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Water Quality Index and Health Risks in a Peruvian High Andean River

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ABSTRACT

Water quality in rivers is affected as it passes through urban areas; this situation can be improved with good management of water resources. High Andean rivers require further studies to indicate their quality status. In addition, it is important to estimate the health risks associated with exposure to contaminants in the river water. Therefore, it is proposed to assess the water quality index (WQI) using the National Sanitation Foundation (NSF) model and the health risks in the urban section of the Ichu River in Peru. Six monitoring points were selected in the section of the Ichu River that includes the urbanized part of the city of Huancavelica. The sample was taken during the months of February to April 2021. Critical parameters were analyzed by multivariate statistical analysis as principal components and cluster test. In addition, Pearson's correlation test was performed, and the water quality status was evaluated using the WQI-NSF model. The Ichu River was of "bad" quality, unfit for human consumption, and confirming the impact of the population on water quality. The WQI-NSF model could be useful for high Andean watercourses suffering from anthropogenic deterioration of quality, with illegal effluent discharges and poor sanitation. There is a high health risk due to fecal coliform contamination from sewage discharges into the river. In addition, the total hazard index indicated that contaminants are causing negative health effects in adult males at a low risk level (risk 2), adult females at a moderate risk level (risk 3), and children at a negligible risk level (risk 1). With the help of this study, an appropriate management plan can be put in place to restore the ecological integrity of the Ichu River.

Keywords: water resources, high Andean River, multivariate analysis, water quality index, non-carcinogenic health risk.

INTRODUCTION

Water resources are crucial for the social and economic growth of populations (Ahmed et al., 2021). Water quality is impacted by both climate change and pollution caused by human activities, with significant impacts on ecosystem health and human health, mainly in poor developing cities (Ahmed et al., 2020; Li et al., 2022). In addition, surface water quality is more susceptible to anthropogenic pollutants than to natural pollutants (Parween et al., 2022; Uddin et al., 2022). Therefore, the challenge for decision-makers is to achieve sustainable management of water resources, especially in developing countries (Karaoui et al., 2022). Yan et al. (2022) report that surface water quality is studied through the water quality index (WQI). The estimate from WQI is made from certain physical, chemical and bacteriological parameters. Is a useful tool that transforms a complex data set in a unit numeric expression indicating the state of water quality. Several authors report that the first WQI model developed by Horton in 1965 used 10 water quality parameters with the arithmetic aggregation function and proved to be significant in most cases (Parween et al., 2022). From Horton's work, modified versions were developed for better estimation of WQI. The National Sanitation Foundation (NSF) method generates results from expert opinion, uses mathematical methods of logarithmic transformations to convert the results of water quality variables into sub-index values (Shah & Joshi, 2017).

There are many models for determining the WQI in surface water worldwide (Uddin et al., 2021). Each model is applied to a specific area, neither the same number nor the same water quality parameters are used compared to the standards of a specific region. In addition, most of the available models include structures that users cannot modify (Karaoui et al., 2022). Shah & Joshi (2017) mention that the advantages in choosing a WQI model are fourfold, (1) rating the health of water bodies with one number from multiple water quality parameter data using a mathematical equation; (2) use fewer parameters compared to those used in other cases; (3) communicating general information about water quality and; (4) reflecting the composite influence of different water quality parameters.

Varol & Tokatlı (2023), used 13 parameters to determine water quality level of Çorlu creek, in Turkey, with the WQI minimal model. Cerna-Cueva et al. (2022) evaluated the WQI in Peru from 41 parameters, with the Peruvian WQI model. However, the WQI-NSF model has been used in 50% of the studies carried out around the world (Uddin et al., 2022). Control of water quality through WQI-NFS model has great importance, due to its greater application coverage in free flow water bodies areas (Uddin et al., 2021). WQI models and the use of multivariate statistical techniques are quite competent in classifying and interpreting monitoring data. Thus, the monitoring data analyzed provide sufficiently concise and simple information, which can be used by water management agencies in emergency situations (Parween et al., 2022). Fecal coliforms, phosphate and nitrate contamination can generate environmental problems in surface water sources and can also cause problems to human health (Isiuku & Enyoh, 2020). Pollution caused by excess fecal coliforms has been a pressing environmental problem in many rivers around the world (Xu et al., 2022). Nitrate is a water pollutant considered non-carcinogenic (Pasupuleti et al., 2022), can lead to methemoglobinemia in children, miscarriages, birth complications, increased risk of hemolytic anemia, esophageal cancer and stomach cancer, ulcerations and teratogenic effects (Ayejoto & Egbueri, 2024; Isiuku & Enyoh, 2020; Ji et al., 2022). Phosphate contamination also impairs water quality and can cause parasitic infections (Contreras López, 2021). Both nitrate and phosphate can enter the human body, either orally or through skin contact (Sáez-Huamán et al., 2023). Oral contamination can be caused by ingestion of water or even contaminated food; in the human body, nitrate can be reduced to nitrite and react with amines to produce carcinogenic compounds such as nitrosamines (Isiuku & Enyoh, 2020). In addition, small amounts of nitrogen and phosphorus have recently been reported to have the potential to induce antibiotic resistance in gastrointestinal bacteria such as *Enterococcus faecalis* (Xiao et al., 2024). The latter represents a major public health risk.

The most important water source in the city of Huancavelica is the Ichu River, for drinking water, irrigation, fishing and fish farming (Sáez-Huamán et al., 2023). It was recently reported that the Huancavelica region had high rates of poverty (37.4%) and extreme poverty (9.6%); also, 37.4% of households belonged to the total monetary poverty segment in 2022; regarding chronic malnutrition in children under 5 years of age, this region presented rates of 27.1%, 29.9% and 26.1% and anemia rates in children between 6 and 35 months of 57.4%, 65.0% and 56.6% during the years 2021, 2022 and 2023, respectively (MIDIS, 2023). The Ichu river flows through the city of Huancavelica, where water quality may be altered by the growth of urbanization, poor environmental education, and poor solid waste disposal (Huamaní Astocaza et al., 2022). Some studies have been carried out on organic matter, phosphate and nitrate contamination, and a study on the health risks of phosphates and nitrates in the Ichu River

(Huamaní Astocaza et al., 2022; Sáez-Huamán et al., 2023; Vargas et al., 2024). However, there are no studies of the water quality index of this river, nor has the non-cancer health risk associated with exposure to nitrates and phosphates through ingestion and the dermal route been assessed.

