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Impact of Multiple Socio-Ecological Stressors in the Purnio River Basin, Colombia

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Preface

The creation of this bachelor thesis is based on collaborative research cooperation concerning CO_2-Compensation, climate-, water- and forest-protection, art, activism, and local sustainable development between the Institute of Development Research (IDR) of the University of Natural Resources and Life Sciences, Vienna (BOKU) and the Austrian Institute for Sustainable Development (ÖIN).

The carbon offset program of the University of Natural Resources and Life Sciences, Vienna (BOKU) carbon offset programs strives to offset CO_2 emissions originating from a variety of activities. These initiatives involve investments aimed at preventing CO_2 release and capturing it from the atmosphere. By endorsing projects such as renewable energy deployment, reforestation, and carbon capture, these efforts seek to mitigate the environmental impact of emissions and contribute to broader sustainability objectives.

This nature conversation project focuses on "Las Mercedes", a 600-hectare farm situated near the city of "La Dorada" in Colombia. (ÖIN Austrian Institute for Sustainable Development; University of Natural Resources and Life Science, Vienna [BOKU], 2023).

The project is managed sustainably in cooperation with local farmers to protect the fauna and flora from overgrazing and forest degradation. Sustainable management will lead to higher yields in the long run and ensure forest protection against deforestation. Furthermore, the forest is used for research and art as a sustainable awareness-raising method. Through this project, 12.000 tons of CO_2 are stored in the Las Mercedes project every year (BOKU, 2023).

PD DI Dr. Andreas H. Melcher coordinates the project. We cooperated and worked with Ronny Miguel Quimbayo Garzon and Prof. Carlos Alfonso Devia Castillo, of the Institute for Rural Development at the Pontifica Universidad Javeriana in Bogotá during the fieldwork in Colombia.

Abstract

This study analyses the multiple lines of stressors affecting Central Colombia's Magdalena River and Purnio River. It provides a comprehensive overview of the current state of this socio-ecological system and connects it with the perceptions of the local population. Employing a multi-scale approach, this thesis investigates the hydro-morphological and abiotic parameters of the Magdalena River's tributary rivers, tracing their course from the tropical dry forest where the river originates to its confluence with the mighty Magdalena River. Cross-sectional analyses of hydro-morphological data of 28 sampling sites, collecting 89 abiotic samples. Additionally, 35 face-to-face interviews were conducted with the local people.

In the upper reaches of these rivers, the ecosystem remains remarkably pristine, characterized by an untouched river system with unhindered bed and bank dynamics. However, as one moves downstream, human settlements become denser, and expansive grazing and agricultural areas encroach upon the landscape. This shift brings an influx of sewage runoff into the river, severely limiting the river's natural dynamism.

As one travels along the river's course, abiotic data reveals a concerning trend: electrical conductivity and total dissolved solids increase as oxygen concentration decreases. Many of the regional population doubts the river's water quality, attributing it to cattle breeding, grazing, waste disposal, and wastewater discharge. These impacts were starkly evident during the field survey.

The findings of this research have significant implications for our understanding of river systems in tropical dry forests. They can serve as a valuable management tool, promoting the health of ecosystems and sustainable agricultural practices. Ultimately, these efforts contribute to preserving a healthy river system and maintaining good water quality, benefiting the environment and local communities.

Resumen

Este estudio analiza las múltiples líneas de factores de estrés que afectan a la cuenca de los ríos Magdalena y Purnio, en el centro de Colombia. Proporciona una visión global del estado actual de este sistema socioecológico y lo conecta con las percepciones de la población local. Mediante un enfoque multiescalar, esta tesis investiga los parámetros hidromorfológicos y abióticos de los ríos tributarios del río Magdalena, trazando su curso desde el bosque seco tropical donde nace el río hasta su confluencia con el caudaloso río Magdalena. Los análisis transversales hidro morfológicos de 28 sitios de muestreo recolectaron 89 muestras abióticas en total. Además, se realizaron 35 entrevistas cara a cara con la población local.

En los tramos superiores de estos ríos, el ecosistema se mantiene extraordinariamente prístino, caracterizado por un sistema fluvial intacto con una dinámica de cauces y riberas sin obstáculos. Sin embargo, a medida que se avanza río abajo, los asentamientos humanos se hacen más densos y las extensas zonas de pastoreo y agricultura invaden el paisaje. Este cambio provoca una afluencia de aguas residuales al río, lo que limita gravemente su dinamismo natural.

A medida que se recorre el curso del río, los datos abióticos revelan una tendencia preocupante: la conductividad eléctrica y el total de sólidos disueltos aumentan a medida que disminuye la concentración de oxígeno. Una parte importante de la población regional alberga dudas sobre la calidad del agua del río, atribuyéndola a factores como la cría de ganado, el pastoreo, la eliminación de residuos y el vertido de aguas residuales. Estos impactos se pusieron claramente de manifiesto durante el estudio de campo.

Las conclusiones de esta investigación tienen importantes implicaciones para nuestra comprensión de los sistemas fluviales de los bosques secos tropicales. Pueden servir como una valiosa herramienta de gestión, fomentando la salud de los ecosistemas y las prácticas agrícolas sostenibles. En última instancia, estos esfuerzos contribuyen a la preservación de un sistema fluvial sano y al mantenimiento de una buena calidad del agua, lo que beneficia tanto al medio ambiente como a las comunidades locales.

Content

1. Introduction

Nowadays, the impact of human activities on riverine ecosystems has precipitated challenges at an alarming multitude of levels. Rivers have undergone systematic alterations driven by changes in land use, such as urbanization, industrialization, deforestation, and agriculture. The overexploitation of resources, contamination, reservoirs, irrigation systems, and interbasin transfers have collectively reshaped these vital ecosystems to optimize human water access (Mays, 2008).

This pursuit of water resource management has not been without its consequences. Biodiversity challenges and threats to human water security are connected, presenting a double challenge in preserving biodiversity and water resource management. Rich nations invest massively in water technology when less wealthy nations remain vulnerable (Vörösmarty et al., 2010).

The delicate balance between ecological systems and human societies is encapsulated in the Socio-Ecological Systems (SES) concept, which underscores the inseparable connection between nature and human activities. Our past attempts at combating challenges within these systems reveal a common lack of trans- and interdisciplinary approaches to understanding critical natural resource degradation's ecological and sociological background. The essence of trans- and interdisciplinary synergy, the synergy of socio-ecological systems, and the sanctuary of nature-protected areas, our research interlaces these themes, creating a tapestry of innovation as we envision a world where science, society and nature harmonize for sustainable prosperity.

Our exploration intertwines the significance of nature-protected areas, recognizing them as a critical player in preserving water quality and biodiversity. This protection of areas is done by the CO_2-Compensation program by the University of Natural Resources and Life Sciences Vienna (BOKU) and local stakeholders. One of the programs is the "Las Mercedes" farm (Chapter 2), situated in the center of Colombia, with the setting to preserve and protect the local forests through sustainable forest management and capacity development (BOKU, 2023).

Colombia, characterized by diverse landscapes, hosts over 1.000 natural lakes and numerous artificial reservoirs, spanning a collective surface area exceeding 60.000 km^2. Its extensive freshwater network is fed by a network of major rivers stretching over 100.000 km and classified into distinct drainage basins, including the Amazon, Orinoco, Caribbean, and Magdalena basins (Business Intelligence Software Assessor - BISA Corporation, 2015).

The Magdalena River basin is the most representative fluvial system in the northern Andes. It experiences an average precipitation of 2.150 mm/year and has a flow rate of 7.154 m^3/s. By 2015, it transported around 180 million tons of sediment, classifying it among the top 10 rivers globally with the highest erosion rate. The Magdalena basin has experienced a 34% increase in erosion rates in the past decade, primarily attributed to environmental degradation and deforestation levels exceeding 70% over the past 50 years. More than 90% of its basin remains scientifically unknown regarding channel evolution, floodplain areas, and other fluvial environments (Jiménez-Segura & Lasso, 2021).

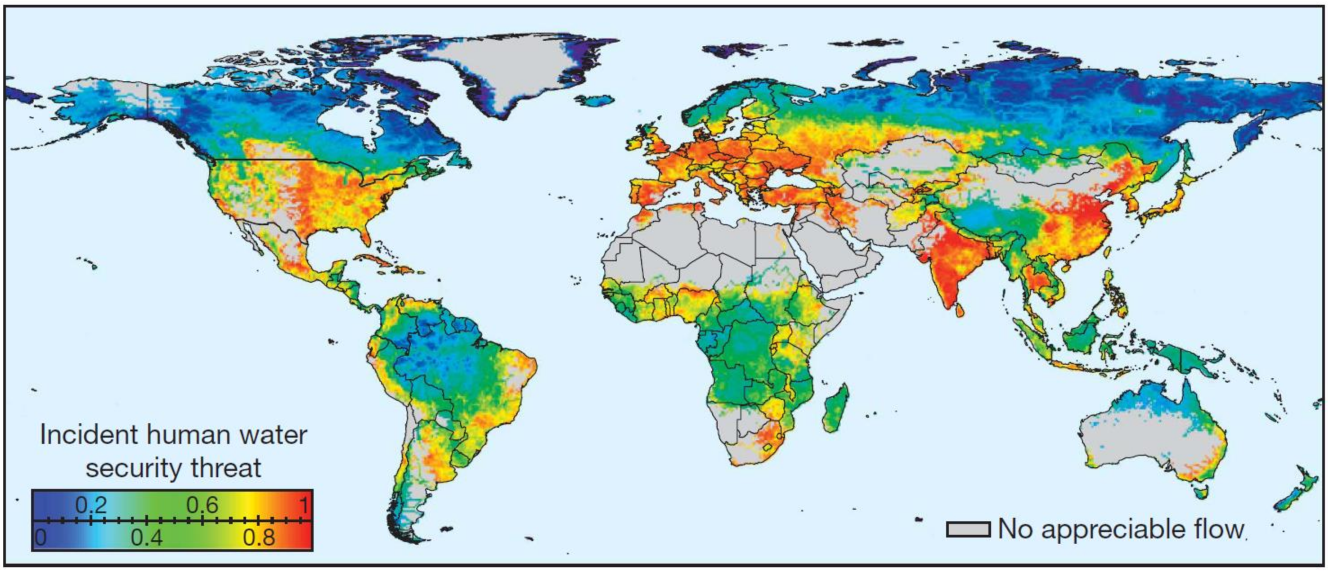


Figure 1.1: *Global geography of incident threat to human water security and biodiversity. The maps demonstrate pandemic impacts on both human water security and biodiversity (Vörösmarty et al., 2010).*

On a Global vision of human threats to water security (Fig. 1.1), the Colombian south-eastern aera seems less threatened than the central area along the Magdalena River Basin. However, one of Magdalena Rivers Tributary, the Bogotá River Basin is considered the most polluted basin in Colombia due to the discharge of wastewater from a population of over 7 million inhabitants (Ospina Zúñiga et al., 2018). When it connects with the Magdalena River, it poses severe threats to the communities living in the basin's health conditions in the country's central region, who rely on natural water resources for domestic use and irrigation.

Integrated Water Resource Management is a holistic approach to managing water resources sustainably by considering social, economic, and environmental factors. It aims to balance competing water needs for various uses while preserving ecosystems and ensuring long-term water availability.

Assessing the state of water quality involves an array of abiotic parameters, encompassing electrical conductivity, pH value, temperature, oxygen concentration, and total dissolved solids (Hassan Omer, 2020).

Notably, the interrelationship between river contamination stressors and abiotic data carries high significance for understanding the health of river systems. River health is analogous to human health (Maddock, 1999). Therefore, physical habitat assessment is essential for evaluating river health over various scales varying from the bread river segment to the microhabitat level (Fig. 1.2).

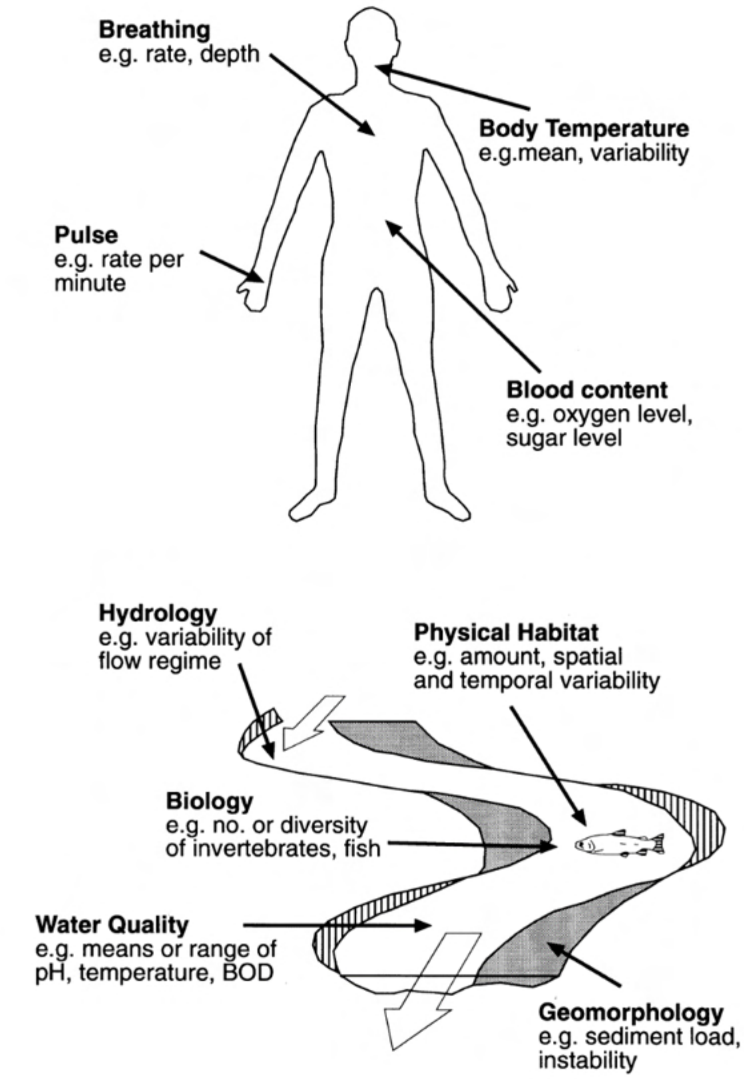


Figure 1.2: *The health of a River can be seen as human health - an analogy by Maddock, 1999.*

The overall aim of this study is a baseline data collection of abiotic and socio-ecological parameters of the Magdalena River and its tributary rivers with a focus on the Purnio River to analyze and understand the importance of natural protected areas such as “Las Mercedes” for the water quality in the region. Hydro-morphological assessments are highly relevant for detecting pressures in river basins (Rauch et al., 2022).
We analyzed the current state of evident stressors along the Magdalena River and Purnio River Basin summarizing it with a structured georeferenced database and factsheets with the most critical information.

Concurrently, a socio-demographic analysis of the regional population will be conducted to comprehensively grasp the socio-environmental dynamics and understand the dynamic interlinkages between the different sources of multiple stressors on aquatic ecosystems adhering to the Driver-Pressure-State-Impact-Response (DPSIR) framework, which was successfully applied in Burkina Faso, Africa (Melcher et al., 2020).
Therefore, we analyzed the perceptions of the regional population regarding the river, summarizing it in a database.

Our research addresses immediate challenges within the Magdalena River basin. It aligns with Sustainable Development Goals (SDGs), connecting local research to global sustainability efforts (United Nations Department of Economic and Social Affairs, 2023). This alignment underscores the broader significance of our work in contributing to clean water, biodiversity preservation, and the development of sustainable communities, enhancing the overall impact and significance of our research.

Consequently, this thesis is answering the following research questions:

R1: How does water health vary along the Magdalena River and the Purnio River, originating in the "Las Mercedes" protected area, with increasing human activity and are there significant variations and interrelations in abiotic factors?

R2: To what extent are communities in the Magdalena River Basin aware of water quality, regional pressures, and the importance of protected areas and how do they see the SDG’s?

2. Research Area

The Magdalena River, meandering for an impressive 1.612 kilometers, carves its way from the southern reaches of Colombia through the Magdalena River Valley, between the Cordillera Central and the Cordillera Oriental. With its network of tributaries, this mighty River finds its aquatic embrace with the Caribbean Sea at the city of Barranquilla in northern Colombia (Jiménez-Segura & Lasso, 2021).

This enchanting landscape is not just a geographical wonder, it holds profound ecological and cultural significance. The Magdalena River Valley is not merely a passage but a cradle of life, supporting diverse ecosystems and hosting communities along its course.

One of Magdalena's tributary Rivers, "Rio Purnio" ("Purnio River"), is characterized as a vital Colombian river, linking atmospheric, land, and aquatic domains. Its role in supporting biodiversity and shaping landscapes is pivotal. Intensifying human activities, like urbanization and agriculture, impact its ecological balance.

The Purnio River basin spans approximately 93.840 hectares and primarily receives water from small streams. The region's vegetation cover is sparse due to agricultural, livestock, and mining pressures. The varying land use in this area stresses on ecosystems, necessitating studies to reveal their impact and generate knowledge to inform conservation and management strategies. As alterations in landscape structure often lead to changes in biodiversity, each geographical unit like a basin, contains diverse landscapes hosting interrelated communities; modifying these landscapes inevitably affects biota diversity (Córdoba Rojas et al., 2017).

Of particular interest are two tributary rivers, "Apacuar" and "Los Monos" originating in the "Las Mercedes" Area. This region serves as the inaugural site for the CO_2-Compensation program (BOKU, 2023). They are situated between Bogotá and Medellín, the Las Mercedes farm shelters one of the tropical dry forests in the region. This unique ecosystem is threatened by deforestation and overgrazing. To combat this, a team of artists, researchers, and partners have established the climate protection and art project, covering over 500 hectares. The collaboration involves local communities, including small farmers and indigenous populations, to develop a model for sustainable land use (ÖIN Austrian Institute for Sustainable Development).

The research area was set up in the Basin of the Purnio River and its tributary Rivers ("Apacuar" and "Los Monos") which joins the Magdalena River downstream. The area also concludes the Magdalena River basin upstream before the city "Honda" till the city "La Dorada" (Fig. 2.1).

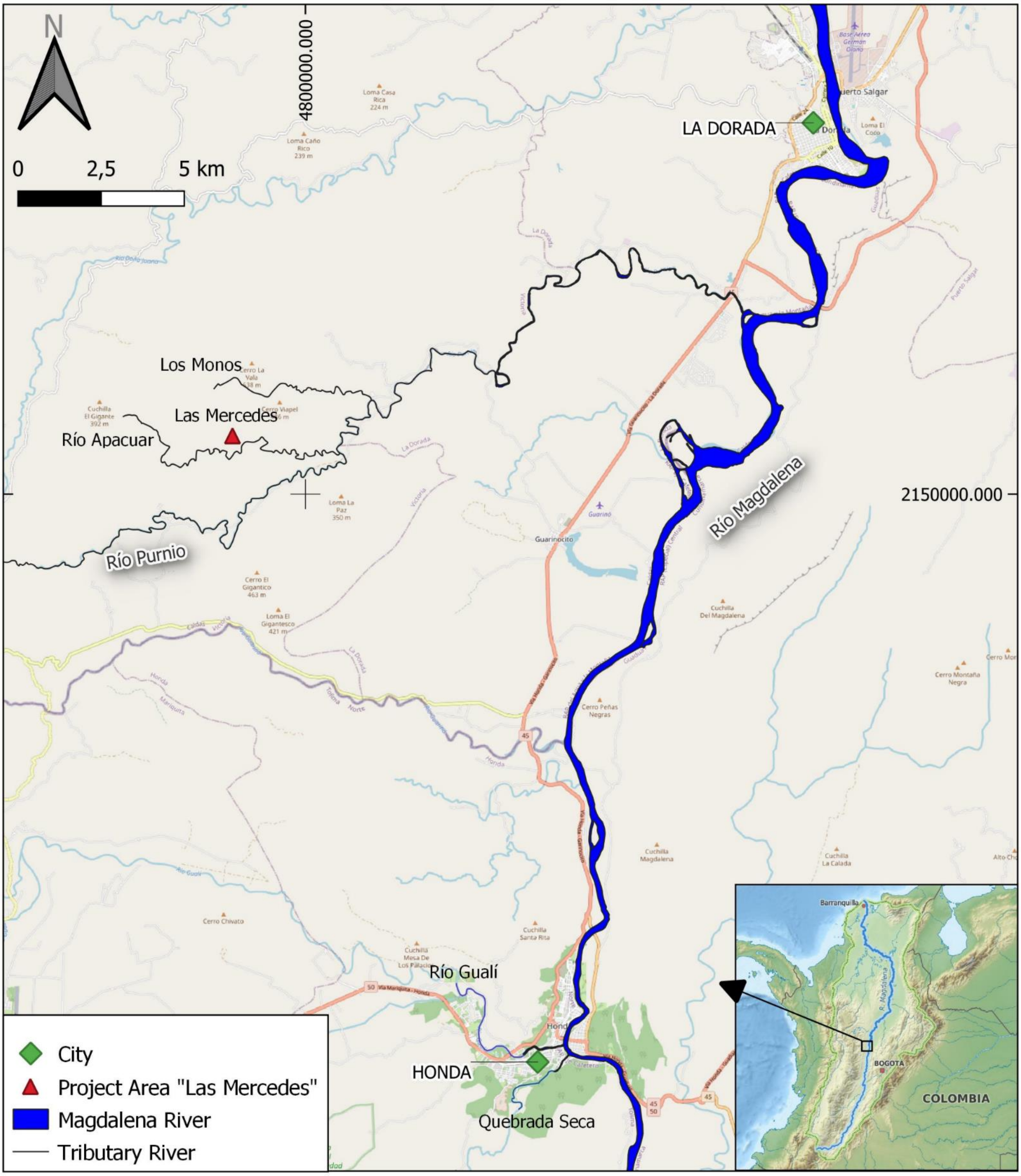


Figure 2.1: Geographical Representation of Study Area within the Magdalena River Basin. The Magdalena River is delineated in dark blue, and its tributaries are shown as thin blue lines. Green diamonds indicate major cities, and a red triangle indicates the Las Mercedes farm. The map was generated using Open GIS and sourced from OpenStreetMap.

