Assessing the Water Quality in Costa Rica and Applicable Waste Management Techniques

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Abstract

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Costa Rica is a well-known tourist location with a variety of diverse biomes. According to the Costa Rican Embassy, Costa Rica actively works toward preserving these areas with 25% of its land being a reserve or national park. However, there is a lack of sewage management within the country. This could potentially be impacting the waters. Costa Rica has an underdeveloped sewage management system for the majority of its population when compared with the United States. This is a potential source of nitrate and phosphate contamination. Nitrates and phosphates can be harmful to humans and aquatic organisms. Untreated sewage can also be a route of access for fecal bacteria to get into the water, such as *Escherichia coli* (*E. coli).*

In this experiment, *E. coli* populations in Costa Rican rivers and streams will be measured and compared to U.S. standards set for public health. Nitrate and phosphate samples will be collected from these locations as well. Locations in the U.S. that tested similarly for the *E. coli,* nitrate, or phosphate contamination will be examined. Methods used to reduce pollutants in these contaminated areas will be discussed as they may have the potential to be utilized in Costa Rican waters. After considering the attainability of each method, a proposed plan to reduce water contamination in Costa Rica will be presented.

Introduction

Costa Rica is a diverse tropical country located in Central America. To keep the country pristine, its government supports environmental regulations and strives to produce cleaner energy. The New Economics Foundations voted Costa Rica as the greenest nation in the world, with 99% of its energy being produced by renewable resources [1]. Costa Rica has recently announced plans to become the first carbon neutral country by 2021 [2]. Its commitment to care for its environment is admirable and highly tenacious.

Figure One: The map above displays Costa Rica's location on a world map.

Costa Rica has also made bounds as a developing country. The nation has made many improvements in supplying its citizens with potable water. In 1992, 92% of its urban population had access to piped, potable water. Currently, 99% of its urban population has access to a piped water supply [3]. However, not all piped water supplied has been properly purified. A survey published by the Yale Tropical Resources in 2006 showed that illnesses from poor-quality piped water were common in rural residents in the watersheds of the Baru and Guabo Rivers and that the community-based organizations in charge of operating the systems lacked adequate support as well as appropriate expertise [4].

One of the keys to making cleaner water more attainable is ensuring contaminates never enter the supply. This is an area where Costa Rica struggles. Its waste management techniques are insufficient to handle the waste that the growing population creates. Approximately 250 tons of solid waste is dumped into rivers or onto streets [5]. Waste that is located in its rural regions may not even be picked up for disposal, which presents risks to those who may come into contact with it [6]. As a result of the lack of organized waste management, the litter becomes a large problem in the community. In 1991, the Costa Rican government was forced to call a state of national emergency over the waste to attempt to correct the pollution [7].

What could be more concerning, and possibly more hazardous, are Costa Rica's issues with providing and maintaining sewage treatment and disposal. "Water for Human Consumption and Sanitation," a study conducted in 2007, states that "In the case of human waste disposal, 67.3% of population used septic tanks; 20.1% used sewage systems *without treatment*; and 4.9% used sewage systems with poor treatment of sewage water. Furthermore, only 3.5% of excrement disposal by sewage systems is efficiently treated, and 3.4% use latrines" [8].

This data indicates that the majority of Costa Rica's residences are in charge of managing their own waste disposal systems. If a septic tank is improperly installed, waste may leak into water supplies and possibly contaminate ground water. Even with properly installed septic tanks, the U.N. has found that the Costa Ricans frequently disposed of the septic waste into the rivers [9]. Costa Rica's lack of proper waste management systems means that fecal matter could easily find its way into water sources.

Fecal contamination will predispose the water to bacterial colonization, such as *Escherichia coli* (*E. coli*). *E. coli* is an intestinal bacteria that can be introduced to the waters through waste contamination.

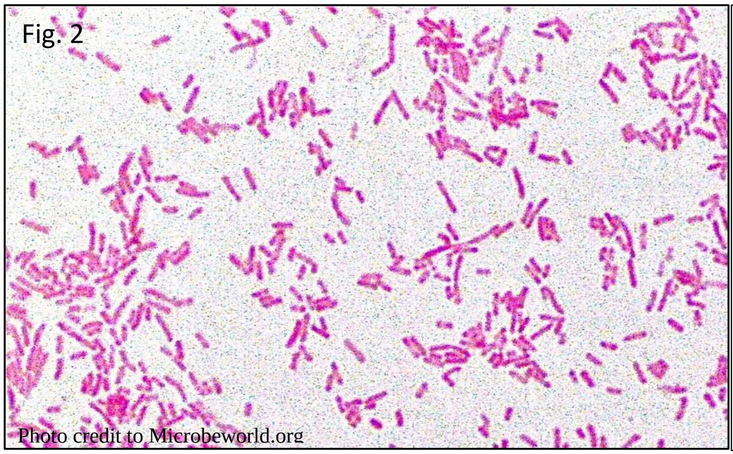


Figure Two:
E. coli is a gram negative rod shaped bacteria. This bacteria is capable of growing in aerobic and anaerobic environments. It also has the capability to synthesize pathogenic toxins. Many of these toxins can cause intestinal infections. However, it also is capable of living harmoniously in the gut.