Therefore, the objective of the present study is to assess the water quality index using the National Sanitation Foundation (NSF) model and the health risks in the urban section of the Ichu River in Peru.

MATERIALS AND METHODS

The study area

The Huancavelica region is located in the Andean zone of Peru, on the western mountain range of the Andes at an altitude of 3660 meters above sea level (Sáez-Huamán et al., 2023). The Ichu River is located entirely in the Huancavelica region, belongs to the Mantaro basin and originates in the altitudinal relief of Chonta, at an altitude of 5237 meters above sea level, the Ichu River sub-basin has a land area of 1 383 823 km^2. (Ayala Bizarro, 2020). The bed of the Ichu River is composed of deposits of boulders, cobbles, gravels and sands, and on both sides of the Ichu valley there are important alluvial deposits (Aguilar Quispe, 2015). The water of the Ichu River is used to supply water for human consumption and irrigation in Huancavelica. It flows through several districts and receives wastewater discharges from homes, institutions and hospitals, which causes deterioration of water quality (Huamaní Astocaza et al., 2022). The urban section of the Ichu River is approximately 15 km long. Six monitoring points (MP) were taken where the samples were analyzed according to the required parameters. Sampling points MP-1 to MP-4 are in the district of Ascensión and MP-5 and MP-6 in the district of Huancavelica (Fig. 1).

Selection and location of monitoring points

The six monitoring sites were selected in both the urban and non-urbanized areas of the city of Huancavelica. They were chosen on the basis of mapping and field investigations, near urban areas. MP-1 is in the catchment area of EMAPA's drinking water treatment plant, which is located outside the urban area. Factors such as accessibility to each monitoring point, River flow, proximity to dwellings and the area of mixing of contaminants from domestic waste were considered (Parween et al., 2022). Total samples were collected

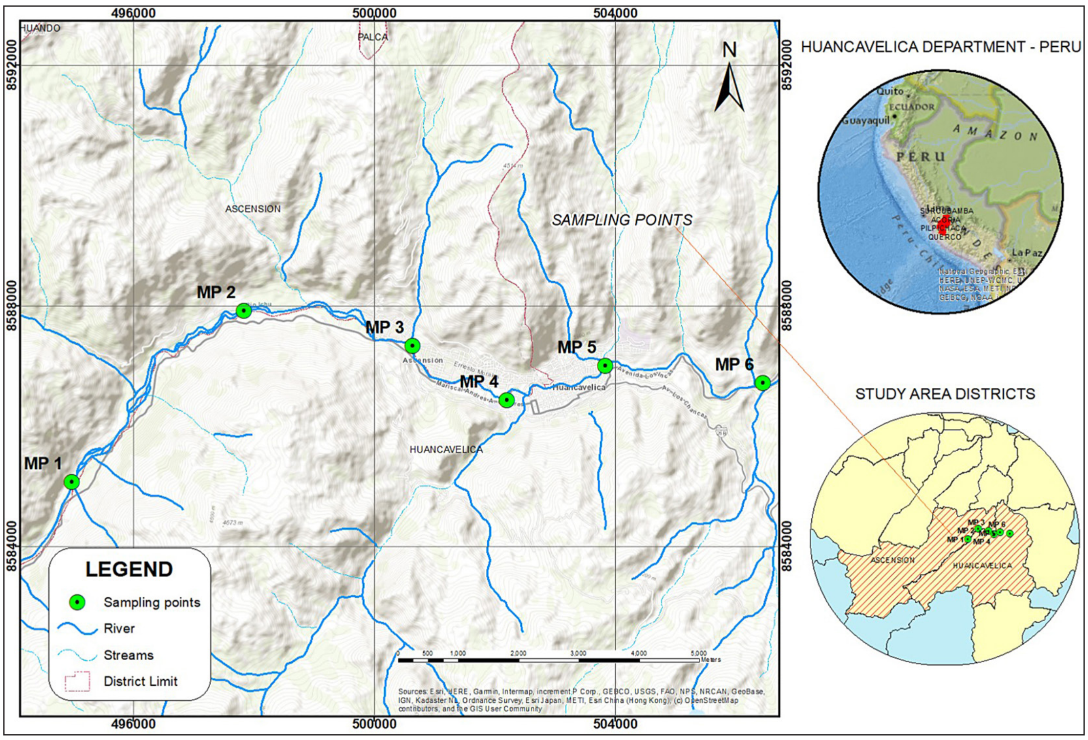

Figure 1. Map of the study area

Table 1. Location of the monitoring points

Monitoring point	Coordinates UTM - 18S		Description
	East	North	
MP-1	494987.7	8585070.6	Catchment treatment plant EMAPA
MP-2	497849.1	8587909.6	Municipal slaughterhouse (Chuñuranra)
MP-3	500648.5	8587333.4	Huancavelica Higher Technological Institute
MP-4	502216.5	8586424.1	Bridge height of the national school the Victory of Ayacucho
MP-5	503844.6	8587005.1	Army bridge of Huancavelica
MP-6	506461.7	8586714.3	Santa Rosa bridge

from six monitoring sites (Table 1) of the studied area during February to April 2021.

Water sampling and analysis

To prevent the samples from suffering alterations due to radiation, temperature, among other conditions and affect the percentage of confidence in the results of the analysis, a chain of custody was followed. Thus, in the process of sample collection and preservation, the recommendations according to APHA/AWWA/WEF (2017) were followed. This sampling process was developed in three sub-stages of sampling and each one of them took a single sample for each point.