This region is in the tropical dry rainforest with a high percentage of humidity (over 80%), hot weather, and yearly two rain seasons due to the phenomena of “el Niño – la Niña” (Restrepo & Kjerfve, 2000), with peaks in April and in October, which are demonstrated at the following Fig. 2.2 (Instituto Geográfico Agustín Codazzi - IGAC, 2023).

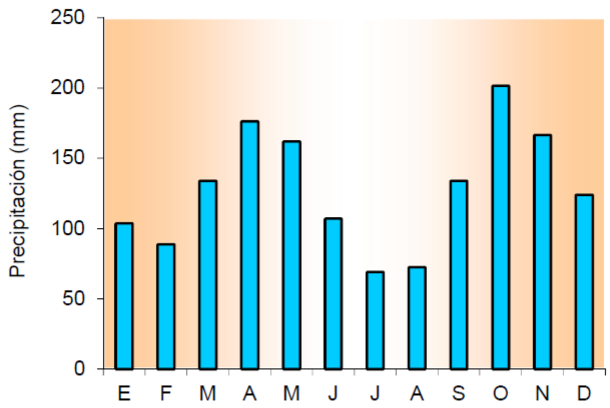


Figure 2.2: *Abscissa: Abbreviation of the Months in Spanish capital letters (E = January, F = February, …, D = December); Ordinate: Precipitation in millimeters (Instituto Geográfico Agustín Codazzi - IGAC, 2023).*

3. Methods

This thesis's workflow was structured into the following parts: literature search, method assessment and selection, field sampling, georeferencing, questionnaire, and resulting data analysis.

3.1. Literature Search / Keywords

This study assessed the international status of the international knowledge on the Magdalena River and Purnio River. A comprehensive literature search using the following keywords was conducted in April and August 2023 in Scopus and Google Scholar in Englisch and Spanish using the Boolean operators ("AND", "OR", "NOT") reasonable (List is just showing the Englisch Version):

Purnio River
Magdalena River
Water quality Magdalena River
Water quality Purnio River
Abiotic Data Magdalena River
Abiotic Data Purnio River
Impact Magdalena River

3.2. Field Sampling

During the rainy season, the field sampling took place in April 2023 with my colleague Andreas Bauer MSc.. Sampling areas were previously selected visually by expert judgment of our supervisors, local people, and the Pontificia Universidad Javeriana of Bogotá using a map provided by the Pontificia Universidad Javeriana. The decision criteria for selection were water availability, accessibility, health safety and different human stressors. Because of limited accessibility in the field 28 measuring sites were selected. IDs were addressed to the measuring sites using letters of the German Alphabet (A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z, Ä, Ö). Within the two weeks, at least three independent samples were taken repetitively at each site/ID (Table 3.2). At some sites not all the scheduled parameters could be taken. One site ("A") was measured on two different days ("A1" and "A2"– Chapter 4).

Due to their similar characteristics (Chapter 4.1.) in human impacts, land use and distance to the project area "Las Mercedes," these measuring sites were classified in reaches according to their river basin and shown in different colors. Green means small human impact (Los Monos, Apacuar, Purnio Upper), yellow means middle human impact (Purnio Lower, Gualí), and red means high human impact (Magdalena, Quebrada Seca, Gualí Sewage Runoff, Magdalena Sewage Runoff). (Tab. 3.1). Measuring Sites categorized by River Reach and Key Characteristics are shown in a map generated using Open GIS and sourced from OpenStreetMap (Fig.3.1).

Table 3.1: *Measuring site classification in reaches, due to their similar characteristics. Bar colors shift the ecological status from green (very good) to yellow (moderate) and orange (bad) to represent increasing levels of human impact.*

Reach Name ***Measuring Site IDs***	**Characteristics**
Apacuar *B, C, D, E, F, G, K*	No settlement, very low density of agriculture, dense forest
Los Monos *H, M*	One small village at the estuary of the river, very low density of agriculture, dense forest
Purnio Upper *I, J, L, N*	No settlement, fincas, low density of agriculture, dense forest
Purnio Lower *A, O, P, Q*	Small settlements, fincas, gold mining, forest and grazing, cattle breeding
Río Gualí *S*	Tributary to Magdalena River as a reference to Purnio River Lower Stream
Magdalena River *U, V, W, X, Y, Z, Ä*	Higher discharge, settlement and cities, anthropogenic impact
Quebrada Seca *R*	Tributary to Magdalena River, anthropogenic impact, contaminated
Magdalena Sewage Runoff *Ö*	Sewage Inflow from the North-Western Part of the City "La Dorada"
Gualí Sewage Runoff *T*	Sewage Inflow from the Southern part of the city "Honda"

Table 3.2: *Measuring Points categorized by River Reach and Key Characteristics. The table enumerates the measurement's ID, Reach, Longitude, Latitude, Weather, Date and Start Hour. Samples indicate the number of individually taken samples at this measuring site. Reach categories, defined by letters, signify environmental attributes: Río Apacuar (B-G, K) indicates no settlements and dense forests; Los Monos (H, M) contains a small village and dense forests; fincas and low agriculture characterize Purnio Upper (I, J, L, N); Purnio Lower (A, O, P, Q) includes settlements and gold mining; Magdalena (U-Z, Ä) has higher discharge and urban and industrial areas; Rio Gualí (S) serves as a reference tributary; Quebrada Seca (R) is contaminated; Magdalena Sewage Runoff (Ö) and Gualí Sewage Runoff (T) indicate sewage inflow points.*

ID	Reach	Longitude	Latitude	Date	Start Hour	Samples
B	Apacuar	-74.80104	5.36566	13.04.2023	14:40	3
C	Apacuar	-74.70463	5.3895	14.04.2023	14:03	3
D	Apacuar	-74.83211	5.36706	14.04.2023	14:50	3
E	Apacuar	-74.70463	5.3895	14.04.2023	15:30	3
F	Apacuar	-74.82818	5.3668	14.04.2023	16:25	3
G	Apacuar	-74.70463	5.3895	14.04.2023	16:42	3
K	Apacuar	-74.79685	5.36674	18.04.2023	11:40	3
S	Gualí	-74.73548	5.20482	20.04.2023	14:19	3
T	Gualí_Sewage_Runoff	-74.73513	5.20484	20.04.2023	14:30	3
H	Los_monos	-74.72145	5.19348	15.04.2023	11:04	4
M	Los_monos	-74.78778	5.38087	18.04.2023	13:12	3
Ä	Magdalena	-74.66074	5.46412	20.04.2023	10:50	3
U	Magdalena	-74.71713	5.19074	20.04.2023	16:24	3
V	Magdalena	-74.72449	5.20108	20.04.2023	15:30	3
W	Magdalena	-74.73472	5.20472	20.04.2023	14:41	3
X	Magdalena	-74.73149	5.22995	20.04.2023	13:04	3
Y	Magdalena	-74.66718	5.40682	20.04.2023	12:15	3
Z	Magdalena	-74.66187	5.45525	20.04.2023	11:40	3
Ö	Magdalena_Sewage_Runoff	-74.66074	5.46412	20.04.2023	11:05	3
A1	Purnio_Lower	-74.75504	5.38878	13.04.2023	11:13	4
A2	Purnio_Lower	-74.75504	5.38878	19.04.2023	15:03	3
O	Purnio_Lower	-74.70097	5.39637	19.04.2023	12:00	3
P	Purnio_Lower	-74.72172	5.4175	19.04.2023	10:45	3
Q	Purnio_Lower	-74.68884	5.41008	19.04.2023	13:11	3
I	Purnio_Upper	-74.79471	5.36451	18.04.2023	10:00	3
J	Purnio_Upper	-74.79678	5.36664	18.04.2023	11:07	3
L	Purnio_Upper	-74.78844	5.3777	18.04.2023	12:34	3
N	Purnio_Upper	-74.6995	5.39887	18.04.2023	13:50	3
R	Quebrada_Seca	-74.73622	5.1989	20.04.2023	17:00	3

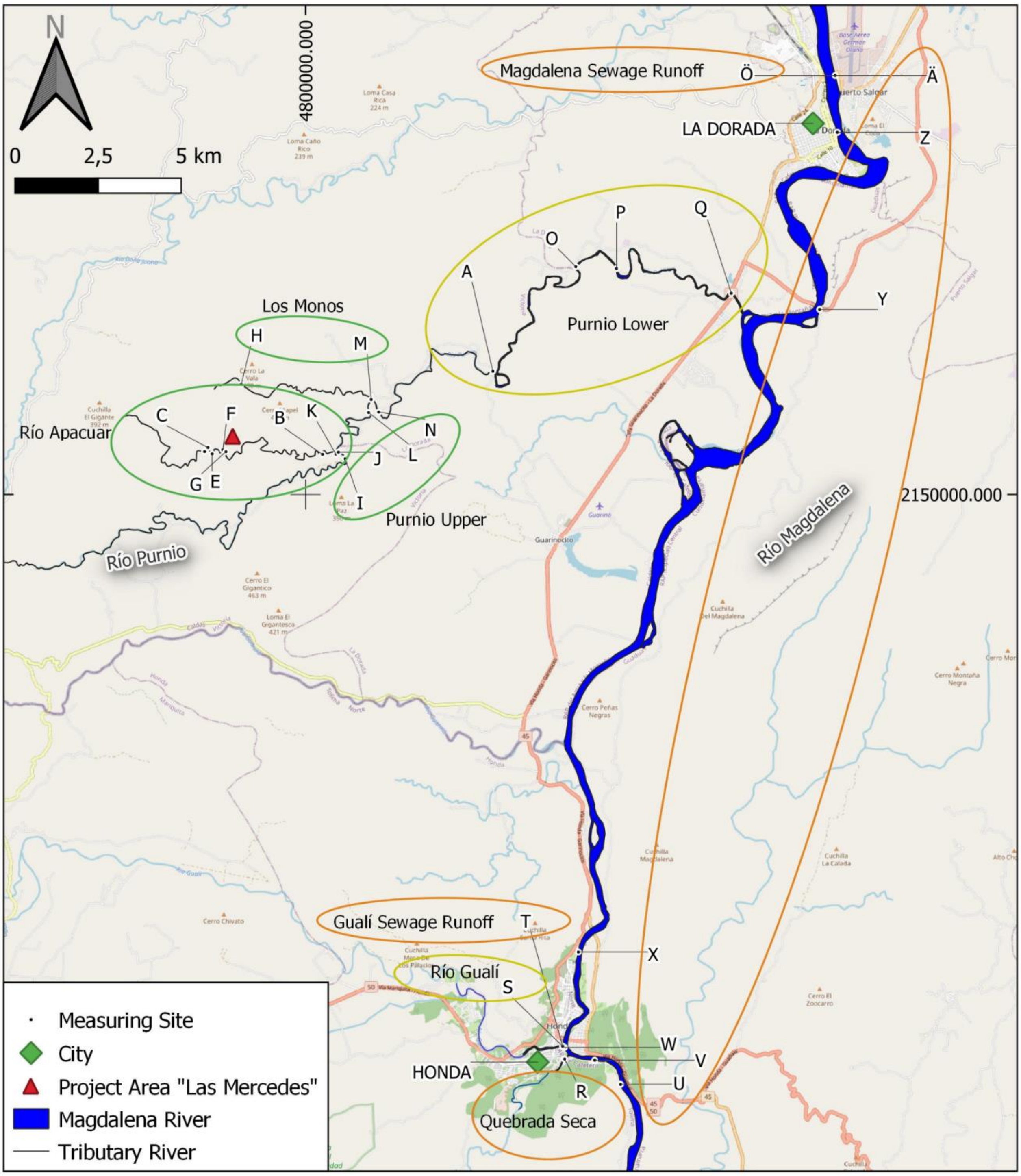


Figure 3.1: Measuring Points categorized by River Reach and Key Characteristics. The Magdalena River is delineated in dark blue, and its tributaries are shown as light blue thin lines. Green diamonds indicate major cities, and red triangle indicates Las Mercedes farm. The markings are shown in different colors due to their distance to "Las Mercedes" project area and their similar characters in land use and human impact. Río Apacuar (B-G, K) indicates no settlements and dense forests; Los Monos (H, M) contains a small village and dense forests; Purnio Upper (I, J, L, N) is characterized by fincas and low agriculture; Purnio Lower (A, O, P, Q) includes small settlements and gold mining; Magdalena (U-Z, Ä) has higher discharge and urban areas; Rio Gualí (S) serves as a reference tributary; Quebrada Seca (R) is contaminated; Magdalena Sewage Runoff (Ö) and Gualí Sewage Runoff (T) indicate sewage inflow points. The map was generated using Open GIS and sourced from OpenStreetMap.

3.2.1. Field Protocol and Data Sampling

The field protocol was modified after Supervisor Andreas Melcher, my colleague Andreas Bauer, and I and adapted after two initial test runs to the conditions and requirements in Central Colombia (Meulenbroek et al., 2013). The final assessment sheet is attached in the Appendix (Tab. 8.1).

General Measuring-Sites-Information:

The general information was an ID and a Site Name, which was given on-site fitting to the geological characteristics of the measuring site. The Date, time and weather were recorded at the beginning of the measuring. Sea level, Longitude, Latitude and Celestial direction of the river (facing downstream) were taken by a Digital Compass (Technoline, SN: EA3050 6N22).

Abiotic Data Sampling:

The abiotic parameters were taken with a Hanna Multiparameter HI98494 (SN: M0346007011) (Photo 3.1) to measure the following parameters:

- Electrical conductivity (EC) in the units µS/cm and MΩ cm
- PH-value (pH) in the Units mVpH and pH
- Temperature (T) in degrees Celsius
- Oxygen Concentration (O_2) in the Units ORP, %DO and ppm
- Total dissolved Solids (TDS) in the Units ppm TDS and PSU

Hydrologic Samples

- A knowledgeable entity saw Waterflow.
- Flow velocity was measured by a floating tracer on the water's surface (Fig. 3.2).
- Bank full width, wetted width, and depth were measured with a Mileseey Laser Meter S6 (SN: 2021103036508).
- Water Surface temperature was taken with the Inkbirdplus Infrared Thermometer INK-IFT03 (SN: 220433054).
- High Definition orthophotos were taken during the fieldwork in the daytime and provided by Ronny Miguel Quimbayo Garzon from the Pontificia Universidad Javeriana of Bogotá.

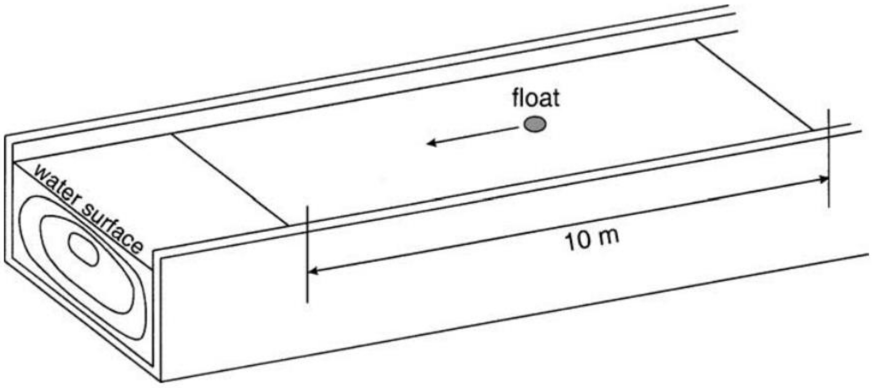


Figure 3.2: Descriptive image of the floating tracer method, to measure the flow velocity (Kra & Merkley, 2004)

The river transect was supposed to be a trapezoid form, closest to the natural flow profile. The bottom width was supposed to be half of the wetted width. Depth was measured on the most significant point, the deepest point in the transect. The discharge was calculated using the float method (Formula 3.1) (Kra & Merkley, 2004).

$$Q = A \times v$$

Formula 3.1: The calculation for the discharge. Abbreviations: Q = discharge (m3/s); A = transect in trapezoid form (m2); v = flow velocity (m2).

Morphology and Land-Use Samples

These samples were visually seen and categorized. The shading was estimated, and "Fisheye"-Pictures were taken at the middle of the cross-section from the water surface in the zenith with a Pro 12MP camera system. The choriotope description was classified according to Austrian ÖNORM 6232.

Photo 3.1: *Picture of the Autor taking abiotic samples while a man is taking water for his finca to drink it.*

3.2.2. Data Processing

All the abiotic and hydro-morphological data was georeferenced with QGIS3 using Open GIS and sources from OpenStreetMap. The data were analyzed using the IBM SPSS Statistics Software. In synthesis of all significant field data, Fact Sheets (Chapter 4) were created utilizing AutoCAD 2022 and Microsoft Office.

3.3. Questionnaire

The project team also structured the questionnaire sheet with Dr. Gabriele Slezak. The final assessment sheet is attached in the Appendix. (Tab. 8.2)

During the fieldwork in April, the regional population was surveyed by conducting face-to-face interviews (Photo 3.2). All these interviews took place in our research area during the field samples close to the rivers and in the two closest cities "Honda" and "La Dorada". Those interviews were taken in Spanish, and according to the German Sociological Association's ethic codes, a previous ethic declaration was made (DSG Deutsche Gesellschaft für Soziologie, 2017). The data were analyzed in IBM SPSS Statistics Software.

The questionnaire was structured in the following way:

1. **Sociodemographic Profile**: Collects basic information about the respondent.
2. **Sustainability Development Goals (SDGs) Importance**: Respondents are asked to rank the importance of select SDGs (2, 4, 6, 7, 8, 12, 13, 14, 15, 16, as outlined by the United Nations Department of Economic and Social Affairs, 2023) using a scale from 0 (not important) to 10 (very important).
3. **Impact of Human Activities on the Magdalena and Purnio River**: Participants rate the importance of the river and its quality on a 1-10 scale and specify their usage of the river. They are also asked to assess the threat level of specific human activities on the river, from 1 (not threatened) to 10 (very threatened). Finally, respondents indicate whether the river has changed in the past 15 years and if they think future human impacts will affect their children.
4. **Climate Change**: Addresses perceptions and concerns regarding climate change.
5. **Land Use**: Explores attitudes and observations concerning land use patterns.

Photo 3.2: *Picture of a face-to-face interview. Author with a local farmer.*

3.3.1. Data Processing

The data were analyzed using the IBM SPSS Statistics software. To better understand the data, the answers were summarized to get results in three main categories (Tab. 3.3).

The main categories are:

- "Not important", "not bad", "no impact", "no change" or "not" depending on the questions for the numeric answer of 1, 2, 3 and 4.
- "Medium" for the numeric answer of 5, 6 and 7.
- "Very important", "very bad", "strong impact", "heavy change" or "very strong" depending on the questions for the numeric answer of 8, 9 and 10.

Table 3 3: *Summarizing the answers in three main categories for more visible results. Number = given Answer at the Questionnaire, Category = Summarized answers in a main category for the bar charts at the results (Chapter 4.4.).*

Number	Category
1 – 4	not important / not bad / no impact / no change / not
5 – 7	Medium
8 - 10	very important / very bad / strong impact / heavy change / very strong

4. Results

In Chapter 4.1. and 4.2. the reaches are described. Chapter 4.3. presents the results of the abiotic parameters and chapter 4.4. the results of the questionnaire.
The data summary of the abiotic data is attached in the Appendix (Fig. 8.3).

