A physical-chemical study of water resources in 5 hydropower projects

Estudo físico-químico de recursos hídricos em 5 projetos hidrelétricos

DOI:10.34117/bjdv8n11-158

Recebimento dos originais:11/10/2022
Aceitação para publicação: 14/11/2022

Sebastian Naranjo-Silva
PhD Candidate, Master in Renewable Energies
Institution: Polytechnic University of Catalonia, Department of Sustainability
Address: Carrer de Jordi Girona, 31, 08034 Barcelona, Spain
E-mail: hector.sebastian.naranjo@upc.edu

Diego Punina-Guerrero
Master in Mechanical Design
Institution: Quevedo Technical University, Faculty of Mechanical Engineering
Address: Av. Carlos J. Arosemena 38, Quevedo, Ecuador
E-mail: dpuninag2@uteq.edu.ec

Jose David Barros-Enriquez
Master in Facilities and Product Design
Institution: Quevedo Technical University, Faculty of Mechanical Engineering
Address: Av. Carlos J. Arosemena 38, Quevedo, Ecuador
E-mail: jbarros@uteq.edu.ec

Jorge Armando Almeida-Dominguez
Magister in Design and Simulation
Institution: Technical University of Ambato, Faculty of Mechanical Engineering
Address: Av. los chásquis, 180207 Ambato, Ecuador
E-mail: ja.almeida@uta.edu.ec

Javier Alvarez del Castillo
PhD in Sustainability
Institution: Polytechnic University of Catalonia, Department of Sustainability
Address: Carrer de Jordi Girona, 31, 08034, Barcelona, Spain
E-mail: javier.alvarez@upc.edu

ABSTRACT
Over the last 60 years, renewable energies have substantially developed; in 2021, around 12.8% of global primary energy came from these technologies. Thus, even though renewable energies have good global acceptance present challenges in quantifying the environmental, social, and cultural effects, generating a lack of knowledge of the impact caused. Nowadays, hydropower is the renewable source with the most significant participation; at the end of 2020, the hydropower installed capacity worldwide was 1,330 GW, and 4,370 TWh were generated in that year. Therefore, the manuscript aims to determine if there are changes in water quality due to the use of hydropower generation in five projects distributed in Ecuador, Argentina, and Uruguay. The methodology is quantitative experimental; experimental because it takes water samples to measure

parameters and qualitatively compares the lab results to do statistical analyses. Based on the ten samples gathered, it concluded that from 14 physical and chemical parameters, the principal divergences fluctuated in the presence of dissolved solids (26%), total solids (21%), bicarbonates (15%), total hardness (14%), suspended solids (6%), and sodium (4%). Additionally, values show organic matter existence due to vegetation decomposition, and metabolites formed in dams such as Salto Grande, Hidroagoyan, Minas San Francisco, Baba, and Coca Codo Sinclair.

Keywords: energy, hydropower, impacts, samples, water.

RESUMO
Ao longo dos últimos 60 anos, as energias renováveis desenvolveram-se substancialmente; em 2021, cerca de 12,8% da energia primária global veio dessas tecnologias. Assim, embora as energias renováveis tenham boa aceitação global apresentam desafios na quantificação dos efeitos ambientais, sociais e culturais, gerando um desconhecimento do impacto causado. Atualmente, a energia hidrelétrica é a fonte renovável com maior participação; no final de 2020, a capacidade instalada de hidrelétricas no mundo era de 1.330 GW, e naquele ano foram gerados 4.370 TWh. Portanto, o manuscrito visa determinar se há mudanças na qualidade da água devido ao uso de geração hidrelétrica em cinco projetos distribuídos no Equador, Argentina e Uruguai. A metodologia é experimental quantitativa; experimental porque leva amostras de água para medir parâmetros e compara qualitativamente os resultados de laboratório para fazer análises estatísticas. Com base nas dez amostras coletadas, concluiu-se que de 14 parâmetros físicos e químicos, as principais divergências flutuaram na presença de sólidos dissolvidos (26%), sólidos totais (21%), bicarbonatos (15%), dureza total (14%), sólidos em suspensão (6%) e sódio (4%). Além disso, os valores mostram a existência de matéria orgânica devido à decomposição da vegetação e metabólitos formados em barragens como Salto Grande, Hidroagoyan, Minas San Francisco, Baba e Coca Codo Sinclair.

Palavras-chave: água, amostras, energia, hidrelétrica, impactos.

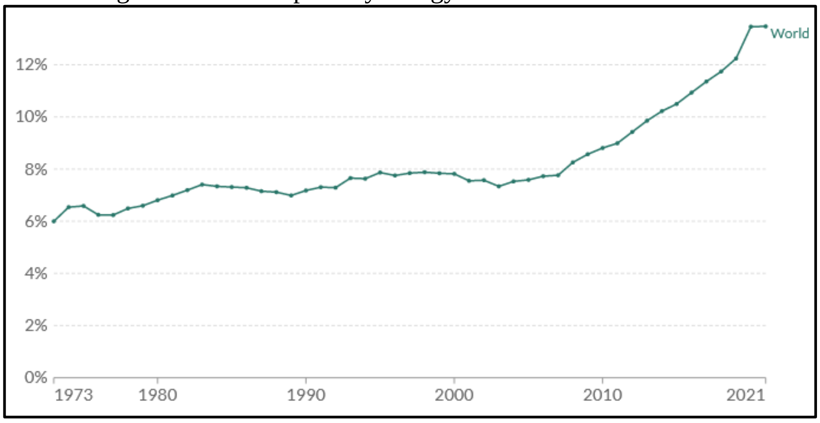
1 INTRODUCTION

As a result of the Industrial Revolution, fossil fuels have become a dominant component of the energy grid of most nations around the world. Consequently, the effects of global warming on the climate will significantly impact human health and the environment. There is no doubt that fossil fuel burning is responsible for three-quarters of all global greenhouse gas emissions. Furthermore, fossil fuels contribute to a large amount of local air pollution, leading to at least five million premature deaths annually (Giannakidis et al., 2018; Kapitonov et al., 2021).