Parameters of river water and analysis methods

The nine quality parameters determined are established in the model of the National Sanitation Foundation (WQI-NSF): temperature, turbidity, hydrogen potential (pH), biological oxygen demand (BOD), dissolved oxygen (DO), total dissolved solids (TDS), nitrate, phosphate and fecal coliforms (FC). These parameters were selected using the Delphi technique by a panel of 142 water quality management experts. (Prabagar et al., 2023). The determination of temperature, turbidity, pH, BOD, DO, nitrate and FC in water samples is performed according to the standardized procedures recommended by the American Public Health Association, the American Water Works Association and the Water Environment Federation (APHA/AWWA/WEF, 2017). The temperature was measured in situ with an AMARELL digital thermometer (range: -10°C to 50°C), turbidity was measured with a PCE-TUM 20 turbidity meter, pH was determined with a HACH multiparameter, BOD used a respirometric method with OxiDirect Lovibond, DO was determined with LAMOTTE oximeter, nitrate was determined with the cadmium reduction colorimetric method and FC was performed by applying the most probable number (MPN) technique.

Total dissolved solids (TDS) were determined according to the method followed by Dimri et al. (2021); it was determined at the control points using a Thermo portable multiparametric equipment, model Orion 4star. For this purpose, the equipment was previously calibrated according to the manufacturer's recommendations to obtain accurate measurements. The phosphate parameter was determined using the USEPA PhosVer® 3 with Acid Persulfate Digestion method (HACH method 8190/ Standard Methods 4500-P E) with detection range of 0.06 to 3.5 mg/L PO_4^{3-} at 880 nm wavelength.

Water quality index

The water quality index in the Ichu River was evaluated using the NSF-WQI model. The calculation of WQI followed four steps according to the methodology mentioned by Abuzaid (2018), first the water quality indicators were selected, then the sub-indices were determined, in the third step the selected parameters were weighted, and finally the aggregation function was processed. To perform the calculation, it is necessary to obtain the analysis of all the parameters considered in the preparation of the quality index. Variations represented by the result of WQI-NSF lead to decision making as it more accurately reflects a change in the quality of the water body (Parween et al., 2022). The following formula was used (Yapabandara et al., 2023):

$$WQI = \sum_{i=1}^{n} SIiWi \quad (1)$$

To obtain the subscript values "*SIi*", the value of the measure provided by the different parameters is acquired from the equipment and/or methodologies used. For each parameter there is a characteristic curve. The NSF WQI model transformed all the water quality parameter information for the Ichu River into a number (Parween et al., 2022). Nine parameters for WQI study and their corresponding weights (Wills & Irvine, 1996) are listed in Table 2. The parameters that have the greatest relative weight are dissolved oxygen, coliforms and those associated with organic matter such as biochemical oxygen demand. In Table 3 five WQI classification ranges are presented, these indicates the quality level of the source or defines the uses for which the water is suitable based on the score obtained (Wills & Irvine, 1996).

Human health risk assessment

The hazard identified for high FC contamination is associated with the reference pathogen (*E. coli*) (Xu et al., 2022). The exposure dose was determined as the product of the volume and the concentration of the microorganism in the water, using the value of the residual rate which is equivalent to the percentage of fecal coliforms representing *E. coli* (Equation 2).

$$D = V \cdot C \cdot Re \tag{2}$$

Table 2. Relative weights for each WQI-NSF parameter

No.	Quality parameter	*Wi*
1	Turbidity	0.08
2	Temperature	0.10
3	pH	0.12
4	Biochemical oxygen demand	0.10
5	Nitrates	0.10
6	Phosphates	0.10
7	Total dissolved Solids	0.08
8	Dissolved oxygen	0.17
9	Fecal coliforms	0.15

Table 3. Reference ranges for the state of the effluents according to the WQI-NSF

Criterion	Range of WQI scores
Excellent	91–100
Good	71–90
Medium	51–70
Bad	26–50
Very bad	0–25

where: *D* – the exposure dose, *V* – the volume of water consumed per day, *C* – the FC concentration, *Re* – the residual rate (8%). (Xu et al., 2022).

The probability of infection and disease after one day's exposure is determined by Equations 3 and 4, respectively.

$$P_{inf-day}(D; \propto; \beta) = 1 - \left(1 + \frac{D}{\beta}\right)^{-\alpha} \tag{3}$$

$$P_{ill-day} = P_{inf-day} \cdot P_{ill-inf} \tag{4}$$

where: D – the exposure dose; $P_{inf\text{-}day}$ – the probability of infection after a one-day exposure; α – the first parameter distributed from Beta Poison (0.1778); β – the second distributed parameter of Beta-Poisson ($1{,}78 \times 10^6$); $P_{ill\text{-}inf}$ – the risk of disease given the infection (0.25) (Xu et al., 2022).

The annual risk of disease is then determined (Equation 5).

$$P_{ill-year} = 1 - \left(1 - P_{ill-day}\right)^{365} \tag{5}$$

Contaminants such as phosphates and nitrates in water can present health risks to people through different routes (Sáez-Huamán et al., 2023). Health risk was assessed using the USEPA mathematical calculation. (Selvam et al., 2023).

Chronic daily intake (CDI) was calculated using the following equations (6).

$$CDI\ (\text{mg / kg. day}) = \frac{C_m \cdot IR \cdot ED \cdot EF}{BW \cdot AT} \tag{6}$$

where: C_m – the observed concentration of phosphate or nitrate, *IR* – the water intake rate (2.5 L/day for adults and 0.78 L/day for children), *ED* – the duration of exposure (20 years for adults and 6 years for children), *EF* – the frequency of exposure (350 days/year); *BW* – the average body weight, *AT* – the average time to non-carcinogenic health effect in days (ED x 365) (HHRA, 2019).

The non-carcinogenic effect of an individual contaminant can be shown as the hazard quotient (HQ) for oral water consumption, calculated by Equation 7 (Selvam et al., 2023).

$$HQ = \frac{CDI}{RfD_o} \tag{7}$$

where: *RfD*o – the reference dose for chronic oral exposure (1.60 mg/kg/day) of nitrate suggested by USEPA (Selvam et al., 2023) and the (provisional) reference dose for oral exposure (1.52 mg/kg/day) of phosphate (EPA, 2011). If HQ <1 is at a tolerable threshold, if HQ> 1, the danger of non-cancer adverse health effects is intolerable (Ayejoto & Egbueri, 2024).