E. coli is identified by the United States Environmental Protection Agency (EPA) as an acceptable way to measure the health risks of recreational waters as well as drinking water [10]. The EPA requires that all water for consumption be free of this bacteria. The side effects of ingesting *E. coli* include nausea, vomiting, diarrhea, and headaches. Very young children and the elderly are most susceptible to complications [11].

The Population Reference Bureau (PRB) states that children under five make up roughly 10% of the current global population and comprise more than 40% of the population that suffers from environmentally caused disease. Additionally, the PRB states that 80 to 90% of diarrhea is caused by environmental factors [12]. If not treated, diarrhea can lead to severe dehydration. It is also a leading cause of malnutrition, which leads to energy loss and poor immune responses. With these factors, diarrhea is the leading cause of death globally in children under five years old [13].

Bacteria isn't the only contaminant sewage can introduce into the water; sewage can also increase nitrate concentrations. According to the EPA, nitrate concentrations above 10mg/l have the potential to affect human health. Nitrates can affect the ability of the blood to transport oxygen, resulting in shortness of breath and a blueish tint to the skin. Nitrates also increase likelihood of bacterial disease [16].

Excess nutrients from sewage can also impact the environment. Nitrates stimulate the growth of algae; when the algae die, they leave decaying organic matter that depletes the oxygen from the water. This can smother the organisms within the water. This process is known as eutrophication. The Water Research Center (WRS) states that "fish may suffer a loss of equilibrium, hyper-excitability, increased respiratory activity and oxygen uptake, and increased heart rate" when nitrites taint their aquatic ecosystems.

The WRS places the lethal concentration for a variety of fish species from 0.2 to 2.0 mg/l [17]. Perdue University's School of Science lists the typical range of nitrates in standing waters between 0.9mg to 3.15 mg. In unpolluted waters, nitrates are less than 4.0 mg/L [16].

Raw dumping similarly increases phosphates. While these may not pose a danger to humans unless present in large quantities, phosphates present the same effects as nitrates regarding the eutrophication of the water. At 0.025mg/l-0.1mg/l concentrations, plant growth is stimulated. At concentrations greater than 0.1mg/l, the eutrophication of the standing water begins, and biodiversity may suffer [18]. The EPA water quality criteria states that the concentrations should not exceed 0.05mg/l if the stream discharges into lakes or reservoirs. In lakes or reservoirs, the EPA limit is 0.025 mg/l. Aquatic biodiversity in Costa Rica may suffer if waste water pollution continues.

Untreated sewage doesn't just affect local streams. If waste is introduced into the water, it can find its way into the sea. The sea surrounding the small nation contains many fragile biomes, such as coral reefs. The majority of coral reefs are under threat. High levels of nutrients can increase the stress on their systems and cause them to fall out of balance. Once such reaction to an increased amount of nutrients in the water is the disruption of a symbiotic relationship that the coral has with the zooxanthellae. The zooxanthellae are a type of single-celled protozoan that normally provide oxygen and waste removal for the coral. In cases where there are increased nutrients in the water, the zooxanthellae no longer works harmoniously with the coral. Instead, the protozoan rapidly multiplies. Eventually, the coral ceases to grow as a result of the disruption [18].

In recent years, the government has been prompted to act upon the raw dumping. In 2007, the Costa Rican government passed a law to cease raw sewage dumping into the Rio Grande De Tarcoles [19]. This river runs to a beach city with many sightseeing attractions. Since beaches are a high revenue asset for the country, more effort will be taken to keep them clean. Costa Rica has shown that it will act to preserve its tourism economy.

On the community level, there are initiatives being enacted. Education is being provided in many of the public schools to promote better waste reduction and management. One of the programs in the schools is the Ecological Blue Banner Program (EBBP). This program has several emphasized points: Costa Rica is to be carbon neutral by the year 2021; proper management of waste is paramount; social environmental projects are to be given priority; conservation of energy and water is important; there is a requirement for clean and safe spaces, including adequate restroom facilities [15].

These points, as well as the creation of the EBBP, seem to be evidence of an awareness for the need to improve waste management.

Currently the newest legal work focuses mostly on management of their solid waste production, with the Nationally Appropriate Mitigation Action ordinary solid waste plan. This plan is sponsored by the Center for Clean Air Policy. It aims to promote recycling and cut down methane gas generated by waste [14]. Unfortunately, no concrete plan exists for the improvement of wastewater management for the majority of the populace.

