



Research article

Evaluation of low-cost alternatives for water purification in the stilt house villages of Santa Marta's Ciénaga Grande



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ABSTRACT

Water purification is indispensable to guarantee safe human consumption and to prevent diseases caused by the ingestion of contaminated water. This requires a series of water treatment processes which require investment. However, the economic limitations of rural communities hinder their ability to implement such water-treatment systems, as is the case in Ciénaga Grande of Santa Marta ("Large Swamp", in English) in Colombia. Low-cost systems can be used instead as simple and safe alternatives. Therefore, the objective of this work was to evaluate non-conventional, low-cost water processes to purify the water from the collection point of two stilt house villages in Ciénaga Grande of Santa Marta. These include: 1) Using two natural coagulants, *Moringa Oleifera* and *Cassia Fistula*; 2) filtration through a biosand filter and a carbon activated filter; and 3) disinfection through UV-C Radiation and through solar disinfection. The results showed a turbidity values reduction between 52% and 96% using the two natural coagulants; both turbidity and total coliforms achieved reductions of 98.4% and 76.9%, respectively in the filtration process; and removal of total coliforms up to 98.8% in the disinfection process. Despite the high rates of reduction in the different parameters, the water does not comply with the recommended limits for safe drinking water.

1. Introduction

Water is fundamental for life and is considered the most important non-renewable natural resource in the world. This vital liquid helps to eliminate resulting substances from biochemical processes that are produced in an organism. However, it can also serve as a means of transportation for harmful substances to the organism damaging people's health. Water can be also contaminated with chemical substances, sediments, microorganisms, or human or animal residuals putting the health of a population at risk (Altenburger et al., 2015). Therefore, the population's sources of water supply must be protected and kept clean from contamination to prevent diseases that could lead to an epidemic. Water quality is a main factor to be considered for human consumption, thereby preventing and avoiding the transmission of gastrointestinal diseases.

Access to safe drinking water is currently considered one of the most pertinent challenges (WHO, 2019). Seven billion inhabitants worldwide

(around 15%) do not have sufficient access to safe drinking water. Approximately 5,000 children die daily from diarrhea due to sanitary problems related to the consumption of water (WHO, 2019).

On the other hand, the urban-industrial growth has increased the problem of water resource contamination in the last decades. This is because increasing the demand of water for different purposes (industrial, agricultural, and urban) generates residuals that will eventually end up in water bodies. The high dependency that humans have on water causes overexploitation reaching the point of unsustainability in some cases. Although the water has high resilience to human actions, water sources have been affected by changes that diminish both their quality and quantity. To mitigate this problem, efficient water management is necessary. Therefore, it is necessary to implement safe drinking water treatment systems that permit the reduction of those contaminants in bodies of water and ensure that human water consumption does not pose a risk for human health (Zhang et al., 2016; Lugo et al., 2019a).

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Communities still do not have purification systems to enjoy safe drinking water, especially in rural communities (Kusuma et al., 2018). Technical and financial challenges do not permit the implementation of purification systems. The World Health Organization (WHO) established simple, acceptable and low-cost measurements for the communities to improve the microbiological quality of the water preventing diseases, including death caused by diarrhea. The reason decentralized low-cost systems, such as the home-made adsorption processes widely used in under-developed countries, can be found in studies carried out by Fabiszewski et al. (2012), Stauber et al. (2012), Timothy et al. (2014), among others.

The stilt-house towns of Ciénaga Grande of Santa Marta (CGSM) are in the north of the Colombian Caribbean and are a part of the municipality of Sitio Nuevo (Magdalena). The inhabitants consume water that is not treated with adequate purification, since these places lack basic sanitation systems such as aqueducts, sewage, and solid residuals integral management (Sarmiento, 2015). No studies have been performed to show the efficiency of low-cost alternatives processes for the purification and cleaning of the water in these populations.

For this reason, the goal of the present work is to compare the efficiency of three different low-cost alternatives for water purification.

2. Materials and methods

2.1. Area of study

The area of study consists of two villages in the Sitio Nuevo municipality in the department of Magdalena, Colombia: Nueva Venecia (10°49'N; 74°34'W) and Buenavista (10°50'N; 74°30'W), located in Ciénaga de Pajarales or Complejo Pajarales (CP), adjacent to Ciénaga Grande of Santa Marta (CGSM) (See Figure 1). The CGSM is also known as the delta plain of the Magdalena River. This timber-roof system, due to its ecological, hydrological, and geomorphological characteristics, is one of the most productive coastal systems in the tropics (Cancio et al., 2006).

The climate of this zone of study is arid tropical and has two primary climatic seasons: dry (December–May) and rainy (June–November). The average temperature is 30 °C (Cancio et al., 2006). In Nueva Venecia, there are approximately 300 houses, while in Buenavista there are 150 (Lugo and Lugo, 2018).

These two towns are located 15 min apart by rowboat, the nearest town being (Nueva Venecia) the urban center of Sitio Nuevo (Magdalena), 40 min away by boat. They are considered stilt-house towns because the wooden homes are constructed on top of a bog complex,



Figure 1. Area of study: location of stilt-house towns and the access routes to safe drinking water in the Ciénaga Grande of Santa Marta. Source: Google Earth Modified.

where the internal transport is carried out via artisanal canoes (See Figure 2).

The access route to safe drinking water goes from Aguas Negras spout (in the northeastern part of the municipality of Sitio Nuevo) to the water collection point in the two stilt-house towns. The communities in these towns suffer serious problems due to the lack of state presence such as: extreme poverty, social exclusion, victimization from internal armed conflict, precarious life conditions and insufficient public services (Sarmiento, 2015). The lack of access to safe drinking water is another blight which has been responsible for millions of deaths in the world due to the contraction of diarrheal diseases from the consumption of contaminated water (WHO, 2019).