4.1. Description of the River Reaches

In chapter 3.2. the mentioned reaches are described, and one representative site each reach is shown in a factsheet in 4.2. This hydro-morphological assessment is an answer to the overall aim as a baseline data collection of abiotic and ecological parameters.

4.1.1. Apacuar

The Apacuar River originates in the higher dry-forest area, crosses the “Las Mercedes” project area, and has almost no human impact as it is surrounded by dense riparian forest and very few, not permanently inhabited fincas.

An Orthophoto (Orthophoto 4.1) shows the Finca Las Mercedes on the right side and downside the meandering Apacuar River and its riparian forest.

Bank and bed dynamics are unrestricted possible, as the riparian vegetation is a closes forest with a natural substrate composition (Photo 4.1; Photo 4.2).

A representative site for this reach is shown in 4.2. as factsheet “Apacuar / ID: G” (Fig. 4.2).

Orthophoto 4.1: *"Las Mercedes" farm on the left side and the Apacuar River (right side and below) are almost not visible due to its dense riparian forest.*

Photo 4.1: *A green water snake at the Apacuar River, looks like a leaf. Some regional snakes can be venomous.*

Photo 4.2: *Unrestricted possible bank and bed dynamics and riparian forest at the Apacuar River.*

4.1.2. Los Monos

Los Monos River originates directly in the Project Area “Las Mercedes” surrounded by dense riparian forest (Photo 4.3). Bank and bed dynamics are also unrestricted possible. The river flows into the Purnio River, where a small village, “Villa Esperanza” is located. Due to this village, washing, irrigation, water abstraction and livestock watering are human impacts.

A representative site for this reach is shown in 4.2. as factsheet “Los Monos / ID: H” (Fig. 4.3).

4.4).

Photo 4.3: The birth of the Los Monos River in the deep tropical jungle.

4.1.3. Purnio Upper

The upper Purnio region is a dense forest, bank and bed dynamics are unrestricted (Photo 4.4). Single people were spotted involved in mineral mining (Photo 4.5). Cattle breeding was another human impact.

An Orthophoto (Orthophoto 4.2) shows the Purnio River in his Upper Stream. A non-bituminized street is below at the right side, next to the river. On one side, there is dense woody riparian vegetation, on the other, the woody riparian vegetation is shortly interrupted by grazing.

A representative site for this reach is shown in 4.2. as factsheet "Purnio Upper / ID: I" (Fig. 4.4).

Orthophoto 4.2: *The Purnio River in his Upper Stream. Below, on the right side is a non-bituminized street. Left-sided dense riparian forest and on the right side the woody riparian vegetation is shortly interrupted by grazing.*

Photo 4.4: *The upper Purnio River meandered through the tropical dry forest without bank and bed dynamics restriction.*

Photo 4.5: *Person at mining activities in the upper Purnio River.*

4.1.4. Purnio Lower

The lower part of the Purnio River is surrounded by light forest and more fincas and settlements, categorized by some non-bituminized roadways (mostly gravel), cattle breeding (Photo 4.7), livestock, water extraction, grazing (Photo 4.6), domestic washing, and waste (primarly clothes and plastic) even if the bank and bed dynamics were still unrestricted possible and the substrate natural. There is rare evidence of eutrophication at small lakes close to the river (Photo 4.8).

An Orthophoto (Orthophoto 4.3) shows the Purnio River in his Lower Stream. Riparian Vegetation is only a thin slip. Small Settlement, a big grazing area and a non-bituminized street are visible.

A representative site for this reach is shown in 4.2. as factsheet "Purnio Lower / ID: O" (Fig. 4.5).

Orthophoto 4.3: *The Purnio River in his Lower Stream. Riparian Vegetation is a narrow strip, Settlement, big grazing area and a non-bituminized street is visible.*

Photo 4.6: *Grazing areas around the lower Purnio River.*

Photo 4.7: *Cattle breeding directly at the lower Purnio River.*

Photo 4.8: *Eutrophicated small lake close to the Purnio River Lower Reach.*

4.1.5. Gualí

The samples were taken at the Gualí River right before it flows into the Magdalena River in the City "Honda". The land use is a residential area, and the bank and bed dynamics are impossible due to its anthropogenic obstruction. Single trees and anthropogenic housing are the riparian "vegetation" and various sewage outflows were seen along the river.

A representative site for this reach is shown in 4.2. as factsheet "Gualí / ID: S" (Fig. 4.6).

4.1.6. Magdalena

The Magdalena River is the second biggest river in Colombia. Its profile was too big to take choriotope and discharge measurements. The river in the research area is mainly surrounded by residential areas, commercial areas, roadways, and agriculture (Photo 4.10). A big Pig farm ("Mr. Pig") right next to the Magdalena River is evident about 2 kilometers upstream before the city "Honda" (Photo 4.11). Various Sewage Runoffs of different sizes were seen along the riverside, the riverbank was contaminated by waste (Photo 4.9). Bank and Bed dynamics are just possible in a few places.

A representative site for this reach is shown in 4.2. as factsheet "Magdalena / ID: Z" (Fig. 4.7).

Photo 4.9: *Most plastic and clothes disposal at the Magdalena Riverbank.*

Photo 4.10: *Small banana farm close to the Magdalena River*

Photo 4.11: *Massive pig farm ("Mr. Pig) next to the Magdalena River.*

4.1.7. Quebrada Seca

Quebrada Seca is a small tributary to the Magdalena, which originates close to the city "Honda" and is surrounded mainly by anthropogenic housing, single trees, and sewage runoffs. Bank and bed dynamics were restricted in places and the riparian woody vegetation was patchy. Clothes washing and waste disposal are evident human stressors.

A representative site for this reach is shown in 4.2. as factsheet "Quebrada Seca / ID: R" (Fig. 4.8).

4.1.8. Gualí Sewage Runoff & Magdalena Sewage Runoff

Two of various anthropogenic constructed Sewage Runoffs (Photo 4.12) directly into the Gualí River and the Magdalena River were tested on abiotic data. Due to health reasons, no more data was taken.

A representative site for this reach is shown in 4.2. as factsheet "Gualí Sewage Runoff / ID: T" and "Magdalena Sewage Runoff / ID: Ö" (Fig. 4.8).

Photo 4.9: *Sewage Runoff from a private House directly into the Gualí River before the Magdalena River.*

4.2. Factsheets

Regarding this study's overall aim, abiotic and socio-ecological parameters were analyzed as a baseline data collection. To make this data more understandable, factsheets of each River reach representative sites were made. The measuring sites for the factsheets are visible on a map, generated using Open GIS and sources from OpenStreetMap (Fig. 4.2).

The factsheets are structured in sections:

- On the top section on the left side, the Reach, ID, and Elevation in "meters above sea level" can be seen. On the right side the location is shown as generated using QGIS and sourced from OpenStreetMap.
- In the upper section, the riverbank structure is seen on the right side. The abiotic data, water parameters, and a fisheye picture are shown to emphasize the shading.
- In the middle section, a profile was drawn using AutoCAD to visualize the measured distances (from the top: wetted width, bank width and river depth) and a stacked bar chart indicates the choriotope (if this data was available)
- The lower section displays representative pictures of the measuring site.

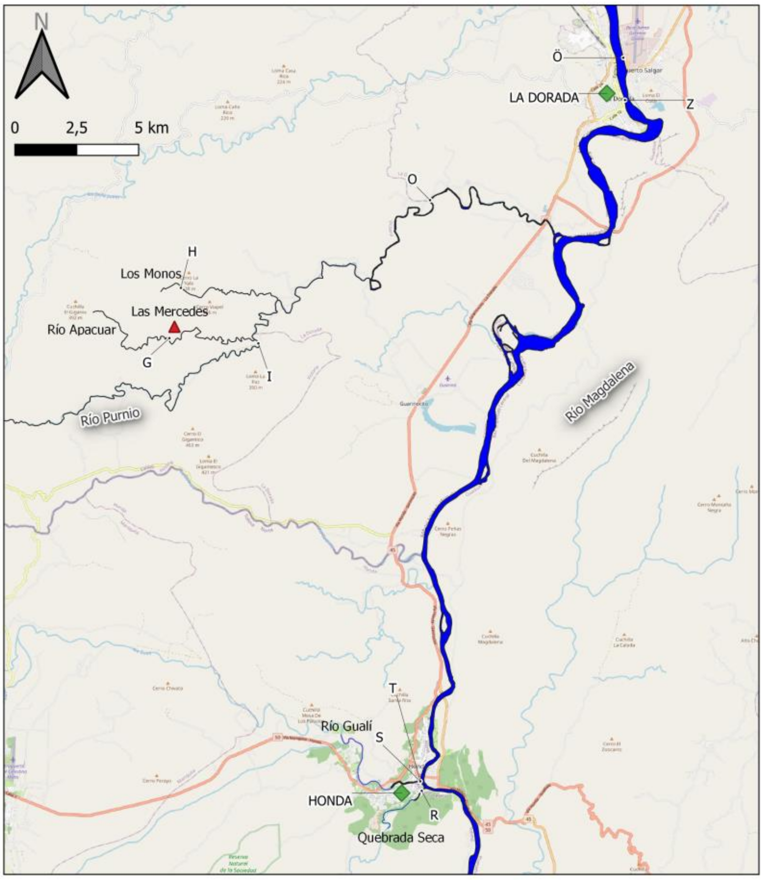


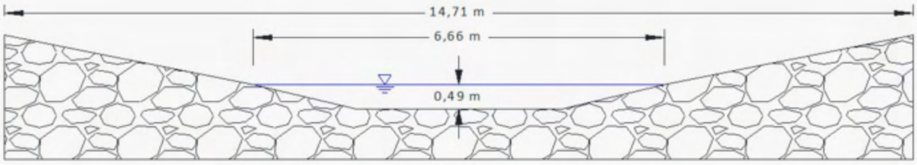
__Figure 4 1:__ Representative Measuring Points to be shown in the Factsheets. The Magdalena River is delineated in dark blue, and its tributaries are shown as light blue thin lines. Green diamonds indicate major cities, and a red triangle indicates the project area, Las Mercedes. The map was generated using Open GIS and sourced from OpenStreetMap.

Apacuar / ID: G / Elevation: 300 m

ABIOTIC DATA (mean)	
Conductivity 1 (µS/cm)	91,67
Conductivity 2 (µS/cmA)	89,00
pH 1 (mVpH)	-52,33
pH 2 (pH)	7,90
Temperature (°C)	26,41
O2 1 (ORP)	189,80
O2 2 (%DO)	90,20
O2 3 (ppmDO)	6,70
TDS 1 (ppm TDS)	44,33
TDS 2 (PSU)	0,04

WATER (mean)	
Flow velocity (m/s)	0,39
Discharge (m³/s)	0,96
Watercolor	transparent
Surface temperature (°C)	25,00
Shading (%)	10-50
Fisheye Picture:	

RIVER BANK	
Bank and bed dynamics	unrestricted possible
Substrate composition	natural
Riparian vegetation	closed riparian woody vegetation
River course	straight
Human Activities at the River	No
Landuse in buffer <100m	natural / dense forest
Landuse further environment >100m	natural / dense forest



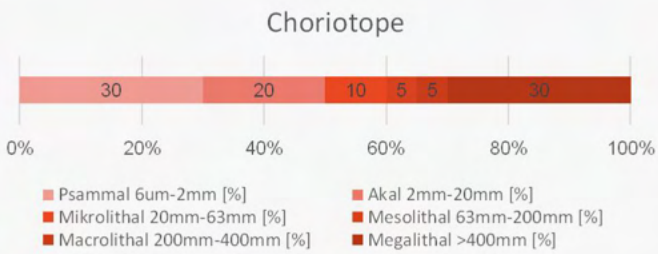


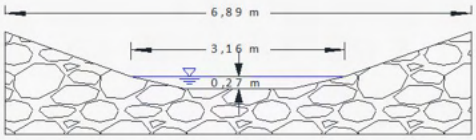
Figure 4.2: *Site ID "G" representing the Apacuar River reach. Reach, ID and elevation are shown in the top section on the left side, and on the right side a QGIS-generated map shows the location. The upper section shows the riverbank structure and abiotic parameters. The middle section shows a profile generated using AutoCAD with the measured distances and a bar chart indicating the choriotope. The lower section displays representative pictures of the site.*

Los Monos / ID: H / Elevation: 547 m

ABIOTIC DATA (mean)	
Conductivity 1 (µS/cm)	61,25
Conductivity 2 (µS/cmA)	62,25
pH 1 (mVpH)	-34,03
pH 2 (pH)	7,57
Temperature (°C)	23,81
O2 1 (ORP)	174,78
O2 2 (%DO)	85,13
O2 3 (ppmDO)	6,39
TDS 1 (ppm TDS)	31,50
TDS 2 (PSU)	0,03

WATER (mean)	
Flow velocity (m/s)	0,15
Discharge (m³/s)	0,10
Watercolor	transparent
Surface temperature (°C)	22,80
Shading (%)	full >90
Fisheye Picture:	

RIVER BANK	
Bank and bed dynamics	unrestricted possible
Substrate composition	natural
Riparian vegetation	closed riparian woody vegetation
River course	curved
Human Activities at the River	No
Landuse in buffer <100m	natural / dense forest
Landuse further environment >100m	natural / dense forest



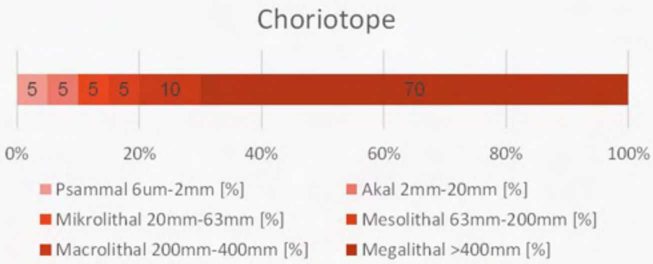


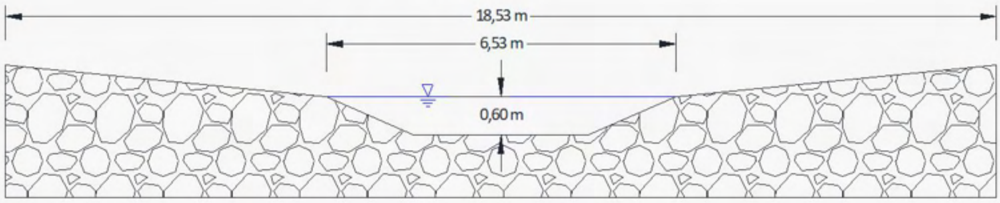
Figure 4.3: *Site ID "H" representing the Los Monos River reach. Reach, ID and elevation are shown in the top section on the left side, and on the right side a QGIS-generated map shows the location. The upper section shows the riverbank structure and abiotic parameters. The middle section shows a profile generated using AutoCAD with the measured distances and a bar chart indicating the choriotope. The lower section displays representative pictures of the site.*

Purnio Upper / ID: I / Elevation: 238 m

ABIOTIC DATA (mean)	
Conductivity 1 (µS/cm)	56,33
Conductivity 2 (µS/cmA)	55,33
pH 1 (mVpH)	-38,07
pH 2 (pH)	7,64
Temperature (°C)	26,07
O2 1 (ORP)	144,47
O2 2 (%DO)	89,70
O2 3 (ppmDO)	6,87
TDS 1 (ppm TDS)	28,00
TDS 2 (PSU)	0,02

WATER (mean)	
Flow velocity (m/s)	0,46
Discharge (m³/s)	1,34
Watercolor	brown
Surface temperature (°C)	24,70
Shading (%)	no <10
Fisheye Picture:	

RIVER BANK	
Bank and bed dynamics	unrestricted possible
Substrate composition	natural
Riparian vegetation	closed riparian woody vegetation
River course	slightly curved
Human Activities at the River	Yes - mining
Landuse in buffer <100m	natural / dense forest
Landuse further environment >100m	mining and gravel extraction



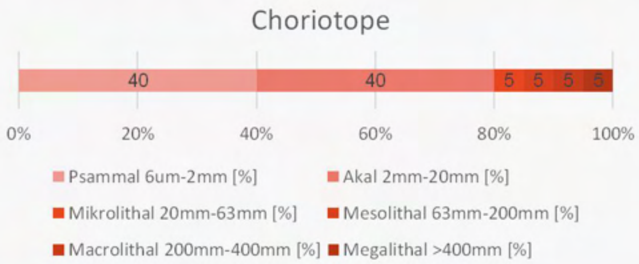
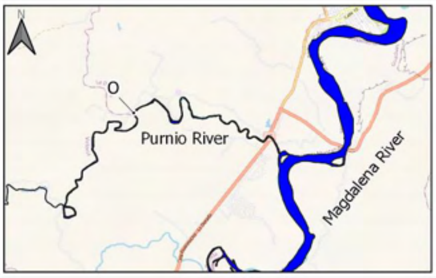


Figure 4 4: *Site ID "I" representing the upper Purnio River reach Reach, ID and elevation are shown in the top section on the left side, and on the right side a QGIS-generated map shows the location. The upper section shows the riverbank structure and abiotic parameters. The middle section shows a profile generated using AutoCAD with the measured distances and a bar chart indicating the choriotope. The lower section displays representative pictures of the site.*

Purnio Lower / ID: O / Elevation: 188 m

[redacted]

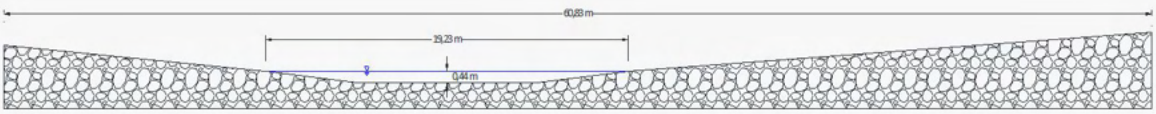


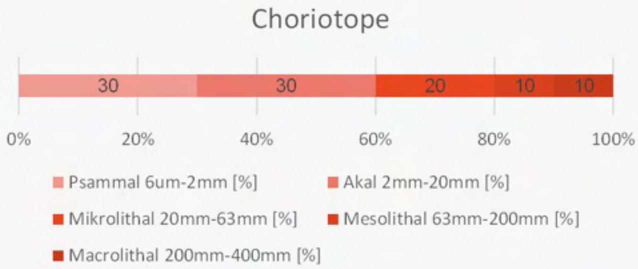
ABIOTIC DATA (mean)	
Conductivity 1 (µS/cm)	73,00
Conductivity 2 (µS/cmA)	79,67
pH 1 (mVpH)	-27,20
pH 2 (pH)	7,43
Temperature (°C)	29,66
O2 1 (ORP)	170,70
O2 2 (%DO)	87,33
O2 3 (ppmDO)	6,31
TDS 1 (ppm TDS)	35,33
TDS 2 (PSU)	0,03

WATER (mean)	
Flow velocity (m/s)	0,60
Discharge (m³/s)	3,80
Watercolor	brown
Surface temperature (°C)	28,93
Shading (%)	no <10
Fisheye Picture:	

RIVER BANK	
Bank and bed dynamics	unrestricted possible
Substrate composition	natural
Riparian vegetation	closed riparian woody vegetation
River course	curved
Human Activities at the River	Small villages, Livestock
Landuse in buffer <100m	natural
Landuse further environment >100m	grazing / small settlement

[redacted]





[redacted]

[redacted]

Figure 4.5: *Site ID "O" representing the lower Purnio River reach. Reach, ID and elevation are shown in the top section on the left side, and on the right side a QGIS-generated map shows the location. The upper section shows the riverbank structure and abiotic parameters. The middle section shows a profile generated using AutoCAD with the measured distances and a bar chart indicating the choriotope. The lower section displays representative pictures of the site.*

Gualí / ID: S / Elevation: 194 m

ABIOTIC DATA (mean)	
Conductivity 1 (µS/cm)	111,33
Conductivity 2 (µS/cmA)	112,00
pH 1 (mVpH)	-3,90
pH 2 (pH)	7,03
Temperature (°C)	25,27
O2 1 (ORP)	135,17
O2 2 (%DO)	103,30
O2 3 (ppmDO)	8,04
TDS 1 (ppm TDS)	57,33
TDS 2 (PSU)	0,05

WATER (mean)	
Watercolor	brown
Surface temperature (°C)	22,80

RIVER BANK	
Bank and bed dynamics	antropogenically obstructed
Substrate composition	N/A
Riparian vegetation	single trees - anthropogenic housing
River course	straight
Human Activities at the River	residential area (Honda City) / fishing / sewage outflow / waste disposal
Landuse in buffer <100m	residential area / comercial area
Landuse further environment >100m	residential area / comercial area

Sewage Runoff

Waste Disposal

__Figure 4.6:__ Site ID "S" representing the Gualí River reach. Reach, ID and elevation are shown in the top section on the left side, and on the right side a QGIS-generated map shows the location. The upper section shows the riverbank structure and abiotic parameters. The middle section shows pictures of a Sewage Runoff and a Waste Disposal next to the measuring site. The lower section displays representative pictures of the site.

