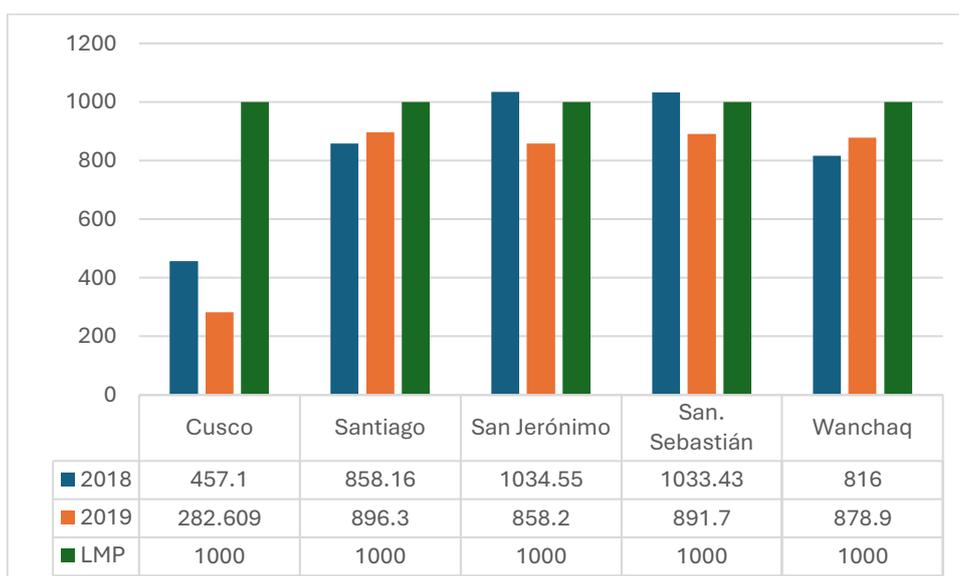


Figure 12. Total soluble solids concentration (in ppm) of drinking water for the five districts in the years 2018 – 2019 (LMP: maximum permissible limit 1000ppm)
Source: Own elaboration

Figure 12 shows the levels of total dissolved solids (TDS) in the drinking water of the districts of Cusco during 2018 and 2019, which remained below the maximum permissible limit of 1000 ppm, except in San Jerónimo in 2018, where 1034.55 ppm were recorded. In 2019, values decreased slightly in all districts, although San Jerónimo and San Sebastián continued to present levels close to the limit. These results reflect a moderate mineralization of drinking water in some districts, which could affect the perception of water quality and taste. Constant monitoring is necessary in districts with high values to ensure compliance with established standards.

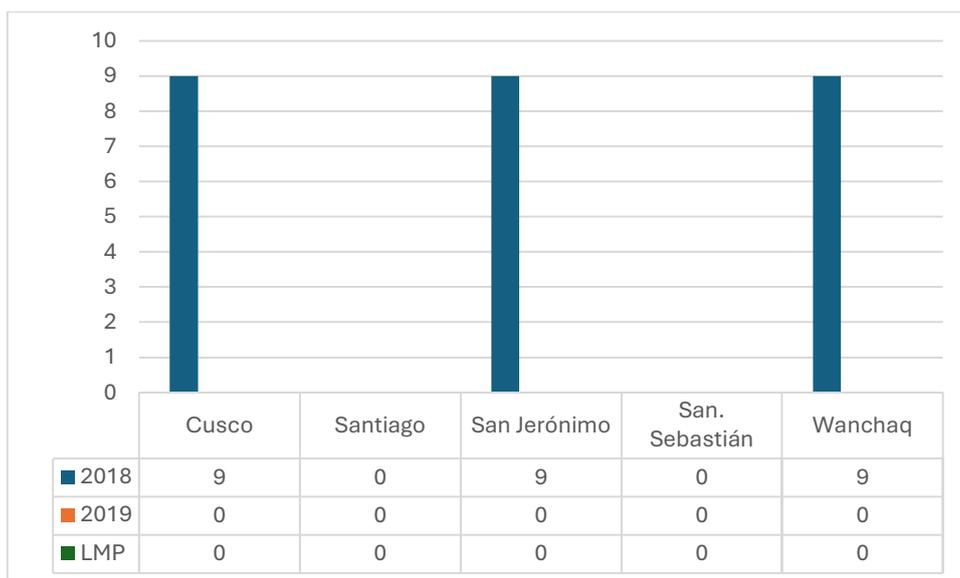


Figure 13. Total coliform concentration (in MPN/100ml) of drinking water for the five districts in the years 2018 – 2019 (LMP: maximum permissible limit 0 MPN/100ml)
Source: Own elaboration

Figure 13 shows the levels of total, fecal and thermo-tolerant coliforms in the drinking water of the districts of Cusco during 2018 and 2019. In 2019, no coliforms were detected in any of the districts, while in 2018, the district of Cusco presented positive values of fecal and thermo-tolerant coliforms (0.1×10^2 cfu/ml). This result reflects a significant improvement in microbiological water quality in 2019, likely due to better treatment or distribution practices. However, the 2018 finding underscores the importance of maintaining constant monitoring to prevent potential risks of microbiological contamination in drinking water.

