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Articles

Water quality index in the high-Andean micro-basin of the Chumbao River, Andahuaylas, Apurímac, Peru

Índice de calidad de agua en la microcuenca altoandina del río Chumbao, Andahuaylas, Apurímac, Perú

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Abstract

The water quality index (WQI) of a water body, indicates the degree of contamination for a given use, and it is related to the anthropic activities that they provoke around. The objective was to determine the WQI, in the high-Andean micro-basin of the Chumbao River, Andahuaylas, Peru. The section of study was included between the head of the basin (13°46'42.5" S, 73°13'50.0" W and 4 295 m of altitude), and last

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sampling point (13°35'26.4" S, 73°27'0.8" W and 2 529 m of altitude), with an average slope of 4%. The WQI Dinius was evaluated considering parameters such as oxygen level (DO and BOD_5), eutrophication level (NO_3^- and PO_4^{3-}), physical characteristics (temperature, turbidity, color and TDS), dissolved substances (alkalinity, hardness, pH, conductivity and chlorides), and microbiological parameters (*E. coli* and total coliforms); it was sampled during the avenues season (02 lentic points and 08 lotics). The data were collected in triplicate, and analyzed through an ANOVA, Tukey test and Pearson's correlation at 5% significance. It was found that the predominant use of river water is for agriculture, pasture and urbanization; the WQI is divided into three categories Excellent (M1, M2, M3, M4 and M5) close to the head of the micro-basin and the lentic points (Pampahuasi and Paccoccocha lagoons), Acceptable (M6), and excessively contaminated points M7 and M8 outside the urban area downstream (p-value < 0.05); presenting a good negative correlation with the study parameters. In conclusion, the water in areas of low population density is good.

Keywords: High-Andean, Dinius, WQI, micro-basin, Chumbao River.

Resumen

El índice de calidad del agua (ICA) de un cuerpo hídrico indica el grado de contaminación para un determinado uso y está relacionado con las actividades antrópicas que suscitan alrededor. El objetivo fue determinar

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el ICA en la microcuenca altoandina del río Chumbao, Andahuaylas, Perú. El tramo de estudio estuvo comprendido entre la cabecera de cuenca (13° 46' 42.5" S, 73° 13' 50.0" O y 4 295 m de altitud), y el último punto de muestreo (13° 35' 26.4" S, 73°27'0.8" O y 2 529 m de altitud), con pendiente media de 4 %. El ICA Dinius se evaluó considerando parámetros como nivel de oxígeno (OD y DBO_5); nivel de eutrofización (NO_3^- y PO_4^{3-}); características físicas (temperatura, turbidez, color y STD); sustancias disueltas (alcalinidad, dureza, pH, conductividad y cloruros), y parámetros microbiológicos (*E. coli* y coliformes totales); se muestreó en temporada de avenidas (02 puntos lénticos y 08 lóticos). Los datos se recolectaron por triplicado y se analizaron a través de un ANOVA, test Tukey y correlación de Pearson al 5 % de significancia. Se encontró que el uso predominante del agua del río es para agricultura, pastura y urbanización; el ICA está distribuido en tres categorías: Excelente (M1, M2, M3, M4 y M5), cercanos a la cabecera de la microcuenca y los puntos lénticos (lagunas de Pampahuasi y Paccoccocha); Aceptable (M6); y Excesivamente contaminado; los puntos M7 y M8 fuera de la zona urbana aguas abajo (*p-value* < 0.05) presentan buena correlación negativa con los parámetros de estudio. En conclusión, el agua en zonas de baja densidad poblacional es buena.

Palabras clave: altoandina, Dinius, ICA, microcuenca, río Chumbao.

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Introduction

Rivers can be polluted on their way from source to mouth, especially rivers that flow through urbanized areas that carry excessive levels of nitrogen, phosphorous, and organic matter that are dispersed through stormwater runoff (Bhatti & Latif, 2011), on the other hand, most rivers are affected by discharges of untreated used water from clandestine landfills, sanitary landfills, liquid and solid industrial waste (Mophin-Kani & Murugesan, 2011), generated environmental problems and in the quality of the water bodies (Blume *et al*., 2010; Benvenuti, Kieling-Rubio, Klauck, & Rodrigues, 2015), and the Chumbao River is no stranger to this reality.

