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Opportunities for improvement in a potabilization plant based on cleaner production: Experimental and theoretical investigations

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A B S T R A C T

Cleaner Production (CP) has been studied mainly in the productive sector, ignoring that in drinking water treatment plants (DWTP) a better environmental performance can be achieved. The objective of this study was to evaluate the processes in a DWTP in order to improve production, reduce environmental impact and generate economic savings, for which a cleaner production plan was implementing. The methodology recommended by UNIDO was used. Three CP opportunities were evaluated and identified. After, each CP opportunity, a technical, environmental and economic feasibility analysis was carried out. The results indicated that by implementing the first opportunity of CP (Good housekeeping), it will save water by reducing the number of filter washes by 29400 m^3/year, without any investment, so the gains will be immediate. With the second chance of CP, a water-saving of 23256 m^3/year will be achieved by recirculating the water from the filters to the decanters. The investment is small, and the recovery period will be 2.4 months. The third CP option, which is based on the coagulant change, would have an annual financial savings of 5361.12 USD, with an immediate payback period. The results showed that the CP applications proposed in this study can significantly reduce water consumption in a WDTP, being able to be implemented in the short and medium-term, without large investments, allowing to address water scarcity today and in the future.

1. Introduction

The implementation of Cleaner Production (CP) techniques prevents environmental impacts, consequently, can reduce operating costs and improve profitability [1]. When water consumption in any activity is decreased, the amount of wastewater and the costs associated with it are reduced [2]. Industries that produce waste liquid effluents control pollution by treating the wastewater generated, a CP approach can be applied to eliminate this problem at the source and prevent pollution [3,4].

The goal of the CP is to reduce consumption and contamination at the source, for which sometimes it is sufficient to consider good housekeeping and on other occasions modifications to the product or process are required, which may include the substitution of the raw material and/or modification of the technology used, as well as the use of renewable energy sources [5–7]. Often times to implement a CP program, no investment is required, and other times, little or no investment is required, which in the future allows you to achieve valuable profits, in short recovery periods [8,9].

The main actions of water-efficient use in the industry are recirculation, water consumption reuse and reduction [10,11]. Recirculation of water consists of reusing it in the process where it was initially used or in the use of effluent from one process to another that requires a different water quality [12,13]. To achieve the reduction of water consumption, it is possible to optimize the processes, improve the operation, modify the equipment or the attitude of the water users, being necessary to calculate the amount of liquid required by a given process, compared to actual consumption and evaluate options to decrease your consumption [13].

Concern over the global drinking water crisis has sparked an

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increased interest in drinking water operating companies to improve treatment systems more efficiently [14]. Sorlini et al. [15] proposed a protocol to evaluate the operation of drinking water plants and optimize their efficiency in terms of water quality control and removal of contaminants, this protocol proved useful for the identification of problems related to the purification process. Drinking water treatment plant operators must continually analyze the performance of drinking water treatment, ensuring that the systems operate with more efficient technologies [16,17]. When drinking water treatment plants do not operate efficiently, operating costs can be extremely high [18].

The fifth paragraph of the introduction has been supplemented by writing: "Chemical products such as aluminum sulfate used during the water coagulation process are used in the purification processes, as well as other chemical products used as oxidants and disinfectants [19,20]. The wastewater produced during the purification can contain aluminum residuals in high concentrations can be dangerous and have a serious impact on the environment [21]. In potabilization plants, water is used for the maintenance of the treatment units, for example for backwashing the filters, as well as for the preparation of coagulant and flocculant solutions [22,23]. As a consequence of the potabilization, liquid effluents are also produced, which can be reduced by optimal use of water or by reuse for other activities of the plant [22,24].

Cleaner Production applied to production processes implies the conservation of raw materials and energy, the elimination of toxic raw materials and the reduction of the amounts and toxicity of waste and emissions. Meanwhile, for service industries, CP implies the incorporation of environmental considerations in the design and provision of services. Most of the CP studies have been carried out applied to production processes. Considering that purification is a service industry, this study aims to demonstrate the viability of sustainable management in drinking water treatment plants.