Finally, the total hazard index (THI) for non-carcinogenic risk was determined (Equation 8) (Selvam et al., 2023).

$$THI = \sum_{i=1}^{n} HQ \quad (8)$$

When THI > 1, contaminants are likely to be causing negative impacts on human health; if THI <1, the contaminants have had no negative influence on human health. The non-carcinogenic hazard is classified in four groups according to THI values: insignificant (THI < 0.1, i.e., risk level 1.), low (0.1 ≤ THI < 1; i.e., risk level 2), moderate (1≤ THI < 4; i.e. risk level 3) and severe (THI ≥ 4; i.e. risk level 4) (Ayejoto & Egbueri, 2024).

Statistical analysis

Descriptive statistical tests (averages, standard deviation, maximum and minimum) were used. Multivariate principal component analysis and cluster Analysis were performed for the following variables, in addition, Pearson's correlation test (Parween et al., 2022; Siraj et al., 2023).

RESULTS

Descriptive statistics for water quality parameters

Descriptive statistics and indicative values, according to the Peruvian water quality standard in force, are shown in Table 4. Due to the lack of statistical records on the average monthly water temperature of the Ichu River, the calculation of the range of temperatures allowed by the EQS for water was made from the water temperature data of the Ichu River published in the reports of the monitoring carried out by the Peruvian National Water Authority (Autoridad Nacional del Agua del Perú) (ANA, 2019, 2020).

Multivariate statistical analysis

The values of the nine parameters were standardized so that they can be analyzed. Then, the adequacy of the data set for factor analysis was assessed with the Kaiser-Meyer-Olkin test (KMO > 0.5) (Shrestha, 2021); and the Bartlett's test (P < 0,05) (Ewaid et al., 2020). Eigenvalues greater than one (Xiao et al., 2023) were explained by the first four components, which accounted for 92.48% of the variance of the data set. Table 5 summarizes the variance, % of variance and cumulative % variance of extracted of PC1, PC2, PC3 and PC4.

Cluster analysis

Cluster analysis of the variables was used to classify the variables into groups. Two main clusters were identified according to the similarity of the variables; Ward's method was applied, and the Euclidean distance was used as a similarity measure (Uddin et al., 2024) (Figure 2).

Relationship between water quality indicators

Pearson's correlation test revealed a statistically valid significant positive and negative correlation between the water quality parameters studied in the Ichu River (Figure 3).

Assessment of water quality parameters using WQI-NSF

From the values obtained for the different parameters, the WQI-NSF water quality index was calculated for each monitoring point. First, the sub-indexes (*Si*) were determined for each parameter, using the weighting factor (*Wi*). Then, the average quality index was determined for each monitoring point (Figure 4).

Human health risk assessment

The Table 6 presents the average annual values of the probability of disease. The results of the USEPA model used to assess the health risks to adult men, adult women, and children from ingestion of phosphate- and nitrate-contaminated water are shown in Table 7.

DISCUSSION

Analysis of water quality parameters

Water temperature can be a determining factor for chemical and biological processes in water

Table 4. Descriptive statistics of water quality parameters

Parameters	Monitoring point	Mean	St. dev.	Min.	Max.	EQS
Temperature (°C)	MP-1	13.0	0.14	12.9	13.1	9.8–15.8*
	MP-2	13.0	0.28	12.8	13.2	
	MP-3	13.0	0.14	12.9	13.1	
	MP-4	13.1	0.07	13.0	13.1	
	MP-5	14.0	0.14	13.9	14.1	
	MP-6	14.0	0.42	13.7	14.3	
Turbidity (NTU)	MP-1	2.0	0.28	1.8	2.2	5.0
	MP-2	5.0	0.71	4.5	5.5	
	MP-3	5.0	0.85	4.4	5.6	
	MP-4	6.0	0.28	5.8	6.2	
	MP-5	6.0	0.42	5.7	6.3	
	MP-6	6.0	0.21	5.9	6.2	
TDS (mg/L)	MP-1	40.0	1.3	39.1	40.9	1000
	MP-2	40.0	0.8	39.4	40.6	
	MP-3	40.0	0.6	39.6	40.4	
	MP-4	43.0	2.7	41.1	44.9	
	MP-5	45.0	4.2	42.0	48.0	
	MP-6	50.0	0.3	49.8	50.2	
pH	MP-1	7.4	0.1	7.3	7.5	6.5–8.5
	MP-2	7.4	0.3	7.2	7.6	
	MP-3	7.5	0.1	7.4	7.6	
	MP-4	7.4	0.0	7.4	7.4	
	MP-5	7.4	0.0	7.4	7.4	
	MP-6	7.3	0.0	7.3	7.3	
BOD (mg/L)	MP-1	17.2	0.71	16.7	17.7	3
	MP-2	20.7	1.84	19.4	22.0	
	MP-3	25.8	2.55	24.0	27.6	
	MP-4	27.2	2.12	25.7	28.7	
	MP-5	27.0	1.84	25.7	28.3	
	MP-6	27.2	0.40	26.9	27.5	
DO (mg/L)	MP-1	4.4	0.57	4.0	4.8	≥ 6
	MP-2	5.2	0.57	4.8	5.6	
	MP-3	4.5	0.52	4.1	4.9	
	MP-4	4.9	0.57	4.5	5.3	
	MP-5	4.5	0.71	4.0	5.0	
	MP-6	4.3	0.45	4.0	4.6	
Nitrates (mg/L)	MP-1	9.5	0.42	9.2	9.8	50
	MP-2	13.7	0.71	13.2	14.2	
	MP-3	13.0	1.13	12.2	13.8	
	MP-4	13.2	0.71	12.7	13.7	
	MP-5	13.2	0.27	13.0	13.4	
	MP-6	13.0	0.57	12.6	13.4	
Phosphate (mg/L)	MP-1	0.5	0.14	0.4	0.6	0.1
	MP-2	0.6	0.13	0.5	0.7	
	MP-3	0.5	0.03	0.5	0.5	
	MP-4	0.6	0.15	0.5	0.7	
	MP-5	0.5	0.16	0.4	0.6	
	MP-6	0.6	0.05	0.6	0.6	
FC (MPN/100 mL)	MP-1	1500	212.00	1350	1650	50
	MP-2	1852	67.90	1804	1900	
	MP-3	2200	84.90	2140	2260	
	MP-4	2267	52.30	2230	2304	
	MP-5	2270	101.80	2198	2342	
	MP-6	2273	566.00	2176	2370	

Note: EQS – environmental quality standard to surface water, Peru (water that can be made potable with disinfection); TDS – total dissolved solids; BOD – biochemical oxygen demand; DO – dissolved oxygen; FC – fecal coliforms. * Δ 3° C of the average water temperature in the Ichu river.