On the other hand, the anthropic activities surrounding the river basin, such as livestock, agriculture, and mining, are sources that generate negative impacts on the quality of water in a river, whose pollutant components in many are not biodegradable or the self-purification capacity of rivers is low, especially if they have traces of dissolved metals and inorganic material.

The quality of the waters is evaluated through physicochemical parameters such as pH, dissolved oxygen, biochemical oxygen demand, and others; also with microbiological indicators such as *E. coli*, which show the anthropic activity of a region (Froehner, Machado, Botelho, & Cordova, 2010; Dhawde *et al.*, 2018; Abbas & Hassan, 2018).

Horton (1965) proposed a way to qualify the state of a water body,through the water quality index (WQI) being the pioneer in developing a unified methodology for its calculation; however, the development and implementation of an WQI in a formal and demonstrated manner was carried out by Brown, Macclelland, Deininger and Tozer, (1970), with the support of the National Sanitation Foundation (NSF) called the NSF and Dinius index (Dinus, 1987), based on physicochemical and microbiological parameters, both considered the structure of the Horton index and the Delphi method to define the parameters, weighted weights, subscripts and classification to be used in the calculation (Prakirake, Chaiprasert, & Tripetchkul, 2009; Bharti & Katyal, 2011).

The city of Andahuaylas in Peru and the Chumbao river share the same space in the micro-basin, however, the city has not been able to establish a positive dynamic of coexistence with the river, it has cut its natural fluids, its outcrops, and its riverside forests. At the same time, it uses its waters for agricultural activities in the dry season, producing

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various vegetables that are commercialized in the local market, which can cause health problems in the population (Aguirre-Martínez, André, Gagné, & Martín-Díaz, 2018). In this sense, the objective of the work was to evaluate the water quality index in the upper Andean micro-basin of the Chumbao River, the results of which will allow the prioritization of environmental sanitation projects in the impact zone.

Materials and methods

Description of the study area

The study was carried out in the rainy season in March 2018, in the Chumbao River micro-basin (Figure 1) located in the Andahuaylas province, Apurímac, Peru, in the section between the head of the basin

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(13° 46' 42 .5" S, 73° 13' 50.0" W and 4 295 m altitude), and last sampling point (13° 35' 26.4" S, 73° 27' 0.8" W and 2 529 m altitude). The micro-basin presents a Cwb climate according to Köppen's, with marked seasons, in avenues with intense rainfall between October and March (from 500 to 1 000 mm/year) and temperatures from 5 to 23 °C, the average relative humidity of 55 %. Figure 2 shows the distribution of rainfall during the experimental period.

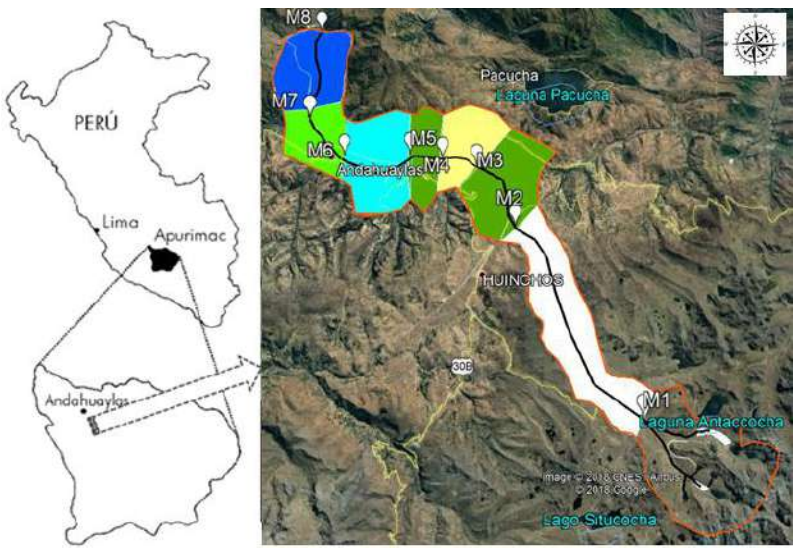

Figure 1. Micro basin of the Chumbao River.