The people and the environment will continually be exposed to a possible vector of disease until a solution is found that addresses issues with the water supply and sewage treatments. These illnesses could be prevented if more effort was directed into maintaining a better sewage disposal system.

Costa Rica needs to be proactive in reducing contamination. Even the simplest of treatments can help clean the sewage that is introduced into their waters. While the country has developed much within the last decade, it still doesn't have the infrastructure to manage a large scale waste treatment system. Smaller scale alternative solutions are a much more applicable route for this developing country. This is what I aim to help establish in my experiment.

The first objective of my experiment is to measure water purity by assessing the quantity of nitrates, phosphates, ammonia, and E. coli present. Sampling in various locations will identify if the waters carry harmful elements. Samples will be taken near attraction areas and routes commonly toured, as Costa Rica has shown that they will act to preserve their tourist economy.

Once these results are established, the second aim of this experiment is to determine what waste management techniques could be successfully implemented into Costa Rica. Since many ecological and health motivations fail to stimulate the Costa Rican government to create an aggressive plan to tackle the widespread waste management issue, the proposed solution must be able to be implemented at a household or community level. The waste management solution must address the contamination found in the results and be effective at reducing it. The treatment method(s) must be low in cost, be carbon neutral or negative, be smaller in scale, and be able to be maintained by the average household or community with limited training or skill.

The Costa Rican government has a commitment to providing structure to the growing population, yet its current waste treatment system shows a lack of organization. While some initiative is being taken through EBBP education, there needs to be a structure or a plan in place to ensure that its populace has a safe way to manage waste. The current system will lead to a lack of water sanitation that will expose its population to risks of disease and potentially decrease environmental health. This experiment can help establish the relative state of the waters and propose a solution to increase the health of the water source.

Methodology

I chose the sampling locations due to their close proximity, 100 ft. or less, to tourist attraction or commonly travelled tourist routes. In addition to this criteria, they had to be safely accessible by foot and have freely flowing water. No samples were taken from locations that had experienced rain within the last thirty minutes. Once I was at the selected locations in Costa Rica, photos and GPS coordinates were taken. Possible sources of contamination (open pipes, drainage tunnels, pastures) were noted if applicable.

I filled a small sterile container with water from the location, after triple rinsing it in the stream. In locations were I was unable to perform immediate testing, the water was stored in its sampling container and then tested within two hours of its collection. I accessed the nitrates, phosphates, ammonia, and pH levels from the samples using the Master Liquid Test Kit. To test for *E. coli,* I inoculated 3M *E. coli* petri films using a pipette filled with 1mL of sample water.

I then incubated the samples with the Revolutionary Science Incufridge for 24hrs to 36hrs to grow the colonies to a visible size. *E. coli* colonies were counted on each petri-film and recorded. I determined the significance of each sample by comparing it to the Environmental Protection Agency's standards for swimming and drinking water.

The EPA states that there cannot be any *E. coli* forming colonies in a 100ml sample if the sample is taken from drinking water. In recreational waters, samples taken on average must have less than 126 *E. coli* per 100ml. However, if a single sample from a location exceeds 235 colonies, then the EPA deems it unsafe and recommends infrequent visitation of that water source. Waters that exceed the single sample limit are recommended to be avoided to reduce risks to health.

As single 1ml sample was taken, locations with samples that exceed the average of 2.35 colonies will be deemed significant for this research project. All culture results were recorded, then marked as pass or fail for EPA standards. Phosphates above concentrations of 0.025mg/l are capable of stimulating plant growth. Nitrates at concentrations greater than 0.2 mg/l can impact aquatic species. Samples above these nutrient concentrations were deemed significant and marked as failing EPA standards. Correlations between the nutrients and bacteria were observed. Upon return from sample collection, I created a physical and electronic map with all sampled locations.

In addition to reporting the sampled data, I researched local areas that faced similar nitrate, phosphate, or *E. coli* contamination. I then examined their treatment plans. From these, I described the methods used to reduce *E. coli* counts, nitrates, and phosphates. After determining the obtainability of the methods for the average Costa Rican household or community, an applicable sewage or water purification/preservation plan was made. The suggested treatment options were assessed based on their relative ease of installation, as well as their potential costs and benefits. Ideas to promote and implement the treatments were included in the research.

Equipment Used:

Carolina™ Laboratory Pipette, 100 to 1,000 µL, Micropipette Tips (sterile), 100-1,000 uL, Rack 100, Discovery MX10 Professional Revolutionary Science Incubator, Pond Care Master Liquid Tester Kit, Dixie Cups (single use), triple rinsed sample collection bottle, E. coli Petri film plates 6404 3m, Garmin GPS 72H, digital camera.

Map of Locations Sampled

Figure Three: The map above displays numbered locations that are linked to the data points of the results table. All numbers correspond to the order that the locations were sampled.

