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Effects associated by the change of cauce río San Lorenzo, Carmen de Viboral Antioquia

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Abstract: The research object of this project revolves around the changes in the riverbed during river diversion. For this purpose, sampling work was conducted in the San Lorenzo River basin of El Carmen de Viboral city in eastern Antioquia, taking into account physical and chemical variables and biological indicators such as benthic macroinvertebrates. It has been confirmed that the diversion and/or changes in the San Lorenzo riverbed have led to changes in its physical, chemical, and biological characteristics, manifested in a decrease in dissolved oxygen concentration and saturation, an increase in pH value (due to increased peripheral coverage and photosynthesis), and water temperature (with almost no water flow, resulting in an increase in its kinetic energy). Compared to normal river beds, the richness and diversity of aquatic macroinvertebrates have sharply decreased. It was also found that the community structure of large invertebrates with weaker resistance to other more tolerant pollution has changed, leading to a loss of aquatic biodiversity and an increase in phosphorus concentration in the water generated by trout waste.

Key words: channel diversion; disturbance; aquatic macroinvertebrates; phosphorus enrichment

1 Introduction

Water is crucial for maintaining all biological processes, social quality of life, and economic activities. Water quality is determined by its chemical composition and physical properties, which are obtained through natural and human processes that limit or impair its use. This is evaluated by comparing the values assumed by the indicator parameters with established standards and criteria. The spatiotemporal changes in quality are influenced by various socio-economic and natural activities, and the intensity of these changes depends on these dynamic characteristics [1].

It is evident that in the past century, many actions have been taken for hydrological regulation (reservoirs), hydrological forest restoration (reforestation, water retaining dams), flood control (dams, embankments, channelization), resource development (quarries), and other purposes. These actions have profoundly changed the water and sediment balance in the downstream, thereby changing the morphology of river channels [2]. A whole series of disturbances has been introduced by man in an environmental system of fragile equilibrium such as the fluvial system. It has been pointed out that the construction of the dam, whether used for hydropower projects, water supply or flood control, has had an impact on the biology and ecology of the river themselves (habitat loss, ecological niche loss, fish migration obstruction, etc.) [3].

Morphological changes are changes in the shape of rivers. They represent all or part of the changes in the river system. Actions such as defense, dredging, aggregate extraction, river regulation, pipelines, urbanization, and edge structure construction will be carried out here [4]. These changes and activities have a serious impact on the spatiotemporal availability of water supply, thereby deteriorating the physical, chemical, and biological conditions of water [5].

Studies conducted in different rivers have shown that the riverbed morphology has undergone changes due to human factors [1][5]. These effects are reflected in the physical, chemical, and biological components of water, which are important indicators. It has been inferred that changes occurring upstream will have an impact on the downstream and will have a temporary delay effect, especially in the middle and lower reaches of the river [2].

Currently, benthic macroinvertebrates and other biological communities have been listed as indicators of environmental conditions of aquatic ecosystem, because their universality in the environment where they live reflects the level of human pressure on them [3][6][7]. For ecologist, aquatic ecosystem is a functional system, in which there is a cyclic exchange of matter and energy between biological and abiotic environments. Therefore, biology and chemistry are closely related. They play a complementary role in evaluating natural and polluted water [8].

Taking into account the fundamental role played by macroinvertebrates in fluvial systems, the objective is to evaluate the presence of these organisms based on a spatial and temporal comparison of the biological communities of the San Lorenzo River, after the detour of the river channel for the implementation of ponds for productive purposes.

2 Materials and methods

The San Lorenzo River basin is located within the jurisdiction of El Carmen de Viboral City in the southeastern part of the Antioquia Province in the San Nicolas Valley subregion. The geographical coordinates are 6 º 05'09 "north latitude and 75 º 20'19" west longitude, with an elevation of 2150 meters and an average temperature of 17 º C [10].

Six (6) sampling stations were established at strategic points directly observed in the field on the San Lorenzo River. Station 1 (E1) was used to implement a fish pond (comparing natural and baseline conditions with other conditions) before the river diversion. Station 2 (E2) receives residual water (underground corridor) of the rainwater channel, through which the natural river passes before the intervention. Station 3 (E3) returns the water from the pond to the natural river channel (truck exit). Station 4 (E4) is located downstream of St. Lorenzo Avenue School. Station 5 (E5) can receive low-level (turbid) tributaries. Station 6 (E6) is a point in the bridge area connecting the San Lorenzo School and a possible location for the future El Carmen de Viboral municipal crossing (Fig. 1-2).