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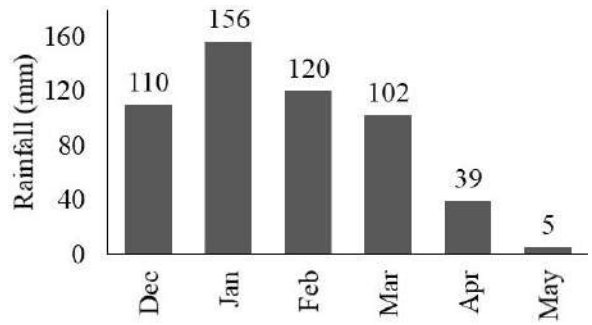

Figure 2. Precipitation between December to May 2018.

Puntos de muestreo

They were identified 08 lotic points along the Chumbao river and 02 lentic points at the head of the micro-basin, corresponding to the Pampahuasi and Paccoccocha lagoons (Figure 3).

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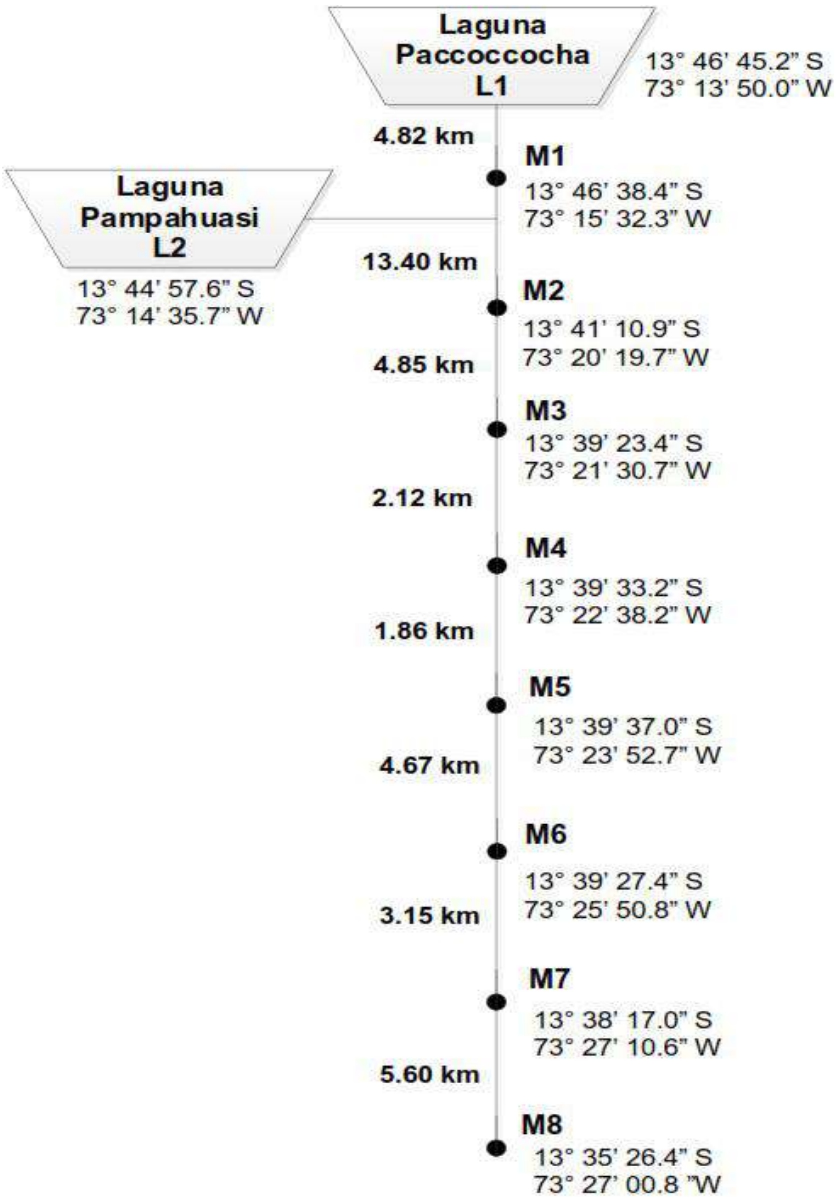

Figure 3. Sampling points in the Chumbao river micro-basin.

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Methodological scheme

The study was carried out according to the field and laboratory methodological scheme, shown in Figure 4.