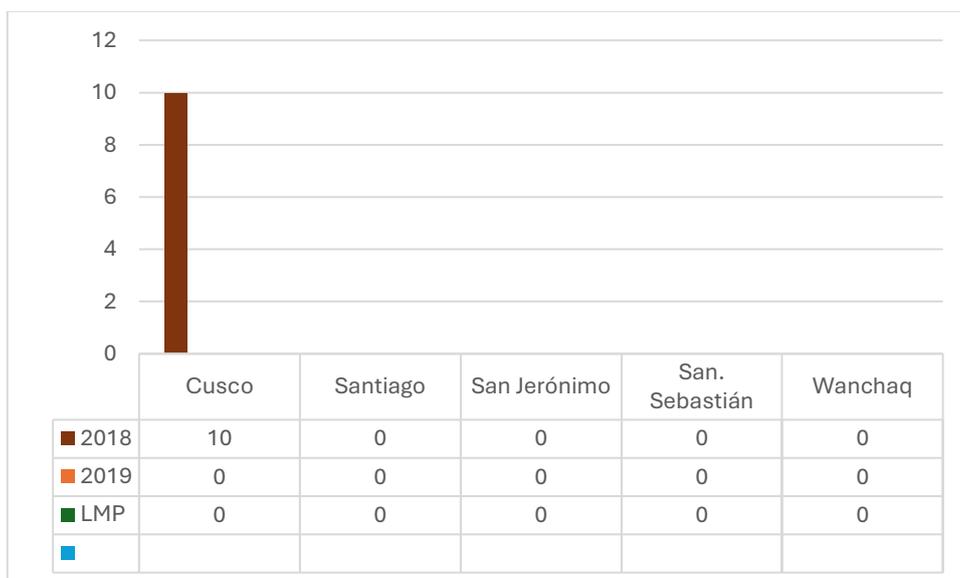


Figure 14. Fecal coliform concentration (in CFU/ml) of drinking water for the five districts in the years 2018 – 2019 (LMP: maximum permissible limit 0CFU/ml)
Source: Own elaboration

Figure 14 shows the levels of thermo-tolerant coliforms in the drinking water of the districts of Cusco during 2018 and 2019. In 2019, no thermo-tolerant coliforms were detected in any of the districts, while in 2018 positive levels were recorded only in the

district of Cusco (0.1×10^2 cfu/ml). This result indicates an improvement in the microbiological control of drinking water in 2019, suggesting advances in water treatment or distribution processes. Despite this improvement, it is crucial to maintain constant monitoring to ensure the sustainability of these results and prevent potential public health risks.

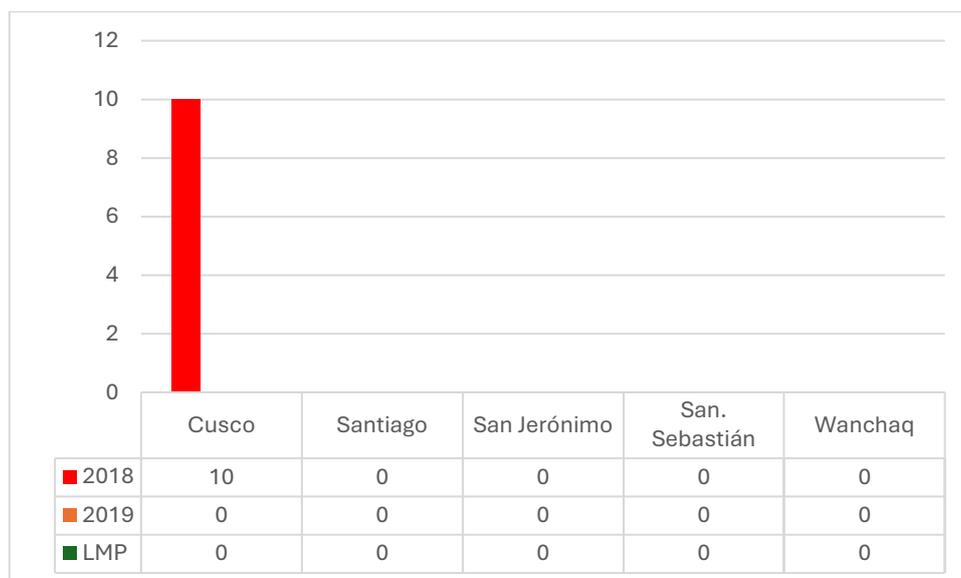


Figure 15. Concentration of thermo-tolerant coliforms (in CFU/ml) of drinking water for the five districts in the years 2018 – 2019 (LMP: maximum permissible limit 0CFU/ml)
Source: Own elaboration

Figure 15 shows the levels of fecal coliforms in the drinking water of the districts of Cusco during 2018 and 2019. In 2019, no fecal coliforms were detected in any of the districts, while in 2018, the district of Cusco presented positive levels (0.1×10^2 cfu/ml). This finding shows a significant improvement in the microbiological quality of water in 2019, reflecting possible advances in treatment and distribution processes. However, the 2018 result highlights the importance of maintaining constant monitoring to prevent recurrences and ensure the microbiological safety of drinking water.

