Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268 (Print copies up to 2016)
e-ISSN: 2395-3454
Vol. 23 | No. 2 | pp. 899-909 | 2024
Original Research Paper
https://doi.org/10.46488/NEPT.2024.v23i02.025
Open Access Journal

Seasonal Variability of Water Quality for Human Consumption in the Tilacancha Conduction System, Amazonas, Peru

Jaris Veneros*(**), Llandercita Cuchca Ramos*(***), Malluri Goñas*(****), Eli Morales***, Erick Auquiñivín-Silva******, Manuel Oliva* and Ligia García*†**

*Instituto de Investigación para el Desarrollo Sustentable de Ceja de Selva, Universidad Nacional Toribio Rodríguez de Mendoza de Amazonas, Chachapoyas 01001, Perú
**Department of Ecology, Montana State University, 1156-1174 S 11th Ave, Bozeman, Montana 59715, USA
***Instituto de Investigación en Ingeniería Ambiental (INAM), Universidad Nacional Toribio Rodríguez de Mendoza de Amazonas, Chachapoyas 01001, Perú
****Centro Experimental Yanayacu, Dirección de Supervisión y Monitoreo en las Estaciones Experimentales Agrarias, Instituto Nacional de Innovación Agraria (INIA), Carretera Jaén San Ignacio KM 23.7, Jaén 06801, Cajamarca, Perú
*****Facultad de Ciencias Naturales y Aplicadas, Universidad Nacional Intercultural Fabiola Salazar Leguía de Bagua, Bagua, Perú
******Facultad de Ingeniería y Ciencias Agrarias, Universidad Nacional Toribio Rodríguez de Mendoza de Amazonas, Chachapoyas 01001, Perú
†Corresponding author: Ligia García; ligia.garcia@untrm.edu.pe

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 08-09-2023
Revised: 29-10-2023
Accepted: 08-11-2023

Key Words:
Water quality
Microbiological parameters
Physical parameters
Chemical parameters
Maximum permissible limits

ABSTRACT

This study evaluated the seasonal variability of water quality in the Tilacancha River, the water source that supplies Chachapoyas, and the rural communities of Levanto and San Isidro del Maino of Perú. Eighteen physical, chemical, and microbiological water parameters were evaluated at five sampling points in two seasons (rainy and dry). To determine water quality, the results obtained for the parameters evaluated were compared with the Maximum Permissible Limits (MPL) established in the Regulation on Water Quality for Human Consumption (DS Nº 031-2010-SA), approved by the Environmental Health Directorate of the Ministry of Health. In addition, a Pearson correlation was performed to estimate the correlation between the variables evaluated. The results showed that microbiological parameters exceeded the MPLs in both periods evaluated, such as the case of total coliforms (44 MPN.100 mL^{-1}), fecal coliforms (25 MPN.100 mL^{-1}), and E. coli (5.45 MPN.100 mL^{-1}), these microbiological parameters reported a positive correlation with turbidity, temperature, total dissolved solids, and flow rate. In addition, aluminum (Al) and manganese (Mn) exceeded the MPL in the rainy (0.26 mg Al.L^{-1}) and dry (1.41 mg.Mn^{-1}.L^{-1}) seasons, respectively. The results indicated that the water of the Tilacancha River is not suitable for human consumption. Therefore, it must be treated in drinking water treatment plants to be used as drinking water.

INTRODUCTION

Population growth and economic development have affected the quantity and quality of the water sources that supply human beings (Tognelli et al. 2016). However, mountain ecosystems represent large water reserves. They are exposed to high human pressure, which threatens the supply of this elemental liquid for its different uses (Wiegandt 2008). Therefore, anthropic activity is one of the main causes of damage to the hydrogeomorphological quality of river systems (Rojas-Briceño et al. 2020). The high vulnerability to water scarcity can lead to the forced migration of millions of people or the overexploitation of these ecosystems, causing negative impacts on the water resources (Messerli et al. 2004). Therefore, the studies of mountain water systems and the inclusion of the population settled in the lowlands are of great relevance since 7% of these ecosystems provide water resources and 37% other environmental services (Formica et al. 2015). In addition, the alterations that may occur in the headwaters of river basins have repercussions in the lower parts of the basin (Pino et al. 2017) and result in the degradation of water resources, climate, hydrological conditions, ecosystems, and soils, among others (Perez et al. 2018).

The Tilacancha Private Conservation Area (PCA) is home to the Tilacancha and Cruzhuayco sub-basins, two important sources of water supply, for the city of Chachapoyas, which has a population of approximately 32 589 inhabitants as of 2017 and for the surrounding rural communities (Arellanos 2018, Lucich et al. 2014, Salas et al. 2018). In addition, the Tilacancha PCA provides important ecosystem services related to the provisioning and regulation of water quantity and quality; this provisioning service depends on precipitation, horizontal catchment of remnant forests and grasslands, surface runoff, and aquifers, while quality and quantity regulation services will depend on the soil structures through which water percolates and on the storage capacity of the soil, respectively (Seitz 2015).