2.2. Methodological design

This research was carried out in three stages: (1) the evaluation of the initial water quality of the surface fountain, as well as that of an exemplary tank where raw water was treated with aluminum sulfate without any technical procedure, (2) the determination of the optimal conditions of two proposed natural coagulants to evaluate their efficiencies, and (3) comparison of low-cost filtration and disinfection process of the water at the collection point. The mentioned processes were part of sequences to evaluate which ones were the most efficient combinations: (1) coagulation-flocculation: Moringa y Cañandonga; (2) Filtration: biosand filter and activated carbon filter; (3) Disinfection: UV-C radiation (UV-C lamp) and solar disinfection (SODIS).

2.2.1. Water quality evaluation

The water quality evaluation was carried out at the collection point of water for consumption (Aguas Negras spout) ($10^{\circ}48'41.01''$ N, $74^{\circ}36'21.21''$ W) and in a water storage tank (1000 L), where it was treated with aluminum sulfate and chlorine and sold to the stilt-house community.

The analysis of the quality of water in these two points had two goals: (1) to learn the initial conditions of the untreated water and variation during the rainy and dry seasons of the first semester of 2017; and (2) to compare the quality of water that is distributed to the stilt-house populations from the water source supplier (Aguas Negras spout). The samples were collected in two rounds: March 23 (first sample) and April 26 (second sample).

2.2.1.1. Water sample collection. Water samples from the Aguas Negras spout were collected in 20 L plastic bottles and those from the storage tank were collected in 1 L glass bottles, being previously sterilized. Both samples were refrigerated and transported to the Water Quality laboratory of the Universidad del Norte. Water quality analyses were performed the same day. Water samples in 20 L bottles were used for the proposed

low-cost treatment, while those of the 1 L bottles were used for the analysis of the water quality of the treated water supply tank in the study communities.

2.2.1.2. Analytical methods of water quality. In this water quality study, the following physical-chemical and microbiological parameters were determined for the water samples: Temperature, conductivity, pH, alkalinity, total hardness, turbidity, amount of chlorides, sulfates, nitrates, and total coliforms, defined by Standard Methods for Examination of Water and Wastewater (APHA, AWWA, WEF, 1995).

The temperature, conductivity and pH were analyzed by the electrometric method, which are the reference methods of the Standard Methods for Examination of Water and Wastewater, STM 2550 B, STM 2510 B and STM 4500H + B, respectively. Turbidity was analyzed using the nephelometric method (Method 2130 B). The alkalinity, total hardness and chlorides were determined by the volumetric method, the references being SM 2320 B, SM 2340 C and SM 4500-Cl, respectively. Sulfates and nitrates were determined by spectrophotometry, whose reference methods were: SM 4500 SO₄ E and SM -4500- NO₃-B, respectively. Total coliforms were evaluated by the membrane filtration method (Method SM 9222 B). The quality of the data analyzed in the laboratory was guaranteed by procedural blank measurements and making duplicates for each parameter of water quality evaluated.

Specifically, the microbiological analysis through the membrane filtration method was carried out using the following steps: the culture medium for Total Coliforms (Merk Chromocult Agar brand) was prepared one day before the laboratory test, following the indications of the product label. The prepared medium was served in sterilized Petri dishes. The membrane filter (0.45 μ m pore) was then removed with a flamed clamp and placed in the funnel of the bottles for vacuum pumping of the 100 ml of sample water. The membranes that filtered the water were encapsulated in the respective Petri dishes and incubated at 37 °C for 24 h. At the end of the incubation period, the colonies (salmon and violet) were counted with a colony counter. Microbiological analysis samples were performed duplicately, recording the average total coliform counts. Finally, the same procedure was performed with sterile distilled water (control test), verifying that there was no bacterial growth in this sample.

2.2.1.3. Materials and equipment. The relevant materials and equipment used for the tests were: Moringa and Cañandonga obtained from Barranquilla (Colombia), fine sand, crushed gravel, activated carbon, 60 L plastic tanks, UV-C lamp CREATOR brand model GPH150T5L, plush cloth, distilled water, tubes and water valves, 2 L plastic bottles, distilled water, mortar and a homemade colander, HACH model 2100P turbidimeter, HACH model DR5000 UV-VIS spectrophotometer, HANNA HI 9828 multiparameter meter and inputs for the determination of Coliforms totals by the membrane filtration method (vacuum pumps for



Figure 2. (a) Stilt-house. (b) Transport canoes. Source: Authors.

filtration, filtration systems, a vertical laminar flow cabinet, Chromocult agar, 0.45 µm diameter membranes and colony counter).

2.2.2. Determination of local coagulants for the clotting process

Once the microbiological and physical-chemical water quality was evaluated, two natural coagulants were employed to potentially remove suspended material from raw water. The two coagulants, *Moringa oleifera* and *Cassia fistula*, derived from the seeds of trees that are found in the Colombian Caribbean coast and have been effective for the agglomeration of water particles. Afterwards, an experimental design was employed to find the optimal dose and the fast-mixing times to remove suspended particles from the water.

The experimental design was elaborated and carried out by the authors, keeping in mind low-cost alternatives for water purification. The evaluation consisted of measuring turbidity before and after applying the respective natural coagulants. The coagulants were applied at different concentrations to determine the optimal dose for the clarification of raw water from the study's source. Similarly, the fast-mixing time of the sample varied with the respective coagulant applied.

The concentrations used to find the optimal dose of *C. fistula* were 10, 15, 20, and 25 mg/L, are similar to some of those used by Guzmán et al. (2015) in a highly turbid surface water source. For the *Moringa*, concentrations of 50, 100, 150, and 200 mg/L were employed. These concentrations were established according to Babu and Chaudhuri (2005).

The preparation of the coagulants was carried out in three steps:

2.2.2.1. Grinding and sifting of the seeds. The *Moringa* seeds were peeled and ground with a laboratory grinder, and the *Cañadonga* seeds were peeled and ground with a special seed grinder. Then, each of these products was sifted separately to obtain a fine powder which was stored in Ziploc bags to avoid humidity absorption.

2.2.2.2. Active compound extraction. The active compound of the coagulants was extracted according to Yin (2010). One difference, however, was the use of raw river water filtered with a sand biofilter constructed within this research and described in later sections instead of distilled water. Because of this change, 10g of powder from each coagulant was added to 1L of filtered water in plastic bottles, obtaining a concentration of 10 g/L (10000 mg/L). In Figure 3, the bottles are shown before and after the coagulation process.