But, in addition to environmental changes, energy, and economic development that depends on fossil sources, climate change is accelerated, triggered by uncontrolled carbon dioxide emissions, causing incessant heat waves, droughts, and floods to a population that does not stop increasing and generating new energy demands.

Supplying the world's population requires energy expenditure with the decided increase in renewable and clean energies due to its ability to reduce the burning of fossil fuels. Over the last 60 years, renewables have been important development; as indicated in Figure 1, in 2021, around 12.8% of global primary energy came from renewable technologies (Naranjo-Silva, Punina, et al., 2022; Ritchie & Roser, 2022).

Figure 1. Share of primary energy from renewable sources.



Source: (Ritchie & Roser, 2022).

As Figure 1, renewable energy growth from 1973 to 2021 has doubled from 6% to 12.8% of primary energies. Still, although renewable energies have good global acceptance that is growing, the current world situation of energy production presents several challenges in quantifying the effects that are often intangible environmental, social and cultural, generating a lack of knowledge of the impact caused by renewable energies, and among them hydropower as the largest renewable source globally (Llamosas & Sovacool, 2021; Uamusse et al., 2020).

Although hydropower is the renewable energy source with the most significant participation, ensuring it is sustainable requires a broad discussion. In general, in recent years, this source has had considerable development. At the end of 2020, the hydropower installed capacity worldwide reached 1,330 GW, and in that year, 4,370 TWh were generated, enough electricity to supply world demand for more than two months (International Energy Agency, 2020; Kelly-Richards et al., 2017; Vaca-Jiménez et al., 2019).

A development example of this renewable source is Latin America as the second region with the most deployment; in Ecuador, over the last 15 years, large hydropower constructions began, this deployment started operations in 2016 and opened many opportunities for economic and industrial development, due to a large amount of energy, investing approximately USD 4.9 billion in eight plants to add 2,832 MW to the country's total energy. However, at the same time, since the start-up of the new hydropower plants, challenges have been observed due to social changes and executed environmental regulations. Therefore, there is a need to establish state policies for energy efficiency and the development of sustainable energies, both in the medium and long term (Llerena-Montoya et al., 2021; Ponce-Jara et al., 2018; Rivera-González et al., 2020). Currently, in Ecuador, in 2021, there is an installed capacity of 5,071 MW of hydropower, representing 77% of its entire energy grid (International Energy Agency, 2022).

On the other hand, according to data from the International Hydropower Association, other Latin American countries such as Argentina and Uruguay manage various energy sources. Still, there is significant hydroelectric development, with 11,340 MW and 1,538 MW installed respectively in each country by 2020 (International Hydropower Association, 2021). An important plant is the Salto Grande hydropower project which contains a shared channel in a humid tropical border region that delivers energy to the two countries; this binational work formed an artificial lake with one of the largest dams in Latin America with 80,000 hectares of water surrounded by forests. It was also built in an area of rapids and rocky hills in the middle course of the Uruguay River, taking advantage of a natural slope called Salto, upstream from the cities of Concordia (Argentina), and Salto (Uruguay) for hydropower generation (International Renewable Energy Agency, 2020; Regional Energy Integration Commission of South America, 2021).

Based on these data of the hydropower deployment of the three countries, it was projected to know what the water resource characteristics are in two conditions, before generating hydroelectricity and after generating energy, to verify if the conditions change (Naranjo Silva & Álvarez del Castillo, 2020). In addition, the loss of water quality in hydropower production due to physical, chemical, and biological changes must be analyzed to manage water sustainability. Thus, to verify said quality, this study presents the results of tests carried out through ten samples in five projects in Argentina, Uruguay, and Ecuador (Jimenez-Mendoza & Terneus-Paez, 2019; Naranjo-Silva, Rivera-Gonzalez, et al., 2022).

It is essential to mention that the novelty of this manuscript is to analyze changes in the leading natural resource due to hydropower dams: Fresh water is a finite resource, each year, it becomes more polluted, its properties change, and if it is not managed sustainably in the future, the effects will be on all natural ecosystems and human life (Bondarenko et al., 2019; Bongio et al., 2016).

Hydroelectricity in Ecuador, Argentina, and Uruguay is representative and is the leading renewable source in the world; therefore, the manuscript aims to determine if there are changes in water quality due to the use in hydropower generation.

2 METHODOLOGY

The methodology of the manuscript is quantitative experimental; experimental because it takes water samples to measure parameters; therefore, a protocol was defined empirically as follows.

a) To begin with, first 1 kilometer before the water resource enters the turbines in dams, and,

b) The second sample was taken 1 kilometer downstream of the hydropower plants, as shown in Figure 2.

Figure 2. Sampling example in Hidroagoyan hydropower central

Source: (Open Street Map, 2021).
Note: Upstream= Before passing the water = Entrance to the turbines = Dam
Downstream= After passing the water through the systems = Exit the water through the turbines

In order to collect data, the sampling period lasted between June and December 2021 (7 months), with pipettes used to fill two liters of water for each of the rivers superficially up to 25 cm inside in clean containers and then maintaining the water characteristics. These samples are tabulated into physical and chemical items, so Figure

2 lists the parameters measured in the study.