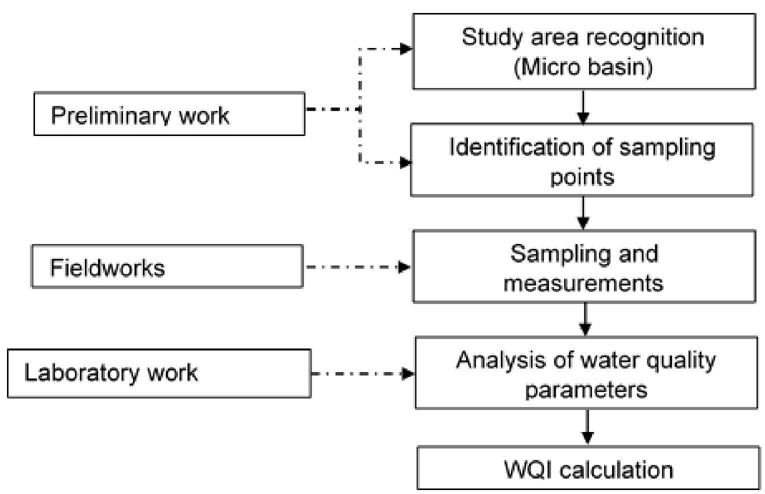

Figure 4. Methodological work flow chart.

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Physicochemical and microbiological indicators

Indicators such as biochemical oxygen demand (BOD), nitrates, phosphates, total dissolved solids (TDS), color, alkalinity and hardness were determined following the standard methodology for the analysis of water and wastewater proposed by APHA (2012), while the dissolved oxygen (DO), temperature, turbidity, pH, and conductivity were determined considering the HI 9829 multiparameter user manual, previously calibrated. Likewise, total coliforms and *E. coli* were quantified through the use of 3M Petrifilm Plates.

Determination of the WQI

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The WQI was evaluated according to Dinius, considering the weighted parameters shown in Table 1, based on the geometric mean (equation 1), the quality categorization of the WQI is detailed in Table 2:

$$WQI_m = \prod_{i=1}^{n} I_i^{W_i} \quad (1)$$

Where WQI$_m$: Water Quality Index; I_i: Subscript of Parameter i; W_i: Weighting factor for subscript *i.*

Table 1. The weighting of indicators for the WQI

Parameter	Unit		Quality index	
			NSF	Dinius
DO	mg O_2/L	P1	0.170	0.109
BOD	mg O_2/L	P2	0.110	0.097
Nitrates	mg/L	P3	0.100	0.090
Phosphates	mg/L	P4	0.100	---
Temperature	°C	P5	0.100	0.077
Turbidity	NTU	P6	0.080	---
TDS	mg/L	P7	0.070	---

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Color	PCU	P8	---	0.063
Alkalinity	mg $CaCO_3$/L	P9	---	0.063
Hardness	mg $CaCO_3$/L	P10	---	0.065
pH	Log[H^+]	P11	0.110	0.077
Conductivity	μS/cm	P12	---	0.079
Chlorides	mg/L	P13	---	0.074
E. coli	NMP/100 mL	P14	0.160	0.116
Total coliforms	NMP/100 mL	P15	---	0.090
Sum			1.00	1.00

Where: Pi, parameters.

Table 2. Dinius categorization for WQI

Quality	**Rank**	**Color**
Excellent	70-100	Blue
Acceptable	60-70	Light blue
Slightly contaminated	50-60	Green
Contaminated	40-50	Yellow
Heavily contaminated	30-40	Orange
Excessively contaminated	0-30	Red

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The physicochemical parameters studied were compared with Category 4 water: Conservation of the aquatic environment for rivers of the Andes, proposed in the D.S. N° 004-2017-MINAM, Perú (MINAM, 2017).

Statistical analysis

The data were collected in triplicate, and an analysis of variance (ANOVA) and Tukey multiple comparisons were performed, and Pearson's correlation coefficient was determined at a significance level of 5 %.

Results and discussions

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In Table 3, the description of the study area is presented, 23.6% is considered as a collecting basin, and in a smaller percentage the land is destined for urbanization and urban industry. The lentic and lotic sampling points of the Chumbao River are distributed through a 40.47 km water route (Figure 2), presenting three sections of steep slopes, in the section from point M1 to M3 (18.25 km) the slope it is 5.4%, from M3 to M7 (11.8 km) the slope decreases to an average value of 2.2%, and the last section of 5.60 km presents a slope of 4.3%. The steep slopes increase the speed of the water and consequently allow better aeration (Rivera, 2011), which improves the self-purification potential of water in a river (Feria-Díaz, Náder-Salgado, & Meza-Pérez, 2017).