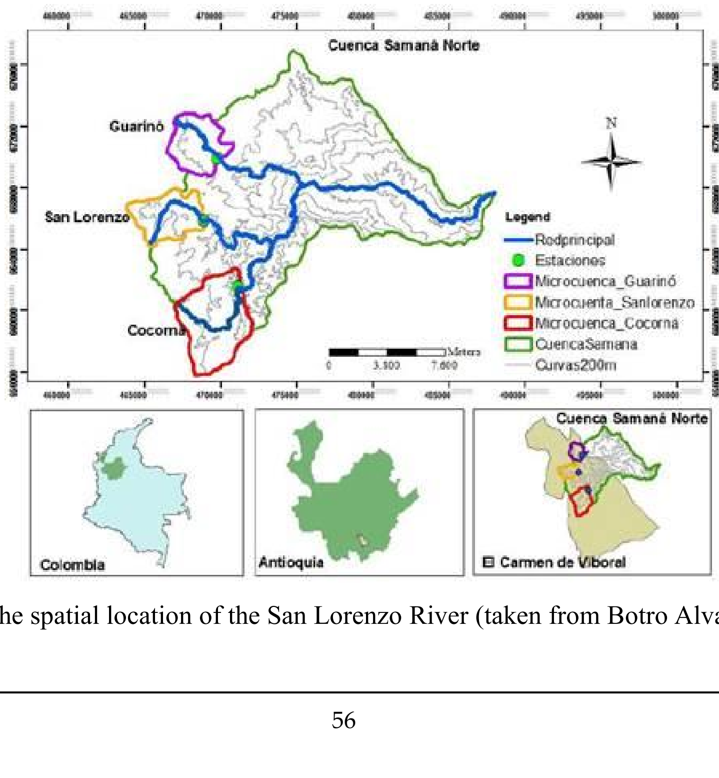

Fig. 1. The spatial location of the San Lorenzo River (taken from Botro Alvarez, 2019)

Fig. 2. Space station location

2.1 Sampling

In order to measure the physicochemical variables of water and collect biological samples, four visits were conducted for each season during different rainy seasons in November 2018, February 2019, March 2019, and May 2019.

2.2 Physicochemical variables

To determine the physicochemical water quality, these sampling sites were visited during different hydrological periods in a time window of seven (7) months with a bimonthly periodicity and parameters such as pH, electrical conductivity, dissolved oxygen, oxygen saturation percentage, water temperature, total dissolved solids were recorded in situ using a WTW multiparameter equipment.

Water samples were collected and analyzed at each station in the Water Laboratory of the School of Engineering at the University of Antioquia. The following parameters were evaluated through colorimetric and spectrophotometric methods: nitrate, nitrite, active soluble phosphorus, and iron.

2.3 Bentonic macroinvertebrates

Large invertebrates were collected countercurrent through a network, with replicates at each sampling point, supplemented by manual collection of organisms attached to rocks using tweezers. The collected specimens were stored in a 90% alcohol solution and placed in plastic containers appropriately labeled with the date and location of collection for subsequent identification at the household level. This collection enabled quantitative analysis of the morphological species of large invertebrates based on specialized classification keys [11] [3] [12] [13] [14], in order to understand the richness and abundance of their taxonomic units at the collection site. Based on the reported family list, the BMWP/COL index was calculated [6].

2.4 Data analysis

The central trend statistic (arithmetic mean) and the dispersion statistic (Pearson's relative coefficient of variation, C.V.) were used for exploratory analysis of the data obtained from the four samples. A rectified canonical correspondence analysis was performed to identify the length of the gradient and then a canonical redundancy analysis (RDA) was performed where the most important genera, evaluated variables and collection sites were integrated to identify the distribution patterns of aquatic macroinvertebrates. The aforementioned statistical analyses were carried out with the statistical package Statgraphics Centurion XV and Canoco 5.0. Community indices were calculated using the PAST package.

2.5 Indexes

When analyzing benthic macroinvertebrate communities, the ecological index was applied, which involved four elements of community structure: wealth, equity, advantage, and abundance. In addition to these indices, the BMWP/COL index was also calculated to evaluate the biological water quality of the sampling station [6].

3 Results

3.1 Climate and physicochemical characteristics

Four samples were taken during the hydrological cycle, including the humid period in November 2018, followed by the dry period from February to March, and finally the regression of the humid season where the latest samples were obtained in May 2019.