The PCA land cover, which is represented by 74.5% grassland, 14.8% forest, 5.2% shrubland, and 4.1% pine forest, is being threatened by deforestation, grassland burning, agriculture, and cattle ranching (CONDESAN 2014) since deforestation rate of 2.06% has been reported in recent years (Salas et al. 2018). In addition, it was reported that the presence of livestock grazing (cattle, horses), wild animals, and land use changes contribute to coliforms and sediments in the river water (Arellanos 2018). In addition, EMUSAP S.R.L (Municipal Company for Drinking Water and Sewerage Services, Chachapoyas, Amazonas) measurements of the amount of water or water flow in recent years report that the rate of water flow has been decreasing (Lucich et al. 2014). Given this scenario, in 2013, EMUSAP, with the support of the National Superintendence of Sanitation Services (SUNASS), developed the Mechanisms of Rewards for Ecosystem Services (MRSE) in the Tilacancha PCA to achieve efficiency in the integrated management of the basin and to serve as a means of compensation through projects and actions for the rural communities of Levanto and Maino, for the conservation of water bodies (Lucich et al. 2014); therefore, EMUSAP S.R.L. has been investing in activities oriented to the implementation of programs aimed at education and training for the conservation of natural resources (SUNASS 2015).

On the other hand, water quality is a key determinant of human well-being and is closely related to health and economic growth (Baque-Miite et al. 2016, Villena 2018). This is essential for countries to establish measures and strategies to achieve sustainable development, taking into account the sanitary situation of the population and the protection of water bodies for their different uses (Villena 2018). Thus, for the quality control of drinking water, several countries have adopted or developed standards and tools based on the determination of concentrations of physical, chemical, and microbiological parameters provided by the World Health Organization (WHO) (Rodriguez-Alvarez et al. 2017). Peru is one of the countries with the greatest vulnerability to the impacts of climate change on the quantity and quality of water resources. The national government promotes key decisions to counteract these threats to human health, damage to ecosystems, and economic development (Aquino 2017).

Peru also has two regulations for drinking water consumption. The first is the D.S N° 004-2017-MINAM, which approves the Environmental Quality Standards (ECA) for water (MINAM 2017), and the second is the Regulation of Water Quality for Human Consumption D.S N° 031-2010-SA (MINSA 2010), The first standard establishes the requirements to be met by water bodies according to the category of use designated by the National Water Authority (ANA), while the second establishes the Maximum Permissible Limits (MPL) for microbiological, parasitological, organoleptic, organic and inorganic chemical and radioactive parameters for human consumption water. This standard was promulgated to ensure the safety of water, prevent health risk factors, and promote the health and well-being of the population.

Considering that the quality of water designated for human consumption should be controlled and monitored by measuring physical, chemical, and microbiological parameters (Morales et al. 2019) since they offer multiple advantages as quality indicators due to their ease of quantification (Baque-Miite et al. 2016). This study aimed to determine the seasonal variability of water quality for human consumption, characterizing and comparing 18 physicochemical and microbiological parameters from five sampling points established along the Tilacancha River and the water conduction system to the city of Chachapoyas during the months of February (rainy season) and August (dry season) of 2020.

MATERIALS AND METHODS

Study Area

The Tilacancha PCA is located in the Central Andes of South America, in the Páramo ecoregion of the Cordillera Central, covering the lands of the Levanto and San Isidro del Maino Rural Communities (Fig.1) and this PCA is located at altitudes ranging from 2650 to 3491 meters above sea level and covers an area of 6 800.48 hectares, occupying 4% of the total territory of the Amazon region (Salas et al. 2018). It was recognized as a PCA on July 6, 2010, by Ministerial Resolution N° 118-2010-MINAM, conserving the upper parts of the Tilacancha and Cruzhuayco sub-basins, the mountainous grasslands, the montane forests, and the biological diversity, which contribute to the adequate management and functioning of the Yuyac - Osmal watershed, guaranteeing ecosystem services over time and contributing to sustainable development (Lucich et al. 2014).

According to the National Meteorological and Hydrological Service of Peru (SENAMHI), the climate of the Tilacancha PCA varies from very humid to cold temperate, generally rainy (Salas et al. 2018), the average annual temperature ranges between 12 °C and 17 °C and the average annual rainfall is 850 mm; however, rainfall records are not regular throughout the year, the months of October to April correspond to a rainy period with an average rainfall of 100 mm/month, while in June to September rainfall decreases to 54 mm/month, with August being the month with the least rainfall (CONDESAN 2014).

Samples and Sampling

Samples were collected in February 2019 and August 2020. For this purpose, five sampling points were established, four of them in the Tilacancha River section, including the catchment, and one at the end of the water conduction line that reaches the city of Chachapoyas (Fig. 1). The selection of the sampling points was carried out taking into account the Protocol for Monitoring the Sanitary Quality