Magdalena / ID: Z / Elevation: 171 m

[redacted]

ABIOTIC DATA (mean)	
Conductivity 1 (µS/cm)	169,33
Conductivity 2 (µS/cmA)	175,67
pH 1 (mVpH)	-33,10
pH 2 (pH)	7,35
Temperature (°C)	26,85
O2 1 (ORP)	71,90
O2 2 (%DO)	58,20
O2 3 (ppmDO)	4,44
TDS 1 (ppm TDS)	85,33
TDS 2 (PSU)	0,08

WATER (mean)	
Watercolor	brown
Surface temperature (°C)	25,50

RIVER BANK	
Bank and bed dynamics	only possible in places
Substrate composition	N/A
Riparian vegetation	Patchy riparian woody vegetation / anthropogenic housing
River course	straight
Human Activities at the River	settlement / commercial area / waste disposal
Landuse in buffer <100m	commercial area / Port
Landuse further environment >100m	residential area / commercial area

[redacted]


Riparian Vegetation


Port

[redacted]

Figure 4.7: *Site ID "Z" representing the Magdalena River reach. Reach, ID and elevation are shown in the top section on the left side, and on the right side, a QGIS-generated map showing the location. The upper section shows the riverbank structure and abiotic parameters. The middle section shows pictures of the Riparian Vegetation and the Port next to the Measuring site. The lower section displays representative pictures of the site.*

Quebrada Seca / ID: R / Elevation: 200 m

[redacted]

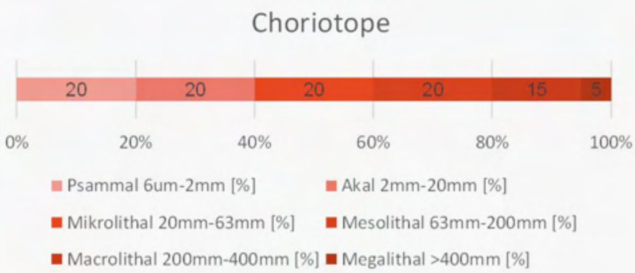
ABIOTIC DATA (mean)	
Conductivity 1 (µS/cm)	238,67
Conductivity 2 (µS/cmA)	267,67
pH 1 (mVpH)	-53,47
pH 2 (pH)	7,91
Temperature (°C)	31,55
O2 1 (ORP)	136,90
O2 2 (%DO)	78,60
O2 3 (ppmDO)	5,47
TDS 1 (ppm TDS)	119,33
TDS 2 (PSU)	0,11

WATER (mean)	
Watercolor	transparent
Surface temperature (°C)	31,90
Shading (%)	no <10

RIVER BANK	
Bank and bed dynamics	restricted in places
Substrate composition	natural
Riparian vegetation	Patchy riparian woody vegetation
River course	straight
Human Activities at the River	Sewage Runoff Upstream / waste disposal
Landuse in buffer <100m	residential area
Landuse further environment >100m	residential area / roadway

[redacted]

Waste Disposal



[redacted]

Figure 4.8: *Site ID "R" representing the Quebrada Seca River reach. Reach, ID and elevation are shown in the top section on the left side, and on the right side a QGIS-generated map showing the location. The upper section shows the riverbank structure and abiotic parameters. The middle section shows a picture of the waste beside the river and a bar chart indicating the choriotope. The lower section displays representative pictures of the site.*

Gualí Sewage Runoff / ID: T / Elevation: 194 m

[redacted]

ABIOTIC DATA (mean)	
Conductivity 1 (µS/cm)	552,00
Conductivity 2 (µS/cmA)	580,00
pH 1 (mVpH)	-48,70
pH 2 (pH)	7,83
Temperature (°C)	27,58
O2 1 (ORP)	8,70
O2 2 (%DO)	25,70
O2 3 (ppmDO)	2,20
TDS 1 (ppm TDS)	282,00
TDS 2 (PSU)	0,27

WATER (mean)	
Watercolor	brown
Surface temperature (°C)	N/A

RIVER BANK	
Bank and bed dynamics	antropogenically obstructed
Substrate composition	N/A
Riparian vegetation	single trees - anthropogenic housing
River course	straight
Human Activities at the River	residential area (Honda City) / fishing / sewage outflow / waste disposal
Landuse in buffer <100m	residential area / comercial area
Landuse further environment >100m	residential area / comercial area

[redacted]

Waste Disposal

Sewage Runoff

[redacted]

Figure 4.9: *Site ID "T" representing the Gualí Sewage Runoff reach. Reach, ID and elevation are shown in the top section on the left side, and on the right side a QGIS-generated map shows the location. The upper section shows the riverbank structure and abiotic parameters. The middle section shows pictures of the Waste Disposal and other Sewage Runoff. The lower section displays representative pictures of the site.*

Magdalena Sewage Runoff / ID: Ö / Elev: 170 m

[redacted]

ABIOTIC DATA (mean)	
Conductivity 1 (µS/cm)	1081,33
Conductivity 2 (µS/cmA)	1170,67
pH 1 (mVpH)	-2,73
pH 2 (pH)	7,00
Temperature (°C)	29,39
O2 1 (ORP)	-185,07
O2 2 (%DO)	7,50
O2 3 (ppmDO)	0,53
TDS 1 (ppm TDS)	538,67
TDS 2 (PSU)	0,53

WATER (mean)	
Watercolor	brown
Surface temperature (°C)	N/A

RIVER BANK	
Bank and bed dynamics	anthropogenically obstructed
Substrate composition	N/A
Riparian vegetation	Patchy riparian woody vegetation
River course	straight
Human Activities at the River	Sewage Runoff / Waste disposal / Washing
Landuse in buffer <100m	residential area / roadway (La Dorada)
Landuse further environment >100m	residential area / roadway (La Dorada)

Sewage Runoff

Waste Disposal

Figure 4.10: *Site ID "Ö" representing the Magdalena Sewage Runoff reach. Reach, ID and elevation are shown in the top section on the left side, and on the right side a QGIS-generated map shows the location. The upper section shows the riverbank structure and abiotic parameters. The middle section shows pictures of the Sewage Runoff and the Waste Disposal. The lower section displays representative pictures of the site.*

4.3. Abiotic Parameters

The data were analyzed using the IBM SPSS Statistics software in various ways, with the emerging bar chart as the most effective visualization method. This chapter answers to the Research Question 1: “How does water health vary along the Magdalena River and the Purnio River, originating in the "Las Mercedes" protected area, with increasing human activity and are there significant variations and interrelations in abiotic factors?”.

River reaches are characterized by various human impact factors: Los Monos contains a small village and dense forests; Apacuar signifies no settlements and dense forests; Purnio Lower has small settlements and gold mining; Purnio Upper features fincas and low-density agriculture; Gualí serves as a reference tributary; Magdalena includes higher discharge and urban areas; Quebrada Seca is contaminated; and both Magdalena and Gualí Sewage Runoffs indicate sewage inflow.

The bars are shown in different colors due to their distance to the “Las Mercedes” project area and their similar characters in land use and human impact. Green means small human impact (Los Monos, Apacuar, Purnio Upper), yellow means moderate human impact (Purnio Lower, Gualí) and red means high human impact (Magdalena, Quebrada Seca, Gualí Sewage Runoff, Magdalena Sewage Runoff).

As shown in the following sections, we registered 89 samples for all abiotic parameters (Tab. 4.1).

Table 4.1: *Each River Reach’s Taken Samples (“N”). The row’s colors show similarities in human impacts, land use and distance to the project area “Las Mercedes”. These measuring sites were classified in reaches according to their river basin and shown in different colors: green means small human impact, yellow means middle human impact and red means high human impact.*

Reach	**N**
Los Monos	7
Apacuar	21
Purnio Upper	12
Purnio Lower	16
Gualí	3
Magdalena	21
Quebrada Seca	3
Gualí Sewage Runoff	3
Magdalena Sewage Runoff	3
Total	89

In chapter 4.3.8. a comparison between abiotic data and the impact of rainfall is shown.

A summary statistic and mean comparison with means, number of measurements and standard deviation for abiotic parameters by River Reach and Human Impact Characteristics is attached in the Appendix (Tab. 8.3).

4.3.1. Electrical Conductivity

The electrical conductivity shows a highly significant difference between the natural upper reaches (lowest mean-value 60,06 µS/cm) and the anthropogenic threatened reaches (highest mean-value 1.081,33 µS/cm) (Fig. 4.11).

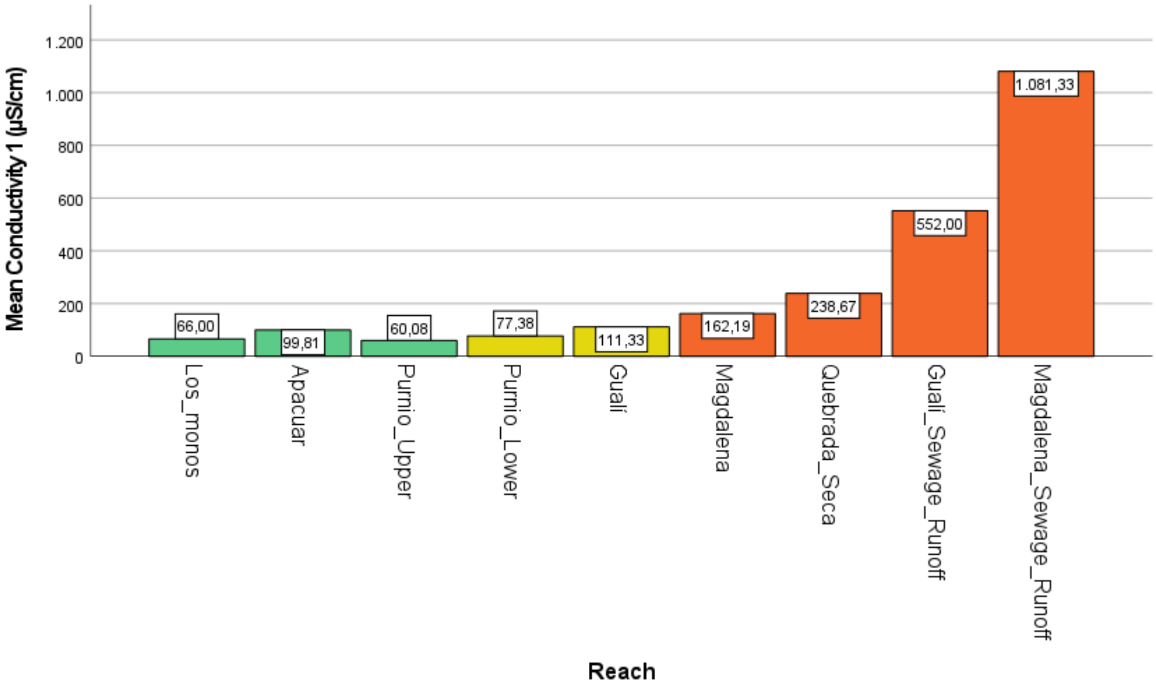


Figure 4.11: *Electrical Conductivity by River Reach and Associated Human Impact. Electrical conductivity levels are given in micro-Siemens per centimeter (µS/cm) across various river reaches. Mean conductivity values are indicated within each bar. Total number of measurements (N=89). Los Monos (N=7), Apacuar (N=21), Purnio Upper (N=12), Purnio Lower (N=16), Gualí (N=3), Magdalena (N=21), Quebrada Seca (N=3), Gualí Sewage Runoff (N=3), and Magdalena Sewage Runoff (N=3), totaling 89 measurements. Bar colors shift from green to yellow and orange to represent increasing levels of human impact.*

The specific electrical conductivity also shows a highly significant difference between the natural upper reaches (lowest mean-value 61,92 µS/cm) and the anthropogenic threatened reaches (highest mean-value 1.170,67 µS/cm) (Fig. 4.12).

The electrical conductivity with another unit also shows a highly significant difference between the natural upper reaches (highest mean value 0,0172 MΩ cm) and the anthropogenic threatened reaches (lowest mean value 0,0009 MΩ cm) (Fig. 4.13).

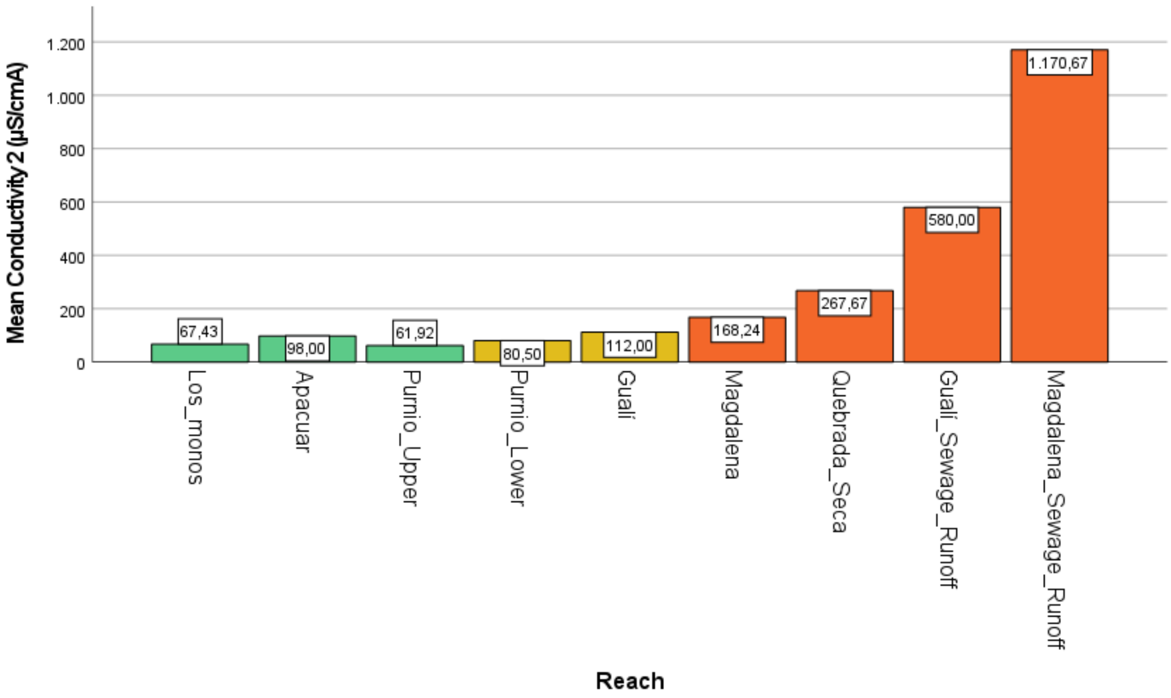


Figure 4.12: *Specific Electrical Conductivity by River Reach and Associated Human Impact. Specific Electrical conductivity levels are given in micro-Siemens per centimeter (µS/cm) across various river reaches. Mean conductivity values are indicated within each bar. Total number of measurements (N=89). Los Monos (N=7), Apacuar (N=21), Purnio Upper (N=12), Purnio Lower (N=16), Gualí (N=3), Magdalena (N=21), Quebrada Seca (N=3), Gualí Sewage Runoff (N=3), and Magdalena Sewage Runoff (N=3), totaling 89 measurements. Bar colors shift from green to yellow and orange to represent increasing levels of human impact.*

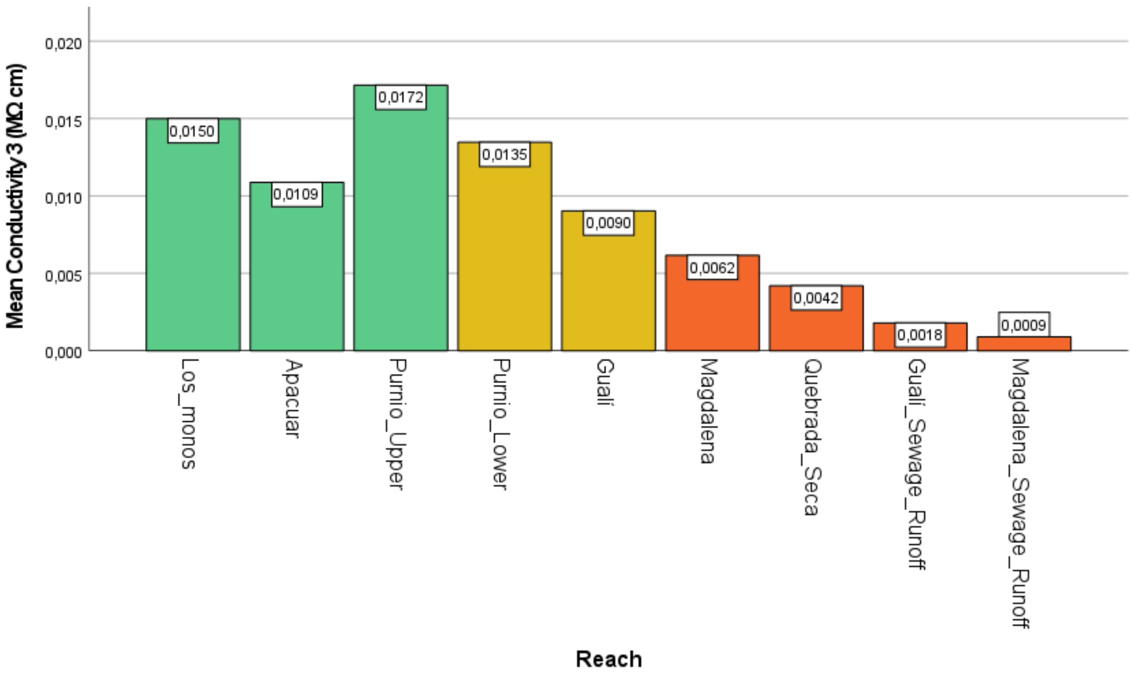


Figure 4.13: *Electrical Conductivity by River Reach and Associated Human Impact. Electrical conductivity levels are given in mega-ohm centimeters (MΩ cm) across various river reaches. Mean conductivity values are indicated within each bar. Total number of measurements (N=89). Los Monos (N=7), Apacuar (N=21), Purnio Upper (N=12), Purnio Lower (N=16), Gualí (N=3), Magdalena (N=21), Quebrada Seca (N=3), Gualí Sewage Runoff (N=3), and Magdalena Sewage Runoff (N=3), totaling 89 measurements. Bar colors shift from green to yellow and orange to represent increasing levels of human impact.*

4.3.2. pH-Value

The reduction potential of a pH Value shows mixed results through all the reaches with the lowest mean value of -55,5 mV to the highest mean value of -2,7 mV (Fig. 4.14). As shown in the boxplots, a high standard deviation is evident for the millivolts per pH-Unit (Fig. 4.15).

The pH-mean-values between 7,0 and 8,01 show constant results through all the reaches. (Fig. 4.16).

