**Water Quality in Small-Scale Coffee Production Units, Amazonas, Peru**

1,2,3Eli Morales Rojas, 3Segundo Chávez Quintana, 3Magali García, 2,3Jaris Veneros, 2Manuel Oliva, 2José Carlos Santa Cruz Guerrero, 4Manuel Emilio Milla Pino, 5Alex Lenin Guivin Guadalupe and 6Tito Sanchez Santillan

1Faculty of Natural and Applied Sciences, Universidad Nacional Intercultural Fabiola Salazar Leguí de Bagua, Bagua, Peru
2Instituto de Investigación para el Desarrollo Sustentable de Ceja de Selva, Universidad Nacional Toribio Rodríguez de Mendoza, Chachapoyas, Peru
3Department of Ecology, Montana State University, Bozeman, Montana, United States
4Faculty of Engineering, National University of Jaén, Cajamarca, Peru
5Professional School of Global Business Administration, Universidad Nacional Intercultural Fabiola Salazar Leguí de Bagua, Bagua, Peru
6Instituto de Investigaciones de la Amazonía Peruana, Iquitos, Peru
7Institute of Data Sciences, National University of Jaén, Cajamarca, Peru

**Abstract:** The objective of this research was to determine water quality in small-scale coffee production units in the Amazon Region, Peru. The characterization of the factors associated with coffee farmers was collected through surveys. The Standard Methods for the Examination of Water and Wastewater (APHA) method was used to determine the physicochemical and microbiological parameters of the incoming water (AE) (water for human consumption) and the outgoing water (AS) (wastewater from coffee washing). The results indicated that the coffee growers do not have adequate technology for washing the coffee and that they use water for these activities. In the characterization of the water, significant differences were found between the parameters of the AE and the AS, where the pH of the AE ranged from 7.00 to 7.32 and the pH of the AS from 3.76 to 4.44. The turbidity of the AS showed high values of 1814.47 NTU. Total Coliforms (TC) and heavy metals such as copper and chromium all increased in value up to 0.20 and 0.15 ppm in the AS compared to the AE. The characteristics of the water quality consumed by the coffee growers are poor and values above Peruvian standards were found.

**Keywords:** Coffee Fermentation, Water Quality, Coffee Growers, Technology

**Introduction**

Farmers are exposed to perceived economic, health, and lifestyle risks reflected in water quality (Bohnet, 2015). Areas with polluted water are a high health risk compared to less polluted areas (Withanachchi et al., 2018). During the last years, the deterioration of drinking water in rural areas has increased (Yermolenko et al., 2021), so the state has the responsibility to improve water quality (Miranda et al., 2010).

The wet milling of coffee generates coffee honey water with high organic matter content, directly impacting water, flora, fauna, and soils (Torres-Valenzuela et al., 2019). Water quality conditions for coffee washing are deficient, the parameters are not standardized, and coffee growers extract water from nearby streams or others (Akenroye et al., 2021). It is also known that large volumes of water are used during coffee washing, generating associated socio-environmental impacts on water bodies (Ruiz-Najera et al., 2021). In this sense, economic and easy-to-apply technologies should be adopted (Hernández-Sarabia et al., 2021). An important factor is training in good coffee washing practices, through modified tanks that provide good water use during washing (Lopez Blanco, 2014). Water quality and bad practices in coffee washing influence the quality of the coffee bean and as a consequence, the loss of income is devalued by its quality (Fernández-Cortés et al., 2020). Agricultural
technologies have technical and environmental advantages; however, the high cost of the technology and the economic conditions of producers make it impossible to mass-market them (Sanz et al., 2011).

In the Amazon region, water quality in small-scale coffee production units has not been studied. The quality of the water consumed by coffee growers is unknown and the characteristics of the residual water after coffee washing are unknown. Based on the above, the objective was to determine the quality of water in small-scale coffee production units in the districts of Cajaruro and Pisuquía, Amazonas region, Peru.

Materials and Methods

Location

The study was conducted in the hamlets of San Isidro and Nuevo Belén in the district of Cajaruro, which has 25,104 inhabitants (INEI, 2017). The selection of farms was carried out in the annexes of Paujamarca at 2069 masl and Milagros at an altitude of 2080 masl, belonging to the district of Pisuquía. While the towns of San Isidro are at an altitude of 990 masl, Nuevo Belen 985 masl (Fig. 1), these towns are located on the right bank of the Utcubamba River (Morales-Rojas et al., 2021). The soils of the selected farms present adequate physical characteristics to promote coffee growing, in terms of depth, texture, and structure (Minagri, 2019).