2.2.2.3. Dilution of the initial sample. From the initial concentration (10000 mg/L) of each coagulant, the required concentrations for the samples were prepared in bottles of 2L through a dilution process.

For every coagulant concentration prepared, two 2L plastic samples were shaken quickly (fast mix) for 1 and 2 min, respectively, then for 5 min more slowly (slow mix). Finally, the samples were left to sit for 2 h to allow the destabilized water particles to sediment. Both the fast mix and the slow mix were carried out manually with the help of a group of volunteer students from the Universidad del Norte in Barranquilla, Colombia, that were trained to execute the mixing in the same way, time, and frequency. The way in which the mixing of the water with the coagulant was carried out was through homogeneous movements from top to bottom and bottom to top to obtain a complete dissolution of the natural compounds tested in this research.

Once the sitting time was reached, the researchers tested the turbidity every 30 min until the 2 h of sedimentation were completed on each sample. This lab analysis was carried out on samples taken on the 4th and 16th of May 2017, during the first precipitation of the season.

2.2.3. Determination of low-cost alternatives for filtration and/or disinfection processes

After carrying out the coagulation test in all the samples, the optimal characteristics (dose and time of fast mix) for removal of colloid particles were chosen for each coagulant studied. Then, a filtration process was performed through two homemade filtration matrices (a slow biosand filter and an activated carbon filter) without using disinfection. Additionally, one control was used, filtering raw water without coagulants. The descriptions of the two filters are shown in Figure 4 (biosand) and in Figure 5 (activated carbon).

The operation process of the filters was intermittent and downward flowing. The water samples of the plastic bottles with better coagulant performance and the control sample (raw water), approximately 4 liters for each treatment, were added slowly to the filter, the upper part of the filter being covered with spandex cloth to prevent the remaining suspended particles from passing through to the filters. The filters were only

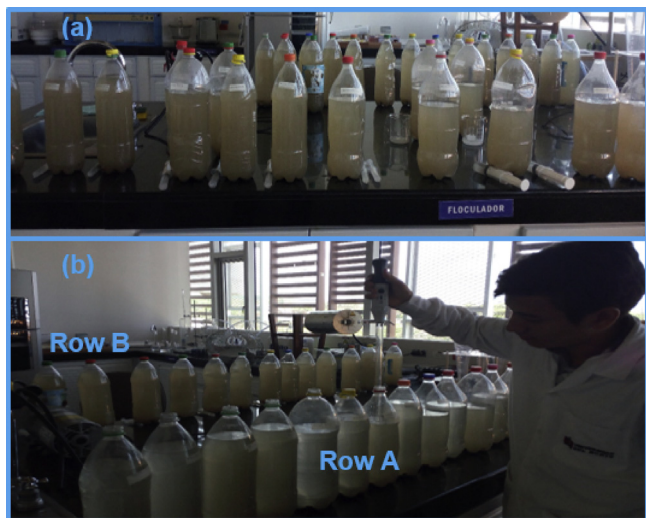


Figure 3. Coagulation test. (a) Water samples before applying the coagulants. (b) Samples after applying the coagulant and sedimentation time; *Moringa* is in Row A and *Cañadonga* in Row B.

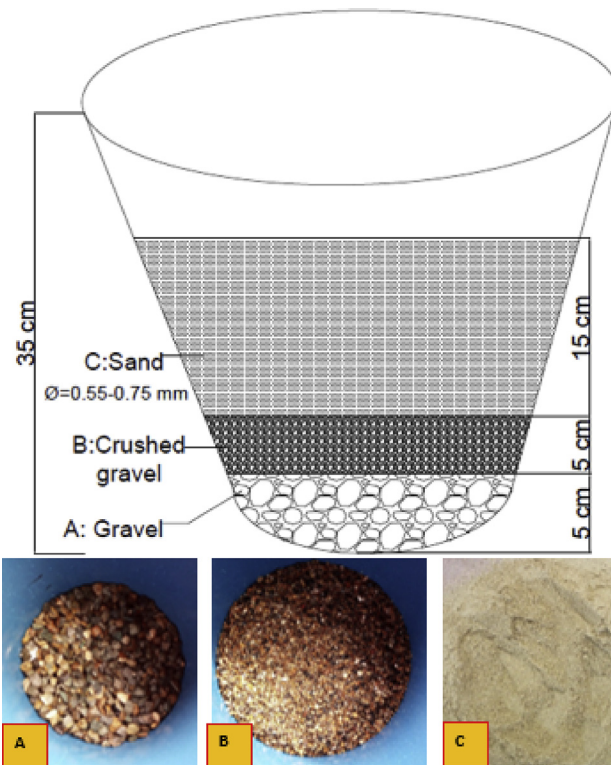


Figure 4. Biosand filter.

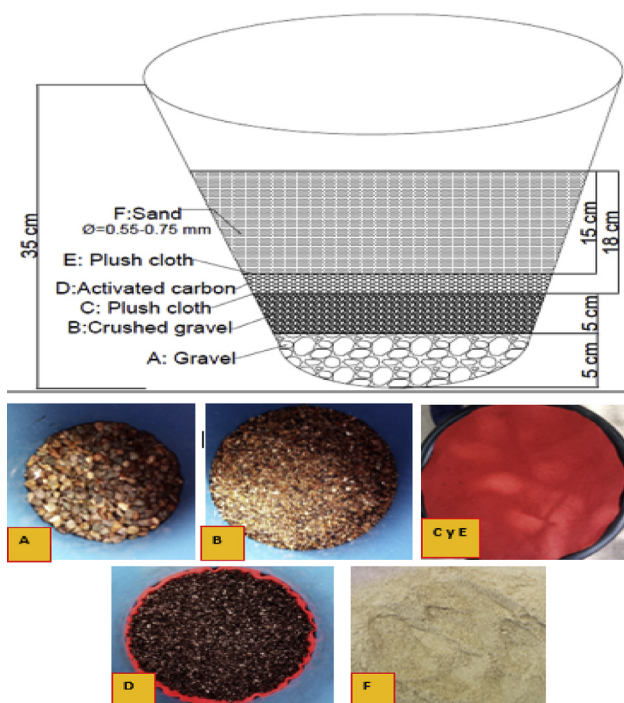


Figure 5. Carbon activated filter.

used during the experimentation period. When the filter operated, the valve at the bottom of the filtration tank was opened for the collection of water samples for the respective physicochemical and microbiological analysis.