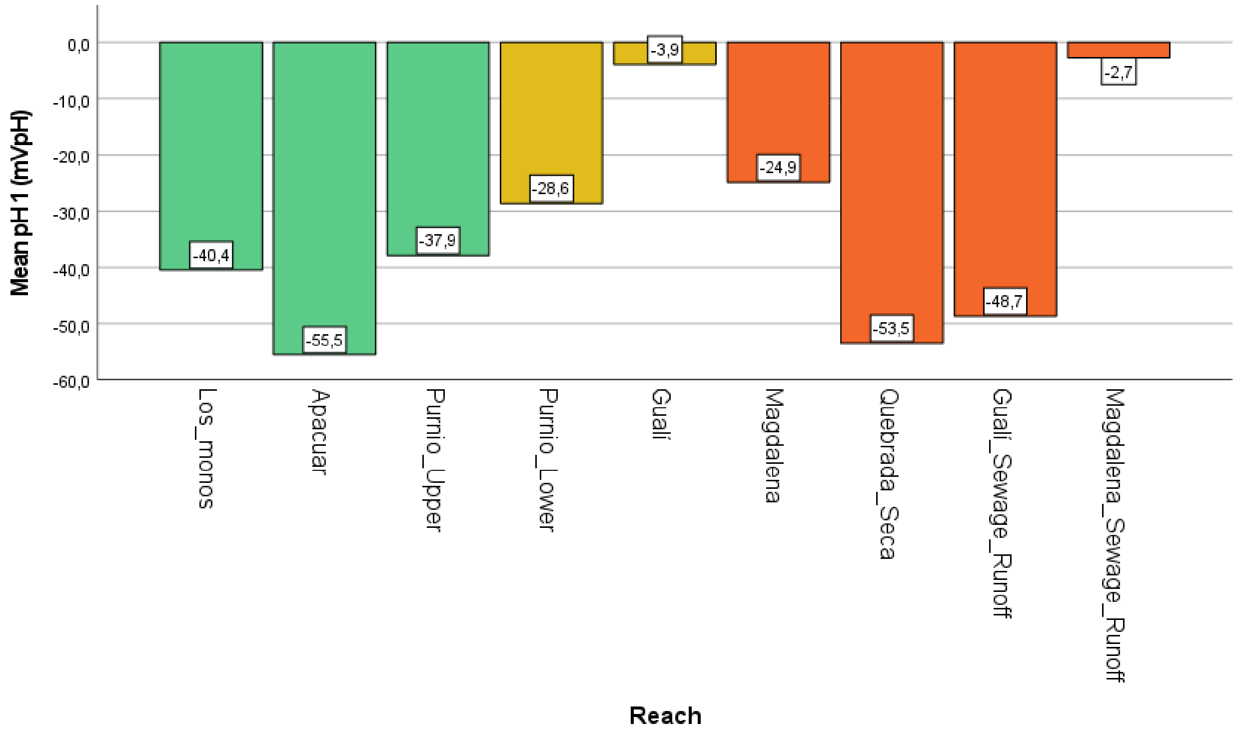


Figure 4.14: *pH-Value by River Reach and Associated Human Impact. pH-Value levels given in millivolts (mV) across various river reaches. Mean values are indicated within each bar. Total number of measurements (N=89). Los Monos (N=7), Apacuar (N=21), Purnio Upper (N=12), Purnio Lower (N=16), Gualí (N=3), Magdalena (N=21), Quebrada Seca (N=3), Gualí Sewage Runoff (N=3), and Magdalena Sewage Runoff (N=3), totaling 89 measurements. Bar colors shift from green to yellow and orange to represent increasing levels of human impact.*

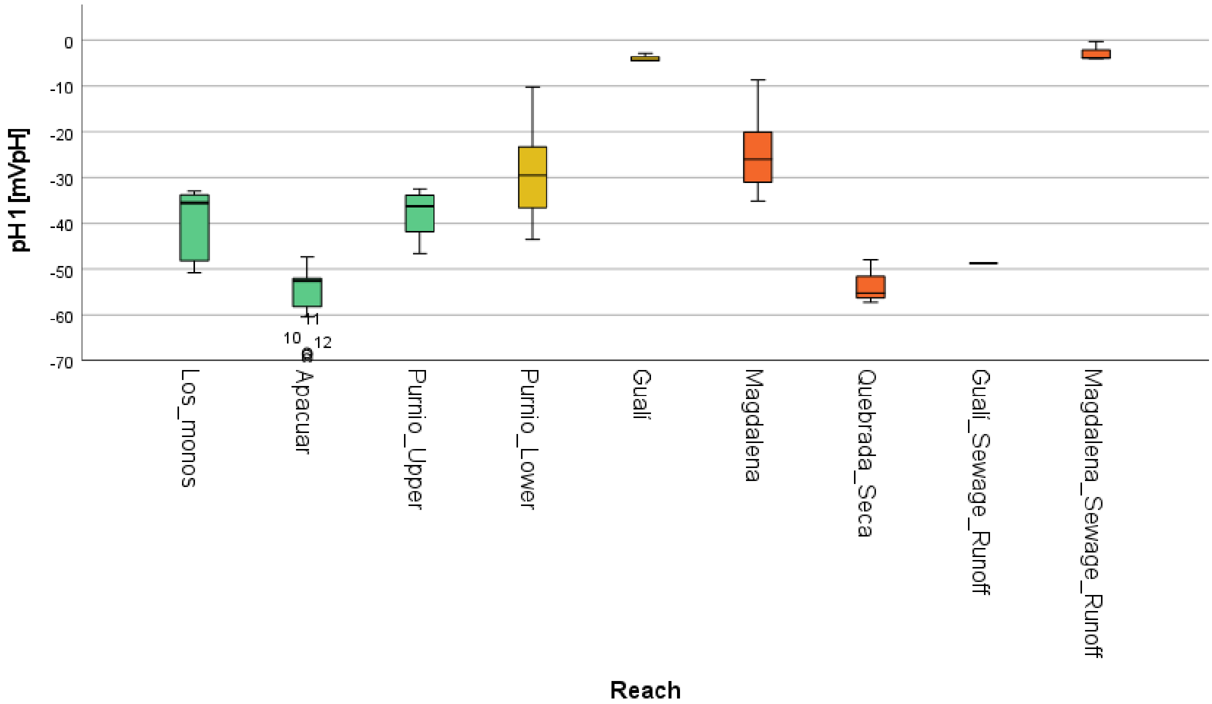


Figure 4.15: *Boxplot of the pH-Value by River Reach and Associated Human Impact. PH-Value levels are given in millivolts per pH-Unit (mVpH) across various river reaches. Mean values are indicated within each bar. Total number of measurements (N=89). Los Monos (N=7), Apacuar (N=21), Purnio Upper (N=12), Purnio Lower (N=16), Gualí (N=3), Magdalena (N=21), Quebrada Seca (N=3), Gualí Sewage Runoff (N=3), and Magdalena Sewage Runoff (N=3), totaling 89 measurements. Bar colors shift from green to yellow and orange to represent increasing levels of human impact.*

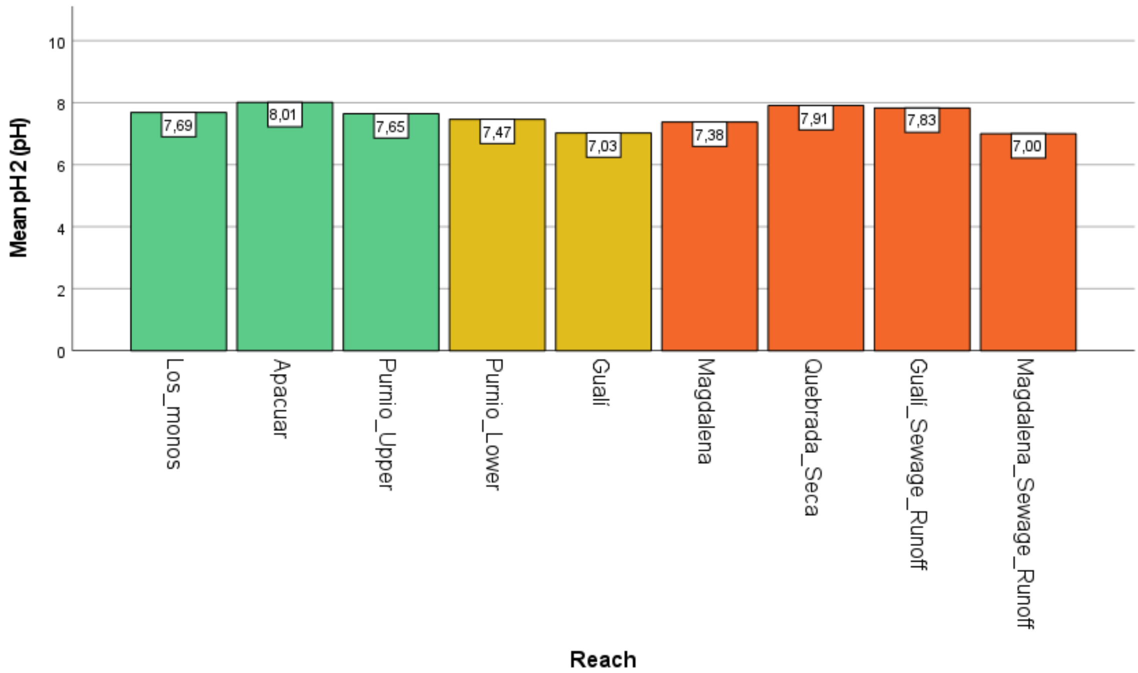


Figure 4.16: *pH-Value by River Reach and Associated Human Impact, given in standard pH-Unit (pH) across various river reaches. Mean values are indicated within each bar. Total number of measurements (N=89). Los Monos (N=7), Apacuar (N=21), Purnio Upper (N=12), Purnio Lower (N=16), Gualí (N=3), Magdalena (N=21), Quebrada Seca (N=3), Gualí Sewage Runoff (N=3), and Magdalena Sewage Runoff (N=3), totaling 89 measurements. Bar colors shift from green to yellow and orange to represent increasing levels of human impact.*

4.3.3. Temperature

Due to the higher atmospheric temperature in the region, rivers originate with higher temperatures than we expect in central Europe. The lowest mean temperature was 24,9°C and the highest 29,8°C was measured (Tab. 4.17. Temperature increases with anthropogenic impact, such as sewage runoff and cattle breeding.

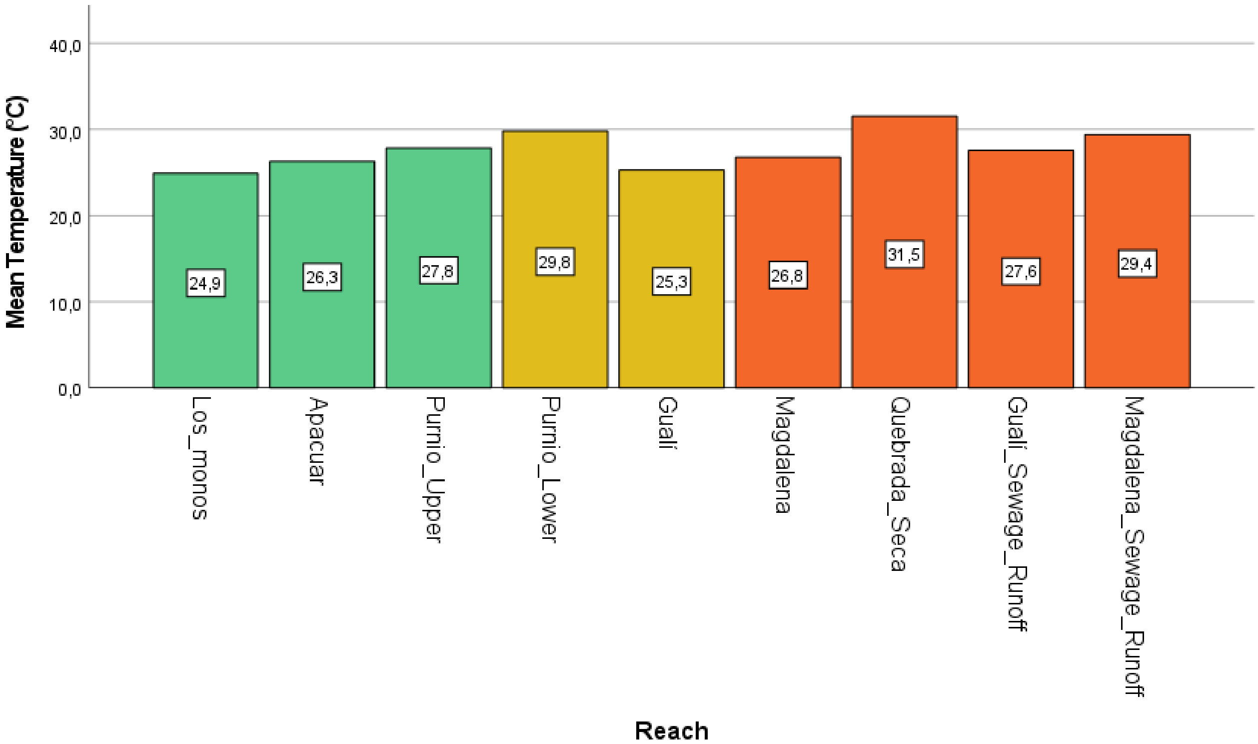


Figure 4.17: *Temperature by River Reach and Associated Human Impact. Temperature is given in degrees Celsius (°C) across various river reaches. Mean temperature values are indicated within each bar. Total number of measurements (N=89). Los Monos (N=7), Apacuar (N=21), Purnio Upper (N=12), Purnio Lower (N=16), Gualí (N=3), Magdalena (N=21), Quebrada Seca (N=3), Gualí Sewage Runoff (N=3), and Magdalena Sewage Runoff (N=3), totaling 89 measurements. Bar colors shift from green to yellow and orange to represent increasing levels of human impact.*

4.3.4. Oxygen Concentration

The Oxygen-Redox-Potential shows mean values from 187,75 ORP to negative values of -185,07 ORP (Fig. 4.18). Negative oxygen-redox potential can be seen in oxygen-bearing inorganic compounds, like nitrates and sulfates.

The oxygen concentration shows mean values from 8,04 ppmDO to 0,53 ppmDO (Fig. 4.20).

The dissolved Oxygen showed mean values from 103,30 %DO to mean values of 7,50 %DO (Fig. 4.19).

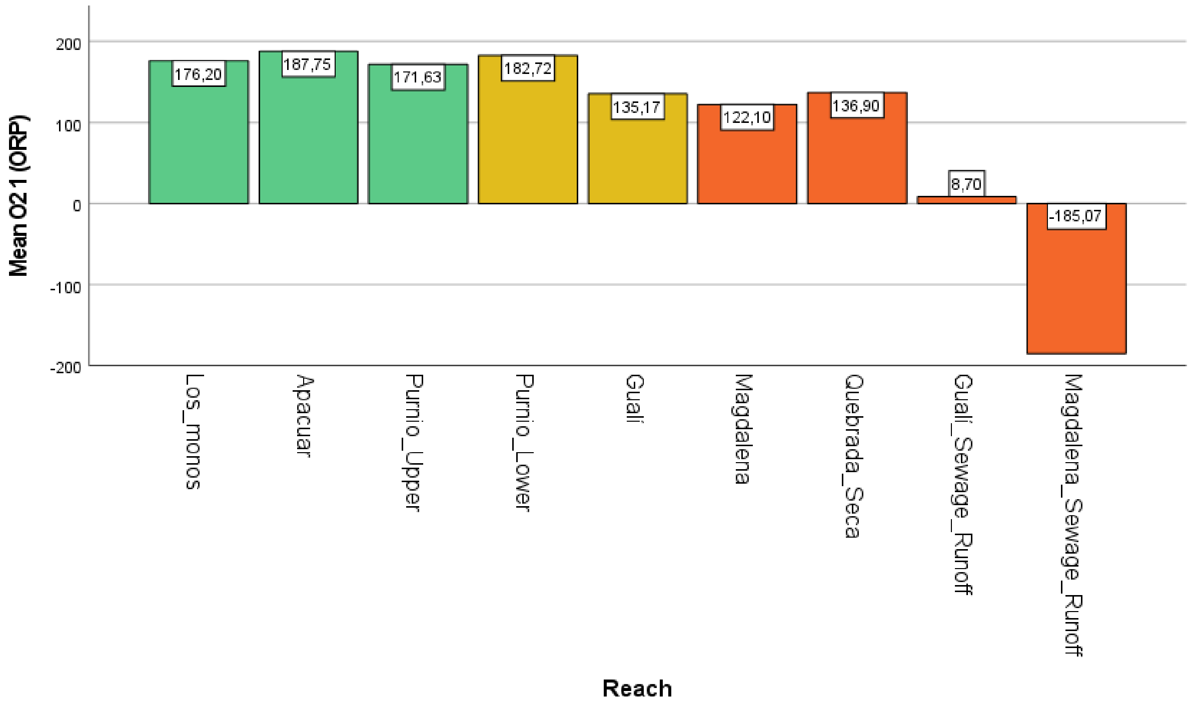


Figure 4.18: *Oxygen Concentration by River Reach and Associated Human Impact. Oxidation concentration is given in Oxidation-Redox-Potential (ORP) across various river reaches. Mean potential values are indicated within each bar. Total number of measurements (N=89). Los Monos (N=7), Apacuar (N=21), Purnio Upper (N=12), Purnio Lower (N=16), Gualí (N=3), Magdalena (N=21), Quebrada Seca (N=3), Gualí Sewage Runoff (N=3), and Magdalena Sewage Runoff (N=3), totaling 89 measurements. Bar colors shift from green to yellow and orange to represent increasing levels of human impact.*

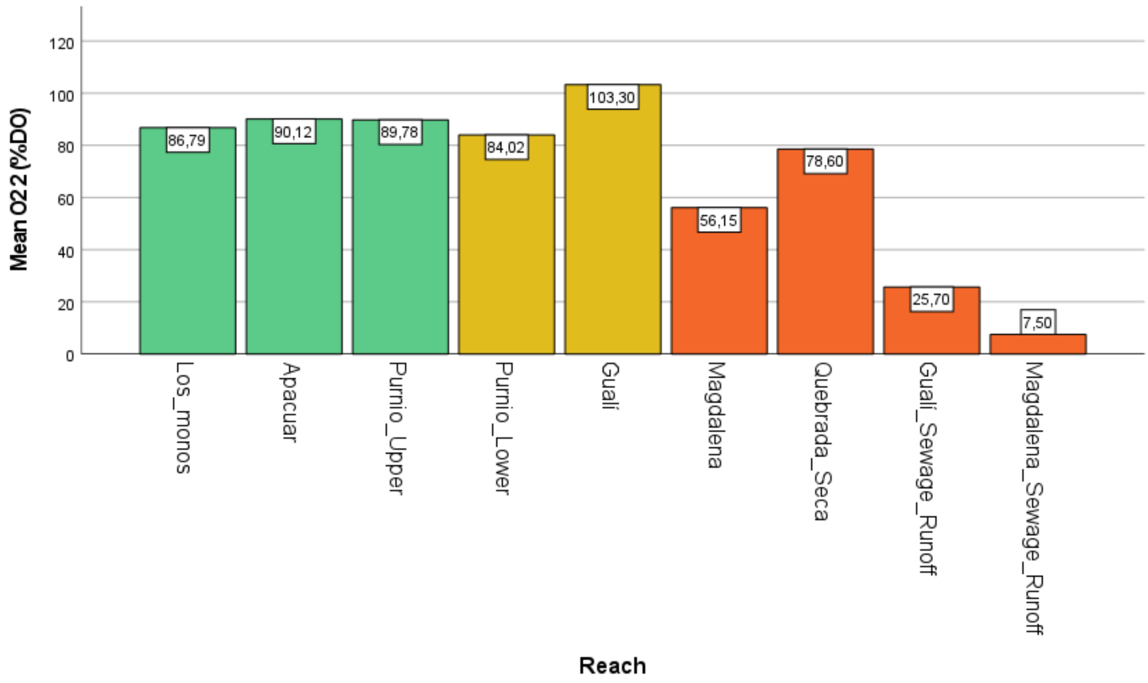


Figure 4.19: *Oxygen Concentration by River Reach and Associated Human Impact. Oxidation concentration is given in Percent Dissolved Oxygen (%DO) across various river reaches. Mean percent are values indicated within each bar. Total number of measurements (N=89). Los Monos (N=7), Apacuar (N=21), Purnio Upper (N=12), Purnio Lower (N=16), Gualí (N=3), Magdalena (N=21), Quebrada Seca (N=3), Gualí Sewage Runoff (N=3), and Magdalena Sewage Runoff (N=3), totaling 89 measurements. Bar colors shift from green to yellow and orange to represent increasing levels of human impact.*

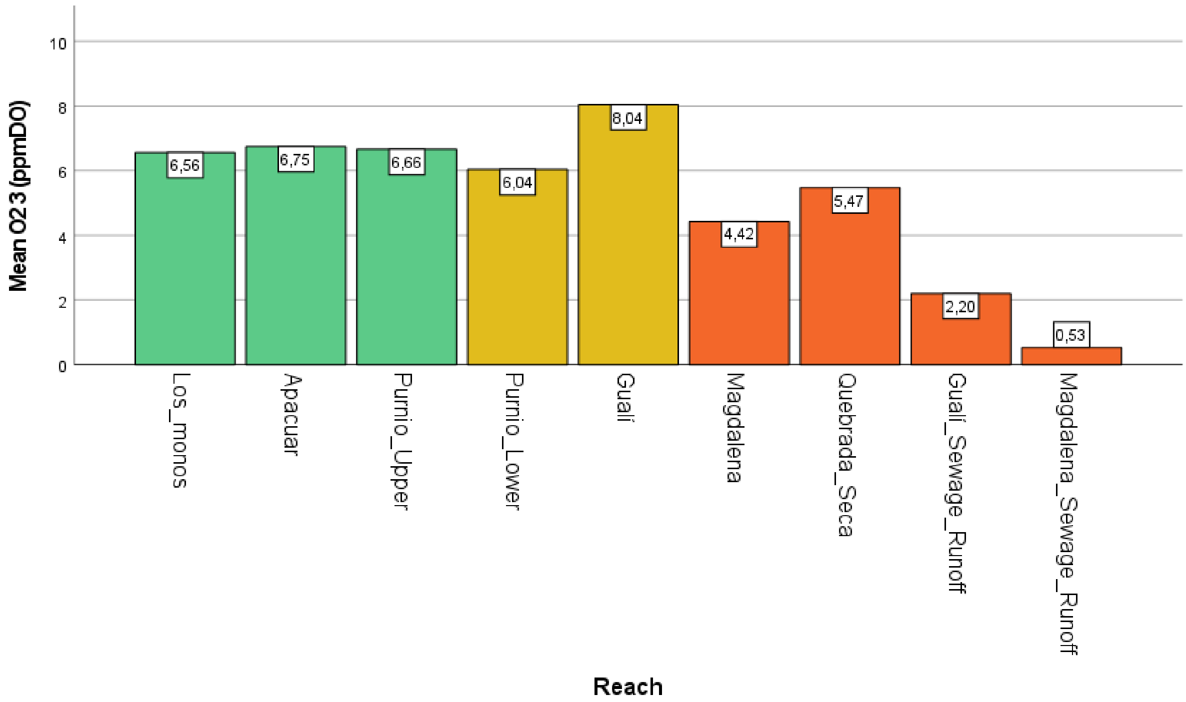


Figure 4.20: *Oxygen Concentration by River Reach and Associated Human Impact. Oxidation concentration is given in parts per million Dissolved Oxygen (ppmDO) across various river reaches. Mean values are indicated within each bar. Total number of measurements (N=89). Los Monos (N=7), Apacuar (N=21), Purnio Upper (N=12), Purnio Lower (N=16), Gualí (N=3), Magdalena (N=21), Quebrada Seca (N=3), Gualí Sewage Runoff (N=3), and Magdalena Sewage Runoff (N=3), totaling 89 measurements. Bar colors shift from green to yellow and orange to represent increasing levels of human impact.*

4.3.5. Total Dissolved Solids

The total dissolved solids found in the anthropogenic threatened reaches were massively higher (highest mean-value 538,67 ppmTDS) than the dissolved solids in the upper reaches (lowest mean-value 29,33 ppmTDS) (Fig. 4.21).

