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Analysis of Water Characteristics by the Hydropower Use (Up-Stream and Downstream): A Case of Study at Ecuador, Argentina, and Uruguay

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Abstract

This study aims to evaluate the water use characteristics of five hydropower stations in Ecuador, Uruguay, and Argentina to verify if the resource will change by their use on energy production, mainly to natural dam flow. The methodology is quantitative by taking water before inlet of the generation turbines (up-stream) and outlet of discharge after the process (downstream), there are ten samples to study for each one, at eleven physical-chemical parameters (three physical and eight chemical). This study found that hydropower projects analyzed present changes between inlet dammed water and outlet water from the turbine after generating electricity. The measured parameters are variables, some ranges demonstrate large deviations, for example, total dissolved solids with 100 mg/l, total solids 93 mg/l, and hardness 46 mg/l. There are differences between upstream and downstream water quality because the projects with dams stagnate the source of increasing development of the solids, verifying that the expansion of the extensive infrastructures, such as dams, generates the suspended matter presence, compared to outlet water at the discharge stage, these materials are clay, silt, organic material, vegetation decomposition, and living bodies such as algae, snails, and floating plants that produce opacity, which is the reason for the color difference in the samples. It recommends monthly sustainability plans for all hydropower projects to check the water conditions and ecosystems, monitoring climate behavior to issue improvements or fixes continuously.

Keywords: energy, hydropower, renewable, sustainable development, water characteristics

1. Introduction

Convention on Climate Change, known as the Paris Agreement, carried out at the end of 2015, pledged world leaders to make efforts to stabilize the climate by below 2° C and border worldwide temperature upsurge to 1.5° C, such as striving goal before the end of the century (Tobin et al., 2018; Villamar et al., 2019). To implement this long-term goal, countries worldwide presented before COP 21 their Nationally Determined Contributions with an emission reduction plan for 2025 or 2030 and will be updated every five years from 2020 (International Renewable Energy Agency, 2020). These plans are part of the emissions from hydropower development in rejoinder to the necessity to deploy an budget with low carbon emissions (Briones Hidrovo et al., 2017).

The International Renewable Energy Agency mentioned that the renewable share in capacity expansion increased from 33% in 2018 to 35% in 2019 (International Renewable Energy Agency, 2020). Nowadays, the International Hydropower Association (IHA) reported hydropower, the main renewable source with 62% of representation, more than others combined with 38%, such as Figure 1 (International Hydropower Association, 2020).

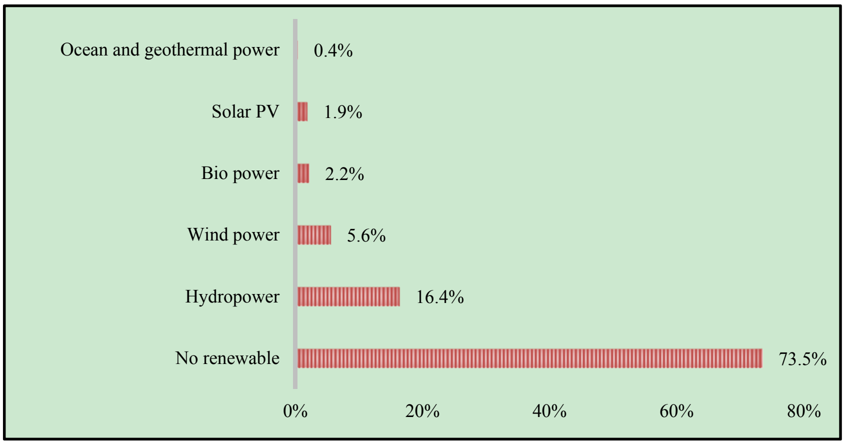

Figure 1. World energy sources in 2019

Source: (International Hydropower Association, 2020, 2021)

According to the IHA in 2020, approximately 180 countries used hydropower with an electricity production of 4370 TWh (International Hydropower Association, 2020, 2021). On the other hand, The International Commission on Large Dams remarks that by 2020, more than 14000 hydropower dams registered on every continent, which supplies almost 70% of all renewable energy worldwide (ICOLD, 2021; Llamosas & Sovacool, 2021). Even so, the technical potential for hydropower production can be increased substantially in a scenario may reach over 8000 TWh by 2050 (Killingtveit, 2018).