The disinfection process through two different techniques, SODIS and UV-C lamps, combined with the two filters proposed after the coagulation-flocculation process, were studied. All of the processes were compared in the following order coagulation – flocculation, filtration and disinfection. A control without disinfection was used to evaluate both the combined treatment and the most efficient absorption (filters).

The UV-C lamp (CREATOR, model GPH150T5L) was obtained by the company Tecnoaguas S.A.S., together with a connection cable and a quartz protection tube. The lamp was installed in a PVC tube with a 3" diameter, 20 cm in length, which was sealed on the sides with 3" caps. Half-inch holes were made at the entrance and the exit of the water, putting a water control at the exit (see Figure 6). In SODIS technique, 2L plastic bottles were exposed to natural solar radiation for 8 h.

The efficiency of the filtration process was evaluated measuring the parameters of water quality described in the quality of the water evaluation phase (numeral 2.2.1). The efficiency of the disinfection processes



Figure 6. UV radiation device.

was determined by total Coliforms as defined. The removal percentage on water quality was calculated using the following equation:

$$Removal(\%) = \frac{Inicial\ value - Final\ value}{Inicial\ Value} * 100 \tag{1}$$

The removal, the performance of the filters and proposed disinfection techniques were compared using a mean comparison with Statgraphics centurion XV software (simple ANOVA test or Kruskal-Wallis, depending on the compliance of the ANOVA assumptions).

3. Results and discussion

3.1. Water quality evaluation

Table 1 presents the data obtained of the water quality parameters analyzed in four samples compared with Colombian laws.

The first two samples (23/03/2017 and 26/04/2017) were gathered at the surface water source, the Aguas Negras spout and in the storage tank where the water is distributed to the stilt-house towns, Nueva Venecia and Buenavista. The other two samples (4/05/2017 and 16/05/2017) are from the Aguas Negras spout before carrying out the proposed treatments.

Additionally, the table shows the limits permissible by Colombian law of safe drinking water quality (Resolution 2115/2007), which only applies to the treated water in the storage tank. The water in the Aguas Negras spout has high turbidity oscillating between 633 and 662 NTU, a variation that could be due to the effect of precipitation, given the highest value presented during the rainy season in the pond of the Aguas Negras spout.

The rain can cause erosion around the pond increasing the transportation of natural sediments. However, deforestation and land use can come into play in the high rates of sediment transportation (Lugo et al., 2019b; Restrepo and Escobar, 2016). An increase in rates of sediment transportation can negatively affect bodies of water when the sediment particles contain contaminants (such as pesticides), including microorganisms (Yao and Xu, 2013), which are also dragged through the surface and subsurface runoff (Schreiber et al., 2015). This could potentially explain the increase in microbial concentrations, in which the total coliforms varied from 6700 CFU/100ml during the dry season to 13700 CFU/100ml during the rainy season, given the existing association between precipitation and microbiological contamination in bodies of water (Kostyla et al., 2015).

3.2. Local natural coagulants

Variation in turbidity can be observed in Figure 7. The codes were used to identify the conditions of the coagulants. The letter indicates the coagulant, [M] for Moringa and [C] for Cañandonga. The first number represents the coagulant concentration, and the second number is the time of the fast mix, 1 (1 min) and 2 (2 min) of fast shaking.

Moringa achieved the best turbidity removal in the two lab tests with values between 91-96%, while Cañandonga achieved values of 52-70%. This result confirms what is presented in the literature that indicates that Moringa is one of the most employed natural coagulants in the world, presenting removals similar to chemical coagulants such as sulfate, aluminium, or aluminium polychloride (Betatache et al., 2014).

On the other hand, the optimal dose of Moringa was 150 mg/L in the two samples. A difference in the optimal time of the fast mix was found: in the first test it was 2 min and in the second, 1 min, obtaining turbidity removals of 96% in both samples. From the results it is inferred that the manual shaking (fast mix) affected the coagulation process because the manual shaking is not as constant as the mechanical shakers.

The optimal dose of Cañandonga was 25 mg/L in a fast mix time of 2 min in both samples, presenting removals of 70% and 67%, respectively. Although in the study carried out by Guzmán et al. (2015), turbidity

Table 1. Evaluated parameters of the water quality in the water source and distribution site in the stilt-house towns.

Parameters	23/03/2017		26/04/2017		4/05/2017	16/05/2017	Colombian Law (drinking water) 2115/2007
	Aguas Negras spout	Storage Tank	Aguas Negras spout	Storage Tank	Aguas Negras spout	Aguas Negras spout	
pH	7.22	7.16	7.18	7.23	7.12	7.43	6.5–9
Temperature (°C)	25.1	26.7	27.5	27.8	29.8	28.1	N/A
Conductivity (µS/cm)	174	188.1	234	208	345	205	1000
Turbidity (NTU)	633*	17.4*	650*	19.1*	645*	662*	2
Alkalinity (mg/L CaCO ₃)	71.6	52.8	85.8	61.8	65.4	52.8	200
Total hardness (mg/L CaCO ₃)	346.6*	332.8*	276.2	248.6	357.8*	330.8*	300
Chlorides (mg/L Cl ⁻)	42.54	60.97	49.63	56.72	61.68	42.54	250
Sulfates (mg/L)	27	29	33	36	58	57	250
Nitrates (mg/L)	0.7	0.6	1.6	1.4	2.1	1.3	10
Total coliforms (CFU/100 ml)	6700*	203*	8530*	122*	12100*	13700*	0

[*]: Non-compliance with the water quality parameter according to Colombian Resolution 2115/2007.

