Peruvian Agricultural Research
ISSNe 2706-9397
Homepage:
http://revistas.unjfsc.edu.pe/index.php/PeruvianAgriculturalResearch

Received: september 20, 2024 / Accepted: november 21, 2024

Artículo científico

Impact of Domestic Wastewater Discharge on Organic Load and Thermotolerant Coliforms in the Ichu River, Central Highlands of Peru

Impacto de la descarga de aguas residuales domésticas sobre la carga orgánica y coliformes termotolerantes en el río Ichu, Sierra Central del Perú

Kevin Ortega-Quispe[1*], Lucía Enriquez-Pinedo[1], María Aliaga-Rojas[1], Nisbeth Carbajal-Quispe[1], Eybi Solis-Porras[1], Dennis Ccopi-Trucios[1]

DOI: 10.51431/par.v6i2.967

Abstract

Objective: This study aimed to evaluate the impact of domestic wastewater discharge on the organic load and presence of thermotolerant coliforms in the Ichu River, located in the central highlands of Peru**. Methodology:** Water samples were collected at two points in the river, both upstream and downstream. The sample collection followed national protocols for water quality monitoring, and the samples were then analyzed to determine the levels of Biochemical Oxygen Demand (BOD5), Chemical Oxygen Demand (COD), thermotolerant coliforms, and oils and greases, using standardized scientific methods. **Results:** The study revealed significant differences between the sampling points. The concentration of thermotolerant coliforms downstream exceeded environmental quality standards, indicating considerable bacterial contamination due to untreated domestic discharges. BOD5 and COD values were also higher downstream, reflecting an increase in organic pollution. Oils and fats remained within acceptable limits but were higher downstream compared to upstream. **Conclusion:** The results show the negative impact of untreated domestic wastewater on the Ichu River, with elevated levels of thermotolerant coliforms and organic pollution downstream. The study highlights the urgent need for corrective measures to improve water quality and protect both public health and the aquatic ecosystem.
Keywords: Domestic wastewater, thermotolerant coliforms, microbiological contamination, organic load, Ichu River.

Resumen

Objetivo: Este estudio tuvo como objetivo evaluar el impacto del vertido de aguas residuales domésticas en la carga orgánica y presencia de coliformes termotolerantes en el río Ichu, ubicado en la sierra central del Perú. **Metodología:** Se tomaron muestras de agua en dos puntos del río, tanto aguas arriba y aguas abajo. La recolección de las muestras siguió los protocolos nacionales para el monitoreo de la calidad del agua, las cuales luego fueron analizadas para determinar los niveles de Demanda Bioquímica de Oxígeno (DBO5), Demanda Química de Oxígeno (DQO), coliformes termotolerantes y aceites y grasas, utilizando métodos científicos estandarizados. **Resultados:** El estudio mostró diferencias significativas entre los puntos de muestreo. La concentración de coliformes termotolerantes aguas abajo superó los estándares de calidad ambiental, lo que indica una contaminación bacteriológica considerable debido a descargas domésticas sin tratamiento adecuado. Los valores de DBO5 y DQO también fueron más elevados aguas abajo, reflejando un incremento en la contaminación orgánica. Los aceites y grasas se mantuvieron dentro de los límites aceptables, pero fueron mayores en las aguas abajo en comparación con las aguas arriba. **Conclusión:** Los resultados evidencian el impacto negativo de las descargas de aguas residuales domésticas sin tratamiento en el río Ichu, con niveles elevados de coliformes termotolerantes y contaminación orgánica en las aguas abajo. El estudio destaca la necesidad urgente de implementar medidas correctivas para mejorar la calidad del agua y proteger la salud pública y el ecosistema acuático.
Palabras Clave: Aguas residuales domésticas, coliformes termotolerantes, contaminación microbiológica, carga orgánica, río Ichu.

[1] Institute of Nature Conservation and Climate Change (BIOCLIMATE), Universidad Nacional del Centro del Perú, Huancayo 12006, Perú. kevinorqu@gmail.com, luciacep7@gmail.com@gmail.com, aliaga.ambiental@gmail.com, nisbeth1993@gmail.com, 71307192@continental.edu.pe,dennisccopit@gmail.com

Introduction

Water resource contamination ranks as one of the most critical environmental challenges worldwide, especially in developing regions where wastewater management remains inadequate (Bustíos, et al., 2013). At the same time, global water demand continues to rise due to population growth and the expansion of industrial and agricultural activities (Singh et al., 2024). The World Health Organization (WHO) estimates that around 80% of the wastewater produced globally is discharged into water bodies without prior treatment, according to the Environmental Assessment and Enforcement Agency (OEFA), 2023; United Nations Children’s Fund (UNICEF), 2023), contributing to the degradation of aquatic ecosystems and the increase of waterborne diseases (Díaz –Cuenca et al., 2012). This problem is particularly severe in low- and middle-income countries, where access to sanitation facilities is limited, and wastewater treatment infrastructure is insufficient (Buslima et al., 2024).

Domestic wastewater, generated by daily activities in homes and institutions (Chen et al., 2024), contains organic matter, nutrients, and chemicals in low concentrations. Although these concentrations may seem low, their continuous discharge into rivers and other water bodies can cause significant negative effects (Koul et al., 2022; Obaideen et al., 2022; Singh et al., 2024). Rivers, essential for ecosystems and as a primary water source, are especially affected (Lai et al., 2022). Additionally, this wastewater often presents elevated levels of specific pollutants, such as ammonia (NH4+-N), phosphorus, organic matter, biochemical oxygen demand (BOD), and microorganisms (Chen et al., 2024), predominantly bacteria and fecal pathogens, which may originate from various sources, including humans, wildlife, rodents, and livestock (Gomaa et al., 2022).