In addition, this study can serve as a future reference for the literature, as there are still many research opportunities for this industry. Therefore, the objective of this work was to identify CP opportunities that allow the prevention of contamination and the minimization of wastewater, which in turn allows achieving sustainable processing of drinking water and that the company can obtain financial improvements and on all environmental improvements.

2. Methodology

2.1. Integrated description of the drinking water treatment plant

The drinking water treatment plant (DWTP) where this study was carried out is located in the Bayas parish, Azogues city, Ecuador. The DWTP is a conventional plant with gravity operation, consisting of: Coagulation, Flocculation, Sedimentation, Rapid Filtration and Disinfection, with complementary buildings for storage and dosing of chemicals, quality control laboratories (Fig. 1). The treatment flow in this plant is 100 L/s.

2.2. Cleaner production methodology in the treatment plant

For the execution of this study, the methodology recommended by the United Nations Industrial Development Organization consisting of sequential steps was used [25–28]: 1. Planning and organization: define in detail the tasks to be carried out and the resources necessary to carry out the project successfully; 2. Evaluation: define and evaluate the activities of the company to facilitate the identification of CP options; 3. Feasibility analysis: determine the feasibility, technical, economic and environmental of each option;

2.3. Planning, organizing and collecting data

Information was collected on the purification process, information was collected on the potabilization process, for which several visits were made to the plant to obtain general information and a clear understanding of the water treatment processes. Step by step the potabilization processes were observed, in order to find existing problems and thus identify the critical processes [28]. The information and data were collected by analyzing the chemical input purchase records, DWTP operation records, as well as through interviews with the technical and administrative personnel of the plant. This collected information was used to develop a process flow diagram (Fig. 1) to have a clear understanding of the potabilization processes, it also allowed identifying inefficiencies in operations.

2.4. Assessment of the treatment plant activities to identify cleaner production opportunities

At this stage, all possible CP options were considered, then the CP options that are only feasible to implement were chosen and the non-feasible options were set aside. The evaluation focused on critical operations, where the deficiencies cause were identified [26,29]. The detailed quantification of the consumption of chemical inputs such as the coagulant aluminum sulfate was taken into consideration. The amount of raw water entering the plant and the amount of treated water were also considered, which served as the basis for generating CP options. The water used by the plant for the maintenance of the filters was also considered, which is directly discharged into the sewer system, in such a way that it can be reused. The water consumption in the plant was divided into two categories, which were 'process water' and 'non--process water'. The 'process water' was the raw water considered as raw material, while the 'non-process water' referred to the water used for cleaning activities and for domestic purposes within the WDTP. The volume of process water was obtained directly from the electronic water meter. Meanwhile, the volume of non-process water was considered as the volume of wastewater discharged into the stream [28].

The causes of inefficiencies in the use of raw material (raw water), inputs (coagulant) and the causes of the generation of liquid effluents were identified and finally, the CP options were considered. The CP options are classified as Good housekeeping, material substitution,

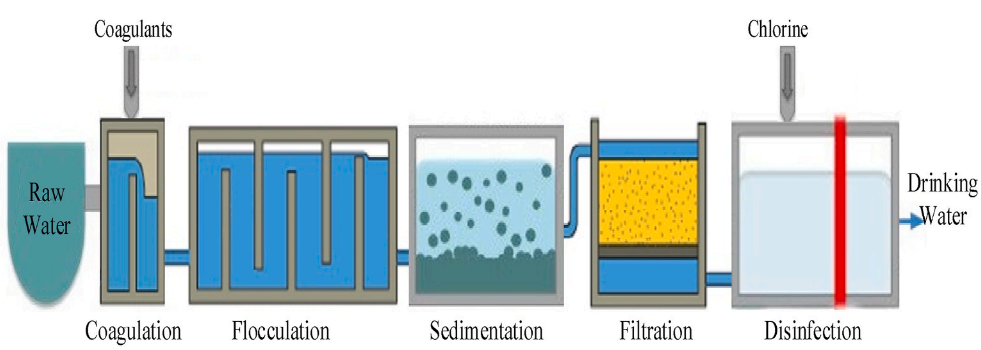

Fig. 1. Flowchart of the purification process.

technological changes, internal recycling and external recycling [27].