UTM coordinates were taken with GPS model GPSMAP 66i-GARMIN (Table 1). Coffee is one of the alternative crops in the Cajaruro district, with one of the main livelihood crops being maize (Aguilar Carranza, 2021). While the towns of Paujamarca and Milagros in the district of Pisuquía are characterized as being considered the main coffee producers in the province of Luya (Guevara Alvarado, 2014). Pisuquía has an estimated population of over 5,175 people (INEI, 2017).

Characterization of Small Coffee Farmers (Coffee Washing and Harvesting Practices)

Data were collected through surveys of small coffee farmers in the four selected communities in the Amazon region of Peru. The visits were made at the end of the 2021 coffee harvest (August and September). The surveys were composed of the following questions: What is your level of education? Are you associated with a cooperative? What is the source of water for washing coffee? What is the technology used for washing coffee? Is the water used for washing coffee the same as the water used for human consumption? How many hectares of coffee do you cultivate? What is the coffee production system? What is the percentage of women's participation in the harvest? How many cans of coffee does a laborer harvest on average per day? How many hours is coffee left to ferment after pulping? How many cans of cherry coffee is a quintal? Is coffee the main subsistence crop? The survey was applied to those producers that cultivate more than half a hectare of coffee. The questionnaire was validated following the "Expert Judgment" guidelines.

Selection of Coffee Samples for Physicochemical and Microbiological Characterization

To standardize the coffee sample, half a can of cherry coffee (10 kg) was harvested from the selected coffee farms, pulped, and left to ferment for 12 h. The pulped coffee (1.5 kg) was used in a container with a capacity of 20 liters, the bucket was gauged with 15 liters of water, and from this residual water, called output water (AS), the sample was collected for physicochemical and microbiological analysis. Samples of the incoming water (AE) with which the coffee was washed were also collected.

To determine the physical, chemical, and microbiological parameters, water samples were taken at the inlet and outlet during the 2021 coffee season, during the months of March, April, May, and August. The collection, storage, and transfer of the samples, as well as the laboratory analysis, were carried out according to Apha (2017).

The pH was measured in situ with a Hanna multiparametric water meter model HI 98194, while samples for determining the physicochemical parameters of Electrical Conductivity (EC), turbidity, Dissolved Oxygen (DO), alkalinity, cadmium, copper, chromium, lead, and zinc was collected in transparent plastic containers. Samples for microbiological analysis of Total Coliforms (TC) were collected in properly sterilized glass bottles with a capacity of 500 mL. These were transported in a cooler with dry ice at a temperature of 5°C. The parameters were analyzed at the Water and Soil Laboratory of the Research Institute for Sustainable Development of Ceja de Selva (INDES-CES) of the National University Toribio Rodríguez de Mendoza (UNTRM). The AE results were compared with the water quality standard for human consumption (031-2010-SA). Likewise, the AS, a product of coffee washing, was compared with the environmental quality standards (ECA), given that these standards contemplate the concentration levels of elements, substances, and physical, chemical, and biological parameters present in the water as a receiving body.

Statistical Analysis

The surveys were processed using the Excel spreadsheet, expressed in bar graphs. For the experimental units, two measurements were made for each of the variables, the sample size was less than 30 and the population variance is unknown; therefore, a T-student test for related or paired samples was applied to determine the existence or not of statistically significant differences between the first and second group of observations. The software used was Minitab 17 (Custodio and Chanamé, 2016).
San Isidro and Nuevo Belén, where the quality of the coffee exceeds the water used. This may be influenced by altitudinal conditions, because it is known that the lack of these services conditions the presence of different types of diseases among small coffee growers (Cabezas, 2002). In this sense, these should be improved, as the result of the characterization of the coffee growers evaluated show that 80% of the coffee growers have primary education and 20% have secondary education. All of the coffee growers in Nuevo Belén are not members of any cooperative, while Milagros and Paujamarca have 56 and 22% of members. The source of water used to wash the coffee comes from piped water in San Isidro and Nuevo Belén, and the water used for human consumption is the same water used to wash the coffee. Regarding the technology used to wash the coffee, 35% of the farmers use concrete tanks, while the majority of the population washes their coffee in the open air (sacks stored on the ground). In this sense, these should be improved, taking into account engineering, which has played an important role in developing technologies that have allowed water reduction (Oliveros-Tascón and Sanz-UrIBE, 2011).