During the sampling period of different seasons, the physical and chemical variables recorded in the San Lorenzo River underwent the following changes: the water temperature (° C) at E3 station (truck outlet) was lower in March (15 ° C), and the temperature in February was higher in the same season (20.5 ° C). The pH value of station E5 (turbid tributary) was higher than 7.99 in February, while the pH value of station E2 (underground corridor) was lower than 6.2 in February and May. In November 2018, the concentration of dissolved oxygen (PPM) at E3 station was relatively high at 7.83, while in May, the concentration of dissolved oxygen (PPM) at E2 station was relatively low at 3.92. In November and March, the oxygen saturation (%) of E1 station (before shunting) was supersaturated, reaching as high as 105.5%, while the subsaturation value of E2 station in March was 51.7%. The conductivity (μ s/cm) of E2 station was 31 in February, and the lowest conductivity of E4 station (Claro) was 15 in May. The dissolved total solid (STD) (mg/L) was 35 at E2 station in February, 16 at E5 station in November, and 16 at E1 and E4 stations in May. In February and May, the NO3 concentration (mg/L) at station E6 (Alliance) was higher than 2.8, while in November and March, the NO3 concentration at station E4 was lower than 0.01. The NO2 concentration (mg/L) at E2 station was 0.009 in November and March, while the NO2 concentration (mg/L) at E5 station was 0.001 in the same month. The concentration of PO4 (mg/L) showed a high value of 6.72 at E5 station in November and March, and a low value of 0.06 at E6 station in the same month. Finally, the Fe concentration (mg/L) at E2 station was 2.9 in November and March, while the lowest value at E4 station was 0.11 in February and May (Table 1).

Table 1. Physicochemical variables recorded at six stations during four hydrological periods of the year

Muestreo	Estación	pH (unidades de pH)	Oxígeno disuelto (ppm)	Saturación de oxígeno (%)	Temperatura del agua (°C)	Conductividad eléctrica (µS/cm)	Sólidos Totales Disueltos (mg/l)	NO_3 (mg/l)	NO_2 (mg/l)	PO_4 (mg/l)	Fe (mg/l)
1	1	7,678	7,82	105,5	16,3	21,5	21	0,04	0,002	0,87	0,31
1	2	6,4	4,86	64,2	15,8	29,9	32	0,12	0,009	1,2	2,9
1	3	7,01	7,83	105,2	16,2	21,5	22	0,03	0,005	0,08	1,3
1	4	6,39	6,96	94,8	16,2	25,4	26	0,01	0,002	3,4	0,3
1	5	7,35	7,66	103,2	16,2	16,3	16	0,02	0,001	6,72	0,23
1	6	6,7	7,67	103,5	16,1	20	20	0,04	0,004	0,05	0,32
2	1	7,23	7,62	104,2	16,7	19,2	19	2,6	0,006	1,86	0,24
2	2	6,2	4	56	18,7	31	35	0,4	0,006	0,92	0,15
2	3	6,91	6,93	103	20,5	23,8	24	1,1	0,008	0,24	0,2
2	4	7,05	7,54	103,6	16,5	27,8	28	1,2	0,007	0,45	0,11
2	5	7,99	7,53	102,5	16,6	17,4	18	2,4	0,006	0,09	0,3
2	6	6,79	7,58	102,7	16,5	20,8	21	2,8	0,002	0,09	0,14
3	1	7,678	7,82	105,5	16,3	21,5	21	0,04	0,002	0,87	0,31
3	2	6,25	3,93	51,7	15,4	24,1	24	0,12	0,009	1,2	2,9
3	3	7,01	6,66	103,1	15	22,8	23	0,03	0,005	0,08	1,3
3	4	6,96	7,51	101,1	16	25	26	0,01	0,002	3,4	0,3
3	5	7,31	7,53	101,2	15,9	18	18	0,02	0,001	6,72	0,23
3	6	6,93	7,53	101,2	15,9	21	21	0,04	0,004	0,05	0,32
4	1	7,2	7,64	101,6	15,8	16,5	16	2,6	0,006	1,86	0,24
4	2	6,2	3,92	51,8	15,5	22,9	23	0,4	0,006	0,92	0,15
4	3	6,8	7,12	94,9	16,1	17,5	18	1,1	0,008	0,24	0,2
4	4	7,17	7,58	101,1	15,7	15	16	1,2	0,007	0,45	0,11
4	5	6,97	7,68	102,5	15,7	22,9	23	2,4	0,006	0,09	0,3
4	6	6,81	7,63	101,7	15,7	19,8	20	2,8	0,002	0,09	0,14

According to recorded data, the pH value (6.2) of E2 station (underground corridor) was relatively low in February and May; The concentration of dissolved oxygen (PPM) was relatively low in May (3.92); In March, oxygen saturation (%) was low (51.7%); The conductivity (µ s/cm) in February was high (31); The dissolved total solids (STD) (mg/L) value in February was very high (35); The concentration of NO2 (mg/L) in November and March was relatively high (0.009); The latest record of the adopted variable was iron concentration (mg/L), which showed high values in November and March (2.9). All these value ranges showed the degree of influence of underground corridor stations compared to other sampling stations.