2.5. Technical-environmental and economic feasibility analysis

For each CP option selected, a technical-environmental and economic analysis was carried out, which was necessary to make a decision on the feasibility of implementing each option chosen. The priorities of the treatment plant and the low budget available to the company were considered.

Priority was given to the options that allowed the greatest capacity to reduce the water and coagulant consumption during the potabilization process (applying good housekeeping and reduction at the source). Reducing liability and additional costs associated with the management of liquid effluents (wastewater and sludge). Technical feasibility considered factors such as implementation, investment, adaptability to production variation, acceptance by DWTP operators [2]. The options that were not considered feasible were not discarded but were postponed being considered later, when the circumstances may be different [29]. The environmental assessment, evaluated the possible environmental benefits for each CP option, such as: reduction of water and coagulant consumption, reduction of toxicity levels in discharges when changing the coagulant; water recovery through good housekeeping, on-site water recovery by recirculating water from the filters to the settlers [2].

Those options with expected environmental impacts as unfavorable were discarded. In order to facilitate the economic evaluation, it was necessary to establish an economic criterion that allowed analyzing the economic benefit that would be obtained from the investment to implement the CP options. This simple criterion was built based on the financial concept of Payback Period. The economic viability analysis was carried out by estimating the investment cost required to implement CP opportunities and determining the expected savings [28]. Therefore, the Payback period expected was estimated using the equation:

$$\text{Payback period (year)} = \frac{\text{Investment cost}}{\text{annual savings}}$$

Considering small and medium scale companies, they have few financial resources, economically reasonable and affordable CP opportunities were chosen.

3. Results and discussion

The processes carried out in the treatment plant involve significant consumption of water (raw material) and coagulants (inputs), as well as generation of large volumes of wastewater. These characteristics depend, on the one hand, on the technology used and, on the other, on the operation of the plant. Different CP options were proposed with the aim of reducing consumption and the final discharge of effluents without affecting the production of drinking water.

3.1. Cleaner production options identified

Table 1 shows the CP options that were finally chosen to be implemented in the potabilization plant. The CP options are presented considering the environmental problem, the implementation strategies and the reason for the choice, based on the conservation of the water resource and the change of coagulant.

Table 1
CP options chosen based on the main problems identified.

N°	Plant Area	Problems/ Opportunities	Strategies or solution options	Reason for choice
CPO1	Filtration	Longer filtration runs. The number of backwashing filters can be reduced, reducing water consumption.	Increase the washing velocity in the filter bed from 0.5 to 0.64 m/min.	Implementation can be immediate through good housekeeping. No investment required.
CPO2	Filtration	The water evacuated from the filters is sent to the stream every time it is necessary to empty them to wash the filters.	Recirculation of the water contained in the filters prior to washing to the settlers. This measure allows 23256 m^3/year to be recirculated.	Money is being lost as the water drained from the filters contains coagulant. Large volumes of water are lost. It requires little investment.
CPO3	Coagulation	In winter times, the turbidity of the raw water is high (1000–5000 NTU), when applying high doses of Aluminum Sulfate, there is a reduction in pH and the residual aluminum increases. Coagulant can be changed to reduce these problems.	The consumption of aluminum sulfate was 78,840 kg/year, when substituting the alumine for poly aluminum chloride, the consumption of the latter is 37,843 kg/year.	Water-saving in the backwashing of the filters. Improvement of the treated water quality. Reduction of treatment costs. No investment required.

3.2. Data analysis, cleaner production options and feasibility studies

3.2.1. Reduction of water consumption by reducing the number of filter washes (CPO1)

3.2.1.1. Background. Since 2005, the year in which the Treatment Plant began operation, the filters were backwashed at an average number of 2212 per year, which meant 77420 m^3 of water sent to the stream (35 m^3/washed filter). After carrying out the technical tests, it was determined that it is possible to reduce the number of washes. This could be achieved by lengthening the filtration run, which allowed reducing the total water consumption in the plant and minimizing the discharge of wastewater that is discharged into the stream adjacent to the treatment plant.