Table 1: UTM coordinates the coffee farms for the districts of Cajaruro and Pisuquia, Amazonas

| East          | West          | Altitude (msnm) | Sampling point |
|---------------|---------------|-----------------|----------------|
| 818083.00     | 9291738.598   | 2069            | Paujamarca     |
| 818224.00     | 9290765.000   | 2080            | Milagros       |
| 8114289.64    | 9350273.020   | 990             | San Isidro     |
| 813782.05     | 9351152.890   | 985             | Nuevo Belén    |

Fig. 1: Location map of the four coffee farms sampled

Results and Discussion

Characterization of the Evaluated Coffee Farms

The results of the characterization of the coffee growers evaluated show that 80% of the coffee growers have primary education and 20% have secondary education. All of the coffee growers in Nuevo Belén are not members of any cooperative, while Milagros and Paujamarca have 56 and 22% of members. The source of water used to wash the coffee comes from piped water in San Isidro and Nuevo Belén, and the water used for human consumption is the same water used to wash the coffee. Regarding the technology used to wash the coffee, 35% of the farmers use concrete tanks, while the majority of the population washes their coffee in the open air (sacks stored on the ground). In this sense, these should be improved, taking into account engineering, which has played an important role in developing technologies that have allowed water reduction (Oliveros-Tascón and Sanz-UrIBE, 2011).

Table 2 shows that irrigated coffee production is minimal and even San Isidro does not have any irrigation. In the annexes of Milagros and Paujamarca, the participation of women in the coffee harvest ranges between 40 and 38.00% compared to San Isidro and Nuevo Belen, where the participation of women is 80%. Showing great similarity with the study by Martelo and Beutelspacher (2010), who mentions that women’s participation in the coffee harvest was 86%, however, they are excluded from the benefits derived from commercialization and other personal development opportunities.

Harvest progress per laborer is 3-5 cans/day for the Milagros and Paujamarca annexes. In San Isidro and Nuevo Belén it is 3-4 cans/day. Coffee fermentation in Milagros and Paujamarca is usually left to ferment for an average of 18-24 h. In Nuevo Belén and San Isidro, the fermentation of pulped coffee ranges between 12 and 18 h. The amount of cans of cherry coffee needed to obtain a quintal of gold coffee (50 kg) is an average of 17 cans of cherry coffee for Milagros and Paujamarca. For Nuevo Belen and San Isidro, they need an average of 19 cans of cherry coffee to produce one quintal (50 kg). This may be influenced by altitudinal characteristics, as it has been shown that the higher the altitude, the higher the quality of the coffee (Martins et al., 2020).

Table 3 shows the descriptive statistics for the physicochemical and microbiological parameters, showing that the maximum pH of the AE was 7.27 and that of the AS was 4.44. The AE showed an alkaline pH, which may be due to the limestone that promotes the formation of carbonates and bicarbonates. The AS results show an acid pH, which is associated with the organic matter and dissolved solids in the coffee mucilage (Torres-Valenzuela et al., 2019).

The turbidity of the AS is high for all the sampled sites, reaching 1814.47 NTU. While for the AE the maximum value reached 9.17 NTU, a value that exceeds the water quality standard for human consumption. Turbidity values increased in the AS, which could be directly associated with the discharge of coffee mucilage, which contains suspended particles of different diameters (Fereja et al., 2020). The dissolved oxygen of the AE ranges from 7.29 to 7.83 mg/L, while for the AS it decreases its value to 0.19 mg/L. The decrease of DO in AS could be associated with coffee mucilage. Consequently, oxygenation systems should be included to degrade organic matter and not decrease the DO (Radzi et al., 2020). It is important to maintain the DO because it is important for living beings (Breitburg et al., 1997). Total coliforms showed high values in all samples, however, the highest values occurred in AS, reaching up to 4515.33 NMP/100 mL. The water consumed by the villagers is the same water used to wash the coffee and this water is contaminated by TC and heavy metals, which is above Supreme Decree N° 031-2010-SA. In this sense, it is necessary for the population to have access to safe water and basic sanitation, because it is known that the lack of these services conditions the presence of different types of diseases among small coffee growers (Cabezas, 2002). In Peru,
especially the urban and rural population consumes piped water from different water sources, which is transported and stored in reservoirs where sometimes calcium hypochlorite solution is added as a disinfectant. It is then distributed through the piped network to households (Choque-Quispe et al., 2021).

The electrical conductivity of piped water for human consumption ranged between 30 and 1115 mS/cm. While coffee honey water values were higher, ranging between 938.67 and 1137 mS/cm. The electrical conductivity of water depends on the water temperature: The higher the temperature, the higher the electrical conductivity (Solís-Castro et al., 2018).

Alkalinity showed low values in AE, which is consumed by coffee farmers and is between 107.28 and 333.76 CaCO$_3$, compared to AS up to 27058.40 CaCO$_3$. The increase in alkalinity can be attributed to the effect of coffee mucilage, studies describe that alkalinity is determined by the ability to neutralize acids (Lecca, 2013).