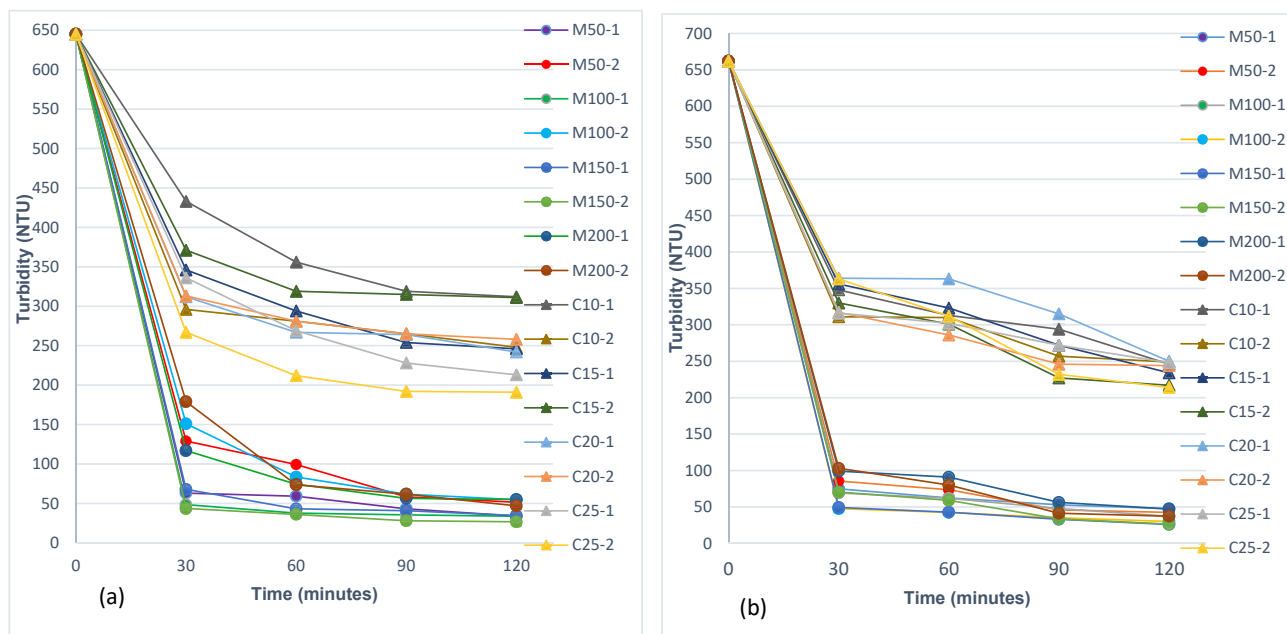


Figure 7. Turbidity variation at the time of sedimentation of the employed coagulants. (a) Turbidity in the first lab test. (b) Turbidity in the second test.

removals were up to 95%. The initial turbidity was less (120 NTU) than the collection source of the stilt-house towns (>600 NTU).

3.3. Determination of low-cost alternatives for filtration and/or disinfection processes

3.3.1. Efficiency of the employed filters (biosand and activated carbon)

The results of the two tests evaluated are shown in Table 2. The table also indicates the date of the sampling, the values of the measured parameters of the initial sample and the treatments with coagulant combinations, the employed filters and of the Colombian drinking water law (Resolution 2115/2007).

A removal in all analyzed water quality parameters is observed in Table 2. However, turbidity, total hardness, and total coliforms did not fulfill the potable water criteria defined by Colombian legislation.

3.3.1.1. Turbidity. The turbidity values after filtration varied between 6.9 and 11.7 NTU, as can be observed in Figure 8. These figures mean that the percentage of removals was between 68.8% and 98.4% (See Figure 9). The lowest turbidity removals were obtained in combination with the two filters evaluated and with Moringa as a coagulant, the values varied between 68% and 74%. The greatest water particle removal

was obtained with this coagulant during the coagulation-flocculation process, from 91% to 96%. It also presented the lowest turbidity values before filtration, and the range in variability after filtration was low in all samples (Figure 8). On the other hand, the highest removals obtained in raw water without coagulants were between 98.2% and 98.4%. Although the rates were high, the filtered water does not meet the criteria according to the standing Colombian legislation.

3.3.1.2. Total hardness. In the majority of the filtration tests in the second sampling, the total hardness was below the permissible limit. Only in two cases did it exceed the permissible limit during the second period of analysis, with percentages of 0.7% and 1.13%, which correspond to a 2.1 mg/L CaCO₃ and 3.4 mg/L CaCO₃ (see Figure 10). However, the total hardness removals were low, with the highest removal being 14% (see Figure 11). Of all the cases, the maximum value leaving the filters was 324.6 mg/L CaCO₃, which, although it exceeds the Colombian law, is within the tolerable range for some consumers (>500 mg/L CaCO₃) according to the WHO manual of drinking water quality. If we take this criterion into account, the exceeding levels for this parameter would not present a risk to the health of the inhabitants of the studied towns. On the other hand, low removals for this parameter are expected, since other processes or techniques are required, such as: cationic exchange (cationic

Table 2. Measured data of the water quality parameters after the filtration versus the initial simple.