Table 1. Measurable physical and chemical criteria of water resources

Item	Parameter	Characteristic
1	Physical	Turbidity, presence of solids (dissolved, total, and suspended).
2	Chemical	Minerals and inorganic indicators such as pH, hardness, iron, and calcium, as well as organic materials such as sulfates, alkalinity, magnesium, sodium, bicarbonate, chlorine, and phosphates.

Source:(Kibaroglu & Gürsoy, 2015; van der Zwaan et al., 2018).

With the measurable physical and chemical parameters to be determined, the quantitative part of the methodology is based on analyzing each sample in the laboratory with 14 different items of interest. The statistical concepts below support the characterization of the quantified items, and the features of each hydropower project studied are listed in Table 2. All the plants are reservoir types, and the 10 samples were taken from the dams or turbines outlet with a code.

Table 2. Samples collected from water in hydroelectric plants

Country	River	Project	Sample denomination	Place	Observation	Weather type
Argentina & Uruguay[a]	Uruguay	Salto Grande 1900MW	A1	Before the hydroelectric	Dam	Subtropical zone without dry season, characteristic of the northeast region of Argentina with an average temperature of 18.7° C.
			A2	After the generation of the reservoir	Salto Grande	
Ecuador	Pastaza	Hydroagoyan 156 MW	E1	Before the hydroelectric	Dam	The Interandean region of Ecuador, near the geometric center, has an average rainy tropical climate of 19 ° C.
			E2	After the generation of the reservoir	Hydroagoyan	
	Jubones	Minas San Francisco 270MW	E3	Before the hydroelectric	Dam	In the subtropical region close to rainy climate forests, the average temperature is 19.5 ° C.
			E4	After the generation of the reservoir	Minas San Francisco	
	Baba	Baba 42MW	E5	Before the hydroelectric	Dam	Center-north of the coastal region of Ecuador, with a rainy tropical climate of 27 ° C on average.
			E6	After the generation of the reservoir	Baba	
	Quijos – Coca	Coca Codo Sinclair 1500MW	E7	Before the hydroelectric	Dam	It is located north of the Amazon Region of Ecuador, with an average rainy tropical climate of 18 ° C.
			E8	After the generation of the reservoir	Coca Codo Sinclair	

Source: a. (Salto Grande - Binational Corporation, 2014); b.(International Hydropower Association, 2020; Ministry of Energy and Non-Renewable Resources, 2018)

Finally, with the laboratory values, two tabulations types are generated to define differences in the physical and chemical data of the samples, and then each Calculation determined at the researchers' discretion is specified.

$$\text{Differential Calculation} = |\text{Entrance water} - \text{Turbinated water}| \qquad \textbf{Equation 1}$$

$$\text{Proportional Calculation} = \left|\frac{\text{Entrance water} - \text{Turbinated water}}{\text{Turbinated water}}\right| \qquad \textbf{Equation 2}$$

Laboratory Labolab was used for the analysis of the samples, which used standards of the Ecuadorian Organizations, and according to ISO 17025 procedures, which are based on common methods (Standard Methods) that are conducted at a constant temperature of 24 degrees Celsius with a relative humidity of 37% (LABOLAB, 2021).

3 RESULTS

For the results, the analysis begins with the support of the laboratory verifying the 10 samples determining the 14 parameters of Table 3; there are 12 parameters of similar units that are grouped in alphabetical order from the third item, and the pH and turbidity are shown first because they manage different international units.

Table 3. Physical-chemical contrast results of water resources

Projects			**Salto Grande**		**Hydroagoyan**		**Minas San Francisco**		**Baba**		**Coca Codo Sinclair**	
Samples Code			**A1**	**A2**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**
No.	Parameters	Unit	Before	After	Before	After	Before	After	Before	After	Before	After
1	pH	Standard	7.0	6.3	6.8	6.3	7.3	6.8	7.1	7.0	8.0	6.3
2	Turbidity	NTU	3.0	2.0	2.0	1.0	3.0	1.0	3.0	1.0	3.0	0.1
3	Bicarbonates	mg/l	29.1	49.9	169.8	33.2	59.5	138.5	47.7	47.9	61.9	151.7
4	Calcium	mg/l	5.1	11.8	32.1	4.0	7.2	22.8	8.3	8.0	18.2	26.3
5	Chlorides	mg/l	5.8	9.6	17.8	4.2	6.9	15.5	6.9	6.1	7.7	23.3
6	magnesium	mg/l	4.7	5.3	16.8	0.7	8.7	13.9	0.5	0.3	2.1	14.7
7	Phosphates	mg/l	5.1	7.4	9.1	1.8	6.2	3.8	0.1	0.1	0.1	0.4
8	Sodium	mg/l	3.0	5.0	37.0	2.0	8.0	25.0	4.0	6.0	4.0	19.0
9	Sulfates	mg/l	15.2	14.5	44.2	14.2	19.6	46.4	5.6	4.2	15.3	37.6
10	Suspended solids	mg/l	121.0	132.0	64.0	32.0	114.0	43.0	29.0	22.0	44.0	41.0
11	Total dissolved solids	mg/l	32.0	50.0	226.0	24.0	245.0	19.0	39.0	38.0	76.0	207.0
12	Total hardness	mg/l	31.8	51.0	149.6	12.8	189.0	114.3	26.7	21.4	54.2	126.1
13	Totally iron	mg/l	0.2	2.5	2.7	1.0	3.6	2.4	0.1	0.1	0.3	0.1
14	Total solids	mg/l	156.0	182.0	290.0	56.0	120.0	50.0	68.0	60.0	120.0	248.0

Source: (LABOLAB, 2021).