The TC values ranged between 552.00 and 1600 NMP, these values correspond to the water of the four towns analyzed, which allowed determining the quality of the water, concerning the indicators of fecal contamination (Ishii and Sadowsky 2008). In that sense, water with TC generates infections in people, causing a significant health risk, for this they must perform a conventional or special type of treatment depending on the magnitude of contamination in both the AE and the AS for this, the Regulation of Water Quality for Human Consumption should be contemplated (DIGESA, 2010; Chibinda et al., 2017).

Concerning cadmium in the EC, high values were reported for San Isidro and Nuevo Belén. While for the AS the values decreased to 0.01 mg/L. Therefore, it is observed that the intake of water is the highest in cadmium and requires prevention measures since cadmium in the resources natural resources can pose a serious threat to the ecosystem and human health through the food web (Zhang et al., 2017). High concentrations can happen due to domestic and industrial activities, as well as urban (sewage) and agricultural runoff (Kilunga et al., 2017).

The highest copper values correspond to the AE in the towns of Paujamarca and Milagros, ranging from 0.22 to 0.16 mg/L. While the copper values for the AS were 0.01 mg/L. The presence of copper in coffee residues may occur due to the application of copper-based fungicides used in the control of coffee diseases and this also applies to the concentration of copper in nearby surface waters (Chanakya and De Alwis, 2004). Heavy metals, such as cadmium, copper, and chromium, are evidenced in the EC with lower values compared to the outflow water, which increases the values. It is important to note that the EC is above the water quality regulations for human consumption and that the AS is also above the environmental quality standards.

The lead had a marked behavior between AE and AS, having minimum values for AE with values of 0.02 mg/L and AS 0.28 mg/L. Drinking water can be a source of lead poisoning when acidic water is combined with a system of lead pipes, as well as lead naturally (Blanco Hernández et al., 1998). Lead can affect systems, organs, and tissues and its effect can be proportional to the amount present in the organism (Poma, 2013). Lead can also change the alkalinity of the soil and decrease its productivity and can even lead to desertification (Pamela et al., 2014).

Zinc in the EC showed minimum values of 0.01 mg/L, while the maximum value for the AS was 0.36 mg/L. The presence of zinc in drinking water above the permitted limits is considered hazardous to human health, the presence of zinc can be caused by anthropogenic activities including oil burning, industrialization, and urbanization (Zahra et al., 2015). Zinc also occurs naturally in the earth's crust and is considered a vital component necessary for plants in adequate concentrations (Futalan et al., 2019).

Fig. 2: Relationship of coffee fermentation hours with pH, H/Fer = Hours of fermentation of pulped coffee (A); Relationship between the number of cans of cherry coffee harvested per worker and the amount of dry coffee for the yield of one kintal.
Table 2: Coffee washing and harvesting characteristics

| Characteristics of coffee growers | Milagros | Paujamarca | Nuevo Belén | San Isidro |
|-----------------------------------|----------|------------|-------------|------------|
| Irrigated coffee production       | 37.5%    | 22.2%      | 11.1%       | 0%         |
| Coffee production without irrigation | 62.5%    | 77.7%      | 88.9%       | 100%       |
| Women's participation in the harvest | 40%      | 38.0%      | 60%         | 65%        |
| Males in the harvest              | 60%      | 62.0%      | 40%         | 35%        |
| Daily wage cost                   | S/20-30  | S/20-30    | S/20-30     | S/20-30    |
| Average number of harvested cans of coffee per worker | 5-5 lata/día | 5-5 lata/día | 3-4 lata/día | 3-4 lata/día |
| Fermentation hours after pulping  | 18-24 h  | 18-24 h    | 12-18 h     | 12-18 h    |
| Cans of cherry coffee to obtain one quintal | 17.00 | 17.300   | 19.00       | 19         |

Table 3: Results of the physicochemical and microbiological parameters (averages ± standard deviation)