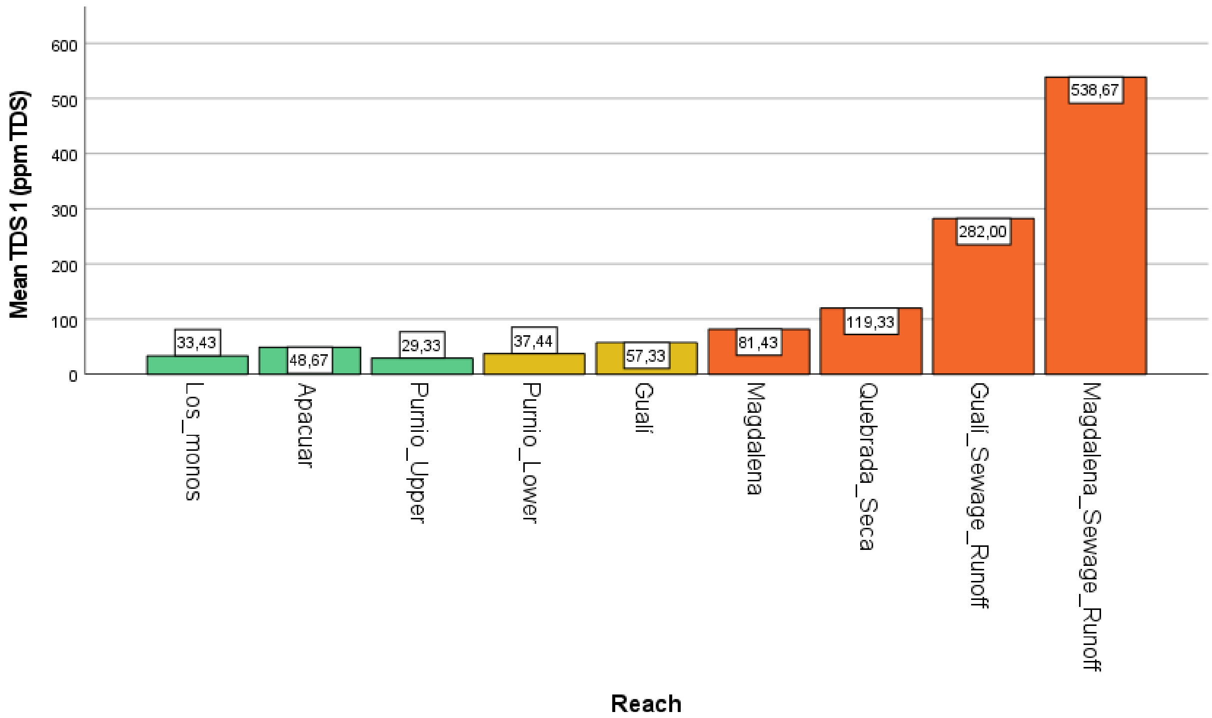


Figure 4.21: *Total Dissolved Solids by River Reach and Associated Human Impact. Dissolved Solids are given in parts per million (ppm TDS) across various river reaches. Mean values are indicated within each bar. Total number of measurements (N=89). Los Monos (N=7), Apacuar (N=21), Purnio Upper (N=12), Purnio Lower (N=16), Gualí (N=3), Magdalena (N=21), Quebrada Seca (N=3), Gualí Sewage Runoff (N=3), and Magdalena Sewage Runoff (N=3), totaling 89 measurements. Bar colors shift from green to yellow and orange to represent increasing levels of human impact.*

The salinity measured in the practical salinity unit in the anthropogenic threatened reaches was massively higher (highest mean-value 0,533 PSU) than the salinity in the upper reaches (lowest mean-value 0,027 PSU) (Fig. 4.22).

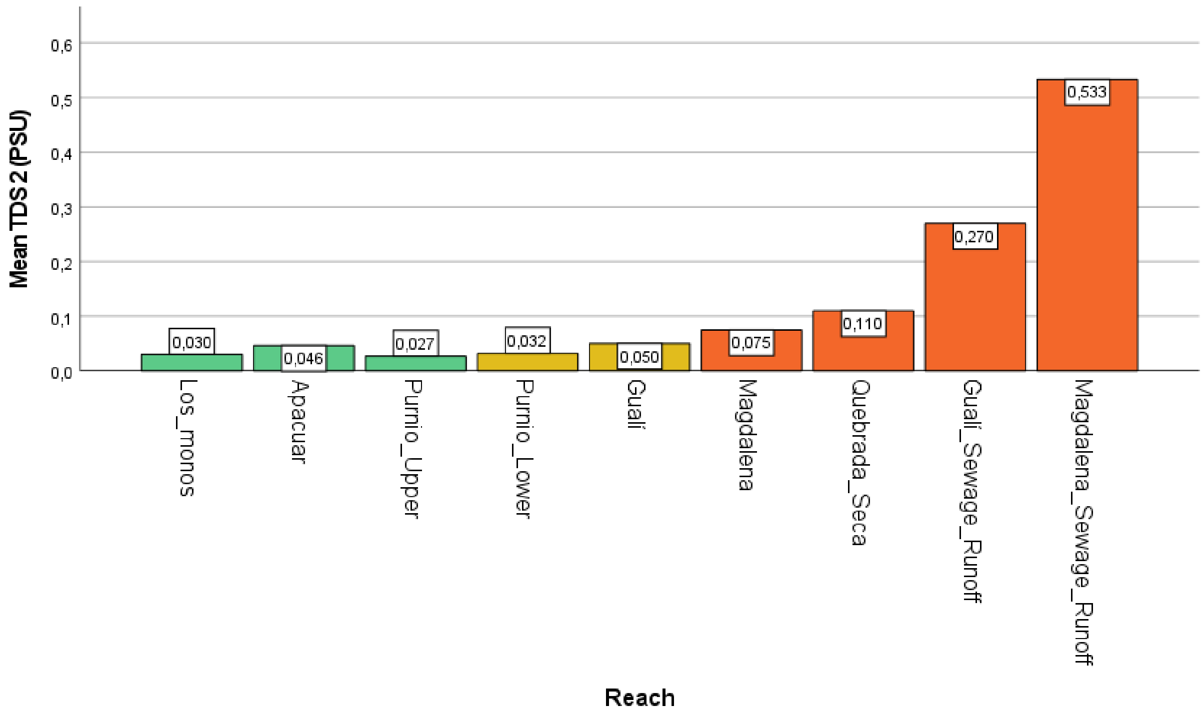


Figure 4.22: *Total Dissolved Solids by River Reach and Associated Human Impact. Dissolved Solids are given in Practical Salinity Unit (PSU) across various river reaches. Mean Salinity values are indicated within each bar. Total number of measurements (N=89). Los Monos (N=7), Apacuar (N=21), Purnio Upper (N=12), Purnio Lower (N=16), Gualí (N=3), Magdalena (N=21), Quebrada Seca (N=3), Gualí Sewage Runoff (N=3), and Magdalena Sewage Runoff (N=3), totaling 89 measurements. Bar colors shift from green to yellow and orange to represent increasing levels of human impact.*

4.3.6. Pearson Correlation:

A Pearson correlation was conducted using all 89 datasets (Tab. 4.2). A highly significant correlation is shown between the units of electric conductivity. The electric conductivity and the oxygen concentration show a highly significant negative correlation, while the conductivity and the total dissolved solids show a highly significant positive correlation.

The pH-Value shows a high correlation between the two Units millivolts per pH-Value and the pH-Value.

The temperature does not show a correlation with the other parameters.

As mentioned with the electric conductivity, the oxygen concentration shows a highly significant positive correlation between its units and a negative correlation with the total dissolved solids.

The total dissolved solids correlate positively within the two units ppm TDS and the practical PSU and with the electric conductivity and the oxygen concentration.

Table 4.2: *Person Correlation for abiotic parameters by River Reach and Human Impact Characteristics (N = 89). ** = Correlation is significant at the 0,01 level (2-tailed); * = Correlation is significant at the 0,05 level (2-tailed). Parameters: Electrical Conductivity (EC) in µS/cm and MΩ cm, pH-value (pH) in mVpH and pH units, Temperature (T) in degrees Celsius, Oxygen Concentration (O2) in ORP, %DO, and ppmDO, and Total Dissolved Solids (TDS) in ppm TDS and PSU. River reaches are characterized by various human impact factors: Los Monos contains a small village and dense forests; Apacuar signifies no settlements and dense forests; Purnio Lower has small settlements and gold mining; Purnio Upper features fincas and low-density agriculture; Gualí serves as a reference tributary; Magdalena includes higher discharge and urban areas; Quebrada Seca is contaminated; and both Magdalena and Gualí Sewage Runoffs indicate sewage inflow.*

		Conductivity 1 (µS/cm)	Conductivity 2 (µS/cmA)	Conductivity 3 (MΩ cm)	pH 1 (mVpH)	pH 2 (pH)	Temp. (°C)	O2 1 (ORP)	O2 2 (%DO)	O2 3 (ppmDO)	TDS 1 (ppm TDS)	TDS 2 (PSU)
Conductivity 1 [µS/cm]	Pearson Correlation	1	1,000**	-,657**	,299**	-,289**	,193	-,929**	-,814**	-,814**	1,000**	,999**
	Sig. (2-tailed)		<,001	<,001	,004	,006	,070	<,001	<,001	<,001	<,001	<,001
Conductivity 2 [µS/cmA]	Pearson Correlation	1,000**	1	-,649**	,308**	-,297**	,208	-,929**	-,812**	-,813**	,999**	,999**
	Sig. (2-tailed)	<,001		<,001	,003	,005	,050	<,001	<,001	<,001	<,001	<,001
Conductivity 3 [MΩ cm]	Pearson Correlation	-,657**	-,649**	1	-,174	,199	,006	,639**	,746**	,708**	-,659**	-,649**
	Sig. (2-tailed)	<,001	<,001		,103	,062	,957	<,001	<,001	<,001	<,001	<,001
pH 1 [mVpH]	Pearson Correlation	,299**	,308**	-,174	1	-,939**	,150	-,391**	-,411**	-,407**	,300**	,295**
	Sig. (2-tailed)	,004	,003	,103		<,001	,161	<,001	<,001	<,001	,004	,005
pH 2 [pH]	Pearson Correlation	-,289**	-,297**	,199	-,939**	1	-,158	,405**	,417**	,413**	-,291**	-,284**
	Sig. (2-tailed)	,006	,005	,062	<,001		,139	<,001	<,001	<,001	,006	,007
Temperature [°C]	Pearson Correlation	,193	,208	,006	,150	-,158	1	-,105	-,124	-,225*	,189	,184
	Sig. (2-tailed)	,070	,050	,957	,161	,139		,328	,248	,034	,076	,085
O2 1 [ORP]	Pearson Correlation	-,929**	-,929**	,639**	-,391**	,405**	-,105	1	,822**	,798**	-,932**	-,928**
	Sig. (2-tailed)	<,001	<,001	<,001	<,001	<,001	,328		<,001	<,001	<,001	<,001
O2 2 [%DO]	Pearson Correlation	-,814**	-,812**	,746**	-,411**	,417**	-,124	,822**	1	,973**	-,818**	-,811**
	Sig. (2-tailed)	<,001	<,001	<,001	<,001	<,001	,248	<,001		<,001	<,001	<,001
O2 3 [ppmDO]	Pearson Correlation	-,814**	-,813**	,708**	-,407**	,413**	-,225*	,798**	,973**	1	-,816**	-,810**
	Sig. (2-tailed)	<,001	<,001	<,001	<,001	<,001	,034	<,001	<,001		<,001	<,001
TDS 1 [ppm TDS]	Pearson Correlation	1,000**	,999**	-,659**	,300**	-,291**	,189	-,932**	-,818**	-,816**	1	,999**
	Sig. (2-tailed)	<,001	<,001	<,001	,004	,006	,076	<,001	<,001	<,001		<,001
TDS 2 [PSU]	Pearson Correlation	,999**	,999**	-,649**	,295**	-,284**	,184	-,928**	-,811**	-,810**	,999**	1
	Sig. (2-tailed)	<,001	<,001	<,001	,005	,007	,085	<,001	<,001	<,001	<,001	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Another Pearson correlation was conducted, to lend credibility to our measurements - between the water temperature and the water surface temperature, which were taken with two different devices. The water surface temperature was not taken at all sites, so the correlation was conducted on 75 datasets and showed a significant positive correlation (Tab. 4.3).

Table 4.3: *Person Correlation Temperature measured with Hanna Multiparameter HI98494 and Water-Surface Temperature measured with Inkburdplus Infrared Thermometer INK-IFT03. ** = Correlation is significant at the 0,01 level (2-tailed); * = Correlation is significant at the 0,05 level (2-tailed). N = Number of measurements.*

		Temperature [°C]	Surface temperature 1 [°C]
Temperature [°C]	Pearson Correlation	1	,946**
	Sig. (2-tailed)		,000
	N	87	75
Surface temperature 1 [°C]	Pearson Correlation	,946**	1
	Sig. (2-tailed)	,000	
	N	75	75

4.3.7. Impact of Rainfall

The measuring site ID "A" at the Purnio Lower reach was measured for abiotic data on two different days. On 13.04.2023, we took four samples when the river had no effect of rain (no rain in the area at least 24 hours before), these samples are titled "A1". On 19.04.2023 we took another three samples ("A2") immediately after an intensive rainfall, so the rain influenced the river. These measurement differences are shown in the following Table 4.4.

Table 4.4: *Mean comparison at the same site without (A1) and with (A2) influenced by the rainfall.*

ID		Conductivity 1 (µS/cm)	Conductivity 2 (µS/cmA)	Conductivity 3 (MΩ cm)	pH 1 (mVpH)	pH 2 (pH)	Temperature (°C)	O2 1 (ORP)	O2 2 (%DO)	O2 3 (ppmDO)	TDS 1 (ppm TDS)	TDS 2 (PSU)
A1	mean	99,00	91,50	,010	-42,90	7,72	29,29	204,20	81,55	5,90	45,50	,04
		4	4	4	4	4	4	4	4	4	4	4
	STD	,00	,58	,001	1,00	,02	,05	7,34	,65	,05	,58	,00
A2 after rain	mean	57,33	64,00	,018	-31,33	7,53	31,02	194,83	86,40	6,05	29,00	,03
		3	3	3	3	3	3	3	3	3	3	3
	STD	6,35	6,93	,002	,45	,03	,01	2,91	,17	,01	2,65	,01

Substantial differences can be seen when there is an influence of the rain on the river. Taking a closer look at the electric conductivity and the salinity, in the following boxplot, After the rain, a lower mean but higher standard deviation is evident (Figure 4.23 and Figure 4.24).

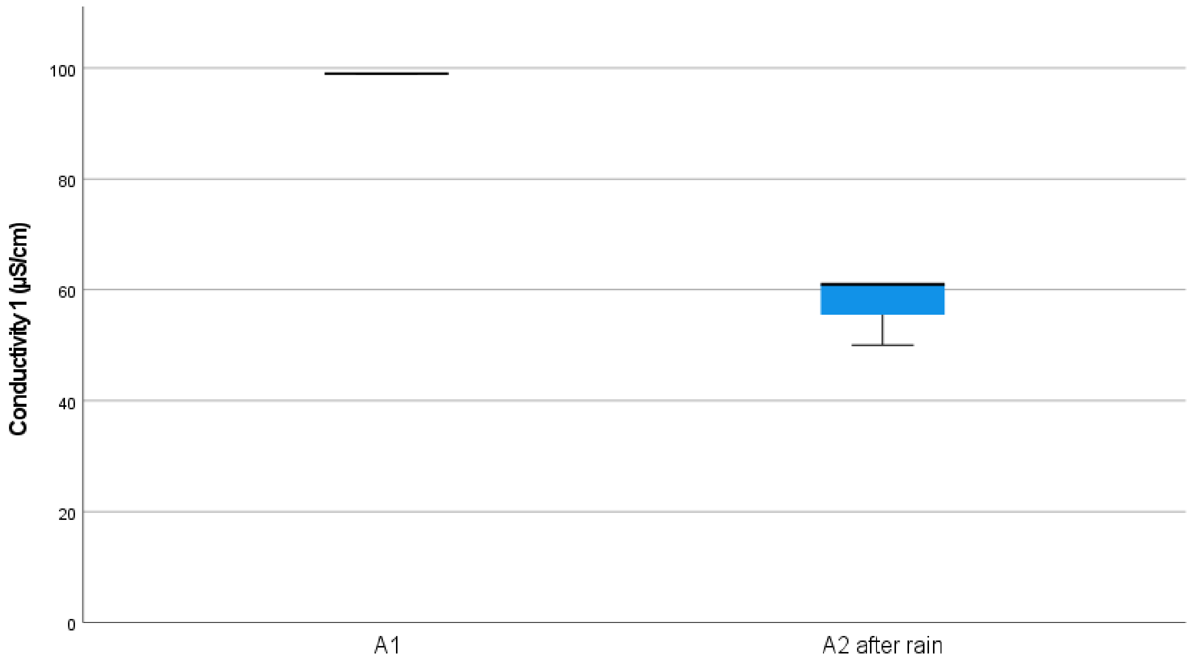


__Figure 4.23:__ Electric conductivity at a site without (A1) showing a higher electric conductivity and with (A2) being influenced by the rainfall showing a lower electric conductivity but higher standard deviation.

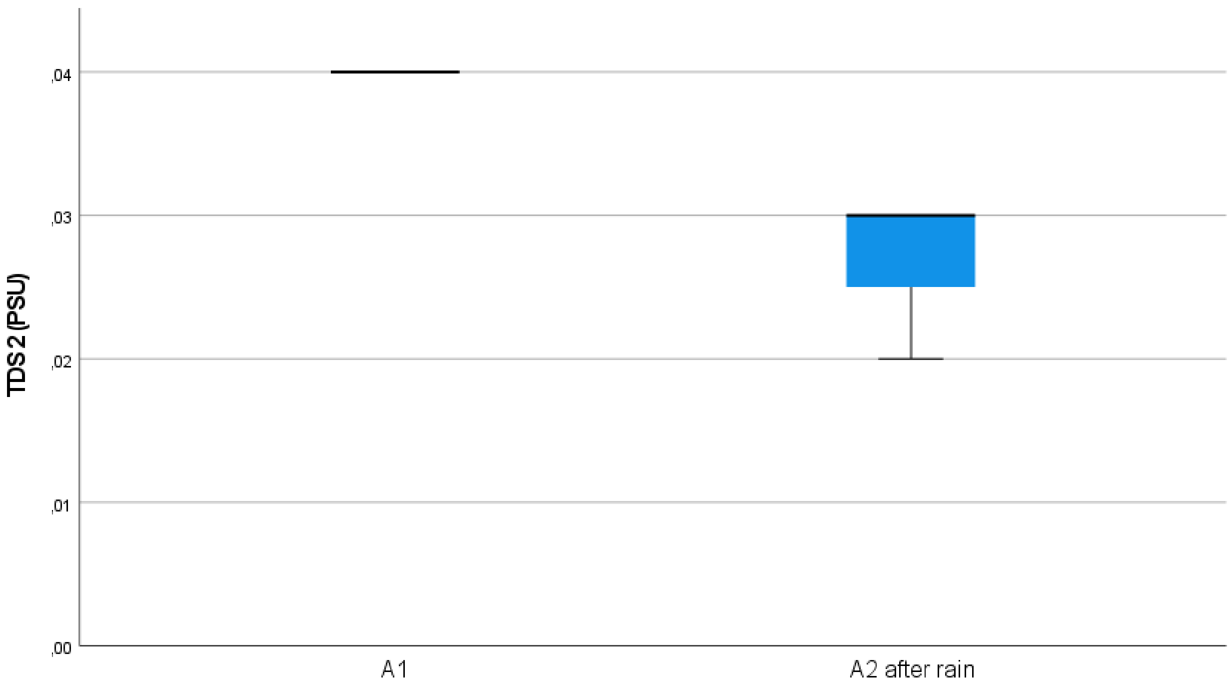


__Figure 4.24:__ Salinity at a site without (A1) showing a higher salinity and with (A2) being influenced by the rainfall showing a lower salinity but higher standard deviation.