3.2.1.2. Technical-environmental feasibility. To determine if this measure was technically feasible, best operational practices were carried out (housekeeping). For which, when a certain filter was washed, the landfill gate corresponding to the outlet of the interconnection channel was closed, this in order that all the flow produced by the remaining filters that make up each of the filtration systems provide a higher wash flow to the filter that being washed at the moment. By applying this measure, the filter medium expansion improved and therefore the washing velocity increased, allowing the filter medium after washing to be as clean as possible, with the least amount of sludge in the filter bed and therefore lengthening the filtration runs.

The detail of this technical analysis can be seen in the document written by Ref. [11]. Table 2 shows that until before implementing this CP option, filter washes are carried out on an average of 184 washes per month, giving a total of 2212 washes in the year (2013). After implementing this CP opportunity, the number of washes decreased, as seen in the following years.

It should be noted that this measure was implemented in August 2014, as of this date the number of filters washed per month decreased. The number of washed filters per month was reduced from 184 to 114. The implementation of this water-saving program by reducing the

Table 2
Number of filters washing in recent years in the WDTP.

Month	Year					
	2013	2014	2015	2016	2017	2018
January	178	147	120	133	116	113
February	174	167	119	110	106	103
March	191	204	110	134	117	113
April	186	179	147	117	112	107
May	195	186	132	129	117	120
June	184	188	98	123	108	113
July	189	189	113	124	114	115
August	191	164	112	119	120	116
September	179	131	112	107	111	116
October	186	144	125	119	123	115
November	188	138	117	113	116	114
December	171	149	121	115	109	126
Total	2212	1986	1426	1443	1369	1371
Average	184	166	119	120	114	114

backwashing of the filters would represent environmental benefits, such as reducing contamination of the stream where the effluents are discharged liquids, being that the number of filter washes would be reduced.

3.2.1.3. Economic feasibility. Table 3 presents the economic analysis of CPO1, once the amount of water saved was determined by implementing housekeeping in the filter washing process. In this table, it can be seen that the economic saving by reducing the water consumption in filter washing is 11760 USD/year.

In Table 4 determined the economic savings that would be obtained by the concept of coagulant, since, as there is a saving in water, there would also be a saving in coagulant. In this table it can be seen that the economic saving for coagulant savings is 331.63 USD/year.

The total savings when implementing this CP program would be 12091.63 USD/year.

3.2.1.4. Expected results. The implementation of the proposed options will reduce the consumption of water used for washing the filters by 38%. What will be directly related to the decrease in production costs. The implementation of this COP opportunity will reduce the number of filters washes and therefore reduce the volume of effluents by 29400 m^3/year. The economic savings would be 12091.63 USD/year. Water consumption has been reduced by 29400 m^3/year, moving from non-processed water to processed water. There is no cost to implement this program since it is a good operating practice. The payback period is immediate.

3.2.2. Recirculation of the water evacuated from the filters to settlers (CPO2)

3.2.2.1. Background. From the start of DWTP operation until the present date, to carry out the backwashing of the filters, previously the water contained in the filter drawer must be emptied, once the filter is empty, the backwash is carried out. Currently, this water evacuated from the filter is sent directly to the stream adjacent to the treatment plant, losing approximately 17 m^3 in each wash. Monthly 114 backwashes are being carried out, losing 1938 m^3 of water per month, that is, 23256 m^3 of water per year. This wasted water is flocculated and settled water, which contains aluminum sulfate, which is being sent to the stream with the water evacuated from the filters.

Table 3
Economic savings by reducing backwashing of the filters.