| Location | pH (Unit) | Turbidity (NTU) | DO (mg/L) | EC (μS/cm) | Alkalinity (mg/L, CaCO3) | TC (mg/L) | CNVMP (mg/L) | Cadmium (mg/L) | Copper (mg/L) | Chrome (mg/L) | Lead (mg/L) | Zinc (mg/L) |
|----------|-----------|-----------------|-----------|------------|--------------------------|-----------|-------------|----------------|--------------|--------------|-------------|-------------|
| M1       | 7.24±0.46 | 1.8±0.000.25    | 7.20±0.2 | 130.47±0.38 | 107.28±11.92             | 1600.0±0.00 | 0.01±0.00   | 0.02±0.01     | 0.03±0.00    | 0.26±0.02    | 0.01±0.01   |
| P1       | 3.84±0.38 | 1814.47±66.51   | 0.30±0.13 | 938.67±165.39 | 1271.67±0790.05 | 1079.67±001.24 | 0.02±0.01  | 0.16±0.05    | 0.01±0.00    | 0.26±0.02    | 0.07±0.06   |
| S1       | 3.56±0.23 | 3147.77±205.22  | 0.26±0.15 | 1137.00±163.05 | 1271.67±0790.05 | 4513.3±660.74 | 0.01±0.00  | 0.22±0.15    | 0.01±0.00    | 0.27±0.15    | 0.03±0.03   |
| S2       | 7.00±0.30 | 0.40±0.000.46    | 7.53±0.62 | 1115.00±629.60 | 335.7±31.34             | 20000.0±000.00 | 0.01±0.00   | 0.02±0.01     | 0.01±0.00    | 0.12±0.04    | 0.02±0.01   |
| N1       | 4.58±0.26 | 524.43±289.83   | 0.35±0.12 | 1315.33±274.70 | 2705.60±385.34          | 60000.0±000.00 | 0.01±0.00   | 0.10±0.02     | 0.01±0.00    | 0.43±0.09    | 0.06±0.28   |
| ACH      | 7.32±0.21 | 1.45±0.000.90   | 7.8±0.45  | 753.00±65.58  | 313.8±9.73              | 1144.7±158.77 | 0.01±0.00  | 0.10±0.01     | 0.04±0.06    | 0.07±0.06    | 0.02±0.01   |
| ECA      | 6.44±0.06 | 885.23±958.43   | 0.19±0.10 | 1157.00±165.05 | 917.6±1287.64          | 1503.7±345.74 | 0.04±0.05  | 0.16±0.26     | 0.28±0.18    | 0.03±0.02    | 0.03±0.02   |

ACh-1: Regulation of Water Quality for Human Consumption; ECA-Environmental Quality Standards

Table 4: Correlation between parameters

| Parameters | Correlation |
|------------|-------------|
| pH1 and pH2 | 0.41286     |
| Turbidity 1 and Turbidity 2 | 0.09231     |
| DO1 and DO2 | -0.31548    |
| EC1 and EC2 | 0.77097     |
| Alkalinity 1 and Alkalinity 2 | 0.26651     |
| TC1 and TC2 | -0.34714    |
| Cadmium 1 and Cadmium 2 | 0.27406     |
| Copper 1 and Copper 2 | -0.40103    |
| Chrome 1 and Chrome 2 | 0.99841     |
| Lead 1 and Lead 2 | -0.19485    |
| Zinc 1 and Zinc 2 | -0.03678    |

*Significant differences (alpha value)

Table 5: Significant differences in parameters

| Matched differences parameters | Media | Confidence interval | Lower confidence interval upper | t | Sig. (bilateral) |
|--------------------------------|-------|---------------------|-------------------------------|---|-----------------|
| pH1 - pH2                     | 2.8750000 | 2.663553 | 3.086456 | 28.124657 | 0.000* |
| Turbidity 1 - Turbidity 2     | -1589.816700 | -2171.442532 | -1008.19081 | -5.654471 | 0.000* |
| DO1 - DO2                     | 7.2150000 | 6.954084 | 7.475916 | 57.203683 | 0.000* |
| EC1 - EC2                     | -419.183330 | -554.859030 | -283.507637 | -6.391320 | 0.000* |
| Alkalinity 1 - Alkalinity 2    | -1520.967000 | -2338.447758 | -702.485576 | -3.844848 | 0.001* |
| TC1 - TC2                     | -1329.430000 | -2767.310546 | 108.450546 | -1.912631 | 0.068* |
| Cadmium 1 - Cadmium 2         | -0.0187500 | -0.035178 | -0.020322 | -2.361039 | 0.027* |
| Copper 1 - Copper 2           | -0.1214667 | -0.181132 | -0.067201 | -4.509035 | 0.000* |
| Chrome 1 - Chrome 2           | -0.0300000 | -0.070339 | 0.010339 | -1.538454 | 0.138* |
| Lead 1 - Lead 2               | -0.2250000 | -0.314211 | -0.135789 | -5.217367 | 0.000* |
| Zinc 1 - Zinc 2               | -0.1008333 | -0.179688 | -0.021978 | -2.645233 | 0.014* |

*show significant differences (P<0.05); ns no significant differences (P>0.05)

Table 4 shows the correlation of physicochemical and microbiological parameters, where the correlation is positive for turbidity, pH, EC, Alkalinity, Cadmium, and Chromium. This reflects that the AE and AS parameters move in the same direction. Whereas DO, TC, Copper, Lead, and Zinc showed a negative correlation.