Coagulant Filter type	Initial sample	Optimal Moringa		Optimal Cañadonga		Without coagulants		Colombian law: Resolution 2115/2007	
		Biosand filter	Activated carbon filter	Biosand filter	Activated carbon filter	Biosand filter	Activated carbon filter		
First sampling (4/05/2017)	pH	7.12	7.04	6.85	6.65	7.02	6.93	7.1	6.5–9
	Temperature (°C)	29.8	29.5	29.4	29.7	29.6	29.6	29.5	N/A
	Conductivity (µS/cm)	345	341	339	290	312	291	314	1000
	Turbidity (NTU)	645	7.7	6.9	9.1	8.8	11.2	10.2	2
	Alkalinity (mg/L CaCO3)	65.4	57.62	54.41	52.98	61.47	63.92	59.64	200
	Total hardness (mg/L CaCO3)	357.8	315	307.6	324.4	318	322.4	324.6	300
	Chlorides (mg/L Cl-)	61.68	42.54	49.63	35.45	42.54	28.38	35.45	250
	Sulfates (mg/L)	58	35	26	57	52	46	41	250
	Nitrates (mg/L)	2.1	1.9	1.5	2.1	1.8	2.1	1.9	10
	Total coliforms (CFU/100 ml)	12100	3100	2800	3500	3800	5200	4300	0
Second sampling (16/05/2017)	pH	7.43	7.39	7.49	7.3	7.31	7.41	7.4	6.5–9
	Temperature (°C)	28.1	28	27.9	27.8	27.7	27.6	27.4	N/A
	Conductivity (µS/cm)	205	199.94	203	201	200.1	203.1	204	1000
	Turbidity (NTU)	662	8.1	7.5	10.2	7.9	11.7	10.6	2
	Alkalinity (mg/L CaCO3)	52.8	46.8	48.3	50.8	52.8	52.8	52.7	200
	Total hardness (mg/L CaCO3)	330.8	293.8	289.3	302.1	286.2	295.4	303.4	300
	Chlorides (mg/L Cl-)	42.54	35.27	31.9	32.36	29.45	42.54	39.43	250
	Sulfates (mg/L)	57	57	48	56	41	57	53	250
	Nitrates (mg/L)	1.3	1.1	0.9	1.2	1.1	1.3	1.2	10
	Total coliforms (CFU/100 ml)	13700	3800	3400	4200	4600	6300	5200	0

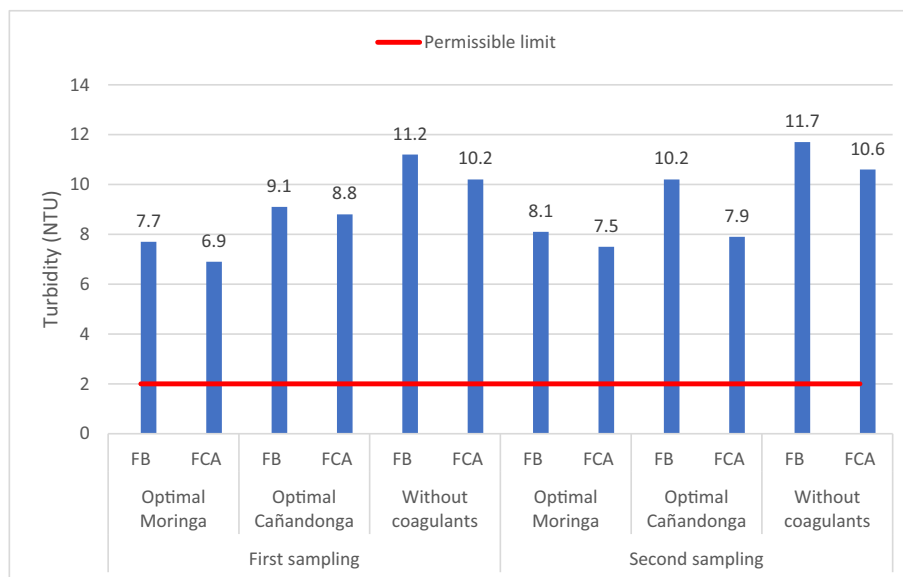


Figure 8. Turbidity variation after filtration.

resin) and softening by precipitation (addition of lime, lime and sodium carbonate or sodium hydroxide) (AWWA, 1999).

3.3.1.3. Total Coliforms. The lowest values of total coliforms after filtration were found in the treatment with Moringa and the two filters, varying between 2800 and 3800 CFU/100ml. The highest values after filtration but without natural coagulants were between 4300 and 6300 CFU/100ml (see Figure 12). The efficiencies in the total Coliforms elimination varied between 54 and 76.9% (see Figure 13), the filtration after the coagulation process using Moringa being the most efficient. This can be explained because approximately 30% of bacterial pathogens in

the water were eliminated during the coagulation process, and an estimate of 50% during filtration process. Therefore, greater reduction in pathogens can be expected in the combination of the two processes (WHO, 2008).

Moreover, applying the comparison of means (ANOVA) or medians (Kruskal-Wallis), there was no statistically significant difference of 0.05 between the reduction of critical parameters evaluated, between the two filters studied and the integration with the coagulation process (natural coagulants). Therefore, it can be concluded that the filters performed at similar levels with a 95% confidence level in terms of the obtained value of the parameters after the filtration process (See Table 3).

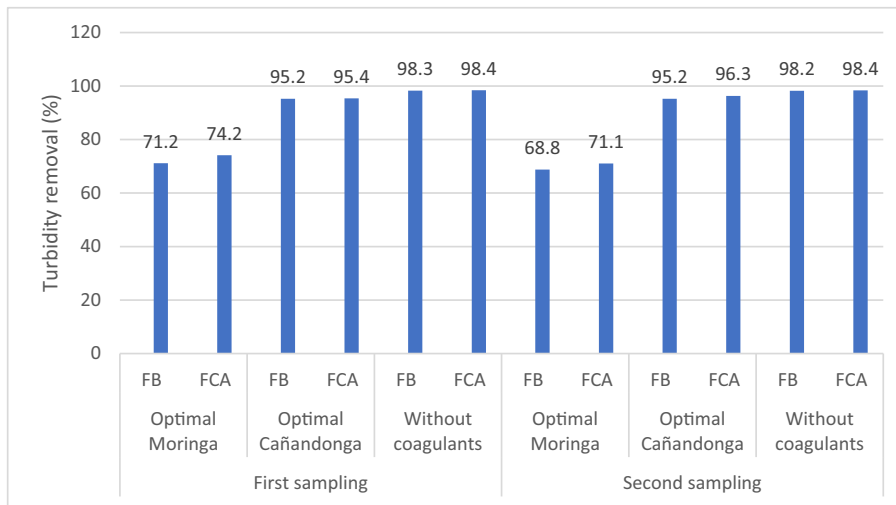


Figure 9. Turbidity removal after filtration – [FB]: Biosand filter, [FCA] – Activated carbon filter.