As established in the methodology, there are two calculation conditions to search for the critical and recurring parameters of change in the water samples, then the first differential calculation, with the average and total frequency per parameter defined in Equation 1.

Table 1. Differential tabulation

No.	Item	ǀA1-A2ǀ	ǀE1-E2ǀ	ǀE3-E4ǀ	ǀE5-E6ǀ	ǀE7-E8ǀ	Average	Frequency
1	pH	0.6	0.5	0.5	0.0	1.7	0.7	0.2%
2	Turbidity	1.0	1.0	2.0	2.0	2.9	1.8	0.4%
3	Bicarbonates	20.8	136.7	79.0	0.1	89.8	65.3	15.4%
4	Calcium	6.7	28.2	15.6	0.3	8.1	11.8	2.8%
5	Chlorides	3.8	13.6	8.6	0.8	15.7	8.5	2.0%
6	magnesium	0.6	16.1	5.2	0.1	12.5	6.9	1.6%
7	Phosphates	23	7.3	2.5	0.0	0.3	2.5	0.6%
8	Sodium	2.0	35.0	17.0	2.0	15.0	14.2	3.3%
9	Sulfates	0.7	30.1	26.8	1.4	22.3	16.3	3.8%
10	Suspended solids	11.0	32.0	71.0	7.0	3.0	24.8	5.8%
11	Total dissolved solids	18.0	202.0	226.0	1.0	131.0	115.6	27.3%
12	Total hardness	19.1	136.8	74.7	5.3	71.9	61.6	14.5%
13	Totally iron	23	1.7	1.2	0.0	0.2	1.1	0.3%
14	Total solids	26.0	234.0	70.0	8.0	128.0	93.2	22.0%
						Total	424.1	100%

As the second tabulation in Table 5, the proportional processing is presented defined in Equation 2; this Calculation serves as an additional study below the values in absolute difference, average, and incidence in frequency.

Table 5. Proportional tabulation

No.	Item	ǀ(A1-A2)/A2ǀ	ǀ(E1-E2)/E2ǀ	ǀ(E2-E3)/E3ǀ	ǀ(E4-E5)/E5ǀ	ǀ(E6-E7)/E7ǀ	Average	Frequency
1	pH	0.10	0.08	0.08	0.01	0.26	0.11	0.3%
2	Turbidity	0.50	1.00	2.00	2.00	29.00	6.90	22.0%
3	Bicarbonates	0.42	4.12	0.57	0.00	0.59	1.14	3.6%
4	Calcium	0.57	7.12	0.68	0.04	0.31	1.74	5.5%
5	Chlorides	0.40	3.28	0.55	0.13	0.67	1.01	3.2%
6	Magnesium	0.11	23.06	0.38	0.42	0.85	4.97	15.8%
7	Phosphates	0.31	4.04	0.66	0.11	0.71	1.17	3.7%
8	Sodium	0.40	17.50	0.68	0.33	0.79	3.94	12.5%
9	Sulfates	0.05	2.13	0.58	0.33	0.59	0.73	23%
10	Suspended solids	0.08	1.00	1.65	0.32	0.07	0.63	2.0%
11	Total dissolved solids	0.36	8.42	11.89	0.03	0.63	4.27	13.6%
12	Total hardness	0.38	10.69	0.65	0.25	0.57	2.51	8.0%
13	Totally iron	0.92	1.70	0.48	0.44	1.70	1.05	3.3%
14	Total solids	0.14	4.18	1.40	0.13	0.52	1.27	4.1%
						Total	31.42	100.0%

With both differential and proportional tabulations, then in Table 5 a third average based on the data called weighted Calculation, the incidences of this control will verify the parameters that stand out the most in the end among the criteria of Equation 1, and Equation 2.

Further, based on the Pareto theory (80-20), the data is grouped by greater to lesser relevance. This can be achieved by applying statistical techniques to classify the information and identify the essential items, thus, proposing changes for them to be implemented Table 6 shows Pareto's values to understand that 20% of the causes originate 80% of the consequences, grouping the data in accumulated frequency (Cárdenas et al., 2021; Noblecilla-Alburque, 2020).

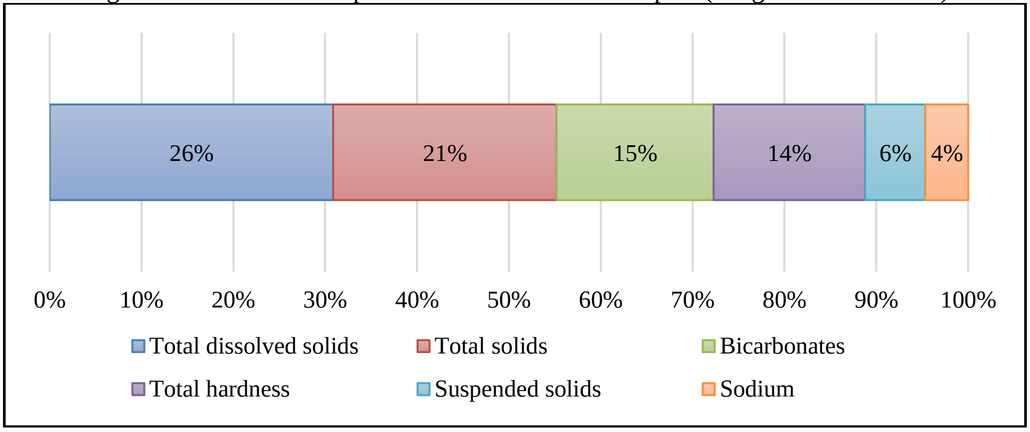
Table 6. Coincident and representative weighted values