Table 5. Matrix of rotated factor loadings with Varimax rotation

Parameter	PC 1	PC 2	PC 3	PC 4	Comunality
Temperature	0.30	0.85	0.18	-0.05	0.850
Turbidity	**0.94**	0.21	-0.17	-0.09	0.969
TDS	0.29	**0.89**	-0.25	-0.19	0.969
pH	0.00	-0.14	0.02	**0.97**	0.966
BOD	**0.88**	0.28	0.27	-0.17	0.946
DO	0.12	-0.38	**-0.82**	-0.21	0.871
Nitrates	**0.85**	0.01	-0.32	0.25	0.895
Phosphates	0.01	0.34	**-0.87**	0.15	0.903
FC	**0.92**	0.32	0.03	0.00	0.954
Variance	3.42	2.02	1.73	1.15	8.323
% Variance	38.00	22.40	19.30	12.80	0.925
Cumulative % variance	38.00	60.40	79.70	92.48	
KMO and Bartlett's test					
Kaiser–Meyer–Olkin measure of sampling adequacy				0.54	
Bartlett's test of sphericity	Approx. Chi-square			332.69	
Df				36	
Sig.				0.000	

Note: TDS – total dissolved solids; BOD – biochemical oxygen demand; DO – dissolved oxygen; FC – fecal coliforms.

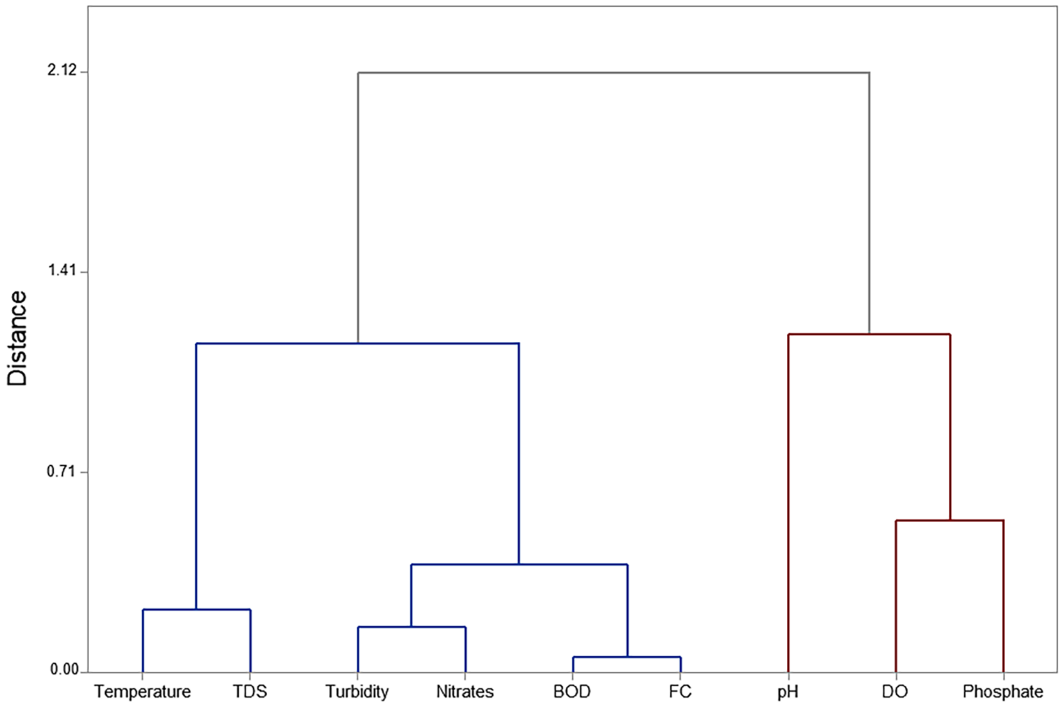

Figure 2. Dendrogram of water quality parameters in the Ichu River

bodies (Custodio et al., 2021). Therefore, temperature is an important quality parameter that could affect the self-purification of river water (Prabagar et al., 2023). The average temperature of the Ichu River at each monitoring point was within the permitted values according to the EQS for water (Table 4), and the average water temperature of the Ichu River was 13.3 °C, l which remained within the allowable Environmental Quality range for water that can be made potable with disinfection. This result is similar to that reported by Sáez-Huamán et al. (2023) (12.50 °C),