Thermotolerant coliforms are a type of coliform bacteria that live in the intestines of warm-blooded animals and can survive at temperatures up to 44.5°C. These primarily include the genera *Escherichia* and *Klebsiella* from the Enterobacteria family (F. O. Da Silva et al., 2024; Wiest et al., 2021). The presence of these microorganisms in water indicates contamination, representing a significant health threat as they can transmit infectious diseases (Babuji et al., 2023; Porob et al., 2020). On the other hand, organic matter in domestic waste can overload wastewater treatment systems, generate additional sludge, and release harmful gases such as methane. Moreover, it can contaminate water bodies, promoting eutrophication, and pose public health risks if not properly treated (Da Silva et al., 2024; Some et al., 2021).

The current situation highlights the urgency of addressing the impact of domestic wastewater discharges on the quality of water bodies, showing how these discharges are significant sources of emerging contaminants, pathogens, and other harmful elements for public health and ecosystems. To tackle this issue, various treatment techniques have been proposed, such as the use of microalgae, which show remarkable potential for the removal of nutrients and heavy metals, thus improving water quality (Mehariya et al., 2024), Additionally, critical studies in rural areas of China underscore the complexity of domestic wastewater and the need to implement effective treatment techniques (Zhang et al., 2024).

The presence of thermotolerant coliforms, a crucial indicator of fecal contamination, highlights the need for continuous monitoring to assess water quality (Da Silva et al., 2024), while research in various contexts, such as the Passagem Canal in Brazil, demonstrates how environmental factors influence the proliferation of these organisms (Jamika et al., 2023). Additionally, the problem is compounded by the presence of microplastics and persistent river contamination, which exacerbate ecological degradation (Hammad et al., 2022) The management of pollutant loads, as seen in the Citarum River, and the impacts on fauna and flora in places like Algeria, underscore the importance of integrated strategies for pollution control and environmental protection (Ibtissem et al., 2023;. Zhang et al., 2017). Cases of antimicrobial resistance in thermotolerant coliforms in China highlight the growing threat posed by wastewater to the spread of resistant bacteria (Wen et al., 2023). Furthermore, seasonal variations in organic matter in urban rivers and coastal pollution, such as in Karachi and Najibabad, underscore the need for corrective actions and rigorous monitoring to mitigate the impact of wastewater in different geographic contexts (Ameta et al., 2023; Nergis et al., 2021; Poma et al., 2016). These studies converge on the conclusion that a holistic and multidisciplinary approach is required to address the challenges associated with domestic wastewater discharges, prioritizing both water quality preservation and public health.

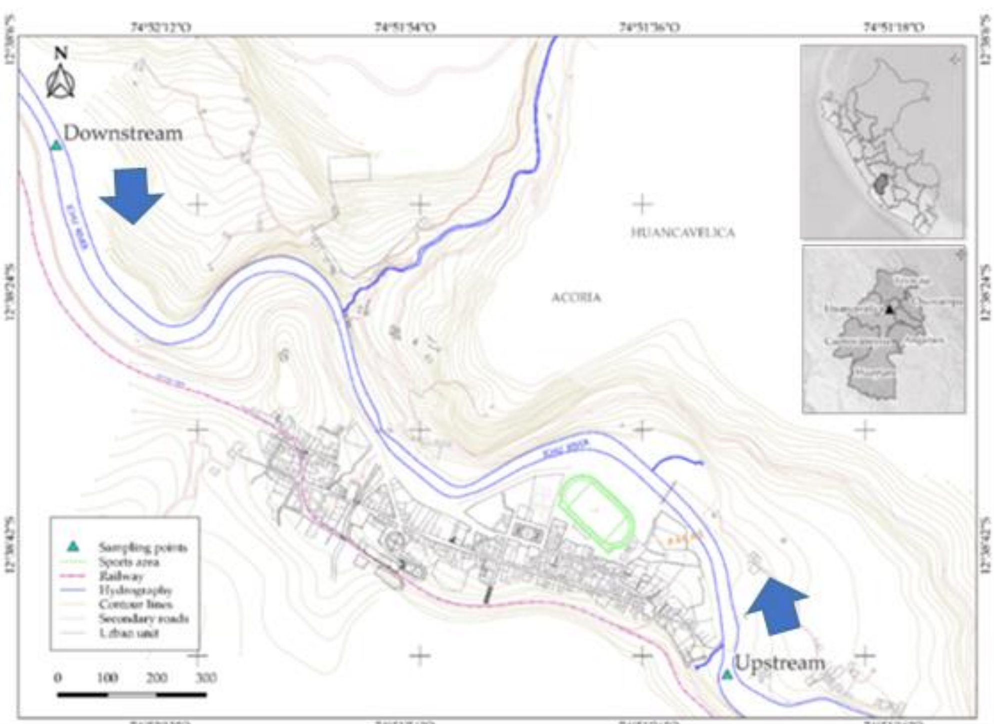
Therefore, the need arises to evaluate the impact of continuous domestic wastewater discharges into the Ichu River. This study aims to analyze how these discharges affect water quality in the Ichu River, located in the central highlands of Peru, by quantifying the organic load and the presence of thermotolerant coliforms. This research seeks to determine the magnitude of the pollution caused by these discharges, with the aim of providing essential information for environmental management and the implementation of corrective measures that support the preservation of public health and the aquatic ecosystem in the region

Methodology

The research was conducted in the Ichu River micro-basin (Figure 1), in the Acoria district of the Huancavelica department, located at 3,660 meters above sea level in the central highlands of Peru, during the year 2021. Huancavelica has an average annual temperature ranging between 12°C and 15°C, reflecting its cold climate due to its altitude in the Andean region. The average annual precipitation varies between 800 mm and 1,200 mm, with most of the rainfall concentrated in the rainy season, which runs from November to March. These climatic data are representative of the region, although they may fluctuate slightly depending on the year and season (Sociedad et al., 2022).

Figure 1

Location map of the study area indicating the sampling points.