No.	Item	Differential	Proportional	Weighted	Average frequency	Accumulated frequency	Pareto
1	Total dissolved solids	115.6	4.3	59.9	26.3%	26%	80%
2	Total solids	93.2	1.3	47.2	20.7%	47%	
3	Bicarbonates	65.3	1.1	33.2	14.6%	62%	
4	Total hardness	61.6	2.5	32.0	14.1%	76%	
5	Suspended solids	24.8	0.6	12.7	5.6%	**81%**	
6	Sodium	14.2	3.9	9.1	4.0%	85%	20%
7	Sulfates	16.3	0.7	8.5	3.7%	89%	
8	Calcium	11.8	1.7	6.8	3.0%	92%	
9	Magnesium	6.9	5.0	5.9	2.6%	95%	
10	Chlorides	8.5	1.0	4.8	2.1%	97%	
11	Turbidity	1.8	6.9	4.3	1.9%	98%	
12	Phosphates	2.5	1.2	1.8	0.8%	99%	
13	Totally iron	1.1	1.0	1.1	0.5%	99%	
14	pH	0.7	0.1	0.4	0.2%	100%	
Total		424.1	31.4	227.8	**100.0%**	**-**	-

4 DISCUSSION

With the Pareto Calculation in Table 6 the critical results of all the samples were verified, and then the six parameters with the highest average distortion of the weighted tabulation are illustrated in Figure 3 to start the discussion and analysis.

Figure 3. Main modified parameters of the water samples (weighted Calculation)



In the weighted Calculation, the main discrepancies obtained affording to Figure 3 are the Total dissolved solids with 26%, Total solids with 21%, Bicarbonates with 15%, Hardness 14%, Suspended solids 6%, Sodium 4%, and the other parameters, showing that these items are the ones that change the most due to the water use in hydropower generation.

From the results when comparing the water samples, it is differentiated that there is a higher concentration of total dissolved solids in the plants concerning suspended solids motive for the variance in color between the samples and the turbidity presence (Walsh et al., 2015). In addition, three of the six parameters that vary the most correspond to some solid (suspended, dissolved, or total). As a result of solids developing in the areas of the dams, light cannot pass through them, which indicates a lack of oxygen, as evidenced in the present study on five Latin American plants (Rasul et al., 2019; Reisancho & Rivera, 2018). Finally, the total solids represent that with water retention in the reservoirs, the hydrological regime of the resource currents is modified first, affecting the runoff processes, increasing the sediments, and changing the geomorphology of the rivers before and after the structures (Cabrera et al., 2021; Zhuo et al., 2020).

On the other hand, bicarbonate, hardness, and sodium represent those different characteristics formed in the dam by stagnating the water, generating micro porosities by calculating the samples, which causes more significant wear when entering the turbines. (Winemiller et al., 2016). Likewise, the concentration of nutrients related to bicarbonates, and sodium increases the production of phytoplankton which reduces the concentration of dissolved oxygen, and the water quality is diminished increasing biomass (Gaudard et al., 2016; Oviedo-Ocaña, 2018). From the organic material found, decomposition processes begin in the reservoirs over time and heat, promoting the production of greenhouse gases such as methane. The International Panel on Climate Change has estimated that dams contribute about 1.3% of greenhouse gas emissions to the global atmosphere, based on their data (Intergovernmental Panel on Climate Change, 2021; Reyes et al., 2021; Schaefli, 2015).

Another issue to discuss is that the five hydropower projects analyzed are presented in tropical climatic conditions where there are high ranges of precipitation, and humidity to proliferate the water abundance, in these areas, there are generally vast ecosystems with little human intervention; under this conception it necessary develop sustainability plans for all hydropower plants verifying the water conditions, and ecosystems monthly to monitoring climate behavior with nearby meteorological stations to issue improvements or fixes on an ongoing basis (Johnson et al., 2019; Naranjo-Silva & Alvarez del Castillo, 2022).

With this brief explanation of the main parameters that present modifications, it is also essential to discuss the comments generated by several authors regarding the variation by damming the water resource in hydropower projects; For example, Joerg Hartmann notes that few studies have been conducted that evaluate the potential effects of hydroelectric plants on the water, and that divergences in the inlet volume will be more important in hydropower plants with reservoirs (Hartmann, 2020; Zhang et al., 2018).

It has been found in other studies that hydropower development has a strong influence on local environmental structures, the biotic community changes environments, and the characteristics of water resources alteration, similar to what we have seen in this study (Eloranta et al., 2018; Vaca-Jiménez et al., 2020). In addition, turbidity of the samples is observed, which is related to organic material (slit, algae, and plants) in suspension produces opacity and endangers the natural development of nutrients (Carapellucci et al., 2015).

Although hydropower plants are friendly as they do not use fossil sources, to take advantage of river tributaries efficiently, it is necessary to create reservoirs and dams so that the flow of water remains continuous, creating impacts on the different life cycles of any species that is found in the area, either due to its construction or implementation, affecting the water basins to the point of impacting the animal's density or their reproduction processes (Liu et al., 2020; Majone et al., 2016).

Another problem is the pressure of the water in the dam by containing it on the ground alters its stability, generating landslides or induced seismicity (Zhong et al., 2019).