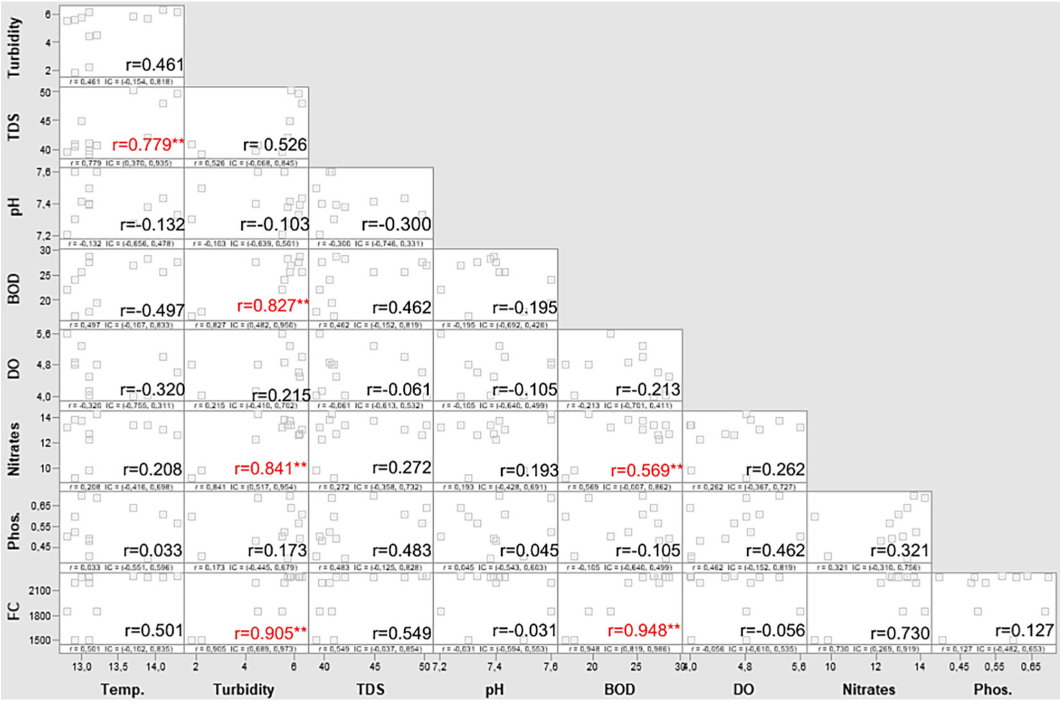

Figure 3. Correlation analysis of water quality parameters

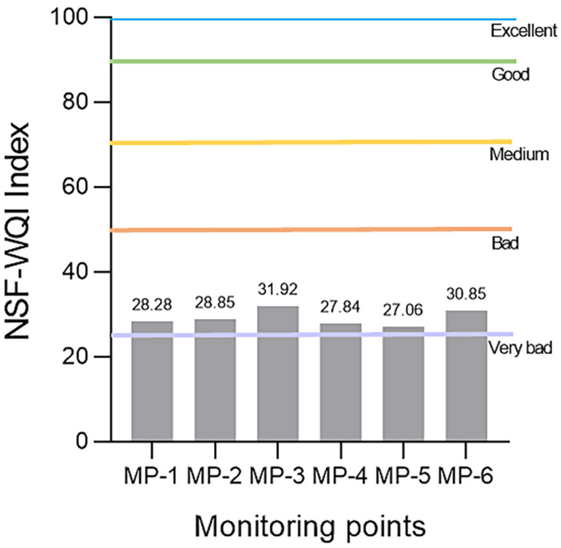

Figure 4. WQI-NSF score calculated at the six monitoring points of the Ichu River

unlike the temperature reported by Huamaní Astocaza et al. (2022) (16.35 °C) in the Ichu river, probably the reason for this difference is the time of the year or the location of the sampling points. Turbidity in water is due to suspended matter (clay, silt, plankton and other microorganisms) that interfere with the passage of light through the water (Prabagar et al., 2023). In this study, the average turbidity in the Ichu River was 5.0 NTU, which is at the limit of the permitted level according to the EQS for water. The lowest turbidity value was recorded at sampling point MP-1 (2.0 ± 0.28), which corresponds to a non-urbanized area. The highest mean values were recorded at sampling points MP-4, MP-5 and MP-6, which exceeded the permitted level according to EQS for water (MINAM, 2017). Maximum turbidity values exceeded the permitted level at the monitoring points located in the urban area (MP-2 to MP-6). Discharge of wastewater into the Ichu River (Huamaní Astocaza et al., 2022), could have increased turbidity in this stretch of the river. This is evidence of the influence of the urbanized part by raising the level of turbidity in the water, to the detriment of its quality.

TDS are all ion particles smaller than 2 μm in diameter, including dissociated electrolytes and dissolved organic matter, and are closely related to turbidity (Prabagar et al., 2023). The mean TDS of the Ichu River at each monitoring point was within the allowable values according to the EQS for water. The TDS in the Ichu River was 43.0 mg/L. The mean TDS values at the six monitoring points did not exceed the allowable level according to the EQS for water. pH affects the solubility of compounds in water (Prabagar et al., 2023). When the pH of water is slightly alkaline it indicates the presence of carbonate, calcium and magnesium ions (Parween et al., 2022). The mean pH of the Ichu River in the section studied was 7.4,

Table 6. Annual risk of disease for adults and children

Monitoring point	P inf-day		Pill-day		Pill-year	
	Adults	Children	Adults	Children	Adults	Children
MP-1	0.99	0.96	0.25	0.24	1.00	1.00
MP-2	0.99	0.96	0.25	0.24	1.00	1.00
MP-3	0.99	0.96	0.25	0.24	1.00	1.00
MP-4	0.99	0.96	0.25	0.24	1.00	1.00
MP-5	0.99	0.96	0.25	0.24	1.00	1.00
MP-6	0.99	0.96	0.25	0.24	1.00	1.00
Mean	0.99	0.96	0.25	0.24	1.00	1.00

Table 7. Hazard quotient (HQ) and total hazard index (THI) values for nitrate and phosphate exposure for adult men, adult women and children

Monitoring point	CDI						HQ						THI		
	Nitrates			Phosphate			Nitrates			Phosphate					
	Male	Female	Children	Male	Female	Children	Male	Female	Children	Male	Female	Children	Male	Female	Children
MP-1	0.39	0.45	0.13	2.04E-02	2.37E-02	7.08E-03	0.24	0.28	0.08	1.34E-02	1.56E-02	4.66E-03	0.66	0.77	0.23
MP-2	0.56	0.65	0.19	2.44E-02	2.84E-02	8.50E-03	0.35	0.41	0.12	3.05E-02	1.87E-02	5.59E-03	0.96	1.10	0.33
MP-3	0.53	0.62	0.18	2.04E-02	2.37E-02	7.08E-03	0.33	0.38	0.12	2.55E-02	1.56E-02	4.66E-03	0.91	1.04	0.31
MP-4	0.54	0.62	0.19	2.44E-02	2.84E-02	8.50E-03	0.34	0.39	0.12	3.05E-02	1.87E-02	5.59E-03	0.93	1.06	0.32
MP-5	0.54	0.62	0.19	2.04E-02	2.37E-02	7.08E-03	0.34	0.39	0.12	2.55E-02	1.56E-02	4.66E-03	0.92	1.05	0.32
MP-6	0.53	0.62	0.18	2.44E-02	2.84E-02	8.50E-03	0.33	0.38	0.12	3.05E-02	1.87E-02	5.59E-03	0.92	1.05	0.31
Mean	0.51	0.60	0.18	0.02	0.03	0.01	0.32	0.37	0.11	2.60E-02	1.71E-02	5.12E-03	0.88	1.01	0.30