Location One (10°10.341', 84° 29.881') **May 13th 2015**

This sample site was within close proximity of a tourist rest stop in Los Angeles. Upstream from the collection area was a small village. Downstream from the sampled area was a field of crop. There was an open pipe discharging water from the village less than 20 ft. upstream from this location, as well as free range chickens. The pH was at 5.0. Ammonia was assessed at 0.35ppm. There were no detectable levels of nitrates or phosphates. The average *E. coli* on each petri-film was 11.67 colonies. This location fails EPA standards for *E. coli*.

Location Two: (10°22.573', 84°32.216') **May 13th 2015**

This location was a large river under an active roadway. It was along the route toward the University of Costa Rica. There was a road down to the river bed where the samples were taken. Upstream and downstream from this location was dense rain forest. The pH was assessed in at 6.8, and the ammonia level was at 0.75 ppm. The phosphate concentration was 0.1ppm. There was no detectable levels of nitrates. The average *E. coli* on the petri-film was 1.33. This location fails EPA standards for phosphates.

Location Three: (10°26.394', 84°40.105') **May 14th 2015**

This location was at La Fortuna waterfall. This scenic waterfall is frequented by many tourist. It allows tourist to swim in the waters downstream. The waterfall came down from a dense forest and into a small river. This location had a pH of 6.8. Its ammonia was tested at 0.25ppm. There was no detectable levels of nitrates or phosphates. The average *E. coli* colonies grown for each culture was 0.33. This location is safe by EPA standards.

Location Four: (10°30.138', 84°35.483') **May 15th 2015**

This location was near a commonly traveled highway. Houses were within 100 ft. of the stream. Upstream appeared to be mostly rainforest, downstream was roadways. This location had a pH of 7.8, and an ammonia level of 0.5ppm. It had a phosphate concentration of 0.25ppm. No nitrates were detected. The average *E. coli* colonies for each petri-film was 6.33. This location fails EPA standards for phosphate and *E. coli.*

Location Five: (10°27.156', 85°07.765') **May 16th 2015**

This location was a river that contained a white water rafting attraction upstream. It also was within meters of a highway, as well as a rest stop. These were both located downstream. The pH was tested at 7.5. The ammonia level was 0.25ppm. There was no detectable levels of nitrates or phosphates. The average *E. coli* was 0.33 colonies. This location is safe by EPA standards

Location Six: (10°20.871', 84°51.893') **May 16th 2015**

This location was along a commonly traveled route toward Monte Verde, a tourist hot spot. The land around the stream appeared to be fields of crop. The location had a pH of 7.3, and no detectable levels of ammonia or nitrates. The phosphate concentration was 0.1ppm. The average *E. coli* was 31 colonies. This location fails EPA standards for phosphates and *E. coli*.

Location Seven: (10°20.505', 84°48.279') **May 16th 2015**

These samples were also taken from an area off the route to Monte Verde. There were several wandering animals near this location, suggesting that the surrounding field was mostly used for agriculture. There was also was loosely strung barbed wire around the creek. Its pH was 6.8, and its ammonia concentration was 0.25ppm. No nitrates or phosphates were detected. The average *E. coli* for this sample was 1.67 colonies. This location passes EPA standards.

Location Eight: (10°18.577', 84°48.717') **May 16th 2015**

This location was in the city limits of Monte Verde. It was very close to a road used from transportation around the area, as well as a foot path. Upstream was dense vegetation, downstream was a tunnel beneath a road. Its pH was 6.6. Its ammonia level was 0.25ppm. There was no detectable levels of nitrates or phosphates. The average *E. coli* colonies on each Petri film was 23.33 colonies. This location fails EPA standards for *E. coli*.

Location Nine: (10°12.924', 84°51.074') **May 17th 2015**

This location was a large river that was located near the continental divide. It was along a route that traveled through the dry forest. Upstream was mostly forest, downstream passed by several houses. Its pH is 7.4, and its ammonia level was 0.1ppm. Phosphates were detected at 0.25ppm. No nitrates were detected. The average *E. coli* colonies grown was 4.67. This location fails EPA standards for phosphate and *E. coli*.

Location Ten: (10°09.276', 84°51.106') **May 18th 2015**

This location was in an area had decrease in expected rain due to El Nino. The area around this location seemed to be used for animal agriculture, as there was barbed wire around the water source. The pH for this location was 7.8. Ammonia and Phosphates showed concentrations of 0.25ppm. No nitrates were detected. The average for the *E. coli* cultures was 3.33. This location fails EPA standards for phosphates and *E. coli*.