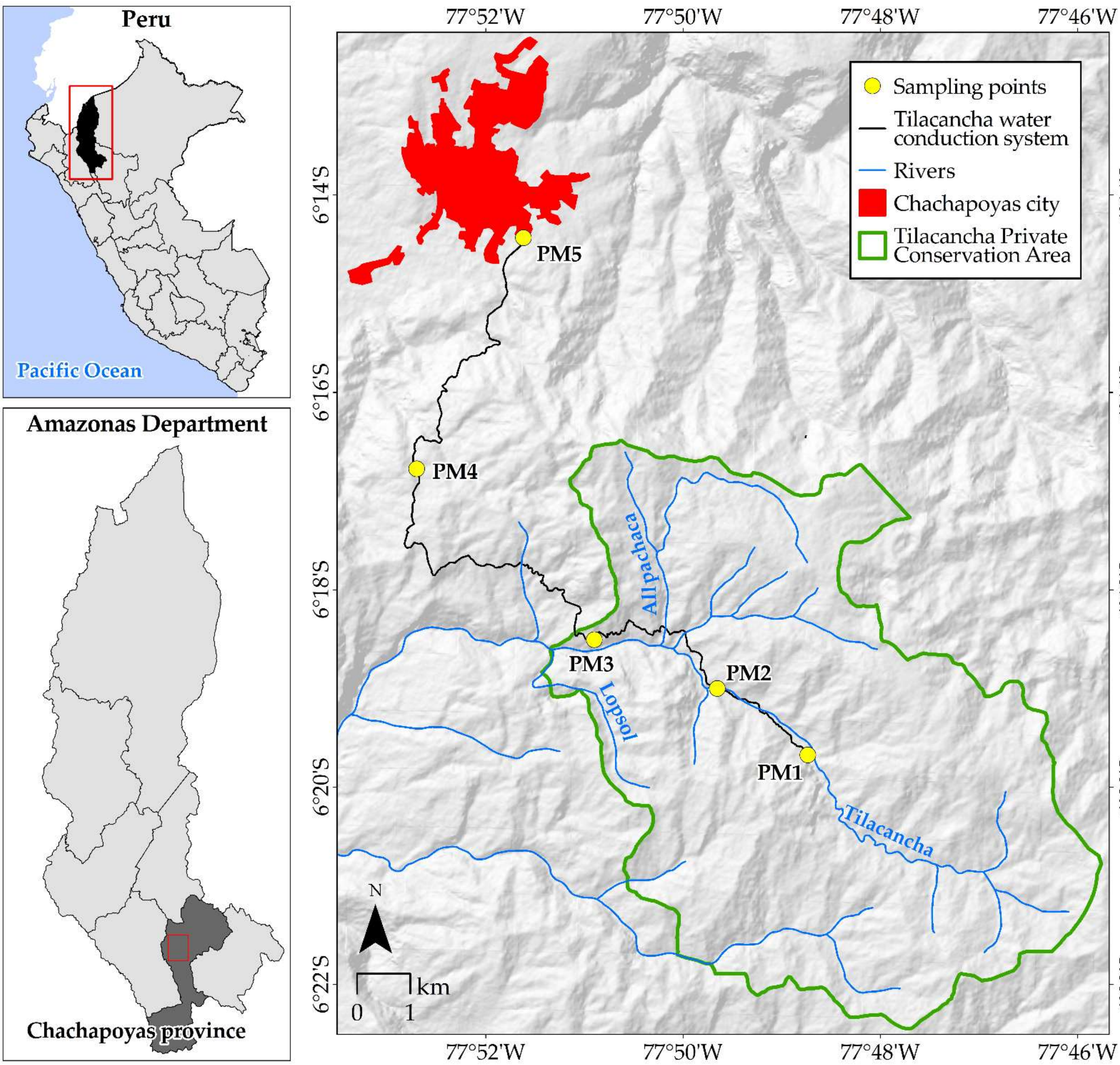

Fig. 1: Tilacancha PCA location.

of Surface Water Resources, Directorial Resolution N° 2254-2007-DIGESA (DIGESA 2007) with appropriate Quality assurance (QA)/quality control (QC) procedures and appropriate standards used for calibration (Konieczka 2007).

In addition, the location of the sampling points was determined according to three criteria: i) Identification: the sites were located so that they were easily identifiable using the Satellite Positioning System (GPS) and recording their UTM coordinates (Table 1); ii) Accessibility: these points were located in places of quick and easy access to collect the samples; iii) Representativeness: taking into account the characteristics of the environment, vegetation cover and the existence of possible factors that influence water quality.

Points PM1, PM2, and PM3 were located along the Tilacancha River, with a minimum separation distance of 1 km (Prat et al. 2012). Point PM4 was located in the water catchment area outside the Tilacacha private conservation area, and point PM5 was located at the end of the water conduction line, located before the entrance to the Chachapoyas Drinking Water Treatment Plant (DWTP) (Table 1).

The samples were collected following the methodology established in the Protocol of procedures for sampling, preservation, conservation, transport, storage, and reception of water for human consumption, as outlined in the Directorial Resolution of the Ministry of Health 160-2015-DIGESA-SA (DIGESA 2015).

Analysis of Physicochemical and Microbiological Parameters

A total of 18 parameters were considered and chosen, taking into of the Supreme Decree DS N° 031-2010-SA (MINSA 2010). The parameters of pH, T° (°C), and EC ($\mu S.cm^{-1}$) were measured in the field. They were performed following the Protocol for monitoring the sanitary quality of surface water resources, approved by Directorial Resolution N° 2254-2007-DIGESA (DIGESA 2007). A Multiparameter was used (Hanna, HI 98194), previously inspected to verify its maintenance and calibration. At the time of measurement, surgical gloves were used to avoid direct contact with the sensors and/or contaminate the samples, which could alter the results. For this purpose, the pH sensor also measures the T° at the same time, and the EC was placed in the samples collected in a container previously rinsed directly on the surface of the water of the Tilacancha River; the method recommended in the Protocol for monitoring the sanitary quality of surface water resources approved whit Directorial Resolution N° 2254-2007-DIGESA (DIGESA 2007).

Table 1: UTM coordinates sampling points.