All these changes to the natural conditions of the water significantly affect the biotic diversity in riparian ecosystems, producing a decrease in native species and promoting the anomalous dissemination of exotic species more adapted to lentic conditions (Hofstra et al., 2019).

Future lines could investigate the water quality to analyze improvements both in their efficiency and the representative water use that require the hydropower plants to generate energy, which leads to intangible impacts that are overlooked and must be analyzed as changes in water molecules when hitting the resource in the generation turbines.

5 CONCLUSIONS

Based on the ten samples gathered in the five plants of Ecuador, Uruguay and Argentina, it can be concluded that the divergences of the measured parameters can vary depending on the sample, but the fluctuating values ranges are significant in the dams, the principal items modified as the presence of dissolved solids (26%), total solids (21%), bicarbonates (15%), total hardness (14%), suspended solids (6%), and sodium (4%).

Several parameters associated with freshwater from Argentina, Uruguay, and Ecuador have been analyzed and found to differ after and before the hydropower. Therefore, the water passage upstream versus downstream results in some significant differences in the water resources characteristics, as indicated in Table 6.

Compared with the discharge water intakes, samples taken before the five hydropower plants are turbid, indicating that the construction of large infrastructures with dams generates suspended matter as silt, and living organisms, we observe algae and floating plants that contribute to the opacity appearance in the hydric source, this value shows organic matter existence due to vegetation decomposition, and metabolites formed in dams as Salto Grande, Hidroagoyan, Minas San Francisco, Baba, and Coca Codo Sinclair.

The results of the experiment indicate that hydropower projects with water accumulation systems (dams) place greater pressure on water resources and river flows because of their use of environmental conditions, which can lead to consequences such as damage to the water reserves located in reservoirs, hydrological changes due to large constructions and flooding of land upstream of the plants, resulting in natural phenomena changing.

This is a small study with only five hydropower plants with fourteen physical and chemical parameters measured. There is still a wide range of places where evaluations of water quality can be generated. It is recommended to take this study methodology, and generate more analysis in other hydroelectric projects.

ACKNOWLEDGEMENT

We specialize and recognize all those scientific authors cited in this document for their time applied to the different articles, thesis, and papers.

FUNDING

This research received no external funding.

CONFLICTS OF INTEREST

All the authors declare no conflict of interest.

REFERENCES

Bondarenko, V. L., Kortunov, A. K., Semenova, E. A., & Khetsuriani, E. D. (2019). Assessment of the Prospect of Using the Hydropower Potential in the Operating Water-Supply and Irrigation Systems of Savropol Krai (Russia). 2019 International Multi-Conference on Industrial Engineering and Modern Technologies, FarEastCon 2019, 1–5. https://doi.org/10.1109/FarEastCon.2019.8934160

Bongio, M., Avanzi, F., & de Michele, C. (2016). Hydroelectric power generation in an Alpine basin: Future water-energy scenarios in a run-of-the-river plant. Advances in Water Resources, 94, 318–331. https://doi.org/10.1016/j.advwatres.2016.05.017

Cabrera, S., Eurie Forio, M. A., Lock, K., Vandenbroucke, M., Oña, T., Gualoto, M., Goethals, P. L. M., & der Heyden, C. van. (2021). Variations in benthic macroinvertebrate communities and biological quality in the aguarico and coca river basins in the ecuadorian amazon. Water (Switzerland), 13(12), 1–26. https://doi.org/10.3390/w13121692

Carapellucci, R., Giordano, L., & Pierguidi, F. (2015). Techno-economic evaluation of small-hydro power plants: Modelling and characterisation of the Abruzzo region in Italy. Renewable Energy, 75, 395–406. https://doi.org/10.1016/j.renene.2014.10.008

Cárdenas, M., Filonzi, A., & Delgadillo, R. (2021). Finite element and experimental validation of sample size correction factors for indentation on asphalt bitumens with cylindrical geometry. Construction and Building Materials, 274. https://doi.org/10.1016/j.conbuildmat.2020.122055

Eloranta, A. P., Finstad, A. G., Helland, I. P., Ugedal, O., & Power, M. (2018). Hydropower impacts on reservoir fish populations are modified by environmental variation. Science of the Total Environment, 618, 313–322. https://doi.org/10.1016/j.scitotenv.2017.10.268

Gaudard, L., Gabbi, J., Bauder, A., & Romerio, F. (2016). Long-term Uncertainty of Hydropower Revenue Due to Climate Change and Electricity Prices. Water Resources Management, 30(4), 1325–1343. https://doi.org/10.1007/s11269-015-1216-3

Giannakidis, G., Karlsson, K., Labriet, M., & Gallachóir, B. (2018). Limiting Global Modelling and Policy 2 °C: Energy System Warming to Well Below Development. Springer. https://doi.org/https://doi.org/10.1007/978-3-319-74424-7

Hartmann, J. (2020). Climate Change and Hydropower Training Manual. AICCA Project, Ministry of the Environment and Water of Ecuador - CONDESAN (p. 1012). https://condesan.org/recursos/manual-entrenamiento-cambio-climatico-e-hidroenergia/

Hofstra, N., Kroeze, C., Flörke, M., & van Vliet, M. T. (2019). Editorial overview: Water quality: A new challenge for global scale model development and application. Current Opinion in Environmental Sustainability, 36, A1–A5. https://doi.org/10.1016/j.cosust.2019.01.001

Intergovernmental Panel on Climate Change. (2021). IPCC AR6 Working Group II Report. https://www.ipcc.ch/assessment-report/ar6/

International Energy Agency. (2020). Renewables, analysis and forecast to 2025. 74(9), 56–57. https://doi.org/10.1002/peng.20026

International Energy Agency. (2022). Hydropower Special Market Report. Analysis and forecast to 2030. www.iea.org/t&c/

International Hydropower Association. (2020). Hydropower Status Report 2020. International Hydropower Association, 1–83. https://www.hydropower.org/sites/default/files/publications-docs/2019_hydropower_status_report_0.pdf

International Hydropower Association. (2021). Hydropower Status Report 2021: Sector trends and insights. https://www.hydropower.org/publications/2021-hydropower-status-report

International Renewable Energy Agency. (2020). Renewable Energy Capacity Highlights 2019. Irena, 00(March 2020), 1–3. www.irena.org/publications.