Location Eleven: (10°03.560', 84°45.488'**)** **May 18th 2015**

This location was a roughly a 100 ft. walk from a tourist bus stop. There was a maintained trail down to the water source. Upstream passed beneath a road way, downstream flowed mostly into field. Its pH was 7.8. There were no detectable levels of nitrates, phosphates, or ammonia. There was an average of 2.33 E. coli colonies grown on each petri film. This location passes EPA standards.

Location Twelve: (09°34.285', 84°31.803') **May 19th 2015**

This location was along the route to Manuel Antonio, a beach tourist location. The location was also within a mile a quarry. There was a trail with vehicles tracks down to the riparian zone. The pH was 7.9. The ammonia and phosphates both had concentrations at 0.25ppm. There was no detectable levels of nitrates. The average *E. coli* was five colonies on each plate. This location fails EPA standards for phosphates and *E. coli*.

Location Thirteen: (09°31.522', 84°08.851') **May 19th 2015**

This location was a small creek that traveled behind several hotels. The sampling location was downstream from the hotels, as there was an existing footpath down in this area. Manuel Antonio National Park was within half a mile of this location. The pH was 7.5. Ammonia concentration was 0.25ppm. Phosphates were detected at 0.3ppm. There was no detectable levels of nitrates. The average *E. coli* was 78.33 colonies on each petri-film. This was the highest of all the locations in regards to number of *E. coli* colonies grown. This location fails EPA standards for *E. coli* and phosphates.

Location Fourteen: (9°46.671', 84°36.411') **May 20th 2015**

This location was a small stream that was along the route to Le Selva. The location was within meters of a commonly traveled tourist route. Upstream and downstream was dense vegetation. Its pH was 8.0, and its ammonia concentration was 0.1ppm. Its phosphates concentration was 0.25ppm. No nitrates were detected. An average of six *E. coli* colonies were cultured on each petri-film. This location fails EPA standards for phosphates and *E. coli*.

Location Fifteen: (10°27.227', 83°59.483') **May 22nd 2015**

This location was taken from a large stream near a banana plantation that was commonly toured. It was downstream from this location. It was also near Le Selva Research station, as well as a small village. Its pH was 6.5. Its ammonia and phosphate concentration was at 0.25ppm. No nitrates were detected. There was an average of 4.33 *E. coli* colonies grown on each petri-film. This location fails EPA standards for phosphate and *E. coli*.

Location Sixteen: (10°25.863', 84°00.219') **May 22nd 2015**

These samples were taken from the Rio Puerto Viejo on Le Selva research station. This river was surrounded by a dense rainforest. Le Selva is considered a tourist attraction as it gives regular tours and provides accommodations for visitors. The sampled water's pH was 6.3, and both its ammonia and phosphate concentrations were 0.1ppm. No nitrates were detected. The petri-film on average grew 11.66 *E. coli* colonies. This location fails EPA standards for phosphates and *E. coli*.

Location Seventeen: (10°26.061', 84°00.495') **May 22nd 2015**

This sample was taken from a small creek along a rainforest trail on Le Selva's property. Its pH was 6.0, and its ammonia concentrations were 0.1ppm. There was no detectable levels of phosphate or nitrates. An average of four *E. coli* colonies was grown on each petri-film. This location fails EPA standards for *E. coli*.

Location Eighteen: (10°26.211', 84°00.597') **May 22nd 2015**

This location was yet another small stream along a rainforest trail in Le Selva. Its pH was 6.2. Its ammonia concentration was assessed at 0.25ppm. There was no nitrates or phosphates detected. On average, each petri-film grew 3.5 *E. coli* colonies. This location fails EPA standards for *E. coli.*

Summary of Results:

Thirteen of the eighteen locations sampled did not meet the recommended standards for water quality. The nine out of the thirteen failing locations had high concentrations of both phosphates and *E. coli*. No nitrates were detected at any locations.

Discussion:

One thing that was noted in this study was that there was no detectable level of nitrates in the water. However, ammonia, a chemical that can be synthesized into nitrate, was present at multiple sample locations. Ammonia is toxic to aquatic life and is typically transformed into nitrate by bacteria. Since nitrate is not present in detectable amounts, this may indicate the occurrence of fast nutrient cycling. It is possible that the nitrate is being quickly absorbed by plants, as the locations samples are dense and diverse in plant population. This density would lead to a high level of competition for nutrients.

If there is a high level of nutrient uptake, it is unusual that phosphate was present in above recommended levels in the results. This could be because phosphorus exists in excess while nitrates act as a limiting reagent. With human waste, there is roughly ten times the amount of nitrites/nitrogen/ammonia compounds than phosphorus containing compounds. Thus, there may be another unknown source of phosphorus compounds. However, these results do not discredit the hypothesis of waste in the water.

Areas that were higher than EPA recommended limits for phosphate were also highly likely to be above EPA limits for *E. coli.* No significant correlations were determined between the nutrients sampled.