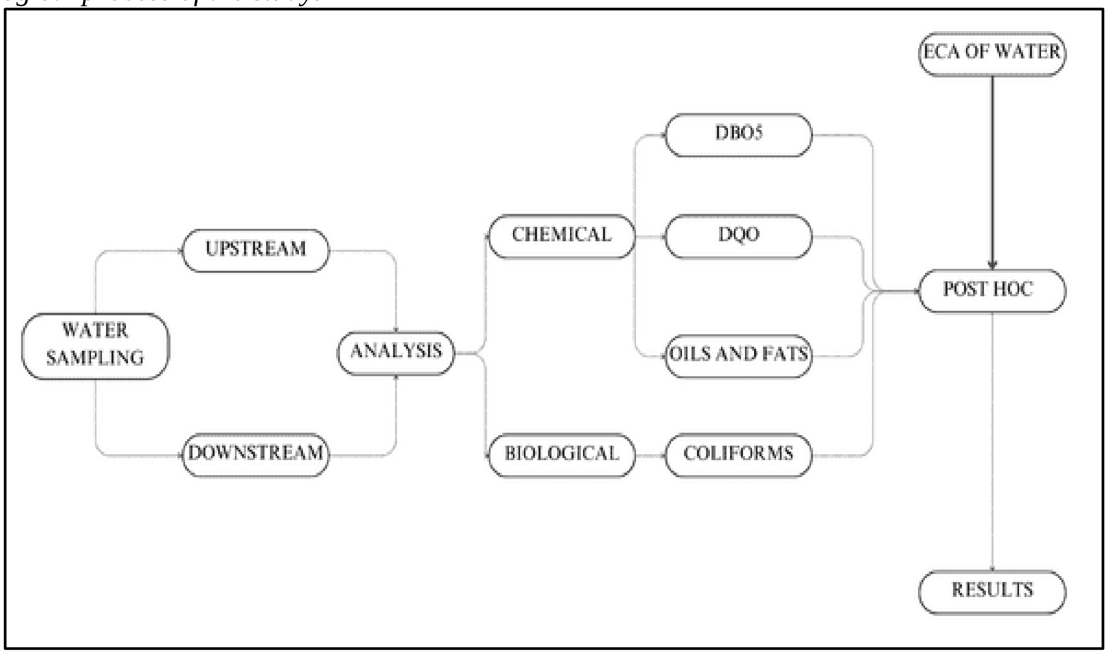


Satellite images were used for the precise identification of the sampling points, selecting two specific sites for water sample collection, which were georeferenced using a GPS device. Based on the flow direction of the Ichu River, the upstream point was identified at 12°38'46.1"S 74°51'32.6"W, and the downstream point at 12°38'13.8"S 74°52'01.8"W

Regarding the methodological process, Figure 2 illustrates the workflow for the development of this research.

Figure 2

Methodological process of the study.



The sampling procedure strictly followed the National Water Quality Monitoring Protocol of MIDAGRI (Ministerio de Desarrollo Agrario y Riego, 2016), which establishes rigorous guidelines to ensure the representativeness and quality of the samples. This protocol included the use of personal protective equipment, such as gloves and masks, and the sterilization of collection bottles with distilled water before use. Each bottle was properly labeled, indicating the date, time, and a unique identification code for the sample

Sampling was avoided in areas with high turbulence, following the protocol recommendations regarding the selection of the sampling point, considering depth, distance from the shore, and current speed. Samples were collected by submerging the bottle at approximately 20 cm depth, against the current, to minimize interference from surface sediments. The bottles were immediately placed in a cooler with an ice pack to ensure that the sample temperature remained below 4°C, as stipulated by the protocol to preserve the integrity of the physicochemical and microbiological parameters of the water. Finally, the samples were transported to the laboratory and delivered within 4 hours of collection, complying with the maximum conservation times established by the protocol. The analyses were performed by "Ambiental Laboratorios S.A.C." in Huancayo, following the established methods and conservation times. pH and temperature measurements were taken with a calibrated multiparameter device, and a rigorous chain of custody was maintained to ensure the integrity of the samples

Regarding the microbiological analysis, the tests were conducted by the laboratory "Ambiental Laboratorios S.A.C." with the aim of evaluating the organic load and thermotolerant coliforms. To ensure the accuracy and reliability of the results, widely recognized reference methods in the scientific community were employed. These included the multiple-tube fermentation method for detecting fecal coliforms (SMEWW-APHA-AWWA-WEF 9221 E-1, 23rd Edition, 2017), the biochemical oxygen demand method (SMEWW-APHA-AWWA-WEF 5210 B, 23rd Edition, 2017), and the method for quantifying oils and fats through extraction and gravimetry (EPA-821-R-10-001, Method 1664 Rev. B, 2010). Samples were collected and analyzed within a specified timeframe, ensuring that the results obtained for each monitoring point (Table 1) were representative of the environmental conditions and water quality at the time of sampling. The values for Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), oils and fats, and thermotolerant coliforms are also presented, expressed in kilograms per day (kg/d) and Most Probable Number per day (MPN/d). For example, BOD showed significant variability in the four measurements, decreasing from 5899.91 kg/d in the first monitoring to 2794.69 kg/d in the second, and then increasing again. The presence of thermotolerant coliforms remained constant, reflecting a high biological load, indicating a considerable level of contamination.

Table 1

Data collected for each parameter and sampling point downstream of the river.

Downstream	M.P 1	M.P 2	M.P 3	M.P 4	U.M
DBO_5	5899.91 kg/d	2794.69 kg/d	2898.20 kg/d	4295.55 kg/d	kg/d
DQO	8798.11 kg/d	7349.01 kg/d	7245.50 kg/d	7142.00 kg/d	kg/d
Oils and fats	1656.11 kg/d	1242.09 kg/d	1138.58 kg/d	ND	kg/d
Thermotolerant coliform	1.24209E+13 NMP/d	1.55261E+13 NMP/d	1.03507E+13 NMP/d	7.55603E+12 NMP/d	NMP/d

Note: M.P = Monitoring Point; U.M = Unit of Measurement.