Table 3. Current land use in the Chumbao River micro-basin.

Area of influence	Altitude (m)	Current usage	Area (km^2)	%
Lagoon Pampahuasi-L1	4 212	Reservoir	0.62	---
Lagoon Paccoccocha-L2	4 274	Reservoir	0.17	---
M1	4 081	Collecting basin	35.3	23.6
M1-M2	4 081 – 3 198	Agriculture, pasture and collecting basin	14.8	9.9

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M2-M3	3 198 – 2 992	Limited agriculture, limited pasture and urbanization	21.7	14.5
M3-M4	2 992 – 2 922	Urbanization and limited urban industry	13.3	8.9
M4-M5	2 922 – 2 875		10.2	6.8
M5-M6	2 875 – 2 817	Limited agriculture, limited pasture and urbanization	21.2	14.2
M6-M7	2 817 – 2 767		12.8	8.6
M7-M8	2 767 – 2 529	Agriculture, pasture and limited urbanization	20.0	13.4
		Total	149.3	100

In Table 4, it can be seen that the dissolved oxygen level increases slightly at the sampling points as it flows downstream (p-value < 0.05), finding values higher than those recommended by the environmental quality standards for water (ECA)-Peru (MINAM, 2017). This is mainly due to the decrease in altitude (Jacobsen & Brodersen, 2008; Torres, Cruz, Patiño, Escobar, & Pérez, 2010), high turbulence caused by the river slope, distribution of animal and plant communities (Sanders, 2002), increasing in varieties, from ichu above 3 000 m altitude, and below to eucalyptus, plants, and trees typical of the area.

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Table 4. Physicochemical and microbiological indicator values

	M1			M2			M3			M4			M5		
	$\bar{x}$	±	s	$\bar{x}$	±	s	$\bar{x}$	±	s	$\bar{x}$	±	s	$\bar{x}$	±	s
P1	6.97	±	0.07	7.33	±	0.11	7.55	±	0.12	7.34	±	0.11	7.37	±	0.07
P2	1.26	±	0.13	2.67	±	0.28	2.39	±	0.25	7.70	±	0.81	7.72	±	0.70
P3	0.00	±	0.00	0.00	±	0.00	0.00	±	0.00	0.07	±	0.06	0.13	±	0.06
P4	0.07	±	0.01	0.04	±	0.01	0.06	±	0.01	0.15	±	0.01	0.11	±	0.01
P5	10.99	±	0.11	13.43	±	0.20	13.65	±	0.21	13.88	±	0.21	14.09	±	0.21
P6	42.50	±	0.43	36.00	±	0.36	36.82	±	0.56	50.87	±	0.77	45.25	±	0.69
P7	14.02	±	0.39	25.04	±	0.69	29.05	±	0.80	42.07	±	1.16	53.10	±	1.45
P8	29.05	±	0.80	24.04	±	0.66	14.02	±	0.39	37.06	±	1.02	27.05	±	0.74
P9	0.00	±	0.00	0.00	±	0.00	0.00	±	0.00	0.00	±	0.00	12.07	±	1.10
P10	11.48	±	0.24	23.50	±	0.49	19.18	±	0.40	31.25	±	0.65	26.93	±	0.56

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P11	7.19 ± 0.08	7.63 ± 0.08	7.36 ± 0.08	7.72 ± 0.09	7.70 ± 0.09	
P12	29.33 ± 1.53	51.00 ± 2.65	60.00 ± 3.61	85.67 ± 4.73	108.0 ± 6.24	
P13	46.93 ± 1.15	17.37 ± 0.83	11.57 ± 0.57	6.30 ± 0.26	10.47 ± 0.47	
P14	0.00	0.00	0.00	692.00	462.00	
P15	15.70	15.70	63.60	1 100.0	1 690.0	