The International Energy Agency says that the global hydropower capacity is predicted to grow by 125 GW in 2023, although annual growth has slowed recently (International Energy Agency, 2018). Besides, an estimated 22 gigawatts of new hydropower capacity were put into operation in 2020, with global hydropower installed capacity of 1330 GW, including nearly 2 GW of pumped storage (International Energy Agency, 2020; International Renewable Energy Agency, 2021).

Also, the United Nations suggests that economic development based on guiding strategies as the 2030 Agenda, in the water case, it is established that the hydric heritage must generate conservation mechanisms to ensure the future, water in quantity and quality with responsible use in projects with existing or new hydropower projects (Ministry of Environment and Water of Ecuador, 2019; Ministry of the Environment and Water of Ecuador, 2017). Moreover, the water used for any activity as electricity generation establishes fragility to the surrounding ecosystems (Sovacool & Walter, 2019).

Furthermore, of a necessary hydropower construction, the current world situation presents several challenges to produce energy sustainably and, arises the questioning, what it costs to build and operate a hydropower project, a question that involves environmental effects, water characteristics changes, and social and cultural impacts related to the renewable's sources (Daniel & Gaviria, 2018; Naranjo-Silva et al., 2022; Van Der Zwaan et al., 2015).

On the other hand, hydropower deployment has variables such as the total cost of the investment, power, netload, and river flow, among other essential variables (Berga, 2016). Currently, developing countries such as Ecuador, Uruguay, and Argentina seeking to cover the electricity demand but the energy expansion plans are built in a disorganized way, that produce abrupt changes without relating effects as the social, environmental, or economic impacts; enough reasons to study the hydropower development and water characteristics (Briones Hidrovo et al., 2019; Mattmann et al., 2016; Voegeli et al., 2019).

As it shows, hydropower has come a long way since first emerging as a new power source and have significant effects on generation caused by variations in the meteorological magnitude, seasonality, river runoff, increased evaporation of effluents, and water use that affects its quality (Briones Hidrovo et al., 2020; Cavazzini et al., 2016; Teräväinen, 2019).

Hartmann mentions that very few studies have been conducted evaluating the possible changes in river water by hydropower projects developing, and those carried out suggest that the divergences in input volume will have a more significant influence on projects with dams (Carapellucci et al., 2015; Hamududu & Killingtveit, 2012; Hartmann, 2020). Furthermore, there is the wrong criterion for determining whether or not a hydropower project can be sustainable for a resource like water that is vulnerable. Moreover, it will be demonstrated by the water tests research that this is the wrong strategy (Li et al., 2015; Rosenberg et al., 1995).

Water is the essential resource for the proliferation of ecosystems, knowing and measuring its physical and chemical characteristics will allow controlling its free use in the various productions (Koch et al., 2016; X. Zhang et al., 2018).

Therefore, with the data search, it was verified that there is little specific information on how water varies due to the use in hydropower systems; in the problematic identification, it was confirmed that around the world, there are several studies of the hydropower projections due to climatic changes persistent, simulating temperature, precipitation, and evapotranspiration, but not a concrete analysis of the change in physical, chemical or biological parameters for water use (Mohor et al., 2015; P. Zhang et al., 2019). Thus, it was decided to take samples at the inlet and water outlet from five hydropower plants turbines, generating a knowledge gate as a novel research topic.

Accordingly, this research aims to evaluate the water use characteristics from five hydropower projects by determining a study case, analyzing physical and chemical parameters upstream and downstream, looking for occurrences, and specifying findings showing if there are impacts of hydropower.

2. Method

In this study is applied a quantitative analysis of three physical and eight chemical parameters, studying the water characteristics in hydropower production through data tabulation, and statistical tools to determine the most representative values.

The water samples were taken superficially; the collection was always at ten (10) am when there was an environmental balance in temperature (Cárdenas et al., 2021). The researchers handling the samples used gloves to avoid contaminants or bacteria migration. In addition, the samples are collected up to twenty (20) centimeters inside the rivers with pipettes to take two (2) liters of each one in a clean plastic container.

Then, the water samples were placed in a container at ambient conditions not to change temperatures until the next day to be delivered to the laboratory. Among the eleven (11) parameters measured are those in Table 1. with their respective units based on the international system.

Table 1. Parameters to measure on water samples

No.	Parameter	Unit	Type of item
1	pH	Standard units	Chemical
2	Total hardness	mg/l	Chemical
3	Calcium	mg/l	Chemical
4	Magnesium	mg/l	Chemical
5	Sodium	mg/l	Chemical
6	Bicarbonates	mg/l	Chemical
7	Chlorides	mg/l	Chemical
8	Sulfates	mg/l	Chemical
9	Total solids	mg/l	Physical
10	Total dissolved solids	mg/l	Physical
11	Suspended solids	mg/l	Physical

Source: (Ministry of the Environment and Water of Ecuador, 2017).