PM	UTM coordinates			Altitude (masl)
	Zone	East	North	
PM1	18	189394	9298678	2939
PM2	18	189112	9299257	2947
PM3	18	188973	9299381	2946
PM4	18	188898	9299661	2941
PM5	18	183468	9309339	2463

The physicochemical parameters of Total dissolved solids ($mg.L^{-1}$), Chlorides ($mg.Cl^{-1}.L^{-1}$), Hardness (mg CaCO3/l), Ammonium ($mg.N^{-1}.L^{-1}$), Iron ($mg.Fe^{-1}.L^{-1}$), Manganese ($mg.Mn^{-1}.L^{-1}$), Aluminum ($mg.Al^{-1}.L^{-1}$), Copper ($mg.Cu^{-1}.L^{-1}$), Zinc ($mg.Zn^{-1}.L^{-1}$), Sodium ($mg.Na^{-1}.L^{-1}$), $mg.Fe^{-1}.L^{-1}$, ($mg.Mn^{-1}.L^{-1}$), Sulfates ($mg.SO4^{-1}.L^{-1}$), as well as the microbiological evaluation of Total coliforms (MPN.100 mL^{-1} a 35ºC), Fecal coliforms (MPN.100 mL^{-1} a 44,5ºC), *Escherichia coli* (MPN.100 mL^{-1} a 44,5ºC), were determined according to the methodology by APHA, AWWA, and WEF (American Public Health Association 1999, Walter 1961). For the total dissolved solids, the total dried solids were used. The Turbidity (UNT) was determined with the Nephelometric Method, following EPA specifications (EPA 1970).

Data Analysis

Data analysis was performed by applying the relativization function (Equation 1), transforming the values of the various physicochemical and microbiological parameters to a scale ranging from 0 to 1 (Sepúlveda 2008).

Equation 1

$$f(x) = \frac{x-m}{M-m},$$

Where:

x: Corresponding value of the variable for a given unit of analysis at a given period.

m: Minimum value of the variable in each period.

M: Maximum value of the variable in each period.

This function made it possible to visualize the behavior of the parameters in the rainy and low water seasons concerning the Maximum Permissible Limits established in the regulation by DS N°031-2010-SA. Likewise, a comparison of the averages of each parameter was made with the same regulations and for the same purpose.

In addition, the results of physicochemical and microbiological characteristics were presented in summary tables with mean values and coefficients of variation. The water flow results were subjected to a mean comparison test using Student's t-test to determine the significance of the flow by year of evaluation. Finally, a Pearson correlation was performed in the R software 4.3.1, which made it possible to evaluate the relationship between the physicochemical and microbiological parameters and the flow rate for the rainy and dry seasons, with significance values of 0.05. The ranges for interpreting the correlation were 0 to 0.3 (0 to -0.3) weak linear relationship, 0.3 to 0.7 (-0.3 to -0.7) moderate linear relationship, and 0.7 to 1 (-0.7 to -1) strong linear relationship (Ratner 2009).

RESULTS

Physicochemical and Microbiological Characteristics of Drinking Water in the Pipeline System as a Function of the Sampling Period

According to Table 2, the results show that none of the physicochemical parameters exceed the MPLs established in the DS N° 031-2010-SA in any of the seasons in which the water samples were taken. As for pH, it is higher during the rainy season (8.38), as is temperature (13.70 °C) and turbidity (3.70 UNT). Electrical conductivity, total dissolved solids, chlorides, and hardness were higher in the dry season with values of 100.70 µS.cm^{-1}, 43.80 mg.L^{-1}, 7.26 mg Cl.L^{-1}, and 49.35 mg CaCO3.L^{-1}, respectively. Sulfate and ammonium concentrations were also higher in the dry season, with 4.23 mg SO_4.L^{-1} and 0.12 mg N.L^{-1}, respectively.

Concerning to higher concentrations of iron were reported in the rainy season with 0.11 mg Fe.L^{-1}, and in the dry season, higher concentrations of sodium and zinc were reported with 2.57 mg Na.L^{-1} and 0.04 mg Zn.L^{-1} respectively, the opposite occurred with copper, which remained stable in both seasons with 0.01 mg Cu.L^{-1}.

Aluminum (Al) and manganese (Mn) concentrations exceed the MPLs during rainy (0.26 mg Al.L^{-1}) and dry (1.41 mg Mn.L^{-1}) periods, respectively, since according to DS N° 031-2010-SA, Al, and Mn concentrations should not exceed 0.2 mg Al.L^{-1} and 0.4 mg Mn.L^{-1}, respectively.

Within the microbiological parameters of the Tilacancha river water in the two study periods, such as total coliforms, fecal coliforms, and *E. coli*, the results exceeded the MPL established in the DS N° 031-2010-SA, and 48.50, 49 and 24 MPN.100 mL^{-1} of water were found, respectively. These values exceed the established in the DS, which determines that it should be less than <1.8 MPN.100 mL^{-1} (Table 3).

Fig. 2 shows the relationship between the values of the physicochemical and microbiological parameters concerning the MPL established in the DS N° 031-2010-SA in the two study stations, using the relativization function (Equation 1); the graph shows that the concentration of microbiological parameters visibly exceeds the LMP whose standardized value is 0, while the other parameters are within the LMP or standard value 1.

Table 2: Physical-chemical characteristics of the water in the drinking water supply system.

Variables	Seasons				MPL
	Rainy		Dry		
	Mean	CV %	Mean	CV %	
pH	8.38	0.02	7.70	0.01	6,5-8.5
T°	13.70	0.06	12.70	0.07	**
Turbidities	1.25	0.60	0.77	0.25	5 NTU
EC	55.40	0.03	89.78	0.03	1500 µS.cm^{-1}
TDS	24.85	0.01	43.80	0.03	1000 mg.L^{-1}
Chlorides	3.11	0.68	7.26	0.24	250 mg.L^{-1}
Hardness	33.79	0.07	49.35	0.11	500 mg $CaCO_3$.L^{-1}
Sulfates	0.00	0.00	4.23	0.65	250 mg.L^{-1}
Ammonium	0.02	0.00	0.12	1.76	1.5 mg N.L^{-1}
Aluminum	0.26*	0.31	0.17	0.19	0.2 mg.L^{-1}
Copper	0.01	0.48	0.01	0.25	2 mg.L^{-1}
Iron	0.11	0.11	0.08	0.22	0.3 mg.L^{-1}
Manganese	0.01	0.34	1.41*	0.50	0.4 mg.L^{-1}
Sodium	1.90	0.03	2.57	0.16	200 mg.L^{-1}
Zinc	0.01	0.73	0.04	0.16	3.0 mg.L^{-1}

* Indicates values that exceed the Maximum Permissible Limits established in the Regulation (DS N° 031-2010-SA).