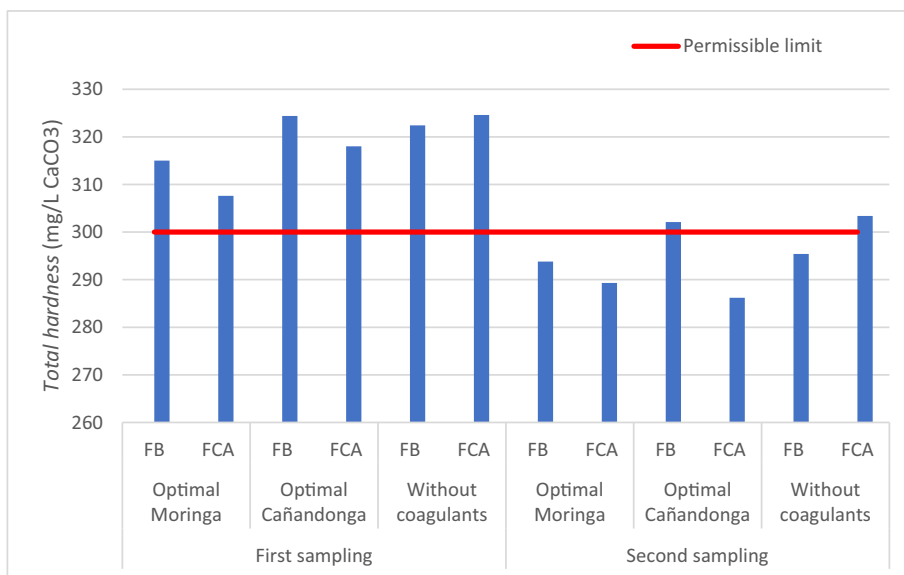


Figure 10. Total hardness variation after filtration.

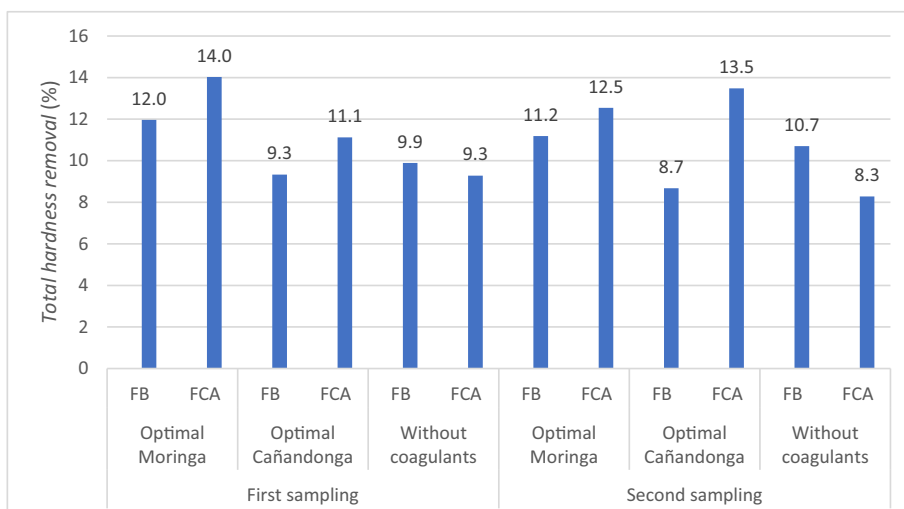


Figure 11. Total hardness removal after filtration.

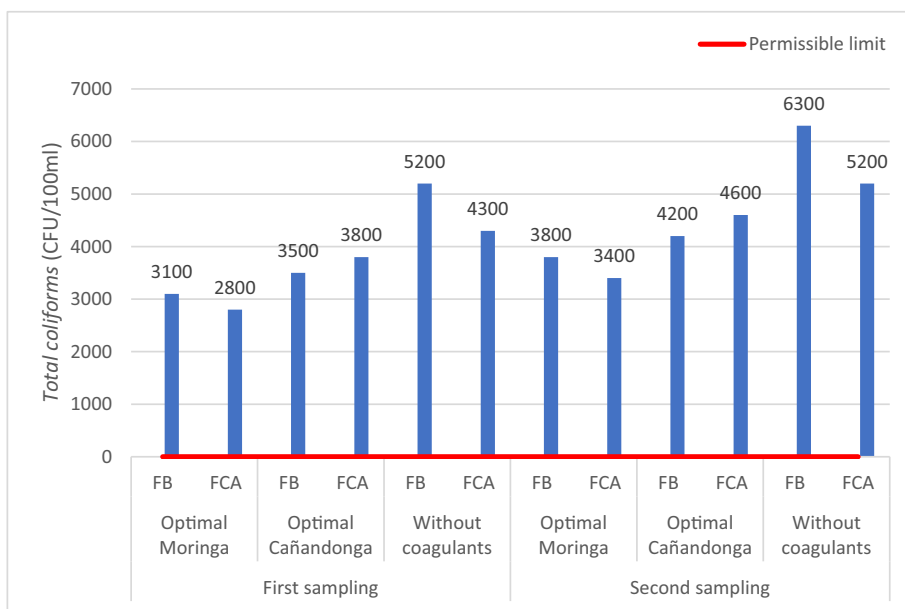


Figure 12. Total coliforms variation after filtration.

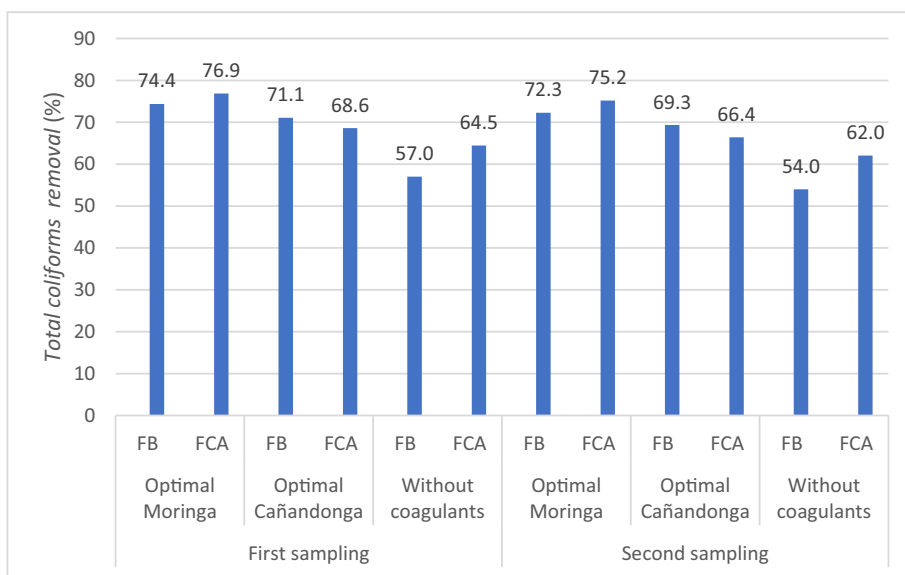


Figure 13. Total coliforms removal after filtration.