With respect to the coefficient of variation of the physicochemical variables, we can group them into the following groups: those with low variation (CV <20%) such as pH, dissolved oxygen, saturation percentage, water temperature and electrical conductivity; those with intermediate variation (20%>CV<50%) such as total dissolved solids; and those with high variation (CV>50%), such as nitrates, nitrites, phosphates and iron (Table 2).

The physical and chemical conditions of water indicate that the water of the San Lorenzo River is very cold, with a neutral pH value, high oxygen saturation, low mineralization (low conductivity and total solid content), and low intermediate concentrations of nitrate, nitrite, and active soluble phosphorus.

Table 2. Measure the central trend and dispersion of physical variables

Variables	Media	Máximo	Mínimo	C.V (%)
Temperatura del agua (°C)	16,30	20,50	15,00	6,88
pH (unidades de pH)	6,96	7,99	6,20	6,70
Oxígeno di-suelto (ppm)	6,94	7,83	3,92	18,81
Saturación de oxígeno (%)	94,41	105,50	51,70	18,96
Conductividad eléctrica (µS/cm)	21,73	31,00	15,00	19,06
STD (mg/l)	22,13	35,00	16,00	21,59
NO_3 (mg/l)	0,90	2,80	0,01	121,02
NO_2 (mg/l)	0,00	0,01	0,001	53,071
PO_4 (mg/l)	1,33	6,72	0,05	144,03
Fe (mg/l)	0,54	2,90	0,11	145,70

3.2 Biological variables

Table 3 shows the large invertebrates collected through quantitative methods during sampling activities in November 2018, February 2019, March 2019, and May 2019. In the San Lorenzo River, a total of 35 genera belonging to 27 families, as well as 1044 species of large invertebrates belonging to the flatworms, annelidae, mollusks, and arthropods phyla, were collected.

In the total number of taxa collected, the most abundant was the Triptera with six (6) genera, followed by the Diptera and Efis with five (5) genera, as well as the Haploid and Basomatoforos with three (3) genera each. The families with the highest abundance were monoptera, chironomidae, Simuliidae, glossomyidae, and Dragonfly. It was pointed out that in most sampling stations during the hydrological period, this difference in distribution occurred at the San Lorenzo Underground Corridor (E2) station, where there were fewer taxonomic groups.

At station E1 (in front of the splitter), the main order was Mortoniella sp (family Muscidae), followed by the family Chironomidae (family Chironomidae) and the family Simuliidae (family Simuliidae). In the underground corridor E2 station, the lack of classification groups and individuals was an indicator of the impact of river channel changes and flow reduction.

At station E3, the trout outflow was mainly Mortoniella sp (family Muscidae), followed by Chironomidae (family Chironomidae), Basomatoros Fisasae sp (Physae), and Nadida monoptera (monoptera). At Claro E4 station, there was no representative number of individuals per household. At the E5 turbid tributary station, Simulium sp (Simuliidae) dominates, followed by Mortoniella sp (Muscidae) in the order Triptera. At station E6, there were a large number of Mortoniella sp in the order Triptera (family Muscidae), followed by Simulium sp in the order Diptera (family Simuliidae).

May 2019 was the month with the highest number of macroinvertebrates collected during the six seasonal sampling periods of the San Lorenzo River, followed by March of the same year. It is worth highlighting station E1 before the diversion, where the number of individuals exceeded the other five stations, which is understandable because it was the least intervened area of the system.

In terms of spatial and temporal distribution, most sampling stations in the upper reaches of the San Lorenzo River had the Naididae, Chironomidae, Tanytarsini, Simulium, and Mortoniella taxa, unlike station E2 hyporheic corridor where there was a decrease in the total number of individuals collected (only seventeen 17 specimens) and several families of aquatic macroinvertebrates Chironomidae, Simulium sp, Gyraulus sp, Ferrisia sp, Microvelia sp and Mortoniella during the entire sampling time.

Some taxonomic groups, such as Collembola, were only present at San Lorenzo Claro station (E4), Naididae, Tabanidae, Helobdella, and Staphylinidae at San Lorenzo Exit Truchera station (E3), Anchytarsus at San Lorenzo Union station (E6), Baetidae, and Acari SP2 at San Lorenzo Pre Derivaci station (E1), and Moribaetis, Chimarra, and Thraulodes at San Lorenzo tributary Turboo station (E5).