4.4. Socio-Demographic Analysis

Thirty-five face-to-face interviews were performed using the same questionnaire. The data were analyzed using the IBM SPSS Statistics software in various ways, with the emerging bar chart as the most effective visualization method. The Questionnaire topics are categorized into the following Chapters. This is answering to Research Question 3: To what extent are communities in the Magdalena River Basin aware of water quality, regional pressures, the importance of protected areas and how do they see the SDG's?

4.4.1. The Importance of the SDGs

For the 35 participants "Life on Land", "Peace", "Clean Water" and "Enough Food" are the most important and "Economic growth" the less important SDGs although all queried SDGs had high importance (Fig. 4.25).

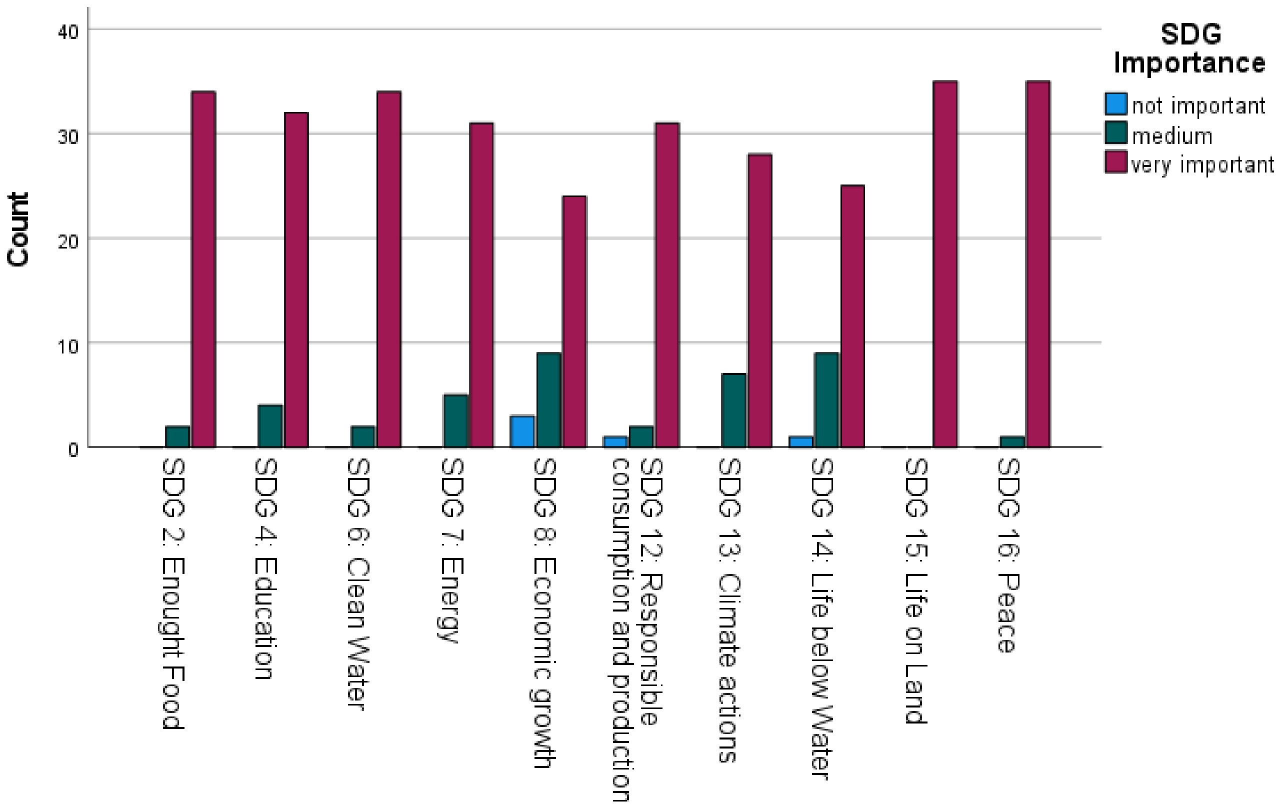


Figure 4.25: *Ordinate: Number of answers on this topic with N = 35; Abscissa: Given Topics (SDGs). Answers should be rated on a scale from 1 as less important to 10 very important. These answers were summarized and shown in a bar chart. Blue bar as a value for no importance (Answer Value 1- 4); Green bar as a value for medium importance (Answer Value 5 – 7), Red bar as a value for high importance (Answer Value 8 – 10). Participants' answers to "How would you rate the importance of the following topics (SDGs)?" showed the most critical topics as Peace, Life on Land, Clean Water and Enough Food and Economic growth as less critical.*

4.4.2. Importance of the River

For 27 participants the river quality is essential. For almost all the participants the river is significant (Fig. 4.26). 11 participants rate that the river quality at the closest river to their house is terrible (Fig. 4.27).

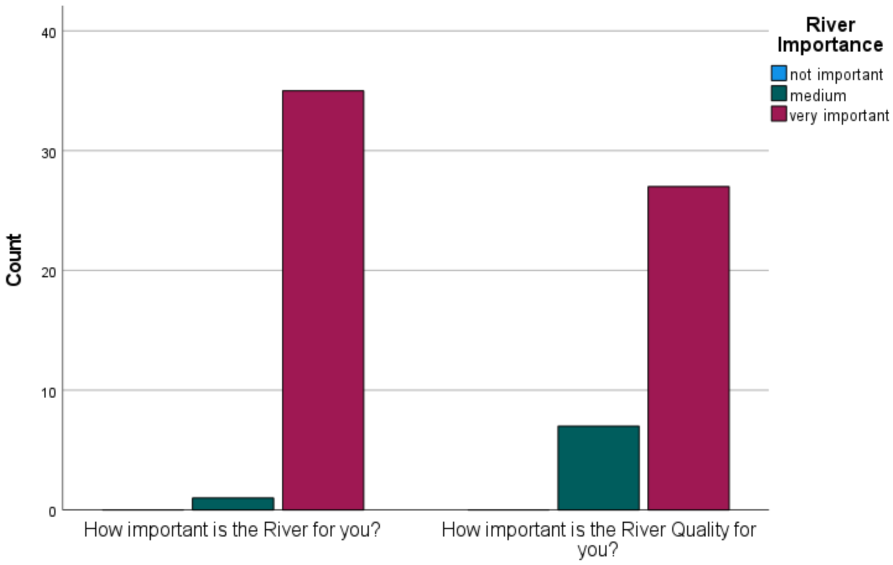


Figure 4.26: *Ordinate: Number of answers on this topic with N = 35; Abscissa: Given Question (SDGs). Answers should be rated on a scale from 1 as less critical to 10 very important. These answers were summarized and shown in a bar chart. Blue bar as a value for no importance (Answer Value 1- 4); Green bar as a value for medium importance (Answer Value 5 – 7), Red bar as a value for high importance (Answer Value 8 – 10). Participants answered on "How important is the river for you?" on the left and "How important is the River Quality for you?" on the right, showing great importance for the population.*

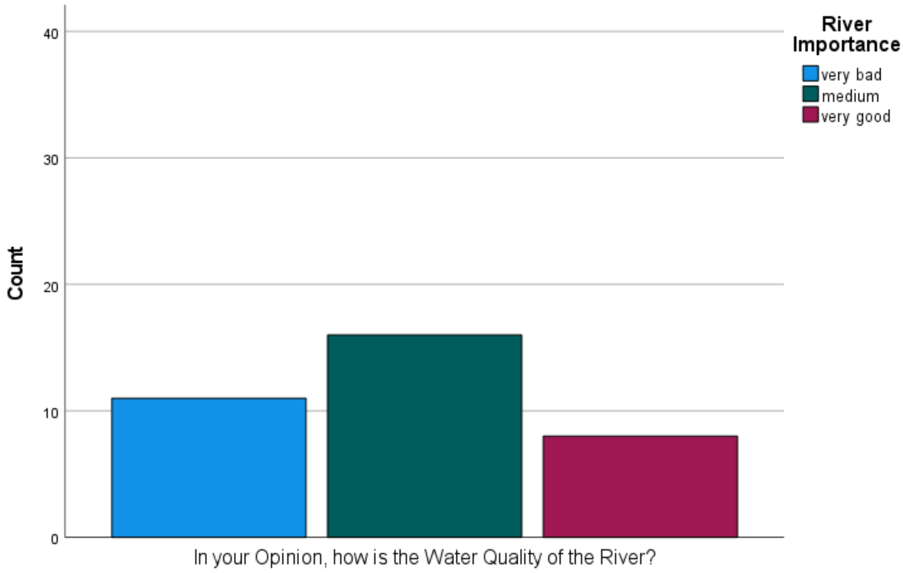


Figure 4.27: *Ordinate: Number of answers on this topic with N = 35; Abscissa: Given Question (SDGs). Answers should be rated on a scale from 1 very bad to 10 very good. These answers were summarized and shown in a bar chart. Blue bar as a value for very bad (Answer Value 1- 4); Green bar as a value for medium (Answer Value 5 – 7), Red bar as a value for very good (Answer Value 8 – 10). Participants rate the river quality in the survey area as mostly bad and medium.*

4.4.3. River Threats

Most participants think the river is threatened by wastewater, waste disposal, climate change and deforestation. However, fishing and plantation (coffee or others) have no impact according to the participants (Fig. 4.28).

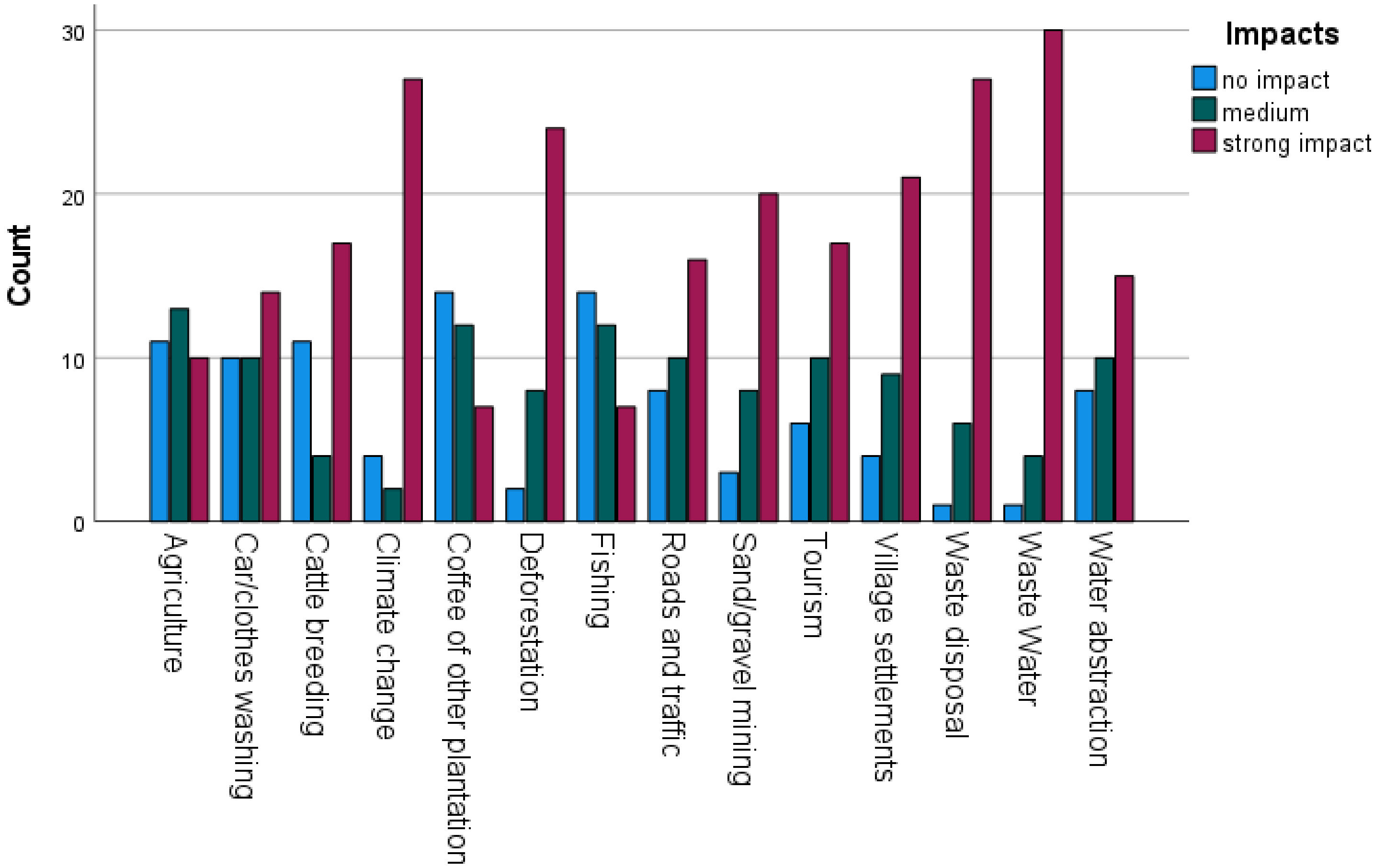


Figure 4.28: *Ordinate: Number of answers on this topic with N = 35; Abscissa: Given Topics (SDGs). Answers should be rated on a scale from 1 no impact to 10 strong impact. These answers were summarized and shown in a bar chart. Blue bar as a value for no impact (Answer Value 1- 4); Green bar as a value for medium (Answer Value 5 – 7), Red bar as a value for high impact (Answer Value 8 – 10). Participants' answers to "Which of these human impacts are threatening the river?" show that Wastewater, Waste, Climate Change and Waste disposals are a thorn in the side of the population.*

4.4.4. Historical Changes

Most participants opine that there was a heavy change in water quality and land use in the last 15 years (Fig. 4.29).

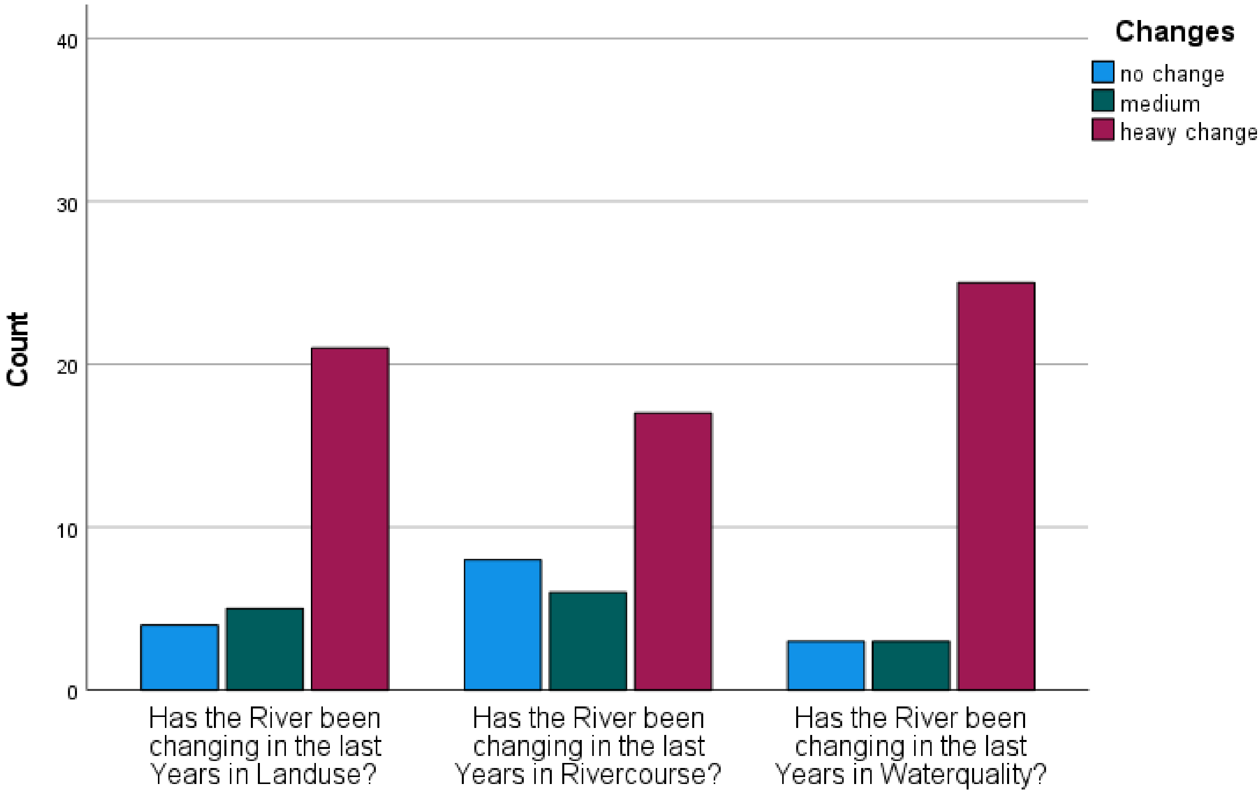


Figure 4.29: *Ordinate: Number of answers on this topic with N = 35; Abscissa: Given Topics (SDGs). Answers should be rated on a scale from 1 as no change to 10 as heavy change. These answers were summarized and shown in a bar chart. Blue bar as a value for no change (Answer Value 1- 4); Green bar as a value for medium (Answer Value 5 – 7), Red bar as a value for heavy change (Answer Value 8 – 10). Participants' answers on "Has the river been changing in the last years?" in the topics "Land-use" (Left side), River course (Middle) and Water Quality (Right side) show the perception of heavy changes in Land-use and Water quality.*

4.4.5. Future

Most of the participants say that the human impacts will affect their children. Most of them opine that protecting land and forests in the region is very important (Fig. 4.30).

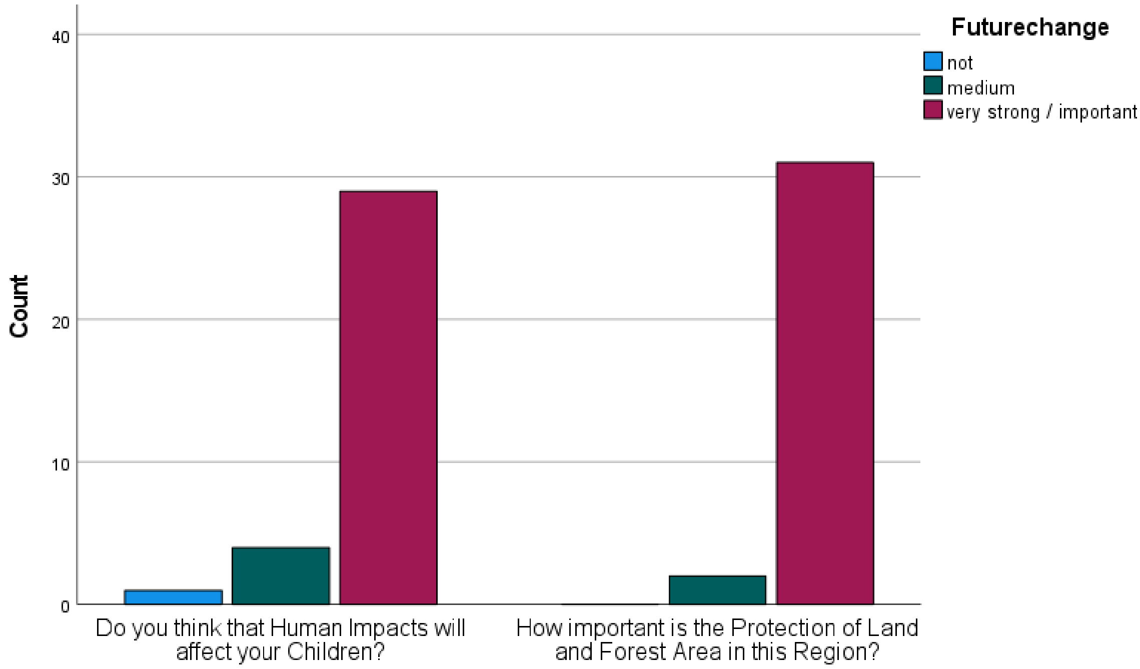


Figure 4.30: *Ordinate: Number of answers on this topic with N = 35; Abscissa: Given Topics (SDGs). Answers should be rated on a scale from 1 as no change to 10 heavy change. These answers were summarized and shown in a bar chart. Blue bar as a value for no change (Answer Value 1- 4); Green bar as a value for medium (Answer Value 5 – 7), Red bar as a value for heavy change (Answer Value 8 – 10). Participants' answers on "Do you think that human impacts will affect your children" on the left and "How important is the protection of land and forest area in this region?" on the right, showing that the region population is concerned about the Future and is in favor of Land and Forest protection.*

5. Discussion

In this study, exploring of our research questions has led us to uncover significant insights into the dynamics of the Magdalena River and its surrounding ecosystem. Addressing these questions has provided valuable perspectives on stressors impacting the river, disparities in abiotic parameters among its tributaries, potential correlations between key factors, and the perceptions of the regional population regarding the river's condition and threats.