The collected samples period was from June to December 2021, and there are ten (10) samples from five (5) hydropower projects, one in the frontier of Argentina and Uruguay and the rest in Ecuador as show in Figure 2.

Figure 2. Hydropower projects at Ecuador, Uruguay, and Argentine on water analysis

Source: (Open Street Map, 2021).

A part of the methodology consisted of hydropower projects visits and the community's surroundings to verify the environment, infrastructure, equipment, water samples collection, and information gathering to facilitate investigative elements with the help of GPS facilities, due to the hydropower operation next the step to collect the samples.

a) A first sample is taken, located one (1) kilometer before entering the resource water to generation turbines in dams, reservoirs, or circulating water (upstream), and,

b) The second intake generated one (1) kilometer after the passage of the downstream hydropower plants, which means outlet water is collected (downstream). Next, a representative image in Figure 3 of the methodology used.

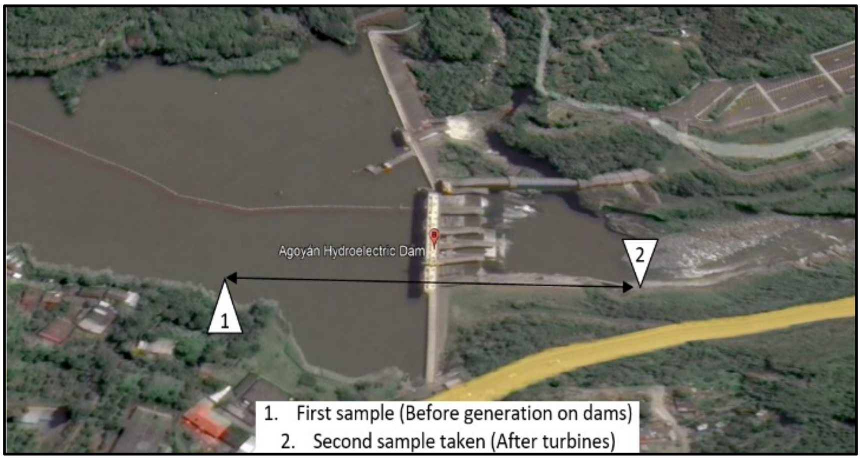

Figure 3. Sample methodology at Hidroagoyan hydropower plant – Ecuador

Source: (Merino, 2021; Open Street Map, 2021)

As mentioned, two (2) water samples were taken for each hydroelectric project superficially. With the samples, the eleven (11) parameters will analyze in the laboratory to do some tabulations. Then, statistical data was used to classify the information from highest to less important relevance and to recognize the most critical items or observations (Noblecilla-Alburque, 2020).

The five hydroelectric projects selected were for the ease of taking water samples. In addition, Salto Grande and Coca Codo Sinclair are representative plants in each one of the countries with more than 1000 MW of capacity production.

Moreover, the water tests were thinking about discovering the implications of developing hydropower infrastructures between natural ecosystems (Naranjo-Silva & Alvarez del Castillo, 2022). Besides, each hydropower project specification with data as a country, capacity, central type, inauguration year, and other data in Table 2.

Table 2. Characteristics of each hydropower project analyzed

Parameter	**Salto Grande**[a]	**Hidroagoyan**[b]	**Minas San Francisco**[b]	**Baba**[b]	**Coca Codo Sinclair**[b]
Country	Argentina & Uruguay	Ecuador	Ecuador	Ecuador	Ecuador
Power capacity [MW]	1900	156	270	42	1500
Energy average [GWh/year]	6700	1000	1003	161	8734
Volume reservoir capacity	5000 hm³	760 hm³	140 hm³	100 hm³	800 hm³
Turbines	14 Kaplan	2 Francis	3 Pelton	2 Kaplan	8 Pelton
Inauguration year	1979	1996	2019	2013	2016
Operation year [No./2021]	42	25	2	8	5
Meters above sea level	70	1651	1710	95	1240
Average temperature	18.5° C	19° C	17° C	27° C	21° C
Climate type	Subtropical transition	Rainy tropical climate	Subtropical transition	Tropical climate	Rainy tropical climate

Source: (a) (Salto Grande - Binational Corporation, 2014). (b). (MERNNR, 2018; Ministry of Electricity and Renewable Energy of Ecuador, 2013; Ministry of Energy and Non-Renewable Resources, 2019).