Table 4 shows the changes in community index values, taxonomic groups and individual numbers, as well as BMWP/COL index values for different sampling stations. Among them, the station with the highest diversity value for large invertebrates was E1 station with the highest value in May; The underground corridor E2 station had a lower value in all samples, with February being the lowest.

Regarding the Simpson Advantage Index, there are differences in the values obtained from different sampling activities. The lower value was found at station E1, with a minimum value of 0.12 in November 2018, which was related to better environmental stability in the region. At station E4, the highest value in February 2019 was 0.84, which may be due to the impact of water flow from nutrient rich fish farms.

Table 3. Aquatic macroinvertebrates collected during sampling activities

Orden	Familia	Género	San Lorenzo antes derivación				San Lorenzo corredor hiporreico				San Lorenzo salida truchera				San Lorenzo claro				San Lorenzo Turbio				San Lorenzo Unión			
			nov-18	feb-19	mar-19	may-19	nov-18	feb-19	mar-19	may-19	nov-18	feb-19	mar-19	may-19	nov-18	feb-19	mar-19	may-19	nov-18	feb-19	mar-19	may-19	nov-18	feb-19	mar-19	may-19
Arthopleona	Isotomidae	*Collembola*																2								
Haplotaxida	Tubificidae	*Oligochaeta*		1		2					1			2			1	2			7	3				
	Haplotaxidae	*Naididae*	1	11	21	5					1	2	3	15		1	2	1				1	2	1		
	Naididae	*Naididae sp*												1												
Coleoptera	Staphylinidae	*Staphylinidae*											2													
	Ptilodactylidae	*Anchytarsus sp*																							1	
Diptera	Chironomidae	*Chironomidae*		12	41	17	1	1			11	3	22	32		1	1	11	1	10	4			4	1	2
		Chironomus										3	1													
		Tanytarsini		1	2	2					1	2	1	5	5						1	2		4	2	3
	Tabanidae	*Tabanidae sp*												2												
	Simuliidae	*Simulium sp*		7	8	27	2			1	2	8		4		1	8	5	15	7		1		11	33	15
Ephemeroptera	Baetidae	*Baetidae*				1																				
		Baetodes sp		2	4	8					1			5											1	1
		Dactylobaetidae sp										2														
		Moribaetis sp																	1							
	Leptophebiidae	*Thraulodes sp*																	2							
Gastropoda	Planorbidae	*Gyraulus sp*					2			1											1					
Basommatophora	Ancylidae	*Ferrisia sp*					1	1		1																
	Physidae	*Physa sp*									2	21	6				9	5		3	10			14	1	
	Lymnaeidae	*Lymnaeidae sp*											1		1											
Hemiptera	Veliidae	*Microvelia sp*							5										1				5			
Lepidoptera	Pyralidae	*sin identificar*			1																					
Odonata	Calopterygidae	*Hetaerina americana*		3	1	1											2	1				1				
Trombidiformes	Hydrachnidiae	*Acari sp1*		1		1								1		1										
		Acari sp2				1																				
Rhynchobdellida	Glossiphoniidae	*sin identificar*										5	1													
		Helobdella sp											1													
Tricladida	Planariidae	*Planariidae*			1								7													
Trichoptera	Hydrobiosidae	*Atopsyche sp*		2		1																		1		1
	Hydropsychidae	*Leptonema sp*		7	3	10					12		7	1					5							
	Hydroptilidae	*Hydroptila sp*				1										1								2		
		Ochtrotrichia sp										1				2								2		
	Philopotamidae	*Chimarra sp*																	1							
	Glossossomatidae	*Mortoniella sp*	14	42	27	59			1		8	16	6	46	1		1	2		9	3	5		17	58	12
Tricladida	Naididae	*Dugesia sp*		1		2					1	5		3		1	6	1		6	3	4	3	10		3
	SUBTOTAL		15	90	109	138	6	2	6	3	40	68	58	117	7	8	30	30	26	35	29	17	10	66	97	37
	TOTAL INDIVIDUOS		352				17				283				75				107				210			

Table 4. Community index, number of taxonomic groups and individuals, and values of BMWP