5.1. Socio-Ecological Systems and Ecosystem Degradation in Context

This research embarked on a multifaceted exploration to understand the dynamics of the Magdalena River and its surrounding ecosystem. It was not only the examination of abiotic parameters and human impacts but also the contextualization of our findings within the broader socio-ecological systems (SES) framework, to elucidate the intricate relationship between water quality dynamics in the river and the influences of human activities.

Socio-ecological systems (SES) offer a lens through which we can comprehend the interconnectedness of human society and the natural environment. The Magdalena River basin presents a complex web of interactions. Human activities, ranging from agriculture to urbanization, have inevitably shaped the ecological character of this region, impacting its water bodies.

This study uncovered that these human activities, such as wastewater discharge, waste disposal, and land-use practices, serve as stressors within the socio-ecological system of the Magdalena River and its tributaries. The consequential shifts in water quality, a vital indicator of ecosystem health, mirror the broader sustainability of this SES.

Our study identified parallels between the stressors and water quality changes observed in the Magdalena River ecosystem and those documented in Africa (Melcher et al., 2020), Europe (Schinegger et al., 2012), and other parts of Colombia (Ospina Zúñiga et al., 2018).

By contextualizing our findings within the SES framework and through international comparisons, we aim to underline the global relevance of our research. The implications derived from this contextualization extend beyond the Magdalena River and its tributaries, offering lessons and guidance for the sustainable management of river ecosystems worldwide.

5.2. Identification and Correlation of Specific Stressors

The analysis aims to identify unique stressors and investigate their correlations with measured abiotic parameters. Furthermore, we assess whether the patterns observed in these river systems are consistent with those documented in other rivers, thus aligning with the exploration of Research Question 1.

The Magdalena River and Purnio River, like many rivers across the globe, face many stressors impacting their water quality, which can be shown in abiotic parameters (Hassan Omer, 2020). However, it is essential to recognize the region-specific stressors that set these rivers apart. These unique stressors are evident in local industrial activities, agriculture practices such as grazing and cattle breeding, urbanization, and sewage runoffs.

Abiotic parameters like electrical conductivity measures the water's ability to conduct an electrical current, which is influenced by ions in the water. Oxygen concentration indicates the water's capacity to support aquatic life, with higher concentrations generally being more favorable. Total dissolved solids encompass various substances dissolved in water, including minerals and organic matter. By investigating the interrelationship among key abiotic parameters, we gain insights into the intricate dynamics of the river ecosystem, offering a holistic view of water quality.

A strong correlation between electrical conductivity and total dissolved solids suggests a prevalence of mineral ions, potentially linked to agricultural runoff. At the same time, a correlation between oxygen concentration and electrical conductivity reveals the impact of anthropogenic activities on the water's oxygen-carrying capacity.

Understanding how these unique stressors correlate with abiotic parameters is critical in unraveling the complex dynamics of these river ecosystems. It was proved by correlation analysis that with the increase in human stressors, electrical conductivity, water temperature and total dissolved solids increase while the oxygen concentration decreases. By examining correlations, we can gain insights into how these stressors directly affect the physical and chemical attributes of the rivers.

In conclusion, this investigation into the correlations among abiotic parameters sheds light on the intricate relationships within the Magdalena River and Purnio River ecosystems. While these parameters offer valuable insights into water quality, it is essential to consider them within the broader context of ecosystem health and human-induced changes.

5.3. Community Awareness and River Utilization

Our objective to align with Research Question 2 is to evaluate the level of awareness among local communities regarding water quality, the significance of protected areas, and the various regional pressures affecting the river systems. Simultaneously, we assess how these communities utilize the river and whether their practices contribute to or alleviate the observed stressors.

The Magdalena River ecosystem is home to diverse communities with varying degrees of exposure to information about water quality, conservation practices, and regional challenges. Assessing this awareness allows us to identify gaps in knowledge and potential opportunities for education and engagement.

The evaluation of the population shows parallels between the hydro morphological assessment and abiotic data. The river and the water quality are essential for the population although they do not believe in good water quality at the river. Most interviews were performed close to settlements, aligning with the degreasing river health close to the settlements and cities. Most pressures precepted by the regional people were also evident by the research team, as the wastewater, waste -disposals and deforestation seen as grazing areas. This aligns well with other studies on the Magdalena River basin (Restrepo A., 2015).

The population believes that future generations will be affected by human impacts. Furthermore, protecting of land and water areas is important to the population, leading to future considerations in the next chapter.

5.4. Synthesis and Implications for Future Research

According to (Restrepo & Kjerfve, 2000) water discharge and sediment load are strongly coupled to the rainy season cycle. Future research should be done in non-rain-season.

Additional research is needed to apply a Driver-Pressure-State-Impact-Response (DPSIR) framework to understand better the dynamic interlinkages between the multiple stressors applied in Africa (Melcher et al., 2020).

The investigation into the Magdalena River and Purnio River has unearthed a wealth of insights into the intricate interplay of ecological and human factors. These findings span a broad spectrum of aspects:

- Socio-Ecological Systems: This study has underscored the significance of recognizing the role of local and traditional knowledge in understanding river ecosystems. Incorporating of such knowledge enriches our comprehension of ecological processes and is particularly valuable in data-scarce regions.
- Identification of Stressors: These river systems have identified Unique water quality stressors. These stressors encompass a range of human activities, from agriculture and industry to urbanization, all of which contribute to the complex web of ecological challenges.
- Interrelationship among Abiotic Parameters: The analysis has unveiled correlations between electrical conductivity, oxygen concentration, and total dissolved solids, shedding light on their utility as indicators of water quality and human impacts.
- Community Awareness and River Utilization: The level of community awareness within the Magdalena River basin has been evaluated, illuminating the significance of protected areas and the impact of local practices on river health.

The findings of this study hold significant implications for understanding the socio-ecological dynamics of the Magdalena River and Purnio River. They emphasize the need for integrated and multi-disciplinary river conservation and management approaches. Incorporating local knowledge, recognizing unique stressors, and addressing community practices are vital to sustaining these ecosystems.

While this research focuses on a specific river basin, its broader relevance extends to river systems worldwide. Global river ecosystems face challenges related to human impacts and changing environmental conditions. Our findings remind us of the importance of considering local contexts while addressing global environmental issues.

Looking ahead, several avenues for future research emerge from this study:

- Community Engagement: Research on effective strategies for engaging local communities in land and river conservation (as the Las Mercedes Project) can provide a memory effect on other communities.
- Long-Term Monitoring: Continued monitoring of the Magdalena River and Purnio River is essential to track changes and assess the effectiveness of conservation efforts.
- Comparative Studies: Comparative analyses with river ecosystems in other regions can deepen our understanding of common stressors and conservation strategies.

In conclusion, a comprehensive exploration of the Magdalena River and Purnio River unveiled their intricate socio-ecological dynamics. The findings provide actionable insights for local conservation efforts and contribute to the broader discourse on river sustainability.

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8. Appendix

8.1. Field Protocol

Table 8.1: *The field protocol was modified by the Project Team after Meulenbroek et al., 2013 and adapted for the requirements of the Project Area.*

Field Protocol Las Mercedes		
ID	Date (dd.mm.yyyy)	Investigator
Site Name	Start (hh:mm)	End (hh:mm)
Longitude	Latitude	Sea Level (meter)
Weather	Strahler Order	Camera and Photo number
Abiotic Data		
Conductivity [µS/cm |µS/cm^{A} | MΩ cm]		
pH [mVpH | pH]		
Temperature [°C]		
O2 [ORP, % DO, ppmDO]		
TDS [ppm Tds | PSU | σ_t]		
Hydrology		
Water flow Turbulent/Laminar		
Flow velocity [m/s]		
Discharge Bank full width Wetted width Depth Water Surface temperature Secci depth(cm)		
Bank structure (left)		
flat <30%	*slanting*	
embanked	*other*	
Bank height		
Picture ID		
Bank structure (right)		
flat <30%	*slanting*	
embanked	*other*	
Bank height		
Xylal (Dead Wood) Fine and/or coarse branches - Larger tree part - Fall tree - Smaller deadwood accumulation (genist) - Deadwood accumulation		

Morphology		
Mesohabitat type rapidly overflowed shallow water areas rapidly flowing areas of medium water depth rapidly flowing areas of large water depths stagnant, slowly overflowing shallow water areas stagnant, slowly flowing areas of medium water depth stagnant, slowly flowing areas of large water depth		
Bearing density optical Loose-solidified-compact		
Choriotope description		
Pelal <6um [%]	*Mikrolithal 20-63mm [%]*	*Megalithal >400mm [%]*
Psammal 6um-2mm [%]	*Mesolithal 63-200mm [%]*	*Primary rock and Concrete [%]*
Akal 2-20mm [%]	*Macrolithal 200-400mm [%]*	
Land use in buffer <100m Natural - agriculture - leveled roadway - residential area - commercial area - roadway		
Land use further environment >100m Natural - agriculture - leveled roadway - residential area - commercial area - roadway		
Land use in buffer >100m Natural - agriculture - leveled roadway - residential area - commercial area - roadway		
Erosion Visible – if yes at which distance to the river in m		
Watercolor Transparent – green – brown etc.		
Bank and bed dynamics unrestricted possible - restricted in places - only possible in places - anthopogenically obstructed - piped/boxed professionall		
Substrate composition natural - insignificantly altered - obviously anthropogenically altered bed substrate (deposits) - large-scale bed remodeling - completely artificial foreign material (paving)		
Riparian vegetation Closed riparian woody vegetation - Patchy riparian woody vegetation - Single trees - Herbaceous vegetation - No vegetation - Agriculture/anthropogenic housing		
Orientation of the river North - East - South – West		
River course straight - curved - meandering - anthrogenically modified		
Shading not present <10% - low 10-50% - medium 50-90% - full >90%		
Human Activitys at the river Water abstraction / Agriculture/Animals, Carwashing, …		
General optional		
General - Landuse		
dense forest	*standing waters*	*horticulture*

light forest	*non-native forest*	*lifestock*
tree savannah	*hilly region*	*partial cutting*
bush savannah	*crop land*	*clear-cutting*
steppe	*crop industrial*	*urban sites (residuals)*
desert	*cotton*	*urban sites (industrial)*
naturally unvegetated	*rice*	*villages*
wetlands	*vegetables*	*mining*
others		
General – Human Activities		
fishing	*irrigation*	*water abstraction*
washing	*life stock watering*	*hydropower*
other		
General - Vegetation		
Floating macrophytes [%]	*Reed [%]*	*Wood bank vegetation [%]*
Unnatural bank vegetation [%]	*other*	
General - Pollution		
source pollution	non-source pollution	sewage overflows
eutrophication	toxic substances	acidification
liming	mining	
other		
General - Waste disposal		
yes	no	comments
Soecific waste:		

8.2. Questionnaire

Table 8.2: *The questionnaire sheet was structures by the project team and adapted for the project area.*

General information	Interviewer's Name:
Date/time of interview:	Questionnaire number:
Socio-demographic information of respondent	
Gender: O Female O Male O Others	Age:
Marital status: O Single O Married O Divorced O Widowed	
Number of people in the household:	Location of your household: O Rural O Urban
Profession:	
What is the highest level of education that you have completed? (Please tick one box only) O Primary school; O Secondary school; O Tertiary education; O University; O Literacy; O Others, specify………………	
Importance of Sustainability Development Goals (SDGs)	
Q1. How would you rate the importance of the following topics? Not important 1 2 3 4 5 6 7 8 9 10 Very important, I don't know 0 • Enough food • Education • Clean water • Economic growth • Energy • Responsible consumption and production (organic farming) • Climate actions • Fisheries • Peace • Life on Land	
Human activities and their impact on the river Purnio/ Magdalena	
Q2. How important is the river for you? Not important 1 2 3 4 5 6 7 8 9 10 Very important, I don't know 0	
Q3. How important is the river quality in the closest river of your home for you? Not important 1 2 3 4 5 6 7 8 9 10 Very important, I don't know 0	
Q4. How do you use the river?	
Q5. Have you ever used the river for the following activities: - Fishing O Yes O No O I don't know - Car washing O Yes O No O I don't know - Clothes washing O Yes O No O I don't know - Swimming O Yes O No O I don't know - Other O Yes O No O I don't know	

Q6. Do you regularly eat fish out of the river, and if no, why not?
Q7. In your opinion, how is the water quality of the river? Very bad 1 2 3 4 5 6 7 8 9 10 Very good I don’t know 0
Q8. Is the river threatened by human activities? O Yes O No O I don’t know
Q9. What do you think are the main human impacts on the river?
Q10. Which of the following human impacts are threatening the river? Not/Slightly 1 2 3 4 5 6 7 8 9 10 Very strong, I don’t know 0 • Agriculture 1 2 3 4 5 6 7 8 9 10, I don’t know 0 • Deforestation 1 2 3 4 5 6 7 8 9 10, I don’t know 0 • Coffee or other plantation 1 2 3 4 5 6 7 8 9 10, I don’t know 0 • Village settlements 1 2 3 4 5 6 7 8 9 10, I don’t know 0 • Roads and traffic 1 2 3 4 5 6 7 8 9 10, I don’t know 0 • Car / Clothes washing 1 2 3 4 5 6 7 8 9 10, I don’t know 0 • Waste water 1 2 3 4 5 6 7 8 9 10, I don’t know 0 • Fishing 1 2 3 4 5 6 7 8 9 10, I don’t know 0 • Waste disposal 1 2 3 4 5 6 7 8 9 10, I don’t know 0 • Water abstraction 1 2 3 4 5 6 7 8 9 10, I don’t know 0 • Sand/gravel mining 1 2 3 4 5 6 7 8 9 10, I don’t know 0 • Cattle breeding 1 2 3 4 5 6 7 8 9 10, I don’t know 0 • Climate change 1 2 3 4 5 6 7 8 9 10, I don’t know 0 • Tourism 1 2 3 4 5 6 7 8 9 10, I don’t know 0 • Others: …………… 1 2 3 4 5 6 7 8 9 10, I don’t know 0
Q11. Why do you think ……………….. has the greatest impact?
Q12. Why do you think ……………….. has the lowest impact?
Q13. Has the river been changing in the last ~15 years in the following points: - Waterquality Not/Slightly 1 2 3 4 5 6 7 8 9 10 Very strong, I don’t know 0 - Rivercourse Not/Slightly 1 2 3 4 5 6 7 8 9 10 Very strong, I don’t know 0 - Landuse Not/Slightly 1 2 3 4 5 6 7 8 9 10 Very strong, I don’t know 0
Q14. Do you think that human impacts mentioned above will affect your children and if yes, how strong will your children be affected? Not/Slightly 1 2 3 4 5 6 7 8 9 10 Very strong, I don’t know 0
Impact of climate change
Q15. In the future, do you think climate change will have an impact on the river? O Yes O No O I don’t know If yes: How will climate change influence the region of the river?
Q16. How important is the protection of Land and Forest area in this region? Not important 1 2 3 4 5 6 7 8 9 10 Very important, I don’t know 0

8.3. Data Summary of the Abiotic Data

Table 8.3: *Summary Statistics for abiotic parameters by River Reach and Human Impact Characteristics. Means, Number of Measurements (N), and Standard Deviation for essential abiotic parameters: Electrical Conductivity (EC) in µS/cm and MΩ cm, pH-value (pH) in mVpH and pH units, Temperature (T) in degrees Celsius, Oxygen Concentration (O2) in ORP, %DO, and ppmDO, and Total Dissolved Solids (TDS) in ppmTDS and PSU. River reaches are characterized by various human impact factors: Los_ Monos contains a small village and dense forests; Apacuar signifies no settlements and dense forests; Purnio Lower has small settlements and gold mining; Purnio Upper features fincas and low-density agriculture; Guali serves as a reference tributary; Magdalena includes higher discharge and urban areas; Quebrada Seca is contaminated; and both Magdalena and Gualí Sewage Runoffs indicate sewage inflow.*

Reach		Conductivity 1 (µS/cm)	Conductivity 2 (µS/cmA)	Conductivity 3 (MΩ cm)	pH 1 (mVpH)	pH 2 (pH)	Temp (°C)	O2 1 (ORP)	O2 2 (%DO)	O2 3 (ppmDO)	TDS 1 (ppm TDS)	TDS 2 (PSU)
Los_monos	Mean	66,00	67,43	,015	-40,44	7,69	24,89	176,20	86,79	6,56	33,43	,03
	N	7	7	7	7	7	7	7	7	7	7	7
	Std. Deviation	6,455	6,949	,001	8,21	,15	1,35	3,84	2,14	,22	2,57	,00
Apacuar	Mean	99,81	98,00	,011	-55,55	8,01	26,29	187,75	90,12	6,75	48,67	,05
	N	21	21	21	21	21	21	21	21	21	21	21
	Std. Deviation	27,136	27,072	,003	6,34	,23	,49	19,48	1,52	,15	13,53	,01
Purnio_Lower	Mean	77,38	80,50	,013	-28,61	7,47	29,80	182,72	84,02	6,04	37,44	,03
	N	16	16	16	16	16	16	16	16	16	16	16
	Std. Deviation	14,773	9,893	,003	11,05	,20	,73	16,79	3,40	,24	5,96	,01
Purnio_Upper	Mean	60,08	61,92	,017	-37,88	7,65	27,85	171,63	89,78	6,66	29,33	,03
	N	12	12	12	12	12	12	12	12	12	12	12
	Std. Deviation	2,503	4,981	,001	5,18	,11	1,48	28,77	1,28	,26	1,56	,00
Gualí	Mean	111,33	112,00	,009	-3,90	7,03	25,27	135,17	103,30	8,04	57,33	,05
	N	3	3	3	3	3	3	3	3	3	3	3
	Std. Deviation	5,508	5,196	,000	,95	,02	,02	5,06	,52	,04	,58	,00
Magdalena	Mean	162,19	168,24	,006	-24,89	7,38	26,76	122,10	56,15	4,42	81,43	,07
	N	21	21	21	21	21	21	21	21	21	21	21
	Std. Deviation	9,081	10,005	,000	8,09	,13	,13	34,33	4,59	,73	5,03	,01
Quebrada_Seca	Mean	238,67	267,67	,004	-53,47	7,91	31,55	136,90	78,60	5,47	119,33	,11
	N	3	3	3	3	3	3	3	3	3	3	3
	Std. Deviation	1,528	,577	,000	4,93	,09	,17	5,44	,40	,03	,58	,00
Gualí_Sewage_Runoff	Mean	552,00	580,00	,002	-48,70	7,83	27,58	8,70	25,70	2,20	282,00	,27
	N	3	3	3	3	3	3	3	3	3	3	3
	Std. Deviation	,000	,000	,000	,00	,00	,00	,00	,00	,00	,00	,00
Magdalena_Sewage_Runoff	Mean	1081,33	1170,67	,001	-2,73	7,00	29,39	-185,1	7,50	,53	538,67	,53
	N	3	3	3	3	3	3	3	3	3	3	3
	Std. Deviation	14,012	13,204	,000	2,11	,03	,02	40,63	,70	,06	8,08	,01
Total	Mean	155,88	162,75	,010	-36,08	7,61	27,42	146,19	75,80	5,68	77,63	,07
	N	89	89	89	89	89	89	89	89	89	89	89
	Std. Deviation	197,116	213,530	,005	16,58	,33	1,84	76,75	21,64	1,59	98,84	,10