** The parameter does not apply according to the regulation (DS N° 031-2010-SA).

Tilacancha River Water Flow Record

Table 4 shows the historical water flow data of the Tilacancha River by EMUSAP S.R.L. for the years 2009 to 2013 (Lucich et al. 2014). T In the development of the present investigation, the water flow for the year 2020 was also taken, these data were taken from the same sampling points

Table 3: Microbiological characteristics of the water in the drinking water supply system

Variables	Seasons				MPL
	Rainy		Dry		
	Meam	CV %	Meam	CV %	
Total coliforms	48.5*	0.45	25.6*	0.99	<1.8 MPN.100 mL^{-1}
Fecal coliforms	49*	0.40	25*	1.10	<1.8 MPN.100 mL^{-1}
E. coli	5.45*	0.58	24*	1.10	<1.8 MPN.100 mL^{-1}

* Indicates values that exceed the Maximum Permissible Limits established in the Regulation (DS N° 031-2010-SA).

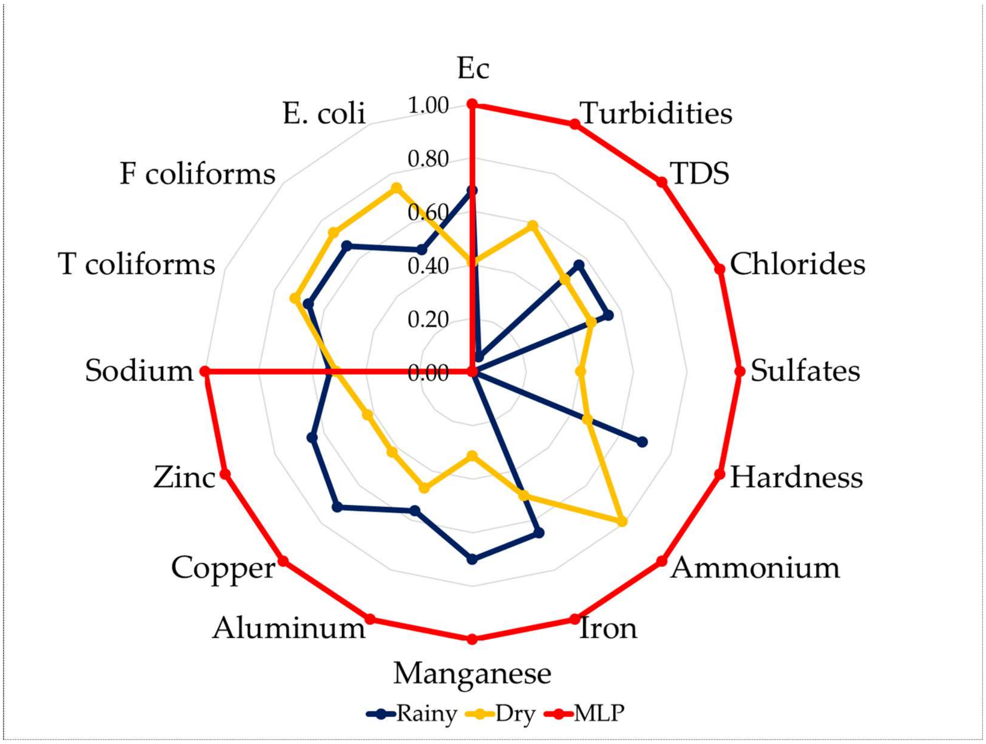

Fig. 2: Level of the relationship of the physicochemical and microbiological parameters concerning the MPLs established in the DS. N° 031-2010-SA

that were found before the treatment plant. The historical water flow of the river reports that in 2009, it had the highest flow (2.528 $m^3.s^{-1}$), followed by 2011 and 2012 with 1.989 $m^3.s^{-1}$ and 1.727 $m^3.s^{-1}$, respectively. However, there were no significant differences between the years evaluated. On the other hand, for the 2020 year of execution of this research, the lowest water flow value was reported (0.19485 $m^3.s^{-1}$) for the rainy season (February) with 0.28 $m^3.s^{-1}$ and the dry season (August) with a flow of 0.11 $m^3.s^{-1}$.

Correlation Level of the Physicochemical, Microbiological, and Flow Characteristics of the Tilacancha River

Fig. 3 shows the level of correlation between the physicochemical and microbiological characteristics and the water flow of the Tilacancha River during the rainy season. The pH is strongly positively correlated (blue color and diagonal to the right) with hardness and Na. At the same time, the presence of chlorine has a moderate negative correlation (orange color and diagonal to the left) with the other parameters such as T°, turbidity, EC, TC, FC, *E. coli*, and flow rate, with a strong negative correlation (red color and diagonal to the left).

The temperature (T°) correlated strongly negatively with TDS, TC, FC, Zn, Fe, and Al. Turbidity has a strong positive correlation with *E. coli* and a moderate correlation with chlorides and a strong negative correlation with Na.