3.3.2. Efficiency of UV lamp and SODIS

Table 4 shows the values of the analyzed microbiological indicator. The influent data corresponds to the processes carried out before the disinfection and the effluent data corresponds to after the disinfection.

Table 3. The comparison between filters and combinations of filters with coagulants of the average of median of the evaluated parameters were considered most important.

Comparison	Parameters	Test	P-value
Filters (Activated carbon and biosand)	Turbidity	ANOVA	0.288
	Total hardness	ANOVA	0.641
	Total coliforms	ANOVA	0.18
Natural coagulant - filter combination	Turbidity	Kruskal-Wallis	0.103
	Total hardness	Kruskal-Wallis	0.761
	Total coliforms	Kruskal-Wallis	0.227

The total coliforms concentrations were above the maximum permissible level. The levels below 100CFU/100ml represented the highest removal in the coagulation, filtration, and disinfection combined processes. Total coliforms removals during filtration were up to 97% and 98.8%. This is meaningful in order to reduce the risk of diseases from consumption of water with pathogen presence from the stilt-house villages studied. As opposed to studies carried out by Muñoz et al. (2014), and D'Alessio et al. (2016) that found removals of approximately 100%, in this study those efficiencies were not achieved perhaps because the filtered water did not end up completely clarified, which can come into play in the decreased efficiency of the elimination of pathogenic microorganisms in the water treated with SODIS and UV-C radiation.

Table 5 summarized ANOVA applied with a 95% confidence level using Statgraphics centurion XV for the comparison between the averages of total coliforms measured after the SODIS and UV radiation treatment, finding that the efficiency of the elimination did not vary significantly with a 95% confidence level. This indicates that both the

Table 4. Total coliforms after filtration versus the filtered water sample.

Sampling			First sampling (4/05/2017)			Second sampling (16/05/2017)		
Coagulant	Type of filter	Disinfection technique	Total coliforms (CFU/100 ml)			Total coliforms (CFU/100 ml)		
			Influent	Effluent	Removal (%)	Influent	Effluent	Removal (%)
Optimal Moringa	Biosand filter	SODIS	3100	57	98.16	3800	73	98.08
		UV radiation	3100	43	98.61	3800	56	98.53
	Activated carbon filter	SODIS	2800	51	98.18	3400	58	98.29
		UV radiation	2800	33	98.82	3400	41	98.79
Optimal Cañandonga	Biosand filter	SODIS	3500	71	97.97	4200	92	97.81
		UV radiation	3500	45	98.71	4200	79	98.12
	Activated carbon filter	SODIS	3800	55	98.55	4600	82	98.22
		UV radiation	3800	51	98.66	4600	71	98.46
Without coagulants	Biosand filter	SODIS	5200	87	98.33	6300	95	98.49
		UV radiation	5200	73	98.6	6300	84	98.67
	Activated carbon filter	SODIS	4300	78	98.19	5200	86	98.35
		UV radiation	4300	65	98.49	5200	93	98.21

Table 5. Total coliforms comparison (after the disinfection) between SODIS and the UV-C radiation.

Comparison	Parameters	Test	P-value
Disinfection (SODIS and UV-radiation)	Total coliforms	ANOVA	0.09

SODIS and the UV-C radiation had similar performances in the total coliforms reduction from the water source analyzed in this work.

4. Conclusions

Moringa was always more efficient than cañandonga as a natural coagulant of the applied dose (doses of 50, 100, 150, and 250 mg/L). The optimal dosage was 150 mg/L with an average turbidity removal of 96%, while Cañandonga had an average of 69% turbidity removal and an optimal dose of 25 mg/L with an average of 69% turbidity removal. On the other hand, these optimal concentrations of both natural coagulants did not alter the pH, which was found to be within the permissible range of safe drinking water quality defined in the Colombian resolution 2115/2007.

Keeping in mind that the optimal dose of Cañandonga was the greatest concentration applied (25 mg/L) to the appropriate raw water from the studied surface source, it is recommended that in future investigations greater concentrations than those within the utilized range are tested for this coagulant; which could increase the efficiency of the suspended material removal from the water, improving the water quality in the coagulation process.

Furthermore, the lowest turbidity value was 6.9 NTU and the greatest was 11.7 NTU after filtration through activated carbon and biosand. However, both values surpassed the standing Colombian law for this parameter, which establishes the permissible limit as <2 NTU. Additionally, comparing the performance of the filters, through the ANOVA or Kruskal-Wallis test, it was determined that the average final values of the parameters: turbidity, total hardness, and total coliforms were no different. Therefore, it can be concluded that both filters operated with the same efficiency of removal at 95% confidence level.

Both, SODIS and UV radiation techniques had an efficiency removal of 99%, for total coliforms (values below 100CFU/100mL).

Even the high removal in the analyzed parameters, the treated water was still not considered safe drinking water according to Colombian law. These efficiencies could potentially reduce the risk of diseases caused by contaminated water consumption in the stilt-house villages studied (Nueva Venecia and Buenavista). However, to confirm this hypothesis, we recommend carrying out other studies in order to apply the described techniques evaluated along with the rates of diarrheal diseases in the relevant population.

Declarations

Author contribution statement

José Lugo-Arias: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Javier Burgos-Vergara: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Elkyn Lugo-Arias: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Audrey Gould, David Ovallos-Gazabon: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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