The collected data also show that *E. coli* is present in the water at above EPA levels (235 cultures/100 mL). Only 33% of locations sampled were within the EPA's guidelines. For example, several locations were more than five times the limit for culture counts. One culture count revealed as much as 7,800 *E. coli* colonies per 100 mL. This culture was taken from a stream just meters from a tourism hot-spot with a noticeable footpath through it. *E. coli* counts this high most likely have some form of human influence.

In the United States, locations with high *E. coli* levels would be closed to the public or placed on the 303(d) list by the EPA. The 303(d) list is composed of ground water sources that do not meet the criteria set forth by the EPA. Some bodies of water in Joplin, Missouri that were placed on this list include the following: Jones Creek, Center Creek, and the Spring River. Once on the 303(d) list, a committee is formed to formulate solutions to reduce the pollutants in the water. If a location has a traceable source of contamination (point-source pollution), dumping limits are put on that source. If it is a non-point pollution (pollution due to an untraceable contaminate or agriculture), a general two-pronged approach is applied.

The first part of the two-pronged approach is to prevent local agriculture from impacting the streams. With livestock operations, it is important to prevent the animals from wading into the streams. Manure bins or piles should be kept a reasonable distance away from a water source. Manure should only be spread as fertilizer when chances of heavy rain are low. This prevents accidental run-off contamination.

In both animal and crop operations, a zone of dense native trees and vegetation is also highly recommended around the water source. This is called a riparian zone buffer. This buffer should be between 25 to 100 feet. While the buffer does take away a small portion of the agriculture, it’s mostly beneficial to the farmer. This buffer can reduce the amount of run-off ground water. That means the top-soil fertilizer is more likely to stay where it is needed and less money has to be spend reapplying it. The buffer also keeps these nutrients from entering the stream. A good riparian buffer can remove up to 80% of excessive nutrient inputs [20].

This riparian buffer vegetation also acts as an anchor for the soil, preventing the erosion of the land. When an area receives a high volume of rain, the buffer helps slow the flow of the water. This can help reduce flood damages downstream. The practice of maintaining a riparian zone buffer is increasing in popularity in the United States and can be easily applied in any location.

To begin cultivating the riparian zone, avoid mowing or altering the land around the stream. Pioneer plants, which are the first plants to grow in a previously disrupted ecosystem, should appear in this area naturally. However, it is helpful to plant small native species that do well with a large amount of moisture in the water. Elephant Ears, or *Xanthosoma*, are an example of this type of plant. Native reeds can also be spread directly alongside the stream bed. On the outermost edge of a riparian zone, trees should be planted. An ideal tree to install is the *cieba*. This genus of trees has been described as a pioneer species, and noted for its quick growth. The general rule of thumb is the more dense the vegetation, the more effective the riparian zone is as a buffer.

Fig. 4

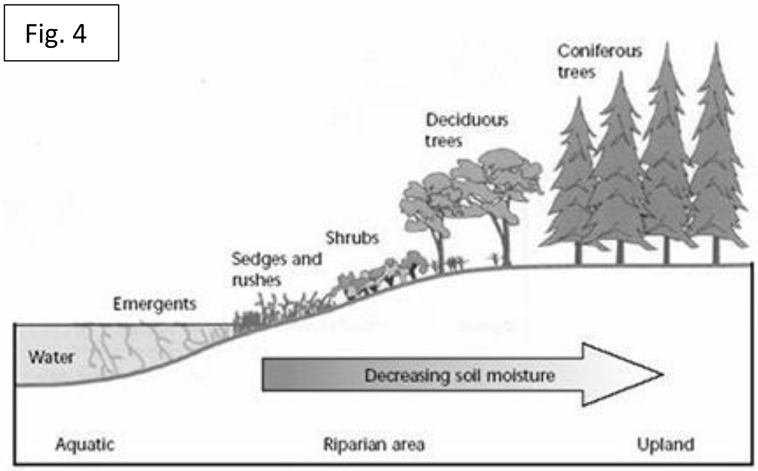


Illustration of the moisture gradient in a typical riparian ecosystem (from Stevens et al. 1995:2).

Figure Four: This image depicts the typical layout of a natural riparian zone. Small plants, such as reeds, reside in the border of the stream bed. Smaller shrubs are planted close to the shore line. At the highest flood mark, trees are planted to help hold the soil. Coniferous trees or native grass is planted directly upland from the riparian zone. Adjacent to this area is land in active use.

The second part of the two-pronged approach is to make sure all homes that are close to the stream have septic tanks that are properly installed and maintained. However, some areas may not be suitable for septic tanks. Septic systems do not properly function when they are built in locations with high groundwater tables because underground water tends to sweep waste into above ground water sources. Systems that are buried too shallow limit the soils ability to neutralize the waste.