Jimenez-Mendoza, S., & Terneus-Paez, F. (2019). The water-energy nexus: Analysis of the water flow of the Coca Codo Sinclair Hydroelectric Project. Ingenius, Jiménez, S, 53–62. https://doi.org/https://doi.org/10.17163/ings.n21.2019.05

Johnson, N., Burek, P., Byers, E., Falchetta, G., Flörke, M., Fujimori, S., Havlik, P., Hejazi, M., Hunt, J., Krey, V., Langan, S., Nakicenovic, N., Palazzo, A., Popp, A., Riahi, K., van Dijk, M., van Vliet, M. T. H., van Vuuren, D. P., Wada, Y., … Parkinson, S. (2019). Integrated solutions for the water-energy-land nexus: Are global models rising to the challenge? Water (Switzerland), 11(11), 33. https://doi.org/10.3390/w11112223

Kapitonov, I. A., Voloshin, V. I., Filosofova, T. G., & Syrtsov, D. N. (2021). Development of experience in the application of technologies in the field of alternative energy: World experience, Russian practice. Renewable Energy, 165, 773–782. https://doi.org/10.1016/j.renene.2020.11.063

Kelly-Richards, S., Silber-Coats, N., Crootof, A., Tecklin, D., & Bauer, C. (2017). Governing the transition to renewable energy: A review of impacts and policy issues in the small hydropower boom. Energy Policy, 101(November 2016), 251–264. https://doi.org/10.1016/j.enpol.2016.11.035

Kibaroglu, A., & Gürsoy, S. I. (2015). Water–energy–food nexus in a transboundary context: the Euphrates–Tigris River basin as a case study. Water International, 40(5–6), 824–838. https://doi.org/10.1080/02508060.2015.1078577

LABOLAB. (2021). Physicochemical analysis of water. http://www.labolab.com.ec/analisis-fisicoquimico/

Liu, B., Lund, J. R., Liu, L., Liao, S., Li, G., & Cheng, C. (2020). Climate change impacts on hydropower in Yunnan, China. Water (Switzerland), 12(1), 1–20. https://doi.org/10.3390/w12010197

Llamosas, C., & Sovacool, B. K. (2021). The future of hydropower? A systematic review of the drivers, benefits and governance dynamics of transboundary dams. Renewable and

Sustainable Energy Reviews, 137(0321), 110–124. https://doi.org/10.1016/j.rser.2020.110495

Llerena-Montoya, S., Velastegui-Montoya, A., Zhirzhan-Azanza, B., Herrera-Matamoros, V., Adami, M., de Lima, A., Moscoso-Silva, F., & Encalada, L. (2021). Multitemporal analysis of land use and land cover within an oil block in the Ecuadorian Amazon. ISPRS International Journal of Geo-Information, 10(3). https://doi.org/10.3390/ijgi10030191

Majone, B., Villa, F., Deidda, R., & Bellin, A. (2016). Impact of climate change and water use policies on hydropower potential in the south-eastern Alpine region. Science of the Total Environment, 543, 965–980. https://doi.org/10.1016/j.scitotenv.2015.05.009

Ministry of Energy and Non-Renewable Resources. (2018). National Energy Efficiency Plan. 2018. https://www.celec.gob.ec/hidroagoyan/images/PLANEE_INGLES/NationalEnergyEfficiencyPlan20162035_2017-09-01_16-00-26.html

Naranjo Silva, S., & Álvarez del Castillo, J. (2020). Análisis de la producción hidroeléctrica en base a las implicaciones en la sostenibilidad energética. V Congreso Científico Internacional, Retos y Perspectivas de Las Ciudades Sostenibles y Desarrollo Local, 27. https://ecotec.edu.ec/content/uploads/investigacion/sociedad-del-conocimiento/2020-memorias-cientificas.pdf%0A

Naranjo-Silva, S., & Alvarez del Castillo, J. (2022). The American Continent hydropower development and the Sustainability: A Review. International Journal of Engineering Science Technologies, 6(2), 66–79. https://doi.org/10.29121/ijoest.v6.i2.2022.315

Naranjo-Silva, S., Punina, J., & Álvarez Del Castillo, J. (2022). Comparative cost per kilowatt of the latest hydropower projects in Ecuador. InGenio Journal, 5(1), 1–14. https://doi.org/10.18779/ingenio.v5i1.473

Naranjo-Silva, S., Rivera-Gonzalez, L., Escobar-Segovia, K., Quimbita-Chiluisa, O., & Javier, A. del C. (2022). Analysis of Water Characteristics by the Hydropower Use (Up-Stream and Downstream): A Case of Study at Ecuador, Argentina, and Uruguay. Journal of Sustainable Development, 15(4), 71. https://doi.org/10.5539/jsd.v15n4p71

Noblecilla-Alburque, M. E. (2020). Administrative management and quality of service in the Metropolitan Municipality of Lima. Cesar Vallejo University.