Table 2 shows the contaminant load in the upstream waters of the Ichu River, evaluating the Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), oils and fats, and thermotolerant coliforms at four monitoring points. The BOD and COD values fluctuated significantly, indicating variations in water quality possibly due to changes in pollution sources. Thermotolerant coliforms, indicators of fecal contamination, showed a decreasing trend, although elevated levels persist, evidencing a continuous presence of contamination. These results reflect an aquatic environment with a significant load of organic and microbiological pollution, highlighting the need for constant monitoring and measures to reduce pollution in the river.

Table 2

Data collected for each parameter and sampling point upstream of the river

Upstream	M.P 1	M.P 2	M.P 3	M.P 4	U.M
DBO_5	3312.23 kg/d	2380.67 kg/d	2173.65 kg/d	3622.75 kg/d	kg/d
DQO	8591.10 kg/d	5382.37 kg/d	5278.87 kg/d	6676.21 kg/d	kg/d
Oils and fats	1242.09 mg/L	1148.37 mg/L	1045.3 mg/L	1198.2 mg/L	mg/L
Thermotolerant coliform	8.17707E+12 NMP/d	6.72797E+12 NMP/d	5.6929E+12 NMP/d	2.17365E+12 NMP/d	NMP/d

Note: M.P = Monitoring Point; U.M = Unit of Measurement.

The parameters for evaluating domestic wastewater are essential measurements for determining water quality and its impact on the environment, being fundamental for monitoring and controlling pollution before its discharge into water bodies or its treatment. These include the Biochemical Oxygen Demand (BOD5), which measures the oxygen required for microorganisms to decompose organic matter; the Chemical Oxygen Demand (COD) (Crainic & Fechete, 2024; Ramos Ascue, 2018), which quantifies the oxidizable substances present; and Total Suspended Solids (TSS), which indicate the concentration of suspended particles. The pH is used to determine the acidity or alkalinity of the wastewater, while nitrogen and phosphorus levels are critical due to their potential to cause eutrophication. Fecal and Thermotolerant Coliforms act as indicators of microbiological contamination, and Total Dissolved Solids (TDS) measure the concentration of dissolved salts and solids. Other relevant parameters include Oils and Fats, derived from domestic activities, and Heavy Metals such as lead and mercury, which pose significant environmental risks. Finally, temperature is monitored for its influence on biological and chemical processes during water treatment (Crainic & Fechete, 2024; El Hafidi et al., 2023; Da. Silva et al., 2024).

In Peru, the water quality standards (ECAs), regulated by Decreto Supremo N° 004 (2017), establish maximum permissible parameters for various categories of use, among which Category 3 focuses on the conservation of aquatic flora and fauna. These standards aim to ensure that water quality is suitable for the life and reproduction of aquatic species, regulating key parameters such as pH, which must be maintained between 6.5 and 8.5; Biochemical Oxygen Demand (BOD_5), which must not exceed 5 mg/L; and Chemical Oxygen Demand (COD), limited to 40 mg/L. Furthermore, a limit of 50 mg/L is set for Total Suspended Solids (TSS), 1.0 mg/L for Total Nitrogen, and 0.025 mg/L for Total Phosphorus (Menendez Gutierrez, 2018; Raffo Lecca & Ruiz, 2014; Ramos Ascue, 2018). Additionally, Thermotolerant Coliforms must remain below 1000 NMP/100 mL, and heavy metals such as lead and mercury are limited to 0.003 mg/L and 0.0005 mg/L, respectively. Other parameters include the concentration of Oils and Fats, which should not exceed 0.5 mg/L, and temperature, which must not exceed the natural water body temperature by more than 3°C. This regulatory framework is essential for evaluating the impact of domestic wastewater discharge on water bodies such as the Ichu River, allowing for the analysis of how these discharges affect water quality and its capacity to support aquatic life (Decreto Supremo N° 004 (2017) Sridhar et al., 2019).

Table 3

Established values in the environmental quality standard for each evaluated parameter.

Parameter	Unit	ECA Category 3
Ph	Unit pH	6.5 - 8.5
Biochemical Oxygen Demand (BOD_5)	mg/L	≤ 5
Chemical Oxygen Demand (COD)	mg/L	≤ 40
Total Suspended Solids (TSS)	mg/L	≤ 50
Total Nitrogen	mg/L	≤ 1.0
Total Phosphorus	mg/L	≤ 0.025
Thermotolerant Coliforms	NMP/100 mL	≤ 1000
Lead	mg/L	≤ 0.003
Mercury	mg/L	≤ 0.0005
Oils and fats	mg/L	≤ 0.5
Temperature	°C	Must not exceed 3°C above the natural temperature of the water body

Note: Environmental Quality Standards (ECA) Decreto Supremo N° 004-2017-MINAM (2017

Results

The following statistical bar diagrams illustrate the monitoring of Biochemical Oxygen Demand (BOD5), Chemical Oxygen Demand (COD), oils and fats, and thermotolerant coliforms at strategic points located upstream and downstream, in accordance with Category 3 of the Environmental Quality Standards (ECA) for water.

Figure 3 presents the concentration of BOD5 during the four monitoring periods. In the first monitoring (M1), a concentration of 3.2 mg/L was recorded, which decreased to 2.3 mg/L in the second monitoring (M2) and to 2.1 mg/L in the third (M3). However, in the fourth monitoring (M4), the concentration increased to 3.5 mg/L, making it the highest value upstream. In comparison, values downstream were higher: 5.7 mg/L in M1, 2.7 mg/L in M2, 2.8 mg/L in M3, and 4.15 mg/L in M4. At both sampling points, the recorded values remained below the environmental quality standards for irrigation of vegetables (D1) and animal drinking water (D2), established at 15 mg/L.