Description	Quantity	Unit
Monthly backwash savings	70	month
Annual backwash savings	840	year
Water used in each backwash	35	m^3
Total water saved monthly	2450	m^3/month
Total annual water saved	29400	m^3/year
Price of water to the user	0.40	USD/m^3
Monthly economic savings	980	USD/month
Annual economic savings	**11760**	**USD/year**

Table 4
Economic savings by reduction of coagulant (aluminum sulfate).

Volume of water lost in the backwash	29400	m^3/year
Average applied dose of coagulant	30	mg/L
Amount of coagulant contained in the backwash water	882.00	Kg/year
Coagulant cost	0.376	USD/Kg
Annual economic savings	**331.63**	**USD/year**

3.2.2.2. Technical-environmental feasibility. This purpose can be achieved by recirculating the water evacuated from the filters to the settlers, in this way the benefit that would be obtained would be a greater amount of treated water and a reduction in the discharge of liquid effluents in the stream.

Technically this option is feasible, requiring for this purpose the installation of a pump with its respective pipe and accessories. The power required for the pump to recirculate the water is 3.15 HP. Additionally, a PVC pipe 30 m long and 75 mm in diameter is required, as well as PVC accessories 75 mm in diameter. The implementation of this water-saving program through the recirculation of water from the filters would represent environmental benefits such as reducing the amount of wastewater. Also achieving a greater amount of treated water and therefore the amount of raw water that should be collected would be reduced, reducing water stress.

3.2.2.3. Economic feasibility. For the economic calculation, the number of 114 monthly filter washes that are currently being carried out in the DWTP was considered. Table 5 shows the economic savings that would be obtained by recirculating the water contained in the filters to the settlers prior to washing these filters.

In Table 6, the economic saving that would be obtained by saving aluminum sulfate was determined, since, since there is a saving in water, therefore, there would be coagulant savings.

This option allows a total savings of 9564.72 USD/year. The investment necessary to acquire a water pump, pipe and accessories from PVC is 1905.00 USD. The payback period would be 0.2 year.

3.2.2.4. Expected results. With the proposed measures, recovery of 100% of the water evacuated from the filters prior to washing would be obtained, recovery of water of 23256 m^3/year, as well as a decrease in the consumption of aluminum sulfate in an amount of 697.68 kg/year and an economic saving of 9564.72 USD/year. The payback period would be 2.4 months.

3.2.3. Coagulant change (CPO3)

3.2.3.1. Background. The Treatment Plant to date uses solid aluminum sulfate for the coagulation process. The coagulation-flocculation process

Table 5
Economic savings by recirculating water from the filters to the settlers.

Description	Quantity	Unit
Monthly backwash number	114	month
Annual backwash number	1368	year
Water evacuated from the filter in each backwash	17	m^3
Total water saved	1938	m^3/month
Total annual water	23256	m^3/year
Price of water to the user	0.4	USD/m^3
Monthly economic savings	775.2	USD/month
Annual economic savings	**9302.4**	**USD/year**

Table 6
Economic savings by reducing coagulant consumption.

Volume of water evacuated from the filters	23256	m^3/year
Average applied dose of coagulant	30	mg/L
Amount of coagulant contained in the evacuated water	697.68	Kg/year
Coagulant cost	0.38	USD/Kg
Annual economic savings	262.32	USD/year

is considered as the basic and essential component of a conventional water treatment system, which largely determines the operating conditions of the treatment plant. The greater or lesser efficiency of the following processes, as well as the total treatment costs, largely depend on this process.

Aluminum polychloride (PAC) is a polymeric inorganic coagulant that can significantly improve the purification process and reduce treatment costs compared to aluminum sulfate. The PAC has advantages over aluminum sulfate in the purification process such as: reduction in the coagulant doses, effective behavior in a wider pH range of raw water; higher sedimentation rate of the flocs produced, which increases the filtration runs, reduction of the coagulation helper [28,31]. The PAC generates a lower residual of aluminum, improves the velocity of floc formation, improving the removal of color and turbidity. The coagulant change program aims above all to improve the treated water quality; as well as improving filtration efficiency, further reducing the frequency of filter backwash [30,31].