which was within the permitted level according to the EQS for water. Similar results were found in each monitoring point; also in the studies of Sáez-Huamán et al. (2023) (6.75) and Huamaní Astocaza et al. (2022) (7.5). These values are within the level allowed by the EQS for water. BOD is the dissolved oxygen used by microorganisms for the biochemical oxidation of organic matter (Prabagar et al., 2023). An elevated BOD generally implies the presence of organic contaminants from untreated wastewater (Parween et al., 2022). The mean BOD of the Ichu River showed a mean value of 24.2 mg/L, which exceeded the permissible level of the EQS for water that can be made potable with disinfection, as did all samples taken in the stretch of the Ichu River studied. These results agree with those reported by Huamaní Astocaza et al. (2022) (27.1 mg/L). The high BOD values recorded may be due to the incorporation of organic matter from sewage discharges or the presence of solid waste in the river (Custodio et al., 2021). DO refers to the concentration of gaseous oxygen in the water (Prabagar et al., 2023). In aquatic ecosystems, the DO level is a critical water quality indicator and its variation is related to photosynthesis (Parween et al., 2022). The DO is also a value of the ecological status of the river (Ding et al., 2017). Aerobic microorganisms, present in contaminated water, degrade organic matter and reduce the dissolved oxygen content (Kükrer & Mutlu, 2019). Dissolved oxygen in the Ichu River showed a mean value of 4.6 mg/L. The mean DO values ranged from 4.3 to 5.2 mg/L. All samples showed low DO levels, affecting water quality. This concentration of dissolved oxygen is below the permitted level, which could be one of the reasons why different species such as trout, catfish and frogs have disappeared from the Ichu river (Sáez-Huamán et al., 2023).

Nitrate pollution in water sources is mainly caused by over-application of nitrogen-rich fertilizers, unregulated discharge of untreated domestic wastewater, industrial wastewater, and discharge from landfills (Selvam et al., 2023). The average nitrate concentration in the Ichu River was 12.6 mg/L. The mean nitrate values ranged from 9.5 to 13.7 mg/L. The lowest value was recorded at sampling point MP-1 (9.5 ± 0.42). All samples were within the permissible level of the EQS for water.

Nitrate concentration was similar to that reported by Sáez-Huamán et al.(2023) (13.10 mg/L).

Phosphate pollution in surface water sources is mainly due to the use of high concentrations of phosphate-based fertilizers in modern high-yield agriculture (Contreras López, 2021). Also due to the use of detergents for washing clothes in the river and wastewater discharges (Xie et al., 2023). Phosphates showed a mean value of 0.6 mg/L. All samples exceeded the permissible level of the EQS for water. The phosphate concentration was similar to that reported by Sáez-Huamán et al.(2023) (0.52 mg/L). About fecal coliforms (FC), this showed a mean value of 2060.3 MPN/100 mL, maximum and minimum concentration of 1350 and 2370 MPN/100 mL, respectively. Exceeded the limit of the standard biological degradation of water quality is often reflected in the prevalence of FC. Fecal coliforms mainly come from sewage discharges and represent a risk to human health (Varol & Tokatlı, 2023). The discharge of untreated domestic wastewater into the River could be the reason for the high total coliform load (Abdelhafiz et al., 2021). The results revealed that the water of the Ichu River is contaminated by organic matter probably from poor solid waste disposal and untreated wastewater discharges.

Role of assessed parameters in water quality

Principal component analysis (PCA) is a multivariate statistical analysis technique, which is classified among the simplification methods; it is also useful to properly assess the role played by each variable in a studied phenomenon. (Pérez López, 2004). The first four components explained eigenvalues higher than one and were accounted for 92.48% of variance for the total datasets (Table 5). The four main components are not interrelated and are ordered according to the information they contain (Pérez López, 2004). The first component (PC1) elucidated 38.0% of the total variance with a variance of 3.42 and included the parameters turbidity, BOD, nitrates, and fecal coliforms. These parameters in PC1 are the most important indicators that affect the quality and indicate the anthropogenic contribution of these variables in the river water (Parween et al., 2022). The second component (PC2) explained 22.40% of the total variance with a variance of 2.02, and water quality parameters such as temperature and TDS were predominant. The third component (PC3) explains the phosphate and DO parameters and accounted for 19.30% of the total variance with an eigenvalue of 1.73. The fourth component (PC4) explains the pH parameter, which represented for 12.80% of the total variables with an eigenvalue of 1.15. The PCA confirmed that all nine variables are significant in the first four components of this study; the most information for water quality analysis in the Ichu River is provided by the parameters included in PC1 (turbidity, BOD, nitrates, and fecal coliforms), followed by PC2 (temperature and TDS), PC3 (phosphate and DO) and PC4 (pH). Cluster analysis is used to classify the parameters into groups that are as homogeneous as possible on the basis of the observed variables (Pérez López, 2004). Cluster analysis classified the nine parameters into two statistically significant groups. The water quality parameters under the resulting clusters are the same as each other, but different from each other (Dimri et al., 2021). Cluster analysis is an exploratory multivariate technique that allows the identification of groups of variables with similar characteristics (Sreejesh et al., 2014). Cluster 1 included six water quality parameters (temperature, TDS, pH, turbidity, nitrates, BOD and FC). There is a close similarity between BOD and FC parameters. This indicated a similar source of origin for these parameters, which are related to the discharge of domestic wastewater into the Ichu River at the monitoring sites. Cluster 2 contained three water quality parameters (pH, DO and phosphate). In this cluster it is observed that the DO and phosphate parameters have a common origin. Phosphate ions in water derive from discharges of detergents, pesticides, fertilizers, and urban and industrial wastewater. High phosphate concentrations promote the process of water eutrophication. This is a process that causes an increase in the productivity rate of some algal species on the surface and the subsequent algal mortality causes the consumption of dissolved oxygen in the water, creating hypoxia and sometimes near anoxic conditions (Xie et al., 2023). Therefore, phosphate in high concentrations becomes a pollutant in water, mainly in urban regions.