EC was strongly positively correlated with TDS, TC, FC, Al, Cu, Mn, Zn, and flow rate and had a strong negative correlation with *E. coli*. TDS was strongly positively correlated with TC, FC, Al, Cu, Fe, Mn, Zn, flow and negatively correlated with chlorides and E. coli. Chlorides had a strong positive correlation only with E. coli and a strong negative correlation only with Na. In addition, microbiological parameters such as TC and FC had a strong positive correlation with Al, Cu, Fe, Mn, Zn, and flow rate; *E. coli*, on the other hand, presented a strong negative correlation with Mn, Na, and flow rate. Finally, Aluminum, Copper, Iron, Manganese, Sodium, and Zinc presented a positive correlation between them, generally a strong and moderate one. It should be noted that sulfates and ammonium had values of 0, which means that there is no linear correlation with any of the parameters.

Fig. 4 shows the correlation between the physicochemical and microbiological characteristics and water flow of the Tilacancha River during the low water season. The pH showed a strong correlation and a moderate negative correlation with hardness, sulfates, Cu, Fe, Zn, flow, turbidity, chlorides, ammonium, TC, CF, *E. coli,* and Al. The same was true for T°, which presented a strong negative

Table 4: Tilacancha River flow record for the years 2009-2020.

Months	Caudales [$m^3.s^{-1}$]					
	2009	2010	2011	2012	2013	2020
January	0.338	1.229	1.672	1.316	1.419	
February	2.447	1.808	0.766	2.694	4.341	0.2835
March	2.174	1.261	4.043	2.337	2.532	
April	12.341	1.108	1.874	1.733	0.886	
May	2.434	1.542	8.937	1.495	1.172	
June	1.872	0.945	0.946	6.809	0.978	
July	1.319	0.424	0.700	0.547	0.784	
August	1.211	0.324	0.210	0.279	2.088	0.1062
September	0.795	0.650	0.290	1.051	0.781	
October	1.814	0.494	2.395	1.034	0.639	
November	1.516	0.675	1.308	0.794	0.498	
December	1.074	1.141	0.997	0.639	0.666	
Minimum	0.795	0.324	0.210	0.279	0.498	
Average	2.528 a	0.967 a	1.989 a	1.727 a	1.399 a	0.19485 a
Maximum	12.341	1.808	8.937	6.809	4.341	

Note: The same letters do not report significant statistical differences according to the Student's t-test $p \leq 0.05$.

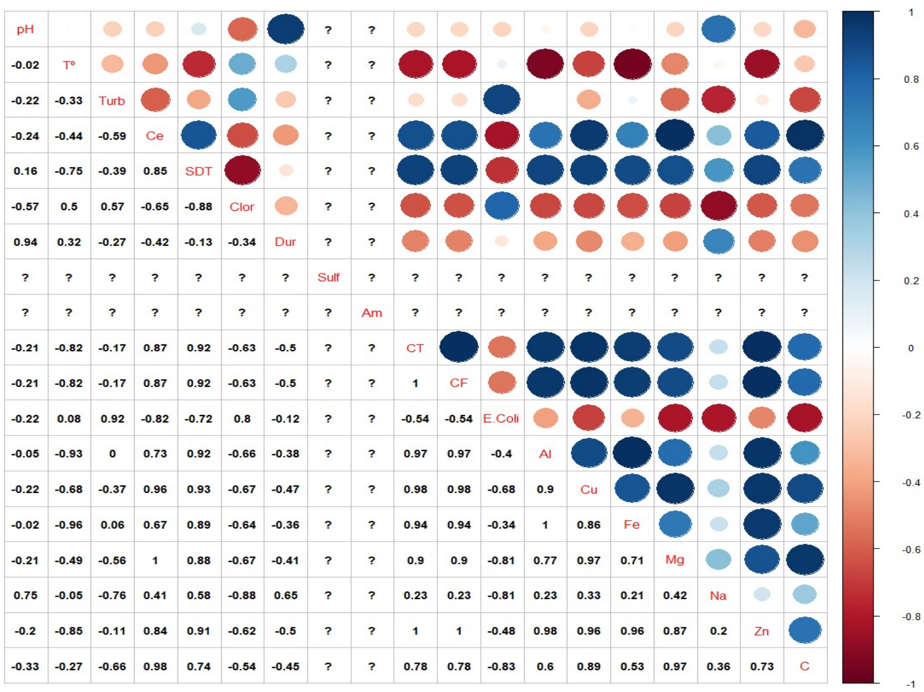

Fig. 3: Correlation of the physicochemical and microbiological characteristics and water flow of the Tilacancha River during the rainy season (?: no data).

correlation with Ce and TDS. Turbidity showed a strong positive correlation with Zn and a negative correlation with Mn. The opposite was true for Ce and TDS, which showed a strong and moderate positive correlation with each other and with TC, CF, *E. coli*, Mn, ammonium, and Fe. Likewise, chlorides presented a strong and moderate positive correlation with hardness, sulfates, ammonium, Al, Fe, Na, and flow rate, as did hardness, which also presented a strong and moderate positive correlation with sulfates, ammonium, Al, Cu, Fe, and flow rate.

Sulfates, on the other hand, had a strong positive correlation with parameters such as Al, Cu, Fe, Zn, and flow rate and only presented a moderate negative correlation with Mn. Ammonium was strongly positively correlated with all microbiological parameters, Fe, and flow rate. These microbiological parameters (TC, FC, and *E. coli*) were strongly positively correlated with each other and with Fe.

Finally, the Aluminum, Copper, Iron, Manganese, Sodium, and Zinc had a strong positive correlation with Na and flow, as did Cu with Zn and Fe.