3.2.3.2. Technical-environmental feasibility. Jar tests were performed to determine if the coagulant change is technically feasible. Jar tests were performed with aluminum sulfate and aluminum polychloride to determine the optimal dose of each coagulant. These tests were carried out with different turbidity of the raw water that varied from 5 to 1100 NTU.

The parameters analyzed in each jar test were turbidity, color and pH. The respective dosing curves were made with the results obtained from residual turbidity. Fig. 2 shows the dosage curve for aluminum sulfate and PAC.

Table 7 shows the optimal dose of aluminum sulfate obtained in each jar test; as well as the turbidity of raw water and treated water, color of raw water and treated water, pH of raw water and treated water. Table 8 presents the same parameters mentioned above, but in this case using PAC.

According to the data obtained in the laboratory, it can be determined that for the same turbidity of the raw water, the dose of PAC applied is less than the dose of aluminum sulfate. When using PAC, a lower dosage could be applied, PAC does not drastically alter pH, something that cannot be achieved with aluminum sulfate, especially in high turbidity when higher doses of coagulant are used. PAC forms larger, better-sized, and stable flocs improve sedimentation, produce longer filtration runs.

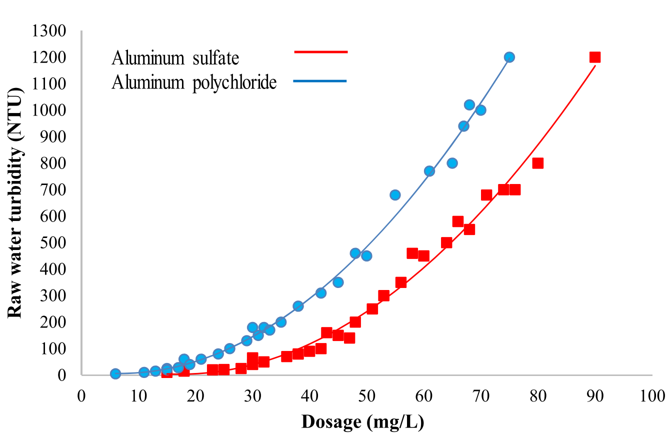

Fig. 2. Dosing curves for Aluminum Sulfate and PAC.

Table 9 shows the average, minimum and maximum doses of the two coagulants obtained after carrying out jar tests. The data in Table 9 were determined considering a turbidity range between 10 and 200 NTU, since this turbidity range occurs during most of the time of a seasonal year (95% of the time).

After the respective tests, it was determined that it is technically feasible to change the aluminum sulfate for PAC since the dose of PAC is less than the dose of aluminum sulfate. At the same time, by using smaller amounts of coagulant, the environmental impact and the operating cost generated will also be substantially lower.

By saving supplies, you would also be protecting the environment. This option would save water in the washing of the filters since the filtration runs would be prolonged, washing fewer filters and therefore the amount of liquid effluents would also be reduced. The change of coagulant would represent environmental benefits such as the reduction of contamination of the stream where the wastewater is discharged since PAC leaves less aluminum residual in the effluents [32,33].

3.2.3.3. Economic feasibility. Table 10 shows the annual consumption and costs of the two coagulants based on the average flow rate (100 L/s) used in the DWTP. A cost of 0.38 USD/Kg of Aluminum Sulfate and 0.65 USD/Kg of PAC were assumed. It can be seen that although the cost of PAC is higher than aluminum sulfate, as there is lower consumption of PAC, there would be a saving of 5361.12 USD/year.

3.2.3.4. Expected results. With this CP option, you would obtain an improvement in the water quality, a lower number of filters washes, a decrease in residual aluminum in the effluent and an economic saving of 5361.12 USD/year. The payback period is immediate.

3.3. Summary of economic feasibility and environmental evaluation of chosen CP opportunities

Table 11 summarizes the CP options with their corresponding results on water savings, economic savings and payback period.