ESTACIÓN Y FECHA DE MUESTREO		Número de taxa	Número de individuos	Diversidad Shannon-Weaver	Dominancia Simpson	Equidad de Pielou	BMWP/col
E1 San lorenzo antes derivación	Noviembre de 2018	2	15	0,24	0,12	0,35	8
	febrero de 2019	12	90	1,76	0,73	0,71	66
	Marzo de 2019	10	109	1,65	0,75	0,71	50
	Mayo de 2019	15	138	1,81	0,75	0,67	73
E2 San lorenzo corredor hiporréico	Noviembre de 2018	4	6	1,33	0,72	0,96	21
	febrero de 2019	2	2	0,69	0,50	1,00	8
	Marzo de 2019	2	6	0,45	0,28	0,65	15
	Mayo de 2019	3	3	1,10	0,67	1,00	19
E3 San lorenzo salida truchera	Noviembre de 2018	10	40	1,80	0,79	0,78	43
	febrero de 2019	11	68	1,99	0,82	0,83	45
	Marzo de 2019	12	58	1,97	0,80	0,79	54
	Mayo de 2019	12	117	1,73	0,75	0,69	55
E4 San lorenzo claro	Noviembre de 2018	3	7	0,80	0,45	0,72	13
	febrero de 2019	7	8	1,91	0,84	0,98	35
	Marzo de 2019	8	30	1,74	0,79	0,84	36
	Mayo de 2019	9	30	1,85	0,79	0,84	38
E5 San Lorenzo afluente	Noviembre de 2018	7	26	1,33	0,62	0,69	50
	febrero de 2019	5	35	1,54	0,78	0,96	34
	Marzo de 2019	7	29	1,69	0,78	0,87	25
	Mayo de 2019	7	17	1,76	0,80	0,90	33
E6 San Lorenzo Unión	Noviembre de 2018	3	10	1,03	0,62	0,94	16
	febrero de 2019	10	66	1,94	0,83	0,84	37
	Marzo de 2019	7	97	0,94	0,53	0,48	37
	Mayo de 2019	7	37	1,49	0,71	0,77	40

Regarding the Shannon Weaver diversity index, we found that the values were very low and the results were close to unity across all sampling and seasons. The San Lorenzo station before the diversion showed its lowest value in November; The Saint Lorenzo station starts from Truchella, and this index reached its highest value in February. For Pielou's stock index, its distribution showed a consistent trend by approaching a value of one (1), except for the San Lorenzo station, which had a value of 0.35 in November 2018 before derivation. Overall, this index indicates to us that the majority of species have the same number as shown in Table 4.

Compared to the community index, the number of classification groups was lower, ranging from 2 to 15. E2 station (underground corridor station) had the lowest values of taxonomic units (2-3), individual numbers (2-6), Shannon diversity index, and BMWP/COL.

E1 station was the highest part of the river assessment, and it was located before the water system diversion area; In this region, the San Lorenzo River had the highest values for taxa and individuals, diversity index, fairness, and BMWP/COL.

The BMWP/COL index had the highest score at E1 station, indicating moderate water pollution in November, February, and March, and mild water pollution in May; Compared to other sites, it showed us less polluted water quality, while the E2 San Lorenzo underground corridor site's score recorded the average value of severely polluted water. Although it must be clarified that this low value was not a sign of organic pollution, it reflected a lack of flow due to disconnection from the river.

The scores of other stations indicated moderate and severe pollution of water quality, which posed difficulties in making it a possible source of supply for the El Carmen de Viboral city aqueduct.

Table 5 shows the physical and chemical variables of each major component and the percentage of variance explained, with bold font highlighting statistically significant relationships. In axis 1, it is observed that the dissolved oxygen concentration and saturation exhibit the highest positive values, while the conductivity and total solids exhibit the highest negative values. In axis 2, the values of the vectors are very low, and none of them have statistical significance. However, the proposed model can explain 40% of community differences.

Table 5. Variables selected for multivariate analysis

Variable	Eje 1	Eje 2
pH (unidades de pH)	0,60	0,01
Oxígeno disuelto (ppm)	**0,70**	-0,06
Saturación de oxígeno (%)	**0,72**	-0,12
Temperatura del agua (°C)	0,05	0,20
Conductividad eléctrica (µS/cm)	**-0,78**	-0,19
Sólidos Totales Disueltos (mg/l)	**-0,79**	-0,18
NO3 (mg/l)	0,57	-0,14
NO2 (mg/l)	0,02	-0,17
PO4 (mg/l)	-0,18	-0,3
Fe (mg/l)	-0,39	-0,13

The RDA generated a percentage of total variance explained of 40% (p=0.02), and therefore it was recommended that the correlation between large invertebrates and environmental variables was significant. For this purpose, 10 variables were used (Table 5). RDA indicated that the most important physicochemical variables in the community included conductivity, dissolved oxygen concentration, total dissolved solids, nitrate, and active soluble phosphorus.

Variables with larger vectors displayed opposite positions, showing an inverse relationship between dissolved total solid concentration, iron, conductivity, and orthophosphate with dissolved oxygen concentration (saturation percentage, nitrate, and pH). Water temperature exhibited a different pattern from the previous one, related to the first sampling.