The association between parameters using Pearson's correlation test was evaluated at a 99% confidence level; it was observed that TDS showed high significant positive correlation with water temperature (r = 0,779). Turbidity showed a very high significant positive correlation with the parameters FC (r = 0.905), nitrate (r = 0.841) and BOD (r = 0,827). BOD also showed a very high significant positive correlation with FC (r = 0,948) and a moderate significant positive correlation with nitrates (r = 0.569). The presence of FC in water is a sign of contamination with fecal matter (Dimri et al., 2021; Hatipoğlu Temizel, 2023) and this type of pollution is related to BOD and water turbidity. The results of the multivariate statistical analysis and Pearson correlation analysis showed a similar association between the water quality parameters evaluated. Moreover, most of the water quality indicators played a vital role in the association of water quality in the Ichu River (Parween et al., 2022). Cluster analysis also supported the PCA result, and all indicated anthropogenic sources of water pollution in the Ichu River.

Water quality index: NSF-WQI model

The WQI-NSF model is considered one of the most comprehensive quality indexes available (Parween et al., 2022). The calculated WQI-NSF scores at the sampling points were in the range of 28.28 to 31.92, which indicated that the water quality of the Ichu River was bad. According to the above analyses, the water of the Ichu River is polluted, the parameters that are outside the permitted levels are turbidity, BOD, DO, phosphate, and fecal coliforms, mainly due to the discharge of domestic wastewater and municipal solid waste. The application of the WQI-NSF model is used to assess water quality for different uses; on the other hand, water quality variability is related to anthropogenic processes (Dimri et al., 2021). These results can help to decide the WQI-NSF as an advantageous model for its application in Rivers and to be used, validated, or adapted in different studies. This study can provide useful information for decision makers to take corrective measures and ensure the conservation and sustainable use of the Ichu River water.

Risks to human health

Human health risks were assessed for exposure to fecal coliforms, phosphates, and nitrates in the river water. The present study took into account that only 10.7% of households in Huancavelica had chlorinated water (MIDIS, 2023). Therefore, the consumption of untreated water may be a situation mainly in the Andean areas or communities around the city of Huancavelica.

Biological deterioration of water quality is reflected in high fecal coliform contamination (Parween et al., 2022). FC are used as an indicator of fecal contamination (Xu et al., 2022). The probability of infection after 1-day exposure in adults was 0.99 on average and 0.96 in children, the probability of illness after 1-day exposure was reduced to 0.25 in adults and 0.24 in children. The annual probability of illness was 1.00 in both adults and children. From these results, it can be concluded that there is a high health risk from fecal coliform contamination. This fecal load comes from wastewater discharges into the river as it passes through the urbanized area at at least three points identified by the local water authority (Vargas et al., 2024). Domestic and livestock wastewater are considered important factors of FC in surface waters (Xu et al., 2022). Fecal contamination by water can generate potential risks of infection and outbreaks of waterborne diseases and also through the food chain or fish cultured in this water (Xu et al., 2022).

Table 7 presents the health risk of chronic ingestion of nitrate and phosphate in adult men, adult women and children. The CDI is a quantitative tool for estimating the potentially toxic effects of exposure to chemicals over a period of time, used to quantify chronic oral health risk (Das et al., 2023). The mean CDI for nitrates were 0.51, 0.60 and 0.18 for adult males, adult females and children, respectively. The CDI values for phosphates on average were 0.02, 0.03 and 0.01 for adult males, adult females and children, respectively. These values are similar to those previously reported for nitrates (adults: 0.38 and children: 0.39) and for phosphate (adults and children: 0.015) (Sáez-Huamán et al., 2023). CDI values were less than 1.0, therefore, chronic intake is not considered to be present (Isiuku & Enyoh, 2020).

The health quotient (HQ) values (mg/kg/day) of nitrate on average was 0.32 for adult males, 0.37 for adult females and 0.11 for children. The HQ (mg/kg/day) of nitrate was on average 2.60×10^{-2} for adult male, 1.70×10^{-2} for adult female and 5.12×10^{-3} for children. THI values ranged from 0.66 to 0.96 (average 0.88) for adult male, 0.77 to 1.10 (average: 1.01) for adult female and 0.23 to 0.33 (average: 0.30) for children. HQ values < 1 indicate that there are no adverse health effects of a chemical substance in adults and/or children due to its ingestion and are at a tolerable threshold (Ayejoto & Egbueri, 2024; Isiuku & Enyoh, 2020). While the total hazard index (THI) indicates a possible concern for a non-cancer risk for all chemical ingestion by adults or children (Isiuku & Enyoh, 2020); According to the THI value, adult men are at a low risk level (risk 2), adult women are at a moderate risk level (risk 3) and children are at a negligible risk level (risk 1). Excessive phosphate contamination is of concern because it is a nutrient that can increase microbial growth even in drinking water distribution systems (Kimbell et al., 2023). Phosphates together with nitrates could induce multidrug resistance in gram-negative bacteria as a potential public health problem (Xiao et al., 2024). Antibiotic resistance is a growing public health problem worldwide, even water that has been made potable is a direct route of exposure for humans and contains antibiotic-resistant bacteria and associated resistance genes (Kimbell et al., 2023). In this work, the route of contamination through the skin has not been considered, which is a limitation.

CONCLUSIONS

The water quality of the Ichu River is affected by untreated domestic wastewater discharges and poor solid waste management. The level of turbidity, TDS, BOD, DO phosphates and fecal coliforms were above the permissible limits according to the environmental water quality standard. The PCA analysis indicated that the contamination was mainly related to biological contamination probably generated by pollutants derived from human activities. Cluster analysis distinguished the association between parameters related to fecal coliforms and BOD and on the other hand phosphate level with DO. From Pearson's correlation test, the water quality variables were found to be significantly correlated. In addition, the results obtained from the WQI-NFS reveal that the water of the Ichu River had a "bad" water quality status. The results of this study confirm that the water of the Ichu River is contaminated. It cannot be used for human consumption, recreation, fishing, and other uses. Therefore, the WQI-NFS model can be used in urban high Andean Rivers. There is a high health risk due to fecal coliform contamination from wastewater discharges into the river. In addition, the total hazard index (THI) indicates that contaminants are causing negative health effects in adult males at a low risk level, adult females at a moderate risk level and in children at a negligible risk level. This could be useful for decision makers, as well as to sensitize and raise awareness among the population on the proper use and care of the waters of the Ichu River.

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