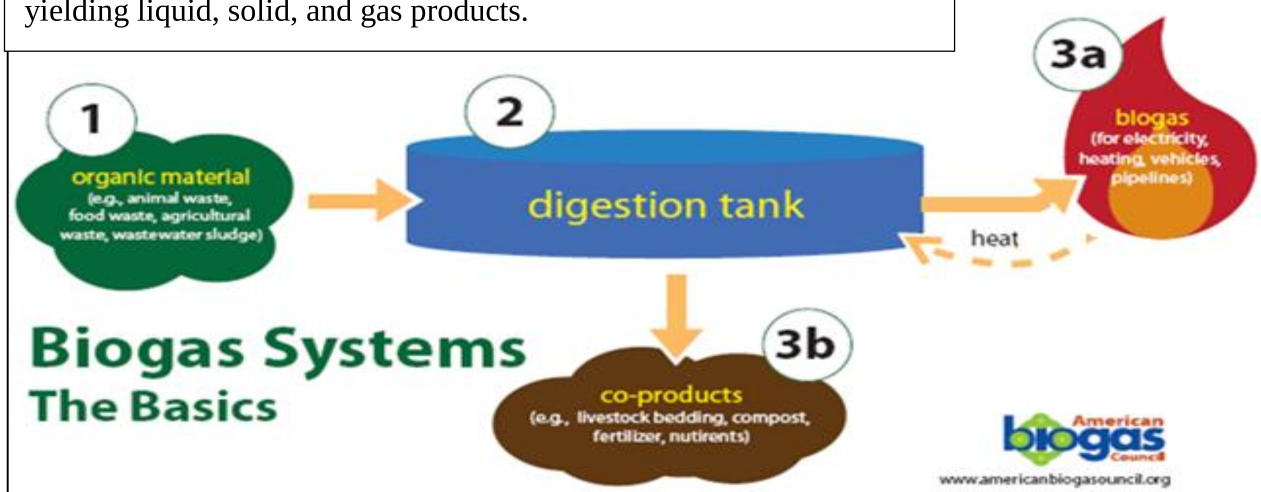
If the area is suitable for septic tanks, regular maintenance must occur to prevent problems. Upkeep of older systems and the recommended pumping every five years for all systems can add up to heavy costs. While it is feasible in the United States, it isn't always in a budget of a household in a third world country. However, there is another waste management system that the University of Georgia calls "a more environmentally friendly alternative to septic tanks and water treatment plants" [21].

This system is called anaerobic bio-digestion (AD). Anaerobic bio-digesters are sealed containers that use bacteria to decompose waste. According to the Michigan Department of Agriculture's (MDA) Environmental Stewardship Division

> [Anaerobic bio-digesters] work similarly to the natural decomposition that occurs in the stomach. The organic material is collected in an enclosed tank where it is degraded in the absence of oxygen by acid formers into fatty Feedstocks. Methane formers then converts the fatty acids into biogas [methane] [22].

Figure Five: This flow chart shows the inputs and the outputs of the anaerobic digester system. The unit takes raw waste and incubates it, yielding liquid, solid, and gas products.

Fig. 5



This biogas can be compressed and used as a source of natural gas. While the vast majority of communities of Costa Rica have access to electricity, many communities experience regular blackouts. Biogas could be used as a reliable source of power. It could also be ignited and used to heat water for those who do not have potable water, while yielding no cost to the individual. The Costa Rica initiative of green energy and reduced carbon footprint is also met by this source of energy.

On average, a small household will produce enough waste to create two hours of useable biogas from an AD. This gas can replace the energy that came from burning wood. Fewer trees will be cut down if wood is replaced by biogas. A household could also choose to collect and sell the biogas. This energy source is completely renewable and directly helps the household.

One of the caveats to the gas production of the AD is that while it would be produced with unaltered human waste, it would require higher carbon inputs to produce a *maximal* amount of biogas. ADs function most efficiently with a carbon nitrogen ratio of 25:1 to 30:1 [23]. Human feces tend to have a ratio closer to 8:1 while urine is closer to 1:12 [24]. In human waste, the ratio for the combined waste is roughly 1:1.6. For optimal gas production, an amount of carbon dense material-- such as shredded paper, sawdust, or dried vegetation-- would have to be inputted regularly.

Approximately 4.7 kg (10.4 lbs) of carbon dense material would be needed per person daily to add enough carbon to create an ideal ratio. While this seems high, keep in mind that Costa Rica is an agriculturally rich area. Using dried plant material as an additional input to the AD may provide a convenient way to dispose of this waste. In the urban areas, grass clippings, shredded paper, or compost piles can be added into the digesters. Once again, gas production and digestion would still occur at the natural carbon nitrogen ratio for feces, but for maximal potential, large amounts of carbon would need to be added. Treatment plants in the U.S. that use digesters do not add any additional carbon, as it is unneeded to digest the waste.