Salto Grande project is located on the Uruguay River, between Argentina and Uruguay, it provides an exciting study scenario because the project includes energy to both countries, affecting similar water characteristic changes (Gattás et al., 2018).

As Table 2 presents, the five hydropower projects are tropical areas with temperatures from 18 to 27° C. They are related to Amazonian regions where the water resources have significant flows to build hydropower plants (de Faria & Jaramillo, 2017; Tupiño Salinas et al., 2019).

They are relevant to the current literature because they can give a perception to the energy policymakers to improve the social, economic, and environmental conditions in future hydropower developments.

3. Results

As the first point of the results, besides the results of the test in Table 3 that exposed the coding, project characteristics, samples origin, location, and lab results:

Table 3. Aspect and negative findings observed by respondents

	Projects/ Samples Code		**Salto Grande**		**Hidroagoyan**		**Minas San Francisco**		**Baba**		**Coca Codo Sinclair**	
			A1	**A2**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**
No.	Parameter	Unit	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
1	pH	S.U.	7.0	6.3	6.8	6.5	7.3	6.8	7.1	7.0	8.0	6.3
2	Bicarbonates	mg/l	29.1	49.9	169.8	33.2	59.5	138.5	47.7	47.9	61.9	151.7
3	Calcium	mg/l	5.1	11.8	32.1	4.0	7.2	22.8	8.3	8.0	18.2	26.3
4	Chlorides	mg/l	5.8	9.6	17.8	4.2	6.9	15.5	6.9	6.1	7.7	23.3
5	Magnesium	mg/l	4.7	5.3	16.8	0.7	8.7	13.9	0.5	0.3	2.1	14.7
6	Sodium	mg/l	3.0	5.0	37.0	2.0	8.0	25.0	3.0	5.0	4.0	19.0
7	Sulfates	mg/l	15.2	14.5	44.2	14.2	19.6	46.4	5.6	4.2	15.3	37.6
8	Suspended solids	mg/l	132.0	120.0	64.0	32.0	114.0	43.0	29.0	20.0	44.0	31.0
9	Total dissolved solids	mg/l	69.0	40.0	206.0	84.0	245.0	19.0	59.0	38.0	176.0	72.0
10	Total hardness	mg/l	31.8	51.0	149.6	12.8	189.0	114.3	26.7	21.4	54.2	26.1
11	Total solids	mg/l	182.0	156.0	290.0	56.0	120.0	50.0	68.0	60.0	248.0	120.0

Source: (LABOLAB, 2020).

Note: Before pass water = inlet the turbines = upstream to the hydropower (dam)/ After = outlet = downstream

In addition, with the results presented in Table 3, the analysis was carried out in the Ecuadorian certified laboratory called Labolab based on categorized standards of the Ecuadorian Accreditation System under ISO 17025 guidelines to comply with test requirements at constant ambient conditions temperatures at 24^{O} C and 37% relative humidity. The comparison took the ten parameters in the same units (milligrams per liter), excluding the ph.

As mentioned, we will tabulate to find the critical parameters and changes in the water samples, then the average and percentual change per item in Table 4 since the outlet and inlet calculation data. Moreover, we add the permissible data limit to river water on natural conditions, according of the Secondary Legislation of the Ministry of the Environment of Ecuador took this normative because Ecuador had the most samples in the study.

Table 4. The difference in data tabulation

Parameter	**Unit**	**Inlet Average**	**Outlet Average**	**Percentual change (Outlet vs. Inlet)**	**Maximum permissible**
Chlorides	mg/l	9.0	11.7	30.4%	250
Sulfates	mg/l	20.0	23.4	17.0%	200
Bicarbonates	mg/l	73.6	84.2	14.4%	**18**
Magnesium	mg/l	6.6	7.0	6.4%	30
Calcium	mg/l	14.2	14.6	2.7%	100
Sodium	mg/l	11.0	11.2	1.8%	50
Suspended solids	mg/l	76.6	49.2	-35.8%	220
Total hardness	mg/l	90.3	45.1	-50.0%	400
Total solids	mg/l	181.6	88.4	-51.3%	1600
Total dissolved solids	mg/l	151.0	50.6	-66.5%	450

As the results show, some parameters show a positive difference that means the average of each specific structure reduces upstream (outlet of turbines); furthermore, some values are negative means on upstream or dammed water, the parameters were high, and after producing energy, the data reduces.