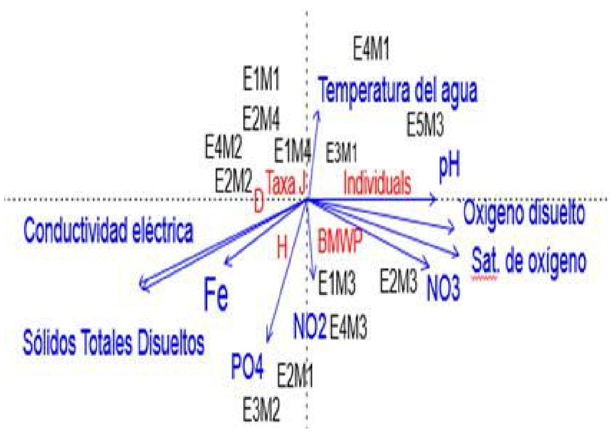

Fig. 3. RDA Triplot between large invertebrate communities, environmental variables, sampling stations, and time. These points represent six seasons and four samples, with blue lines representing environmental variables and red icons representing community indices.

The BMWP/Col index was associated with nitrate and dissolved oxygen concentration. Conversely, it was associated with electrical conductivity, total solids and phosphorus concentration; The community indices were located in the center of the graph and therefore, did not show marked relationships with the environmental variables measured.

Through the graph display, the average BMWP/COL values of the sampling stations (Fig. 4) indicated that although the population of the San Lorenzo River was sparse, the conditions of the San Lorenzo River were subject to organic pollution. There was evidence to suggest that the water in the area has already experienced slight pollution without intervention, and in E3, pollution intensified after discharge from untreated trout. The tributaries received by the river in E5 exhibited turbidity marked by sediment transport, which reduced the biota of large invertebrates, but may lead to dilution of nutrient load. Therefore, in E6, the system successfully stabilized the organic load and re-recorded the biological quality conditions before receiving trout water.

Fig. 4. Using Pindex BMPP/Col to change biological water quality

E2 station was excluded from the above analysis because it was not only a source of pollution, but also indicated that the river system was being disconnected, even though it has been 20 years, which has disrupted the continuity of the river.

4 Discussion

The St. Lorenzo River has been diverted to accelerate its flow, with the aim of diverting its water to establish trout ponds, which means a decrease in circulating flow, and may delay the flow of the rainfall system and dry up the river by 100 meters. These activities, together with other human activities, have affected the dynamics of the aquatic ecosystem [15][16][17][18][19][20].

The average temperature of the San Lorenzo River is 16.3 °C, which is conducive to maintaining optimal levels of dissolved oxygen. This variable is crucial because under high temperature conditions, dissolved oxygen decreases, increasing bacterial activity and sensitivity of aquatic organisms to certain toxic components [5].

The dissolved oxygen concentration has a sub saturated average value, which is close to 7 mg/L, with a slightly smaller range. The value found in E2 is lower than 4 mg/L, indicating a suitable level for aquatic organisms [8]. And for fish, it should be higher than 4 mg/L [21]. These authors claim that this value is related to the values of nitrate and phosphate. In the case of the San Lorenzo River, nitrate levels are close to the lower limit of Colombia's tropical waters, at 0.90 mg/L, indicating that compared to the use of typically nitrogen rich agricultural chemicals and household dumping, nitrate salt water is relatively low. The phosphate concentration is 1.33 mg/L, indicating the presence of a moderate nutrient environment; Higher values are related to factors such as organic matter in river vegetation, solid and liquid emissions from household and agricultural activities. The concentration of phosphate in water is a nutrient that is beneficial for the high growth of algae and leads to eutrophication.

The average pH value of the San Lorenzo River is 6.96, which should be between 6.5 and 9.0 within the allowable range of drinking water quality regulations [5]. The author believes that this standard is crucial as it may lead to changes in the composition of aquatic fauna and flora and the increase in the impact of certain toxic compounds. From the perspective of the value of natural water, the values recorded in these studies are normal [21].

The average conductivity is 21.7 μ s/cm, far below the specified range of 30-60 μ s/cm for mountainous rivers [5]. The results below these values indicate lower productivity [20].

The average value of dissolved total solids (STD) is 22.1 mg/L, which is lower than the limit set for aquatic habitats with a concentration of 100 mg/L. Low concentration is beneficial for the availability of oxygen [5] [21].

In the San Lorenzo River, the largest number of large invertebrates belong to the order Trichota, also known as the family Tongue Chordates. This order is characterized by taxa that are normally intolerant to pollution, so their population numbers decrease with increasing pollution [22]. E2 did not report this family, possibly because as builders of houses, they needed sand to achieve this goal, and the lack of water flow maximized the creep of such materials.