Figura 3
Biochemical Oxygen Demand (BOD) Period: August-September

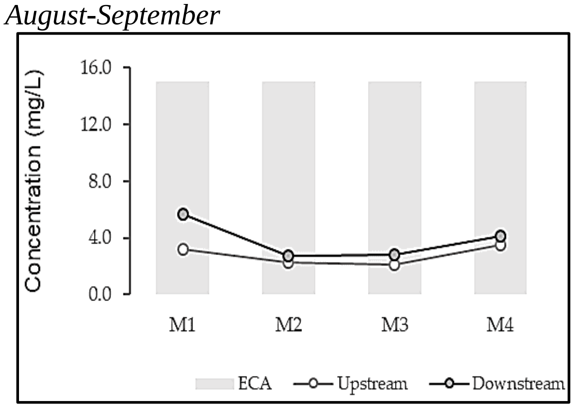


Figure 4 illustrates the concentration of Chemical Oxygen Demand (COD) during the four sampling periods. The data show that the COD concentration in the upstream section was consistently lower compared to the downstream section. The recorded values upstream were 8.3 mg/L in Monitoring 1 (M1), 5.2 mg/L in Monitoring 2 (M2), 5.1 mg/L in Monitoring 3 (M3), and 6.45 mg/L in Monitoring 4 (M4), indicating a higher concentration in M1 with a progressive decrease in M2 and M3, followed by a slight increase in M4. In the downstream section, the concentrations were 8.5 mg/L in M1, 7.1 mg/L in M2, 7.0 mg/L in M3, and 6.9 mg/L in M4. These results indicate that all COD measurements remain below the limits established by the environmental quality standards for water intended for vegetable irrigation (D1) and for animal consumption (D2), both with a threshold of 40 mg/L.

Figure 4
Chemical Oxygen Demand period August-September

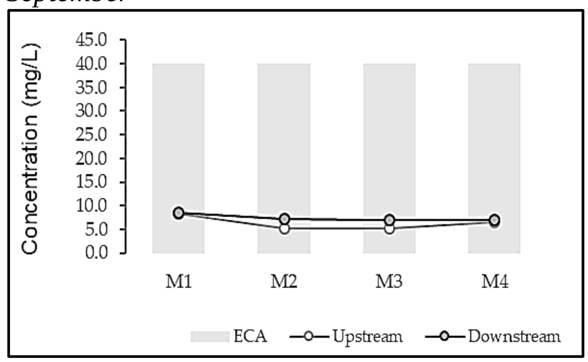


Figure 5 shows the concentration of oils and fats during the four sampling periods. The concentrations of oils and fats were 1.2 mg/L in M1 and <1.0 mg/L in M2, M3, and M4 upstream, while the concentration results downstream were 1.6 mg/L in M1, 1.2 mg/L in M2, 1.1 mg/L in M3, and <1.0 mg/L in M4. The results indicate that the concentration downstream is higher than that upstream. It is evident that for both monitoring points, the concentration of oils and fats is within the permissible discharge parameters, not exceeding the Environmental Quality Standards (ECA) for water used for vegetable irrigation (D1) (5 mg/L) or for animal drinking (D2) (10 mg/L).

Figure 5
Concentration of oils and fats for August-September.

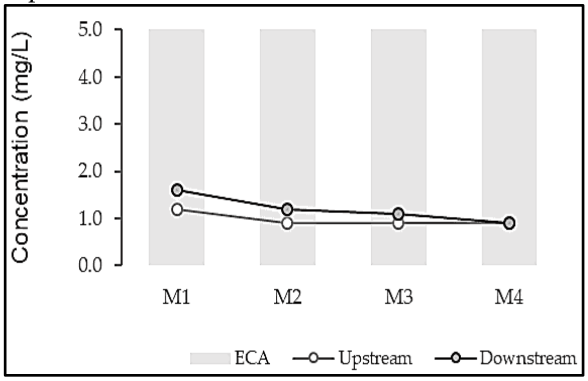


Figure 6 shows the concentration of thermotolerant coliforms. The results at the upstream sampling point were 790 NMP/100 ml in M1, 650 NMP/100 ml in M2, 550 NMP/100 ml in M3, and 210 NMP/100 ml in M4, with the latter being the lowest value in the monitoring. The values from the downstream monitoring were 1200 NMP/100 ml in M1, 1500 NMP/100 ml in M2, 1000 NMP/100 ml in M3, and 730 NMP/100 ml in M4. The results show that in the first and second monitoring downstream, the values exceed the Environmental Quality Standards (ECA) for water used for vegetable irrigation (D1) (1000 mg/L) and for animal drinking (D2) (2000 mg/L).

Figure 6
Thermotolerant Coliform Concentration Period August-September.

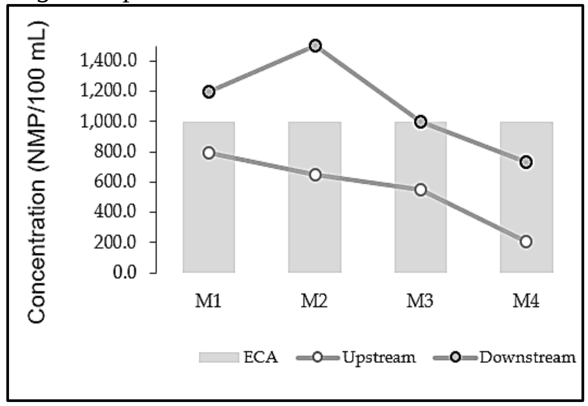


Table 4 shows the analysis of variance (ANOVA) conducted to compare the concentrations of four variables (BOD_5, COD, Oils and Greases, coliforms) upstream and downstream. The results of the statistical analysis indicate that only the concentration of thermotolerant coliforms shows a statistically significant difference ($p = 0.034$), with lower concentrations downstream. For the variables BOD_5, COD, and Oils and Greases, no significant differences were found between the two monitoring points, indicating that their concentrations are similar upstream and downstream. This suggests that the impact on water quality, in terms of these parameters, is comparable at both sites, except for thermotolerant coliforms, which significantly decrease downstream.

Table 4
Analysis of variance comparing the concentrations of four evaluated parameters.