DISCUSSION

For sustainable development, water quality is a determining factor that needs to be permanently monitored to avoid possible threats to people's health (Salvador et al. 2020). Therefore, the study of 18 physicochemical and microbiological parameters of the Tilacancha River and the water conduction line for Chachapoyas in two seasons (rainy and low water) is based on the theory that the use of indicators such as physicochemical and microbiological parameters provide knowledge about the type of water and the various geochemical processes that influence it (Elsayed et al. 2020). In addition to the quantity and physicochemical and microbiological quality of the water, it can be influenced by the climate of the area (Espinal et al. 2013, Morales et al. 2019) and may be different between rainy and dry seasons (Baque-Miite et al. 2016). This is because rainfall performs different mechanical and chemical processes such as erosion, hydration, hydrolysis, and oxide reduction that promote flooding, runoff, washing of soils, weathering of rocks, and influence the discharge of wastewater (Espinal et al. 2013, Morales et al. 2019). The composition of water, or its physical, chemical, and microbiological constituents, will depend fundamentally on the material through which it flows and with which it comes into contact (Formica et al. 2015, Pino et al. 2017), the seasonal period and sampling depth levels (Leiva-Tafur et al. 2022).

The pH of the water ranged from 8.38 during the rainy season to 7.70 during the dry season, which suggests that there is no notable variation in pH regarding the season, and the values reported are within the range prescribed in the MPLs of DS N°031-2010-SA (between 6.5 to 8.5). If the value is higher than the permitted MPL, it would negatively affect aquatic life, corrosion capacity, and soil alkalinity (Awoyemi et al. 2014).

On the other hand, the values of hardness, total dissolved solids, and electrical conductivity are higher in low water. These results contrast with the theory that suggests that the concentration of these parameters is related to the process of concentration of the flow of this season (Rodriguez-

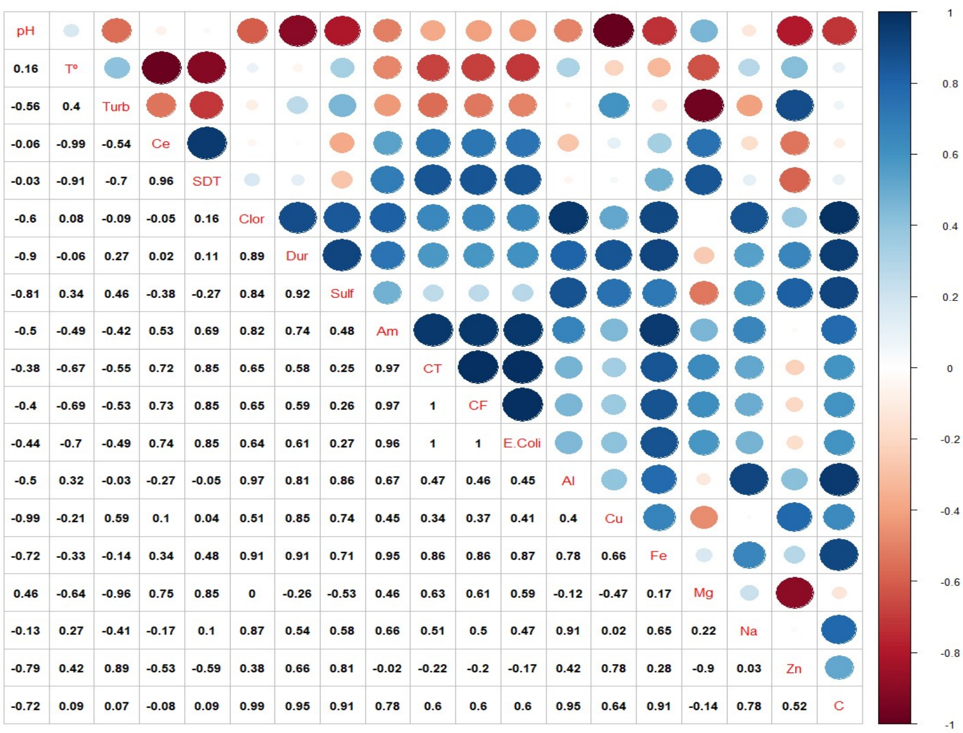

Fig. 4: Correlation of physicochemical and microbiological characteristics and water flow of the Tilacancha River during low water season.

Alvarez et al. 2017). In addition, the electrical conductivity may decrease during wet periods due to the dilution of salts (Akindele et al. 2013). However, the high values of electrical conductivity reflect high values of sodium and chlorides for the dry season, as was found in the results of this research (Awoyemi et al. 2014).

In the case of sulfate and ammonium concentration in the waters of the Tilacancha River, values are within the range of 250 mg $SO_4.L^{-1}$ and 1.5 mg $N.L^{-1}$ of the MPL allowed by the DS N° 031-2010-SA were reported; this could be because sulfates in natural waters are found in low concentrations coming from the leaching of sulfide minerals where sulfur is oxidized forming sulfates and increase their concentration when there is contamination, generally due to mining activities. (Awoyemi et al. 2014, Gómez et al. 2004).

On the other hand, concerning the concentrations of microbiological parameters (total coliforms, fecal coliforms, and *E. coli*), exceeding the MPLs makes the Tilacancha River a river with water unfit for human consumption; this may be due to the livestock activities carried out in the area, threatening the conservation of the PCA and contributing pollutants to the water that diminish its quality (Seitz 2015). Microbiological parameters reported higher concentrations in the rainy season or February, which shows that precipitation is the most influential factor for the concentration of coliform bacteria (Seo et al. 2019); as runoff washes soils, washes sediments, and all kinds of pollutants from livestock farming into the rivers (Rodriguez-Alvarez et al. 2017), reasons why water turbidity may also increase during the rainy season. Although the values of physicochemical parameters are lower than the Peruvian regulation DS N° 031-2010-SA, the presence of coliform bacteria alone is a qualitative indicator of contamination, the consequences of which can result in diseases such as gastroenteritis and diarrhea (Seo et al. 2019).