4.1 Discussion

The results obtained reflect a significant evolution in the quality of drinking water in the city of Cusco during the period 2018-2019, with a general compliance with the permissible limits established by national regulations. In physicochemical terms, parameters such as pH, electrical conductivity, turbidity, iron and chlorides were consistently within acceptable ranges, indicating adequate management of water sources and treatment processes. However, a notable increase in sulfate levels and hardness was observed in some districts, particularly in San Jerónimo and San Sebastián. These results may be due to local geological factors, such as the mineral composition of the soil, or to deficiencies in treatment systems. In 2019, sulfate levels exceeded permissible limits in all districts, raising concerns about the sustainability of water quality and the need to implement targeted corrective measures.

In terms of microbiological quality, the results show a significant improvement in 2019 compared to 2018. During 2018, the district of Cusco presented detectable levels of fecal and thermo-tolerant coliforms, as well as the presence of *Escherichia coli*, which evidenced microbiological contamination that could be related to failures in distribution or storage systems. However, in 2019, no total, faecal or thermo-tolerant coliforms were detected in any district, suggesting advances in treatment processes or health control measures. This change is crucial for the protection of public health, as coliforms are indicators of potential faecal contamination and the presence of pathogens that can cause gastrointestinal illness. However, the variability of the results between years underscores the importance of maintaining constant monitoring to prevent the reappearance of microbiological contaminants.

Overall, the findings highlight the need to strengthen water quality management and monitoring strategies in Cusco. Observed increases in critical parameters such as sulfates, hardness, and total dissolved solids in some districts could compromise perceived water quality and long-term safety. In addition, although the improvement in microbiological quality is a positive development,

the history of contamination in 2018 underscores the vulnerability of the supply system. Therefore, it is essential to implement a comprehensive plan that includes the modernization of treatment infrastructure, strict monitoring of critical parameters, and education of the population on safe water management practices in households. These actions will guarantee a safe and sustainable drinking water supply for the population of Cusco.

5. Conclusions

During 2018 and 2019, the physicochemical and microbiological parameters of drinking water in the evaluated districts of Cusco remained mostly within the permissible limits established by Supreme Decree No. 031-2010-SA, which evidences an adequate management of water quality in general terms. However, critical parameters were identified, such as sulfate levels in 2019, which exceeded the permitted values in all districts, highlighting Santiago and San Sebastián, highlighting the need to evaluate water sources and treatment processes to mitigate the presence of chemical contaminants. Likewise, significant variations were observed between districts, attributable to geological factors and differences in treatment infrastructure, with San Jerónimo and San Sebastián being the districts with the highest values of hardness and total dissolved solids.

In the microbiological aspect, a significant improvement was observed in 2019, with the total absence of fecal and thermo-tolerant coliforms in all the districts evaluated. This contrasts with the results of 2018, where microbiological contaminants were detected in the Cusco district, likely due to deficiencies in distribution systems. These findings underscore the importance of maintaining strict control measures and continuous monitoring to prevent health risks that could compromise the health of the population.

Overall, this study highlights the need to implement constant and rigorous monitoring of the physicochemical and microbiological parameters of drinking water, with special attention to the most vulnerable districts. It is essential that local authorities strengthen treatment infrastructure, prioritize the monitoring of critical parameters and promote education of the population on the proper management of water in households. These actions, combined with effective public policies and a comprehensive approach to water management, will contribute not only to ensuring a safe and sustainable supply, but also to improving the quality of life of the population of Cusco.

Bibliographic references

1. Arauzo, G. (2007). *Acid rain in central Peru*.
2. Cabrera, R., & Robles, E. (1997). Preliminary assessment of the public health impact of selected communities exposed to pollution and air pollutants.
3. Enkerlin, E., & Mier, M. (1997). Soil and water. *Environmental Science and Sustainable Development*, 126-150.
4. Garza, R. A., & Enkerlin, E. (1997). Natural populations and their characteristics. *Environmental Science and Sustainable Development*, 126-150.
5. Garza, C. R., & Gonzáles, L. (1997). Principles of environmental science. *Environmental Science and Sustainable Development*, 99-124.
6. Hedin, L., & Likens, G. (1997). Atmospheric dust and acid rain. *Research and Science*. Barcelona: Scientific Press.
7. Hernández, A. J. (1987). Ecology student collective. Spain: UNCEA S.A.
8. Keniseth, F. H. (2007). Environmental disturbances of human origin. Canada.
9. Scragg, A. (1999). Environmental Monitoring: Environmental Biotechnology, 27-55.
10. Seoánes, M. (2002). Volcanoes and the climate. *Treatise on Climatology Applied to Environmental Engineering: Climate Analysis and its Use in Environmental Studies*, 427-431.