Variable	ANOVA (Type)	ANOVA (Residuals)	Tukey (Diff)	Tukey (*p adj*)
DBO_5	F(1, 6) = 1.85, *p* = 0.223	Sum Sq: 7.324, Mean Sq: 1.221	-1.0625 (Aguas Arriba - Abajo)	*p* = 0.223
DQO	F(1, 6) = 1.773, *p* = 0.231	Sum Sq: 8.374, Mean Sq: 1.396	-1.1125 (Aguas Arriba - Abajo)	*p* = 0.231
Oils and fats	F(1, 2) = 0.107, *p* = 0.775	Sum Sq: 0.140, Mean Sq: 0.070	-0.1 (Aguas Arriba - Abajo)	*p* = 0.775

Thermotolerant coliform	$F(1, 6) = 7.461$, $p = 0.034$	Sum Sq: 499875, Mean Sq: 83312	-557.5 (Aguas Arriba - Abajo)	$p = 0.034$*

Note: Analysis of variance between the data of the type parameters and residuals. * p value < 0.05

Discussion

The concentration of BOD_5, COD, oils and fats, and thermotolerant coliforms at the downstream sampling points is significantly higher than at the upstream points. This can be explained by four reasons: first, the flow rate (11.98 m^3/s) downstream is lower than upstream, which suggests a higher concentration of wastewater over a given period. Second, there is a larger population with wastewater discharge aqueducts downstream (Gil et al., 2012) Third, in bodies of water with low flow or during dry periods, the dilution capacity is reduced, which can lead to higher concentrations of contaminants downstream (Putman et al., 2024). Fourth, hydrological factors can affect how contaminants disperse and degrade. In some cases, these factors can cause contaminants to persist in the water for longer periods downstream (Salazar Huánuco, 2020).

Water quality deteriorates significantly in the lower stretches of rivers due to the accumulation of wastewater and the reduced capacity of river ecosystems to dilute pollutants (Diego & Alfaro, 2023). Consequently, it is important to control human activities that affect organic load in rivers and to implement wastewater treatment measures, especially in downstream areas where contaminants tend to concentrate more due to a combination of factors such as lower flow and higher waste discharge (Raffo Lecca & Ruiz, 2014). Thus, the state of the aquatic ecosystem is compromised, favoring processes of eutrophication and anaerobic decomposition that worsen the environmental situation.

The presence of Escherichia coli and coliforms highlights the severity of bacteriological contamination in various bodies of water. At Pucusana beach in Lima, E. coli values exceeding 1000 NMP/100 ml were detected, surpassing the permissible limits, which indicates a lack of sanitation for recreational use due to discharges of inadequately treated wastewater (Huayanay-Quevedo et al., 2022). Similarly, in sugar mills in Cuba, the water used to wash raw sugar showed fecal and total coliforms above the allowed limits, compromising the quality of water intended for technological uses (Fernández-Santisteban, 2017). In the Valle de Juárez, Chihuahua, the evaluation of the microbiological quality of domestic water revealed a high prevalence of total coliforms and the presence of parasites such as Cryptosporidium and Giardia, despite the absence of E. coli in the samples, suggesting the ineffectiveness of chlorination in the region and a heightened public health risk (Fábrega & Fábrega, 2022). Finally, in the Río Bravo, contamination with enteropathogens, including E. coli, Cryptosporidium, and Giardia, was evident in 100% of the samples.

The average difference in the concentration of thermotolerant coliforms between the monitoring points upstream (550 NMP/100 mL) and downstream (1107.5 NMP/100 mL) was 557.5 NMP/100 mL. This significant increase indicates a deterioration in water quality as the river progresses, particularly at the first three monitoring points of the Ichu River, where upstream values reach levels established by the Environmental Quality Standards (ECA) for surface waters, classifying them as contaminated. These results highlight the increasing organic load in specific sections of the river, suggesting a direct impact from untreated domestic and industrial discharges, exacerbating the level of pollution in the lower basin of the river.

Conclusions

The results reveal a high concentration of thermotolerant coliforms at the sampling points downstream of the Ichu River, exceeding the limits established by the ECA, indicating significant microbiological contamination due to untreated domestic discharges. Although the levels of BOD5 and COD are lower in some monitoring periods, the data reflect a growing trend in organic pollution along the river, highlighting the urgency of implementing more effective treatment systems to reduce the pollutant load in the discharged wastewater.

The analysis of variations in water quality shows that the river's dilution capacity is lower in the downstream sections, exacerbating the accumulation of pollutants and increasing the risk of eutrophication and deterioration of the local aquatic ecosystem. The persistent presence of thermotolerant coliforms, along with the high organic load, highlights the need for constant monitoring and the implementation of environmental management policies that prioritize the control of domestic pollution sources in the Ichu River basin.

References

Ameta, S. K., Mohsin Kamaal, & Ahamad, F. (2023). Impact of Domestic and Industrial Effluent Disposal on Physicochemical Characteristics of River Malin at Najibabad City, India. *AgroEnvironmental Sustainability*, *1*(3), 246–256. https://doi.org/10.59983/s2023010306

Babuji, P., Thirumalaisamy, S., Duraisamy, K., & Periyasamy, G. (2023). Human Health Risks due to Exposure to Water Pollution: A Review. *Water (Switzerland)*, *15*(14), 1–15. https://doi.org/10.3390/w15142532

Buslima, F. A., Abu Hasan, H., Sheikh Abdullah, S. R., & Othman, A. R. (2024). Water recovery from domestic wastewater using integrated biofilm-phytoremediation technology: A review. *Journal of Water Process Engineering*, *65*(May), 105875. https://doi.org/10.1016/j.jwpe.2024.105875

Bustíos, C.; Martina, M. & Arroyo, R. (2013). Deterioration of environmental quality and health in Peru today. *Revista Peruana De Epidemiología*, *17*(1), 1–9. https://www.redalyc.org/pdf/2031/203128542001.pdf