	M6	**M7**	**M8**	**L1**	**L2**	**p-value**
	$\bar{x}$ ± s	$\bar{x}$ ± s	$\bar{x}$ ± s	$\bar{x}$ ± s	$\bar{x}$ ± s	
P1	7.15 ± 0.11	7.30 ± 0.11	7.86 ± 0.08	6.09 ± 0.06	5.92 ± 0.06	> 0.05
P2	9.70 ± 0.88	14.28 ± 1.30	15.26 ± 1.39	0.05 ± 0.00	0.41 ± 0.04	> 0.05
P3	0.47 ± 0.12	0.50 ± 0.10	0.97 ± 0.15	0.00 ± 0.00	0.00 ± 0.00	> 0.05
P4	0.18 ± 0.01	0.43 ± 0.02	0.32 ± 0.02	0.00 ± 0.00	0.00 ± 0.00	> 0.05
P5	14.59 ± 0.22	15.08 ± 0.23	15.86 ± 0.24	9.80 ± 0.15	10.02 ± 0.15	> 0.05
P6	91.00 ± 1.38	112.36 ± 0.92	140.5 ± 1.16	1.43 ± 0.21	0.47 ± 0.42	> 0.05

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P7	75.13 ± 0.96	101.87 ± 1.33	152.5 ± 1.80	39.07 ± 1.10	12.02 ± 0.33	> 0.05
P8	35.06 ± 0.96	40.33 ± 0.76	18.03 ± 0.50	30.05 ± 0.83	12.02 ± 0.33	> 0.05
P9	20.03 ± 0.55	40.07 ± 1.10	55.09 ± 1.51	0.00 ± 0.00	0.00 ± 0.00	> 0.05
P10	53.35 ± 1.10	68.09 ± 1.41	54.88 ± 1.13	17.07 ± 0.35	8.84 ± 0.18	> 0.05
P11	7.82 ± 0.09	7.77 ± 0.09	8.05 ± 0.09	6.97 ± 0.07	7.11 ± 0.08	> 0.05
P12	155.0 ± 8.89	204.00 ± 4.58	302.3 ± 8.50	79.67 ± 3.06	25.33 ± 1.53	> 0.05
P13	11.67 ± 0.57	16.63 ± 0.78	30.07 ± 0.96	38.17 ± 1.82	40.13 ± 1.93	> 0.05
P14	1 100.0	2 716.0	2 159.0	11.00	0.00	
P15	2 716.0	3 282.0	2 305.0	36.00	15.70	

Where $\bar{x}$, mean; s, standard deviation; Pi, parameters; Mi, lotic points; Li, lentic points.

Regarding the BOD_5 (P2), the rivers that cross urban areas, which receive domestic, industrial and livestock effluents, normally present high values (Chung, Li & Chen, 2005; Amado *et al*., 2006; Bhatti & Latif, 2011). This behavior is characteristic for the Chumbao River (Table 4), increasing the BOD due to the presence of organic matter, as well as the

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steep slope of the river, which improves oxygenation (Soon & Seok, 2002).

Nitrate (P3) and phosphate (P4), levels are low at all sampling points, with small increases reported along the river's path (p-value < 0.05), this due to the use of nitrate-derived fertilizers (Tully, Lawrence, & Scanlon, 2012), and the garbage that is thrown into the river that is a source of phosphates (Cieszynska, Wesolowski, Bartoszewicz, Michalska, & Nowacki, 2012), while in the lagoons there is no content of these substances.

Regarding temperature (P5), it increases downstream from 10.99 ± 0.11 ° C in M1 to 15.86 ± 0.24 ° C in M8 (p-value < 0.05), this fact is due to the change in the altitude floor and the time of sampling (Rubio-Arias *et al*., 2017; Gamarra-Torres *et al*., 2018). While the water temperature in lagoons L1 and L2 is lower than in the lotic points, this is due to the altitudinal floor and damming (Webb, Hannah, Dan-Moore, Brown, & Nobilis, 2008; Arbat-Bofill *et al*., 2014), this variable has a direct influence on the chemical composition of water and DO (Rubio-Arias, Contreras-Carveo, Quintana, Saucedo-Teran, & Pinales-Munguia, 2012).

Turbidity (P6) and STD (P7) increase downstream, this fact is largely due to natural erosion in the avenues season (Ospina-Zúñiga, García-Cobas, Gordillo-Rivera, & Tovar-Hernández, 2016), as well as anthropic activity, mainly due to inorganic or organic household waste. (Almeida & Schwarzbold, 2003); Montoya, Loaiza, Torres, Cruz, &

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Escobar, 2011), and largely to the extractive activities of civil construction materials; causing problems in the aquatic habitat and changes in the hydraulic regime of the current, due to sedimentation caused by excess sedimentable solids (Caruso, 2002; Buzelli, Bianchessi, & Cunha-Santino, 2013; Choque-Quispe *et al*., 2020).