Table 5 shows the significant differences in the paired parameters, whereas for TC, Cadmium, and Chromium no significant differences are shown. However, all other parameters show significant differences.

Figure 2 shows the relationship between the average hours of coffee fermentation in both zones studied, where the r2 is 0.8 (Fig. 2A), as well as the relationship that exists between the amount of cherry coffee harvested per
worker/day and the yield of dry coffee, the approximate relationship is 0.85 (Fig 2B). In relation to the hours of coffee fermentation, it is evident that the shorter the fermentation time the pH of the AS increases, studies mention that the pH is a function of the fermentation time and is a potentially reliable parameter to measure the progress and end point of fermentation (Lee et al., 2015).

Conclusion

Coffee syrup water proved to be contaminated for the water, by increasing the values of physicochemical and microbiological parameters. There were also significant differences between the parameters evaluated in both districts (Cajaruro and Pisuquia). From the characterization of the coffee growers, it was found that there are differences in the fermentation times for coffee washing, this may be conditioned to the altitude between the farms in the district of Cajaruro and Pisuquia, as well as the water consumed by the coffee growers is piped without potabilization, the same water is used for coffee washing. No treatment is applied to the AS and when it is discharged, it causes high contamination. Therefore, coffee growers should receive constant training on the impact that coffee processing generates on the environment, to raise their awareness.

Acknowledgment

The authors acknowledge and thank the support of the Instituto de Investigación para el Desarrollo Sustentable de Ceja de Selva (INDES-CES) of the Universidad Nacional Toribio Rodríguez de Mendoza de Amazonas (UNTRM).

Funding Information

The authors acknowledge and thank the funding of the CEINCAFE Public Investment Project (SNIP N° 352439), executed by the Research Institute for the Sustainable Development of Ceja de Selva (INDES-CES) of the National University Toribio Rodríguez de Mendoza of Amazonas (UNTRM).

Author’s Contributions

Eli Morales Rojas, Segundo Chávez Quintana and Magali García: Conceptualization, drafted, and revision of the final version.

Jaris Veneros and Manuel Oliva: Manuscript preparation, statistical analysis, and final version edited.

José Carlos Santa Cruz Guerrero: Designed and laboratory analysis of samples, and review of the final draft.

Manuel Emilio Milla Pino: Methodology, project management, resources, software, validation, and data visualization.

Alex Lenín Guivín Guadalupe and Tito Sanchez Santillan: Manuscript writing, data collection, analysis, and project management. Finally, all authors have read and accepted the final version of the manuscript.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all authors have read and approved the manuscript and that there are no ethical issues.

References

Aguilar Carranza, M. (2021). Plan de cultivo de productos alternativos para mejorar la rentabilidad de los agricultores en el centro poblado Naranjos Alto, Cajaruro–2019. https://hdl.handle.net/20.500.14077/2402
Akenroye, T. O., Dora, M., Kumar, M., Elbaz, J., Kah, S., & Jebli, F. (2021). A taxonomy of barriers to the adoption of sustainable practices in the coffee farming process. Journal of Cleaner Production, 312, 127818. https://doi.org/10.1016/j.jclepro.2021.127818
Apha, A. W. (2017) Standard Methods for the examination of water and wastewater. 23rd ed. Washington, 2017. 1504 p.
Blanco Hernández, A. L., Alonso Gutiérrez, D., Jiménez de Blas, O., Santiago Guervós, M., & Miguel Manzano, B. D. (1998). Estudio de los niveles de plomo, cadmio, zinc y arsénico, en aguas de la provincia de Salamanca. Revista española de salud pública, 72, 53-65.
Bohnet, I. C. (2015). Lessons learned from public participation in water quality improvement planning: A study from Australia. Society & Natural Resources, 28(2), 180-196. https://doi.org/10.1080/08941920.2014.941446
Breitburg, D. L., Loher, T., Pacey, C. A., & Gerstein, A. (1997). Varying effects of low dissolved oxygen on trophic interactions in an estuarine food web. Ecological Monographs, 67(4), 489-507.
Chanakya, H. N., & De Alwis, A. A. P. (2004). Environmental issues and management in primary coffee processing. Process Safety and Environmental Protection, 82(4), 291-300. https://doi.org/10.1205/095758204323162319
Chibinda, C., Arada-Pérez, M. D. L. A., & Pérez-Pompa, N. (2017). Caracterización por métodos físico-químicos y evaluación del impacto cuantitativo de las aguas del Pozo la Calera. Revista cuBANA DE QUÍMICA, 29(2), 303-321. http://scielo.sld.cu/pdf/ind/v29n2/ind10217.pdf.
Choque-Quispe, D., Froehner, S., Ligarda-Samaniez, C. A., Ramos-Pacheco, B. S., Peralta-Guevara, D. E., Palomino-Rincón, H., & Zamalloa-Puma, L. M. (2021). Insights from Water Quality of High Andean Springs for Human Consumption in Peru. Water, 13(19), 2650. https://doi.org/10.3390/w13192650