In recent decades, worldwide research has been conducted associating the use of water and CO_2 emissions. It has been determined that the use of water-saving accessories reduces CO_2 emissions [34]. Carbon credits can be calculated by determining the energy consumption or amount of water saved and multiplying this value by the CO_2 emission factor to convert the energy and water values into the amount of CO_2. The CO_2 emission factor for water is 0.59 kg CO_2/m^3 [35]. By accounting for the total amount of water saved (52656 m^3/year) by implementing these CP opportunities, it is possible to avoid emitting 31.07 Ton of CO_2/year to the environment.

As a result of the study, it can be ensured that these measures help to conserve water through less use within the DWPT, in addition to reducing the amount of wastewater effluent. Increasing the efficiency of water use in DWTPs are strategies that would address water scarcity today and in the future.

The application of CP can help the implementation of better drinking water conservation programs that respond to short-term water scarcity crises; at the same time, it allows reducing the flow of raw water collected for drinking water treatment, ensuring the health of the ecosystem. Likewise, these options allow economic savings and confer a variety of environmental benefits. The results obtained indicate that water treatment companies can successfully reap tangible and intangible benefits after the implementation of Cleaner Production, at the same time improving their reputation in society [36,37].

The dissemination of the cleaner production philosophy is relatively new in Ecuador, which is why this work has been prepared applying a comprehensive preventive environmental strategy with the aim of increasing eco-efficiency in goods and services companies.

Table 7
Physical parameters of raw and treated water obtained in the jar test using aluminum sulfate.

Aluminum Sulfate dosaje (mg/L)	Raw water turbidity (NTU)	Treated water turbidity (NTU)	Raw water color (Pt–Co)	Treated water color (Pt–Co)	Raw water pH	Treated water pH
15	10	0.64	98	2.2	7.64	7.52
18	15	0.91	144	1.8	7.45	7.16
23	20	0.78	205	1.4	7.51	7.01
28	25	0.89	248	3.5	7.54	7.02
30	40	1.02	404	2.5	7.77	7.27
32	50	0.64	487	2.8	7.59	7.01
36	70	0.88	668	2.6	7.46	6.92
38	80	0.96	764	2.5	7.39	6.87
40	90	1.12	824	2.8	7.44	6.82
42	100	1.03	1040	4.1	7.68	7.04
45	150	0.69	1412	2.9	7.66	7.02
48	200	0.98	1844	3.4	7.83	7.2
51	250	0.75	2425	2.5	7.88	7.16
53	300	0.87	2745	1.7	7.65	7.04
56	350	1.25	3210	4.6	7.45	6.82
60	450	1.44	4110	3.5	7.34	6.81
64	500	1.01	4660	5	7.47	6.77
68	550	1.65	5120	4.5	7.41	6.52
76	700	1.24	6050	7.4	7.58	6.71
80	800	0.78	6980	5.6	7.61	6.69
90	1200	1.08	9860	6.5	7.49	6.62

Table 8
Physical parameters of raw and treated water obtained in the jar test using aluminum polychloride.

Aluminum Polychloride dosaje (mg/L)	Raw water turbidity (NTU)	Treated water turbidity (NTU)	Raw water color (Pt–Co)	Treated water color (Pt–Co)	Raw water pH	Treated water pH
6	5	0.48	51	1.4	7.69	7.61
11	10	0.56	98	1.5	7.39	7.28
13	15	0.61	144	1.1	7.65	7.48
15	20	0.49	205	1.9	7.34	7.18
17	28	0.78	272	0.9	7.67	7.55
19	40	0.56	404	1	7.98	7.79
21	50	0.67	487	1	7.86	7.75
24	80	0.58	764	1.5	7.46	7.28
26	100	0.81	1040	1.2	7.84	7.7
29	130	0.64	1195	1.6	7.78	7.59
31	150	0.48	1412	1.5	7.74	7.58
33	170	0.7	1585	2	7.83	7.71
35	200	0.39	1844	1.5	7.9	7.65
38	260	0.69	2395	1	7.6	7.32
45	350	0.92	3210	2.5	7.35	7.04
50	450	0.89	4110	2.2	7.35	7.02
57	600	0.78	5440	2.3	7.77	7.38
65	800	0.92	6980	2.4	7.5	7.09
70	1000	1.02	8990	1.8	7.61	7.25
75	1200	0.84	9860	2.5	8.02	7.68

Table 9
Average, minimum and maximum dose of aluminum sulfate and PAC.