Chen, Y., Chen, Z., Dong, Y., & Wu, H. (2024). Enhanced treatment performance and reduction of antibiotic resistance genes of biochar-aeration vertical flow constructed wetland for treating real domestic wastewater. *Process Safety and Environmental Protection*, *189*, 11–20. https://doi.org/10.1016/j.psep.2024.06.041

Crainic, R., & Fechete, R. (2024). Slaughterhouse Wastewater Properties Assessment by Modern and Classic Methods. *Water*, *16*(17), 2382. https://doi.org/10.3390/w16172382

Da Silva, F. O., Camargo, A. F., & Treichel, H. (2024). Thermotolerant coliform bacteria present in water bodies. *Brazilian Applied Science Review*, *8*(1), 42–67. https://doi.org/10.34115/basrv8n1-003

Decreto Supremo N° 004-2017-MINAM, (2017). *Aprueban Estándares de Calidad Ambiental (ECA) para Agua y establecen Disposiciones Complementarias*. https://www.minam.gob.pe/disposiciones/decreto-supremo-n-004-2017-minam/

Díaz-Cuenca, E., Alvarado-Granados, A. R., & Camacho-Calzada K. E. (2012). El tratamiento de agua residual doméstica para el desarrollo local sostenible: el caso de la técnica del sistema unitario de tratamiento de aguas, nutrientes y energía (SUTRANE) en San Miguel Almaya, México, *Quivera, 14(1)*, 1–21. https://www.redalyc.org/pdf/401/40123894005.pdf

Diego, J., & Alfaro, B. (2023). Calidad del agua superficial y sus implicaciones con el agua potable en Las Brisas de Zarcero. *Intersedes*, *24*(49),196-215. https://doi.org/10.15517/isucr.v24i49

El Hafidi, E. M., Mortadi, A., Chahid, E. G., & Laasri, S. (2023). Monitoring of domestic wastewater treatment via infiltration percolation using impedance spectroscopy. *Environmental Technology and Innovation*, *32*,103421. https://doi.org/10.1016/j.eti.2023.103421

Fábrega, H., & Fábrega, D. J. (2022). Evaluation of coliforms and physico-chemical factors of the water in a sector of the mouth of the San Pablo river, Veraguas, Panama. *Centros, 11*(2), 27-42.

Fernández-Santisteban, M. T. (2017). *Determinación de coliformes totales y fecales en aguas de uso tecnológico para las centrífugas*. *51*(2), 70–73. http://www.redalyc.org/articulo.oa?id=223154251011

Gil, M. J., Soto, A. M., Usma, J. I., & Gutiérrez, O. D. (2012). Contaminantes emergentes en aguas, efectos y posibles tratamientos. *Producción +*

Limpia, *7*(2), 52-73. http://www.scielo.org.co/pdf/pml/v7n2/v7n2a05.pdf

Gomaa, H. E., Charni, M., Alotibi, A. A. A., AlMarri, A. H., & Gomaa, F. A. (2022). Spatial Distribution and Hydrogeochemical Factors Influencing the Occurrence of Total Coliform and E. coli Bacteria in Groundwater in a Hyperarid Area, Ad-Dawadmi, Saudi Arabia. *Water (Switzerland)*, *14*(21), 3471. https://doi.org/10.3390/w14213471

Hammad, A. M., Eltahan, A., Hassan, H. A., Abbas, N. H., Hussien, H., & Shimamoto, T. (2022). Loads of Coliforms and Fecal Coliforms and Characterization of Thermotolerant Escherichia coli in Fresh Raw Milk Cheese. *Foods*, *11*(3). 332. https://doi.org/10.3390/foods11030332

Huayanay - Quevedo, C. M., Basilio Aldoradin, V., & Santa Cruz Guerra, A. (2022). Presence of by Escherichia coli in Pucusana Beach, Lima and its potential effect on public health. *Acta Medica Peruana*, *39*(1), 31–39. https://doi.org/10.35663/amp.2022.391.2305

Jamika, F. I., Pangesti, D. T., Diliarosa, S., Razak, A., & Syah, N. (2023). Impact Pollution Microplastics in Rivers in Indonesia. *AMPLITUDO : Journal of Science and Technology Inovation*, *2*(1), 24–28. https://doi.org/10.56566/amplitudo.v2i1.16

Koul, B., Yadav, D., Singh, S., Kumar, M., & Song, M. (2022). Insights into the Domestic Wastewater Treatment (DWWT) Regimes: A Review. *Water (Switzerland)*, *14*(21), 3542.. https://doi.org/10.3390/w14213542

Lai, Q., Shui, J., Ma, J., He, F., Wang, L., Peng, F., Zhu, X., Pang, Q., & Wang, Y. (2022). Effects of Dissolved Organic Matter (DOM) on Perfluorooctanoic Acid (PFOA) in a Seagoing River—A Case Study of the Wanggang River Flowing into the East China Sea. *Water (Switzerland)*, *14*(21), 3580. https://doi.org/10.3390/w14213580

Mehariya, S., Das, P., Thaher, M. I., Abdul Quadir, M., Khan, S., Sayadi, S., Hawari, A. H., Verma, P., Bhatia, S. K., Karthikeyan, O. P., Zuorro, A., & Al-Jabri, H. (2024). Microalgae: A potential bioagent for treatment of emerging contaminants from domestic wastewater. *Chemosphere*, *351*, 141245. https://doi.org/10.1016/j.chemosphere.2024.141245

Menendez Gutierrez, C., & Dueñas Moreno, J. (2018). Los procesos biológicos de tratamiento de aguas residuales desde una visión no convencional. *Ingeniería Hidraulica y Ambiental*, *39*(3), 97-107. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S1680-03382018000300097&lng=es&tlng=es

Ministerio de Desarrollo Agrario y Riego [MIDAGRI]. (2016). Protocolo nacional para el monitoreo de la calidad de los recursos hídricos superficiales. *2016*. https://www.ana.gob.pe/publicaciones/protocolo-nacional-para-el-monitoreo-de-la-calidad-de-los-recursos-hidricos-0