Regarding color (P8), no significant increase is observed downstream, being slightly higher in urban areas, this fact maybe because the color is related to the presence of chemical and toxic substances in domestic waste, however, in non-urban areas, color is associated with substances such as tannins and humic acids typical of native vegetation. (Camargo-Valero & Cruz-Torres, 1999).

The alkalinity (P9) and hardness (P10) increase significantly, decreasing the buffering capacity of the water, however, the results of the upstream sampling points show that the ability to neutralize acids is low, since it presents low alkalinity values, being susceptible to acidification.

On the other hand, the pH values (P11) increase slightly downstream, this variation is mainly due to anthropic activity and to native and autochthonous substances found in the river bed. This fact causes the conductivity (P12) and the concentration of chlorides (P13) to increase strongly, especially in urban areas (M5, M6, M7, and M8), due to the erosion caused by irrigation water (Tebbutt, 1998) of the cultivation fields in the high areas (M1, M2, and M3). However, the behavior of these

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parameters depends on salt deposits and soil types in the surrounding areas (Páez-Sánchez, Alfaro-Cuevas, Cortés-Martínez, & Segovia, 2013).

The microbial load is observed in two defined sections, an area (M1, M2, and M3) with the presence of cultivation fields and areas of wild fauna and flora, where the levels of *E. coli* (P14) and total coliforms (P15) are almost null, while in urban areas (M4 onwards) the levels of P14 and P15 increase dramatically, due to the presence of domestic effluents, and due to livestock activities whose residues such as manure and slurry increase the levels of coliforms (Olsen, Chappell, & Loftis, 2012; Valenzuela, Godoy, Almonacid, & Barrientos, 2012).

Regarding water quality, the Dinius index considers points M1 to M5 as excellent (Figure 5), while points M7 and M8 are considered excessively contaminated, presenting high levels of health risk (Torres, Cruz & Patiño, 2009), being able to cause diseases of hydric origin to man and animals, being a characteristic behavior of rivers that cross cities (De Maria & Moreira, 2007; Rodríguez-Gil, Cáceres, Dafouza, & Valcárcel, 2018).

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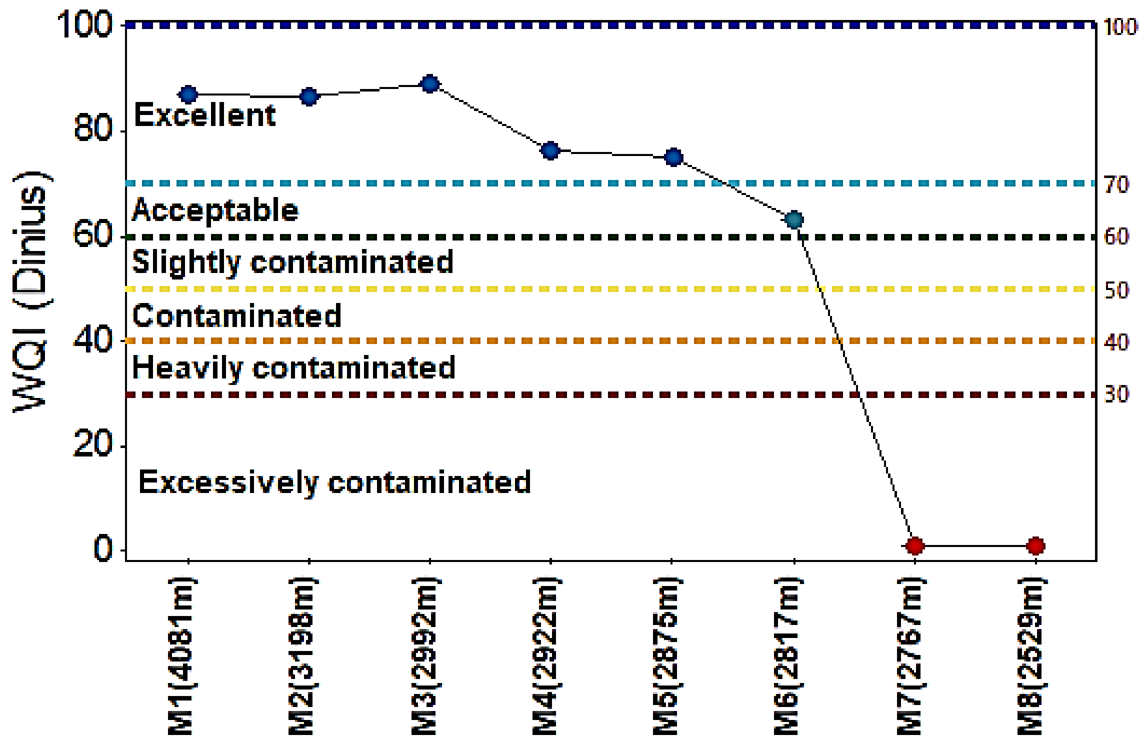