Belonging to the family Baetidae and Leptopelebiiidae of the Ephemeroptera order, the family Hydropsychidae of the Trichoptera order, and the family Chironomidae of the Dipter order, are the most spatiotemporally distributed families. The Dragonfly family is famous for its genus Dragonflies. The distribution of this family in natural waters is believed to be limited by its high sensitivity to environmental changes [23][24]. This sensitivity to pollution has been demonstrated in five out of six sampling stations.

The Hydropsychidae family, individuals of the genus Leptonema sp were collected in the San Lorenzo stations before the trout diverter and departure. The taxonomic groups belonging to this family were found in all types of streams, using stones, tree trunks, and fallen leaves to build shelters, and were associated with high levels of oxygen [14], although they could withstand a certain degree of organic pollution.

The characteristics of the Chironomidae family were the abundance and diversity of Diptera in six sampling stations, although it had the fewest number of individuals collected at E2 station. They mentioned that it was a family of dipterans with the greatest diversity and richness, which was an important condition for determining their extensive role in environmental functions.

The results obtained after applying the BMWP/COL index and community index indicated that water quality had deteriorated, especially at E2 station, as the lack of water flow and disconnection from the main river channel limited the colonization and drift processes of aquatic macroinvertebrates. Among them, it was observed that more tolerant taxa such as mollusks (Ferrisia sp and Physa sp) replaced the characteristic taxa of the raw water (Tanytarsini, Hetaerina americana, Acari, Atopsyche, Leptonema, and Hydroptotila), and reduced the wealth of the taxa by more than 85%.

There is no significant difference in the composition of large invertebrates during different hydrological periods, which may be related to the less obvious climate seasons in tropical regions. Similar results were found by Meza A.M .eal., who suggested that these results may be due to the lack of replicates, making it impossible to compare climate periods.

Although the changes in the riverbed occurred more than 20 years ago, there are differences in the abundance, aquatic macroinvertebrate abundance, and biological quality of the water that constitutes the submarine corridor compared to the river water before the riverbed changes. The low RR zone (HZ, low RR zone) is an important area where solute exchange and nutrient transformation occur. Its existence has been widely recorded and studied in both mountainous and plain rivers. However, in Colombia, there has been almost no characterization study of underground areas in natural water flows [27].

Another aspect to be mentioned involves reducing riverbank forests and constructing a cement "plug" to prevent water from flowing out of the old river channel. Riverbank vegetation plays an important role in protecting water resources and stabilizing river channels; It serves as a dispersed corridor for biota and a shelter for animals during drought periods. In addition, the riverbank forms a network system interconnected with other neighboring ecosystems (bio ecological corridors), so its protection and restoration cannot be considered in isolation, but within the watershed [28][29].

The changes in the riverbed has greatly reduced the input of foreign and local substances, which affects the supply of food, shelter materials, physical and chemical conditions of water relative to the main riverbed. There is even evidence of excessive colonization of rocks in peripheral areas, especially filamentous green algae.

It has been pointed out that interventions conducted 20 years ago at E2 station continue to affect the remaining water bodies, which have not yet been restored as they do not have sufficient living and non living resources to continue development without additional assistance or subsidies [30]. This ecosystem remains simplified in both structure and function, and does not show resilience within normal pressure and environmental changes. In terms of biological and abiotic flow and cultural interaction, it has little interaction with neighboring ecosystems.

5 Conclusion

After 20 years of intervention, it is expected that the ecosystem will recover on its own (resilience, adaptation to interference, entropy dissipation); As for the San Lorenzo River section of the underground corridor of E2 station, due to its low hydrological flow, the river cannot be restored. The limited biodiversity found in water indicates poor water conditions.

Some sections of the San Lorenzo River diversion intervention have very few large invertebrates, which is a result of the current state of the aquatic ecosystem. It has not been restored and at some point was part of a stable dynamic system. According to the BMWP, this section proposes key conditions.

The physical and chemical conditions of water reflect low mineralization, which may be an indicator of weathered soil with low human influence; In terms of nutrient concentration, the value of phosphate is higher than the average level in the region, reflecting the impact of the trout industry on rivers.

El Carmen de Viboral city must ensure the care of this river, therefore the trout farm must be required to develop a management plan and at least urgently establish a basic treatment system to restrict the flow of trout farm to the San Lorenzo River.

Secondly, follow-up action must be taken to identify other sources of pollution, implement septic tank and continue to reduce external inputs to rivers. It is also recommended to continue monitoring the water quality of the San Lorenzo River to verify whether the measures taken are reflected in the improvement of the physical, chemical, and biological conditions of the water.

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Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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