Nergis, Y., Butt, J. A., & Sharif, M. (2021). Assessment of Marine Coastal Water Pollution from Karachi Harbour Pakistan. *International Journal of Economic and environmental Geology*, *12*, (2), 27-31. https://doi.org/10.46660/ijeeg.v12i2

Obaideen, K., Shehata, N., Sayed, E. T., Abdelkareem, M. A., Mahmoud, M. S., & Olabi, A. G. (2022). The role of wastewater treatment in achieving sustainable development goals (SDGs) and sustainability guideline. *Energy Nexus*, *7*, 100112. https://doi.org/10.1016/j.nexus.2022.100112

Poma, V., Mamani, N., & Iñiguez, V. (2016). Impact of urban contamination of the La Paz River basin on thermotolerant coliform density and occurrence of multiple antibiotic resistant enteric pathogens in river water, irrigated soil and fresh vegetables. *SpringerPlus*, *5*(1). https://doi.org/10.1186/s40064-016-2132-6

Porob, S., Craddock, H. A., Motro, Y., Sagi, O., Gdalevich, M., Ezery, Z., Davidovitch, N., Ronen, Z., & Moran-Gilad, J. (2020). Quantification and characterization of antimicrobial resistance in greywater discharged to the environment. *Water (Switzerland)*, *12*(5), 1–16. https://doi.org/10.3390/w12051460

Putman, A. L., McIlwain, H. E., Rumsey, C. A., & Marston, T. M. (2024). Low flows from drought and water use reduced total dissolved solids fluxes in the Lower Colorado River Basin between 1976 to 2008. *Journal of Hydrology: Regional Studies*, 52, 101673. https://doi.org/10.1016/J.EJRH.2024.101673

Raffo Lecca, E., & Ruiz, L. E. (2014). Caracterización de las aguas residuales y la demanda bioquímica de oxígeno. *Industrial Data*. *17*(1), 71-80. https://www.redalyc.org/pdf/816/81640855010.pdf

Ramos Ascue, J. D. (2018). Online measurement of the DQO by correlation of the spectral absorption coefficient of uv light. *Produccion + Limpia*, *13*(2), 67–76. https://doi.org/10.22507/pml.v13n2a8

Salazar Huánuco, J. E. (2020). *Evaluación del impacto de las aguas residuales sobre la calidad del agua del río Tarma en el período 2015-2019*. [Tesis de pregrado, Universidad Continental]. https://repositorio.continental.edu.pe/bitstream/20.500.12394/7893/3/IV_FIN_107_TE_Salazar_Huanuco_2020.pdf

Samai, I., Saloua, N., Ouafia, A., Hanene, R., & Zoubeida, M. (2023). Water pollution of the Oued D'Hous River (Algeria) and its potential impact on fauna and flora. *Journal of Animal Behaviour and Biometeorology*, *11*(1) e2023006. https://doi.org/10.31893/jabb.23006

Silva, C., Almeida, C. M. M., Rodrigues, J. A., Silva, S., do Rosário Coelho, M., Martins, A., Lourinho, R., Cardoso, E., Cardoso, V. V., Benoliel, M. J., Mesquita, E., Ribeiro, R., & Rosa, M. J. (2023). Improving the control of pharmaceutical compounds in activated sludge wastewater treatment plants: Key operating conditions and monitoring parameters. *Journal of Water Process Engineering*, *54*, *103985*. https://doi.org/10.1016/j.jwpe.2023.103985

Singh, D., Singh, D., Mishra, V., Kushwaha, J., Sengar, M., Sinha, S., Singh, S., & Giri, B. S. (2024). Strategies for biological treatment of waste water: A critical review. *Journal of Cleaner Production*, *454*, 142266. https://doi.org/10.1016/j.jclepro.2024.142266

Some, S., Mondal, R., Mitra, D., Jain, D., Verma, D., & Das, S. (2021). Microbial pollution of water with special reference to coliform bacteria and their nexus with the environment. *Energy Nexus*, 1C, 100008. https://doi.org/10.1016/j.nexus.2021.100008

Sridhar, M. K. C., Ana, G. R. E. E., & Laniyan, T. A. (2019). Impact of Sand Mining and Sea Reclamation on the Environment and Socioeconomic Activities of Ikate and Ilubirin Coastal Low Income Communities in Lagos Metropolis, Southwestern Nigeria. *Journal of Geoscience and Environment Protection*, *07*(02), 190–205. https://doi.org/10.4236/gep.2019.72013

United Nations Children's Fund [UNICEF] (2023). *Progress on household drinking water, sanitation and hygiene i 2000-2022: Special focus on gender*. https://data.unicef.org/resources/jmp-report-2023/

Wen, Y., Xiao, M., Chen, Z., Zhang, W., & Yue, F. (2023). Seasonal Variations of Dissolved Organic Matter in Urban Rivers of Northern China. *Land*, *12*(2), 273. https://doi.org/10.3390/land12020273

Wiest, L., Gosset, A., Fildier, A., Libert, C., Hervé, M., Sibeud, E., Giroud, B., Vulliet, E., Bastide, T., Polomé, P., & Perrodin, Y. (2021). Occurrence and removal of emerging pollutants in urban sewage treatment plants using LC-QToF-MS suspect screening and quantification. *Science of the Total Environment*, *774*, 145779. https://doi.org/10.1016/j.scitotenv.2021.145779

Zhang, H., Zhao, X., Zhai, Z., Li, Q., Guo, S., & Chang, W. (2017). Antimicrobial resistance and integrons of ESBL-producing thermotolerant coliforms from a water reservoir in Tai'an, China. *The Journal of Infection in Developing Countries*, *11*(10), 740–746. https://doi.org/10.3855/jidc.8449

Zhang, J., Jiang, Y., Zhang, H., Feng, D., Bu, H., Li, L., & Lu, S. (2024). A critical review of characteristics of domestic wastewater and key treatment techniques in Chinese villages. *Science of the Total Environment*, *927*, 172155. https://doi.org/10.1016/j.scitotenv.2024.172155