Open Street Map. (2021). Coca Codo Sinclair Dam location. https://www.openstreetmap.org/note/2721104#map=6/-0.754/-73.334

Oviedo-Ocaña, E. R. (2018). Hydroelectric Dams: effects on ecosystems and environmental health. Revista de La Universidad Industrial de Santander. Salud, 50(3), 191–192. https://doi.org/10.18273/revsal.v50n3-2018003

Ponce-Jara, M. A., Castro, M., Pelaez-Samaniego, M. R., Espinoza-Abad, J. L., & Ruiz, E. (2018). Electricity sector in Ecuador: An overview of the 2007–2017 decade. Energy Policy, 113(August 2017), 513–522. https://doi.org/10.1016/j.enpol.2017.11.036

Rasul, G., Neupane, N., Hussain, A., & Pasakhala, B. (2019). Beyond hydropower: towards an integrated solution for water, energy and food security in South Asia. International Journal of Water Resources Development, 00(00), 1–25. https://doi.org/10.1080/07900627.2019.1579705

Regional Energy Integration Commission of South America. (2021). Energy publications of South America. https://www.cier.org/es-uy/Paginas/Publicaciones.aspx

Reisancho, F. L., & Rivera, K. D. (2018). Evaluación ambiental de la planta de tratamiento de agua residual de la parroquia rural Belisario.

Reyes, P., Procel, S., Sevilla, J., Cabero, A., Orozco, A., Córdova, J., Lima, F., & Vasconez, F. (2021). Exceptionally uncommon overburden collapse behind a natural lava dam: Abandonment of the San-Rafael Waterfall in northeastern Ecuador. Journal of South American Earth Sciences, 110(April), 103353. https://doi.org/10.1016/j.jsames.2021.103353

Ritchie, H., & Roser, M. (2022). Renewable Energy - Our world in data. https://ourworldindata.org/renewable-energy?country=

Rivera-González, L., Bolonio, D., Mazadiego, L. F., Naranjo-Silva, S., & Escobar-Segovia, K. (2020). Long-term forecast of energy and fuels demand towards a sustainable road transport sector in Ecuador (2016-2035): A LEAP model application. Sustainability (Switzerland), 12(2), 1–26. https://doi.org/10.3390/su12020472

Salto Grande - Binational Corporation. (2014). Hydroelectric Complex. https://www.saltogrande.org/caracteristicas.php

Schaefli, B. (2015). Projecting hydropower production under future climates: a guide for decision-makers and modelers to interpret and design climate change impact assessments. Wiley Interdisciplinary Reviews: Water, 2(4), 271–289. https://doi.org/10.1002/wat2.1083

Uamusse, M. M., Tussupova, K., & Persson, K. M. (2020). Climate change effects on hydropower in Mozambique. Applied Sciences (Switzerland), 10(14). https://doi.org/10.3390/app10144842

Vaca-Jiménez, S., Gerbens-Leenes, P. W., & Nonhebel, S. (2019). The water footprint of electricity in Ecuador: Technology and fuel variation indicate pathways towards water-efficient electricity mixes. Water Resources and Industry, 22(June), 100112. https://doi.org/10.1016/j.wri.2019.100112

Vaca-Jiménez, S., Gerbens-Leenes, P. W., & Nonhebel, S. (2020). The monthly dynamics of blue water footprints and electricity generation of four types of hydropower plants in Ecuador. Science of the Total Environment, 713, 136579. https://doi.org/10.1016/j.scitotenv.2020.136579

van der Zwaan, B., Boccalon, A., & Dalla Longa, F. (2018). Prospects for hydropower in Ethiopia: An energy-water nexus analysis. Energy Strategy Reviews, 19, 19–30. https://doi.org/10.1016/j.esr.2017.11.001

Walsh, B. P., Murray, S. N., & O'Sullivan, D. T. J. (2015). The water energy nexus, an ISO50001 water case study and the need for a water value system. Water Resources and Industry, 10, 15–28. https://doi.org/10.1016/j.wri.2015.02.001

Winemiller, K. O., Nam, S., Baird, I. G., Darwall, W., Lujan, N. K., Harrison, I., Stiassny, M. L. J., Silvano, R. A. M., Fitzgerald, D. B., Pelicice, F. M., Agostinho, A. A., Gomes, L. C., Albert, J. S., Baran, E., Jr, M. P., Zarfl, C., Mulligan, M., Sullivan, J. P., Arantes, C. C., … Sáenz, L. (2016). Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. Science, 351(6269), 128–129. https://doi.org/doi:10.1126/science.aac7082

Zhang, X., Li, H. Y., Deng, Z. D., Ringler, C., Gao, Y., Hejazi, M. I., & Leung, L. R. (2018). Impacts of climate change, policy and Water-Energy-Food nexus on hydropower development. Renewable Energy, 116, 827–834. https://doi.org/10.1016/j.renene.2017.10.030

Zhong, R., Zhao, T., He, Y., & Chen, X. (2019). Hydropower change of the water tower of Asia in 21st century: A case of the Lancang River hydropower base, upper Mekong. Energy, 179, 685–696. https://doi.org/10.1016/j.energy.2019.05.059

Zhuo, L., Feng, B., & Wu, P. (2020). Water footprint study review for understanding and resolving water issues in china. Water (Switzerland), 12(11), 1–14. https://doi.org/10.3390/w12112988