Figure 5. WQI Dinius variation by sampling points.

Temperature and DO are related to the geographical conditions of the study area (Hussein & Ali, 2017), showing a significant correlation (> 0.7) (Table 5), this happens due to the decrease in altitude from 4 081 to 2 529 m; in the same way, the BOD_5 presents a good correlation with most of the parameters under study, except color and chlorides, this is because the Chumbao river receives a discharge of solid and liquid residual organic matter, increasing the levels of Nitrates, Phosphates, Temperature, Turbidity, TDS, Alkalinity, Hardness, pH, Conductivity, who show a high

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correlation between them (Table 5), this is further evidenced by the increase in the level of coliforms along the route of the river, evidencing contamination by anthropic activities (Vieira *et al*., 2012; Peeler, Opsahl, & Chanton, 2006; Linden *et al*., 2015), which is characteristic of rivers that cross urban areas (Cotorro, Gamarra, & Barboza, 2018; Dhawde *et al.*, 2018; Abbas & Hassan, 2018).

Table 5. Correlation of parameters and WQI

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
P2	0.47														
P3	0.55	0.90													
P4	0.31	0.92	0.80												
P5	0.70	0.86	0.78	0.70											
P6	0.46	0.92	0.98	0.89	0.75										
P7	0.63	0.94	0.98	0.85	0.85	0.97									
P8	-0.61	0.31	0.01	0.40	0.02	0.15	0.02								
P9	0.54	0.92	0.97	0.88	0.77	0.97	0.98	0.05							
P10	0.29	0.93	0.83	0.92	0.82	0.89	0.85	0.43	0.85						
P11	0.57	0.87	0.80	0.65	0.91	0.76	0.84	0.17	0.75	0.79					
P12	0.62	0.95	0.98	0.85	0.85	0.97	1.00	0.03	0.98	0.86	0.84				

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P13	-0.20	-0.16	0.13	0.00	-0.49	0.14	0.02	-0.18	0.14	-0.21	-0.36	0.02			
P14	0.36	0.95	0.85	0.99	0.76	0.93	0.89	0.37	0.92	0.95	0.72	0.89	-0.03		
P15	0.17	0.92	0.77	0.87	0.76	0.82	0.80	0.51	0.80	0.94	0.76	0.81	-0.24	0.89	
WQI	-0.48	-0.93	-0.90	-0.97	-0.76	-0.95	-0.94	-0.20	-0.96	-0.89	-0.72	-0.93	-0.08	-0.98	-0.81

The results are calculated at a significance level of 5%

On the other hand, it is observed that the WQI shows a significant negative correlation with the studied parameters (> 0.72), except with DO (P1), color (P8) and Chlorides (P13) (Table 5), the reason why any variation of these parameters outside the limits established in the ECA (MINAM, 2017) would allow to know indirectly the quality of the river water, and eventually decrease its value, as considered by González, Caicedo, and Aguirre (2013), and Quiroz, Izquierdo, and Menéndez (2017).

Conclusions

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The Chumbao River water quality index (WQI) is divided into three well-defined categories Excellent (M1, M2, M3, M4, and M5) near the head of the micro basin and the lentic points (Pampahuasi and Paccoccocha lagoons), Acceptable (M6), and excessively contaminated points M7 and M8 outside the urban downstream area; and can decrease with any change in the parameters under study to values outside the ECA.

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