Moreover, doing an absolute value change on water characteristics, the highlights are that the total dissolved solids (67%), total solids (51%), and hardness (50%) are the principal three top results with the most significant change. In addition, the bicarbonates are the unique parameter that exceeded the maximum permissible limit.

Additionally, following data grouped by percentages from highest to lowest average of the difference between outlet and inlet parameters, we took the details in absolute value to find the incidences to verify that stand out the most in Table 5.

Table 5. Difference by outlet and inlet parameter in descending order

No.	**Parameter**	**Difference [mg/l]**	**Percentual difference [%]**	**The accumulated difference [%]**
1	Total dissolved solids	100.40	35.37%	-
2	Total solids	93.20	32.83%	68%
3	Total hardness	45.15	15.90%	84%
4	Suspended solids	27.40	9.65%	94%
5	Bicarbonates	10.61	3.74%	97%
6	Sulfates	3.39	1.19%	99%
7	Chlorides	2.73	0.96%	100%
8	Magnesium	0.42	0.15%	100%
9	Calcium	0.38	0.13%	100%
10	Sodium	0.20	0.07%	100%
Summatory		283.88	100%	-

4. Discussion

According to the analyzes carried out of the hydro source of Argentina, Uruguay, and Ecuador, before and after the hydropower generation equipment, the water inlet has a pH neutral and shows differences in the water characteristics. However, it could be said that the water quality is good because it does not exceed the permissible limits of natural waters, the water is used to generate energy, and it stagnates in dams but is not polluted.

The principal discrepancies in the final average, according to Figure 4, are the Total dissolved solids with 35.4%, Total solids with 32.8%, and Total hardness with 15.9% of the global average by the water used in hydropower generation.

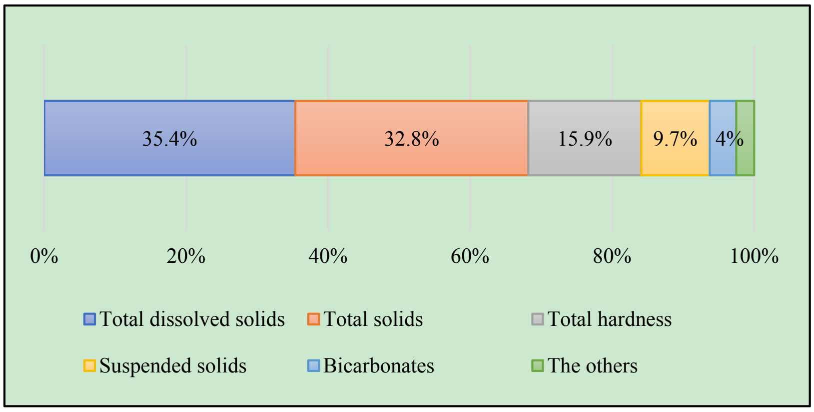

Figure 4. Principal parameters with deviations

The top results show that, the types of solids are more upstream than downstream because the water stagnation generates suspension material. Moreover, the presence of suspension material developed in dams prevents the light passage as a negative indicator of water characteristics; it evidences oxygen lack (Reisancho & Rivera, 2018; X.

Zhang et al., 2018). On the other hand, the magnesium and chlorides show that the water can be rigid in total hardness parameter by the time of damming the natural resource.

Hartmann mentions that very few studies have been conducted evaluating the possible changes in river water by developing hydropower projects, and those carried out suggest that the divergences in input volume will significantly influence projects with dams because the species dead and organic material is prolife (Hartmann, 2020; Holzmann et al., 2010; X. Zhang et al., 2018).

Furthermore, Winemiller finds that the length of time a resource is dammed changes the water quality in a study to balance hydropower and biodiversity in the Amazon, Congo, and Mekong rivers. Many projects will be built by 2030, around 324 in the Amazon region, 13 in Congo, and 98 in the Mekong (Winemiller et al., 2016). The study recommends that the benefits of increased energy supply based on hydropower and job development will outweigh the costs of lost fisheries, agriculture, and property in rural populations in the Amazon, Congo, and Mekong basins. It is critical to improve the way dams are evaluated and sited (Winemiller et al., 2016; Zhong et al., 2019).