Custodio, M., & Chanamé Zapata, F. C. (2016). Análisis de la biodiversidad de macroinvertebrados bentónicos del río Cunas mediante indicadores ambientales, Junín-Perú. Scientia Agropecuaria, 7(1), 33-44. https://doi.org/10.17268/sa.agropecu.2016.01.04

DIGESA. (2010). Digesa. In Reglamento De Calidad Del Agua Para Consumo Humano (Issue 9, pp. 1689–1699).

Fereja, W. M., Tagesse, W., & Bentí, G. (2020). Treatment of coffee processing wastewater using Moringa stenopetala seed powder: Removal of turbidity and chemical oxygen demand. Cogent Food & Agriculture, 6(1), 1816420. https://doi.org/10.1080/23311932.2020.1816420

Fernández-Cortés, Y., Soto-Rodríguez, K. D., & Vargas-Marín, L. A. (2020). Environmental impacts from coffee production and to the sustainable use of the waste generated. Producción + Limpia, 15(1), 93-110. https://doi.org/10.22507/PML.V15N1A7

Futalan, C. M., Kim, J., & Yee, J. J. (2019). Adsorptive treatment via simultaneous removal of copper, lead and zinc from soil washing wastewater using spent coffee grounds. Water Science and Technology, 79(6), 1029-1041. https://doi.org/10.2166/wst.2019.087

Guevara Alvarado, H. M. (2014). Plan de negocio para mejorar la producción y comercialización de café orgánico de la asociación de productores agropecuarios del distrito de Pisuquía, provincia de Luya, Región Amazonas-2013.

Hernández-Sarabia, M., Sierra-Silva, J., Delgadillo-Mirquez, L., Ávila-Navarro, J., & Carranza, L. (2021). The Potential of the Biodigester as a Useful Tool in Coffee Farms. Applied Sciences, 11(15), 6884. https://doi.org/10.3390/app11156884

INEI. (2017). Peru: Crecimiento y distribucion de la poblacion total, 2017. Poblacion censada mas poblacion omitida. Journal of Chemical Information and Modeling 53(9), p. 76. https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1673/libro.pdf

Instituto Nacional de Estadística e Informática. (2017). Evolución Pobreza 2007 a 2016 informe técnico., pp. 1–179. https://www.iie.org.pe/portal/evolucion-de-la-pobreza-monetarya-2007-2016/

Ishii, S., & Sadowsky, M. J. (2008). Escherichia coli in the environment: Implications for water quality and human health. Microbes and Environments, 23(2), 101-108. https://doi.org/10.1264/jsme2.23.101

Kilunga, P. I., Sivalingam, P., Laffite, A., Grandjean, D., Mulaji, C. K., De Alencastro, L. F., ... & Poté, J. (2017). Accumulation of toxic metals and organic micro-pollutants in sediments from tropical urban rivers, Kinshasa, Democratic Republic of the Congo. Chemosphere, 179, 37-48. https://doi.org/10.1016/j.chemosphere.2017.03.081

Lecca, E. R. (2013). Tratado del agua y la legislación peruana. Industrial Data, 16(2), 106-117. https://www.redalyc.org/pdf/816/81632390013.pdf

Lee, L. W., Cheong, M. W., Curran, P., Yu, B., & Liu, S. Q. (2015). Coffee fermentation and flavor–An intricate and delicate relationship. Food chemistry, 185, 182-191. http://doi.org/10.1016/j.foodchem.2015.03.124

Lopez Blanco, C. (2014). Optimización del uso del agua en el lavado del café en los tanques de fermentación (Doctoral dissertation). http://hdl.handle.net/123456789/4049

Martins, P. M. M., Batista, N. N., Miguel, M. G. D. C. P., Simão, J. B. P., Soares, J. R., & Schwan, R. F. (2020). Coffee growing altitude influences the microbiota, chemical compounds and the quality of fermented coffees. Food Research International, 129, 108872. https://doi.org/10.1016/j.foodres.2019.108872