Coagulant	Average dose (mg/L)	Maximum dose (mg/L)	Mínimum dose (mg/L)
Aluminum sulfate	25	50	15
Aluminum polychloride	12	35	6

Table 10
Consumption and annual average cost of aluminum sulfate and PAC.

Coagulant	Consumption (Kg/year)	Cost (USD/year)
Aluminum sulfate	78840.00	29959.20
Aluminum polychloride	37843.20	24598.08

At present, there is a lack of more research on the application of CP in drinking water plants, there are several studies applied in wastewater treatment plants. Nhapi and Hoko [38] developed CP strategies concerning the conservation, treatment and reuse of water; For which, they used water-saving devices, regulation, detection, and repair of leaks, up to treatment and reuse of wastewater. Results showed that applying CP principles would reduce total wastewater production from 487000 m^3/d to 379000 m^3/d (a 27% reduction). Amala et al. [39] in their study showed that the application of CP improves the quality of the water produced by wastewater treatment, they identified four main inefficiencies, aspects: human, methods, material and machine. Rahayu [17] demonstrated that the implementation of CP integrated with wastewater treatment reduced the amount of wastewater to be treated in a treatment plant. This means lower construction and operating costs for wastewater treatment plants.

Zand and Hoveidi [31] in their research found similar results to this study, they determined that PAC has a better performance compared to aluminum sulfate. The haze removal was within 82.9–99.0% for alum and 93.8–99.6% for PAC. To find a similar quality of drinking water, Zouboulis et al. [40] in their study found that the PAC dose was 1.35 mg/L and for aluminum sulfate it was 1.70 mg/L, determining that polychloride has a better performance.

Table 11
Summary of economic feasibility and environmental evaluation of chosen CP opportunities.

Area		Annual savings			
	CP options	Estimated investment (USD)	Water (m^3)	Value (USD)	Payback Period (year)
Filtration	Decreased amount of filter washes (CPO1)	0	29400	12091.63	Inmediate
Filtration	Recirculation of the water evacuated from the filters to the settlers (CPO2)	1905	23256	9564.72	0.20
Coagulation	Coagulant change (CPO3)	0		5361.12	Inmediate

4. Conclusions

The conclusions of this research are: 1. The application of good housekeeping in filters washing (CPO1) and coagulant change (CPO3) are economically and environmentally feasible, reducing the volume of wastewater, they do not require investment and economic savings is immediate. 2. By recirculating the water from the filters to the settlers, it is economically and environmentally feasible, the volume of wastewater is also reduced, it requires a small investment, but the payback period of said investment is 2.4 months. 3. This project is technically feasible, representing an economic benefit to the company and reducing the environmental impact of the potabilization process. The study showed that CP strategies could be used to reduce liquid effluent emissions since there is less water consumption for filter washing. The present study determined that by implementing these CP options, it is possible to avoid sending 52656 m^3/year to the drain, reducing the CO_2 emission by a value of 31.07 Ton of CO_2/year. From the aforementioned, it can be said that the cleaner production measures proposed for the potabilization industry point towards more sustainable development in the sense that they can contribute to a better work environment, a better interaction with the environment and higher production efficiency.

Credit author statement

Fernando Garcia-Ávila: Conceptualization, Experimental design, Methodology, Formal analysis, Investigation, Project administration, Writing – Reviewing and editing. *Lorgio Valdiviezo-Gonzales* and *Horacio Gutiérrez-Ortega:* Data analysis and interpretation, Experimental development, Writing. *Sergio Iglesias-Abad and Manuel Cadme-Galabay*: Writing- Original draft preparation, Investigation, Acquisition of data. *César Zhindón- Arévalo:* Methodology, Formal analysis. *Silvana Donoso-Moscoso:* Reviewing and Editing. All authors read and approved the final manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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