Another comparison arises from Lesya Gnatyshyna; She investigates the hydropower project’s impacts on aquatic life, specifically of unio tumidus mollusc in Ukraine Rivers using biochemical markers tests of eco-toxicity. The samples analyzed 11 indicators, and, as a result of the research lack, the tests done detected that there are insufficient protein levels, generally occurring at waters in natural conditions for the use of the resource in hydropower generation (Gnatyshyna et al., 2020). The evaluation on Ukraine, such as Ecuador, Argentina, and Uruguay, shows an environmental impact on the water used for energy production and a need to promote hydrodynamic policy to avoid ecosystem damage.

Antti Eloranta studied the environmental variation in Norway by the hydropower development; the analysis details the impacts on reservoir fish populations, especially in brown trout present in 69 of the study reservoirs. The results showed the necessity to understand how hydropower modifies the ecosystems and the reservoirs' abiotic and biotic characteristics using the trout's density size and condition, which nowadays is reduced around 5% of population density. The results demonstrate that hydropower development strongly modifies local environmental systems, the biotic community changes the ecosystems and alters the water resource characteristics, similar to the present study's findings (Eloranta et al., 2018; Sivongxay et al., 2017).

Cabrera investigated the composition and distribution of the macroinvertebrate community along two rivers (Coca and Aguarico) in the Ecuadorian Amazon. The test was done in 15 locations, and the macroinvertebrates were used to indicate water quality (WQ). The results suggest that the diversity of macroinvertebrates is generally scarce. However, it was abundant in good quality sites with no dams, showing that hydropower projects changed natural ecosystems. Finally, the authors suggest findings can be used to fill knowledge gaps related to bioassessments, especially for tropical rainforests (Cabrera et al., 2021; Dorber et al., 2019). As we found, the samples show changes in some chemical and physical parameters; thus, proper environmental management is imperative in tropical aquatic ecosystems to reduce impacts since hydropower dams alter the nature of water (Bondarenko et al., 2019; Johnson et al., 2019).

According to Oviedo in a study of hydropower impacts on ecosystems, concludes that projects with reservoirs, several negative effects are generated, as the decomposition of organic matter that promotes the generation of greenhouse gases such as methane also develops the concentration of macronutrients in standing water, increasing the production of phytoplankton, reducing dissolved oxygen concentration and water quality (Oviedo-Ocaña, 2018; Qin et al., 2020).

Overall, the transfer of hydropower technology is a technical process and implies a political practice that is sometimes not sustainable by the environment (Guerra et al., 2019; Hensengerth, 2018).

With the studies data, the discussion is opened to speak about the hydropower development that brings benefits but entails unavoidable impacts (Naranjo-Silva & Álvarez del Castillo, 2021); therefore, around the different studies cited, the discussions need to be opened, if relatively necessary, to build hydropower with dams because it demonstrated that change the natural conditions of the water.

Future lines could analyze the biological characteristics of water quality in hydropower projects, as the increase of algae and cyanobacteria as an observed result of climate change, higher temperatures, increased nutrient loading, and extreme runoff events (Lu et al., 2020; van Vliet et al., 2016).

Moreover, the shortcoming of this comparative approach is that it takes a few water samples as a small study comparison with ten samples in five hydropower projects, giving a big opportunity to develop more comparations. For example, nowadays, in Ecuador there are 71 hydropower plants around the country (CELEC, 2021). The novelty of the present work is the analysis of the water characteristics by the damming water, the highlight is the presence of solids at the inlet of turbines as new knowledge gained from this study.

5. Conclusions

This study concluded since the ten samples that the divergences of the measured parameters are variable, and some ranges show profound deviations, for example, total dissolved solids (35%), total solids (33%), and hardness (16%) as indicated the Figure 4.

There are differences between upstream and downstream waters test in the five hydropower's (Salto Grande, Hidroagoyan, Baba, Minas San Francisco, and Coca Codo Sinclair dams) because the projects with dams stagnant the water increasing the development of the solids, verifying that the expansion of the extensive infrastructures, such as dams, generates the suspended matter presence, compared to outlet water at the discharge, these materials are clay, silt, organic material, vegetation decomposition and living bodies such as algae, snails and floating plants that produce opacity, which are the reason for the color difference in the samples.

From the collected samples, it is interpreted that the hydropower projects with water accumulation (dams) change the environmental conditions use, relating impacts to the water accumulation in reservoirs and hydrological variations and lands flooding upstream of the power plants that modification the natural characteristic.

It recommends monthly sustainability plans for all hydropower projects to check the water conditions and ecosystems, monitoring climate behavior to issue improvements or fixes continuously. Future study lines can compare and analyze improvements in their efficient use of water that requires the generation and thus mitigate intangible overlooked impacts, such as environmental changes and water modification.

6. Patents

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