The accumulation and distribution of some physicochemical parameters in freshwater bodies can make them potentially dangerous, producing toxicity when they reach living organisms that make up the food chain (Salas-Mercado et al. 2020). Heavy metal concentrations in the Tilacancha River were reported in the following sequence: Na > Al > Fe > Cu > Mn > Zn in the rainy season and Na > Mn > Al > Fe > Zn > Cu. This low concentration of these physicochemical parameters, except for aluminum (0.26 mg $Al.L^{-1}$) and manganese (1.41 mg $Mn.L^{-1}$) which reported values above the allowed in the LMPs (0.2 mg $Al.L^{-1}$ and 0.4 mg $Mn.L^{-1}$) in the rainy and dry seasons, respectively, may indicate that there were no significant effects on the suitability of the water for human consumption from the Tilacancha River. The low concentrations of aluminum, copper, iron, manganese, sodium, and zinc in the Tilacancha River may be because there are no mining and industrial activities in the area, and it is only influenced by the mineralogical characteristics of the soil; the quality of the riparian forest and the heterogeneity of the fluvial habitat is one of the key factors to explain the variability of the water characteristics of the high Andean rivers (Villamarín et al. 2014). In addition, the high concentration of sodium in the Tilacancha River in the two studied periods (1.90 to 2.57 mg $Na.L^{-1}$ rain and low water, respectively) may be the result of the weathering of silicate minerals in the rocks (1.90 to 2.57 mg $Na.L^{-1}$ rain and low water, respectively) (Formica et al. 2015), since there is no anthropogenic sodium contamination around the river.

Concerning the metals that exceeded the LMP, such as manganese, with 1.41 mg $Mn.L^{-1}$ in the dry season, and aluminum, with 0.26 mg $Al.L^{-1}$ in the rainy season may be due to the soil textural classes of the PCA, where sandy and clay soils predominate (Pereyra-Cachay 2020). In addition, surface waters in contact with sandstone, silicate, limestone, and dolomite rocks accumulate aluminum, manganese, and iron (Ifatimehin & Ojochenemi 2021) because the decomposition of organic matter eliminates dissolved oxygen and generates carbon dioxide, causing manganese and iron to be incorporated as soluble compounds (Chan et al. 2022). In the case of soils, the presence of manganese and aluminum indicates that they have an acid pH, influenced by the fluctuation of climatic factors such as precipitation and evapotranspiration, which cause the dissolution of rocks and minerals (Salinas 1979, Thomas 2015).

The flow of the Tilacancha River during the rainy season was higher than during the dry season, with 0.28 $m^3.s^{-1}$ and 0.11 $m^3 \cdot s^{-1}$, respectively, which may show that the low rainfall of 54 mm/month in August may influence the water level, reducing the flow by between 8 and 14 $L.s^{-1}$ (CONDESAN 2014). However, they may also be due to the impacts of climate change, deforestation, and the periodic burning of forests and grasslands due to a lack of environmental awareness, which may decrease water supply while demand is growing (Lucich et al. 2014).

The positive correlation between turbidity, temperature, total dissolved solids, flow rate, total coliform, fecal coliform, and *E. coli* content indicates that the lower the concentration of turbidity, total dissolved solids, lower temperature, and flow rate in the Tilacancha River water, the better the water quality, as the microbiological load of the water decreases. High water turbidity increases the concentration of microorganisms, affecting drinking water quality (Montoya et al. 2011). The same happens with the water temperature since it determines the concentration of many parameters. If the T° increases, the chemical reactions also increase. Still, the solubility of gases decreases, and the respiration rate of microorganisms increases, leading to higher consumption of oxygen and decomposition of organic matter (Akindele et al. 2013). Under this scenario, contaminated water requires drinking water treatment before consumption (Baque-Miite et al. 2016). When physical, chemical, and microbiological parameters exceed the MPL, intensive and sectorized monitoring of water sources must be carried out to determine the sources of contamination (Morales et al. 2019).

CONCLUSIONS

According to the 18 physico-chemical and microbiological parameters evaluated, the water from the Tilacancha in the drinking water conveyance system before being treated (at the DWTP) is not suitable for human consumption from the microbiological point of view, both in the rainy and dry seasons, since the bacteria of the Coliform group exceeded the MPLs prescribed in the DS N° 031-2010-SA. There is a dynamic of positive and negative correlations between all parameters, except for sulfates and ammonium, where there is no linear correlation with any of the parameters. These results suggest that the variability of the chemical composition of the water in the different seasons was altered by both anthropogenic and/or natural sources surrounding the water conveyance system. Thus, it is suggested to use this information for water quality management in Tilacancha.

ACKNOWLEDGMENTS

We acknowledge the support given by EMUSAP.

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ORCID DETAILS OF THE AUTHORS

Jaris Veneros: https://orcid.org/0000-0001-6981-4078
Llandercita Cuchca Ramos: https://orcid.org/0000-0002-2996-2786
Malluri Goñas: https://orcid.org/0000-0002-4972-3467
Eli Morales: https://orcid.org/0000-0002-8623-3192
Erick Auquiñivín-Silva: https://orcid.org/0000-0002-9226-9896
Manuel Oliva: https://orcid.org/0000-0002-9670-0970
Ligia García: https://orcid.org/0000-0001-7508-7516