Minagri. (2019). Requerimientos Agroclimáticos del cultivo de café. Ministerio De Agricultura Y Riego, 3–4. https://cdn.www.gob.pe/uploads/document/file/419904/ficha-tecnica-11-cultivo-cafe.pdf

Miranda, M., Aramburú, A., Junco, J., & Campos, M. (2010). Situación de la calidad de agua para consumo en hogares de niños menores de cinco años en Perú, 2007-2010. Revista peruana de medicina Experimental y Salud Pública, 27, 506-511. https://doi.org/10.1590/s1726-46342010000400003

Moraless-Rojas, E., Chávez-Quintana, S., Hurtado-Burga, R., Milla-Pino, M., Sanchez-Santillán, T., & Collazos Silva, E. M. (2021). Macrofauna edáfica asociada al cultivo de maíz (Zea maíz). Journal of the Selva Andina Biosphere, 9(1), 15-25. https://doi.org/10.36610/j.jsab.2021.090100015

Oliveros-Tascón, C. E., & Sanz-Uribe, J. R. (2011). Ingeniería y café en Colombia. Revista de Ingeniería, (33), 99-114. https://doi.org/10.16924/revinge.33.10

Pamela, K., Ledezma, R., Pedro, C., & Revilla, E. (2014). Heavy Metal Contamination. Heavy Metal Contamination of Water and Soil, 51-51. https://doi.org/10.1201/b16566-4

Poma, P. A. (2008, June). Intoxicacion por plomo en humanos. In Anales de la Facultad de Medicina (Vol. 69, No. 2, pp. 120-126). UNMSM. Facultad de Medicina. https://doi.org/10.15381/anales.v69i2.1155
Radzi, M. E. Z. M., Wahab, M. S., Sahdan, M. Z., Hamdan, R., & Zakariah, R. A. (2020). Gravitational aeration tower filter system to increase the dissolved oxygen amount for iron removal in groundwater. International Journal of Integrated Engineering, 12(3), 207-215. https://doi.org/10.30880/ijie.2020.12.03.024

Ruiz-Nájera, R. E., Medina-Meléndez, J. A., Carmona-de la Torre, J., Rincón-Enríquez, G., Sánchez-Yáñez, J. M., & Raj-Aryal, D. (2021). Effect of the disposal of coffee wet milling residues on the physical and chemical characteristics of natural flowing water. Terra Latinoamericana, 39. https://doi.org/10.28940/TERRA.V39I0.884

Sanz, J. R., C. E., Ramírez, C. A., López, U., & Velásquez, J. (2011). Control de los flujos de café y agua en el módulo BECOSUB. Centro Nacional de Investigaciones de Café (Cenicafé). http://hdl.handle.net/10778/40

Solís-Castro, Y., Zúñiga-Zúñiga, L. A., & Mora-Alvarado, D. (2018). La conductividad como parámetro predictivo de la dureza del agua en pozos y nacientes de Costa Rica. Revista Tecnología en Marcha, 31(1), 35-46. https://doi.org/10.18845/tm.v31i1.3495

Torres-Valenzuela, L. S., Sanín-Villacorta, A., Arango-Ramírez, A., & Serna-Jiménez, J. A. (2019). Caracterización fisicoquímica y microbiológica de aguas mieles del beneficio del café. Revista Ion, 32(2), 59-66. https://doi.org/10.18273/revion.v32n2-2019006

Withanachchi, S. S., Kunchulia, I., Ghambashidze, G., Al Sidawi, R., Urushadze, T., & Ploeger, A. (2018). Farmers’ perception of water quality and risks in the Mashavera River Basin, Georgia: Analyzing the vulnerability of the social-ecological system through community perceptions. Sustainability, 10(9), 3062. https://doi.org/10.3390/su10093062

Yermolenko, V., Hafurova, O., Deineha, M., Novak, T., Temnikova, A., & Naidansuren, E. (2021). Quality of drinking water in rural areas: Problems of legal environment. In E3S Web of Conferences (Vol. 280, p. 09022). EDP Sciences. https://doi.org/10.1051/e3sconf/202128009022

Zahra, N., Butt, Y. N., & Nisa, A. U. (2015). Biological and Physiochemical Techniques for the Removal of Zinc from Drinking Water: A Review. Pakistan Journal of Analytical & Environmental Chemistry, 16(2), 10. http://pjaec.pk/index.php/pjaec/article/view/

Zhang, G., Bai, J., Xiao, R., Zhao, Q., Jia, J., Cui, B., & Liu, X. (2017). Heavy metal fractions and ecological risk assessment in sediments from urban, rural and reclamation-affected rivers of the Pearl River Estuary, China. Chemosphere, 184, 278-288. http://doi.org/10.1016/j.chemosphere.2017.05.155