The anaerobic bio-digester also has another beneficial application: its liquid can be used as a fertilizer. According to the MDA, once the input is digested, it contains a plethora of valuable nutrients. These post-digester nutrients are in a form that is easily absorbed by crops. This makes them a high-value fertilizer. The MDA goes on to say that "the increased plant uptake also reduces the possibility of nutrient run-off into surface waters" [22]. Any fertilizer with a decreased chance of run off is an excellent perk in an agriculture rich community.

If a digester's sludge is not being used to fertilizer a garden or crops, a small lagoon may be built to reabsorb the excess nutrients. This lagoon would act as a tertiary treatment, removing excess nutrients. Reeds and other macrophytes are recommended plants for the lagoon. These plants help filter any excess nitrates and phosphates. One of the options to assist the lagoons in their uptake nutrients is to plant edible aquatic vegetation. Certain vegetation can be harvested and fed to cattle or pigs.

Another product of the post-anaerobic digester material is a solid referred to as bio-fiber. Bio-fiber can be dried and used for animal bedding or composted and sold as a high-quality soil amendment. The bio-fiber can also be used to create composite building materials [22]. Another benefit of the digester is that it reduces odor from the sewage.

However, the most important benefit of the digester is that it eliminates pathogenic bacteria. According to Penn State College, there is a 95% pathogen reduction using a twenty day retention time in a digester with a 95°F to 105°F temperature range [25]. Even at lower temperatures, the digesters still make significant bacteria reductions. According to a study published in *Bio-Resource Technology*,

> "anaerobic digestion of swine manure slurry at 20C^{o} [68F^{o}] for 20 days... reduced indigenous populations of total coliforms by 97.94–100%...reduced indigenous populations of E. coli by 99.67–100%...[and] resulted in undetectable levels of indigenous strains of Salmonella, Cryptosporidium, and Giardia" [26].

Bio-digestion is recommended to eliminate bacteria from waste and thus can be used to increase water quality.

Use of digester systems is occurring in many countries. The United States also uses the digesters in municipal waste management and in agriculture. However, the systems have been associated with failure in the agriculture field. Natural Resources Conservation Service (NRCS) examined the AD systems in U.S. livestock production facilities. They discovered that farmers discontinue operating these systems at rate of 50% due to system failure [27]. While that is a high percentage, NRCS states that the reason why these failed in farm settings was due to the system being overly complex. However, they discovered that smaller scale and simpler digesters have succeed in other countries. They state that "these countries are able to operate small digesters profitably due to their relative costs of labor and energy."

A good example of a small scale digester is the bio-latrine. The bio-latrine, which is a below ground digester, would be what may be best in a situation where it is fed solely fecal waste. These are often used in countries without excess water and are thus often referred to as "dry toilets." This reduced demand for water means that higher quality potable water can be saved for ingestion.

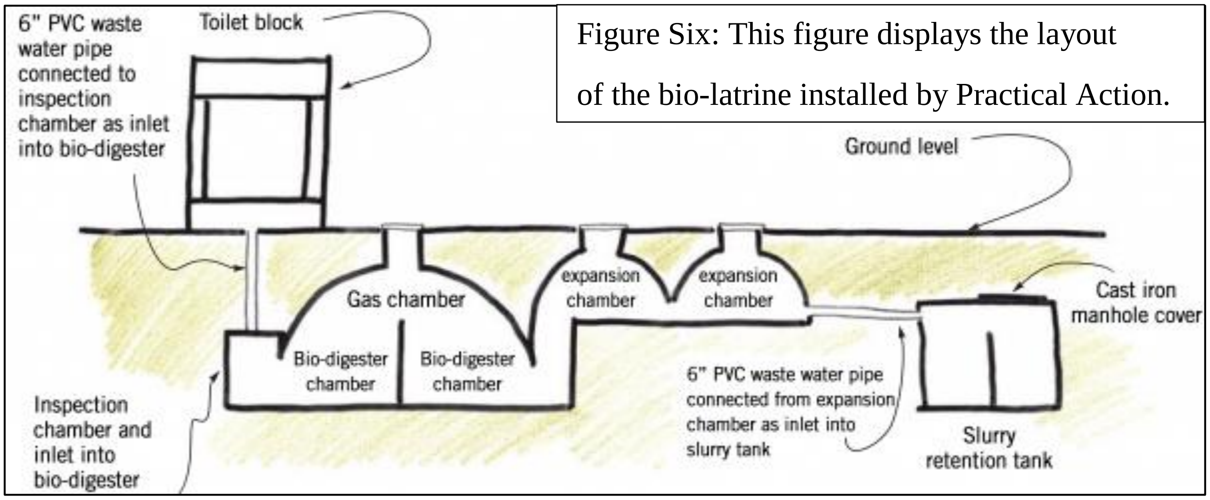
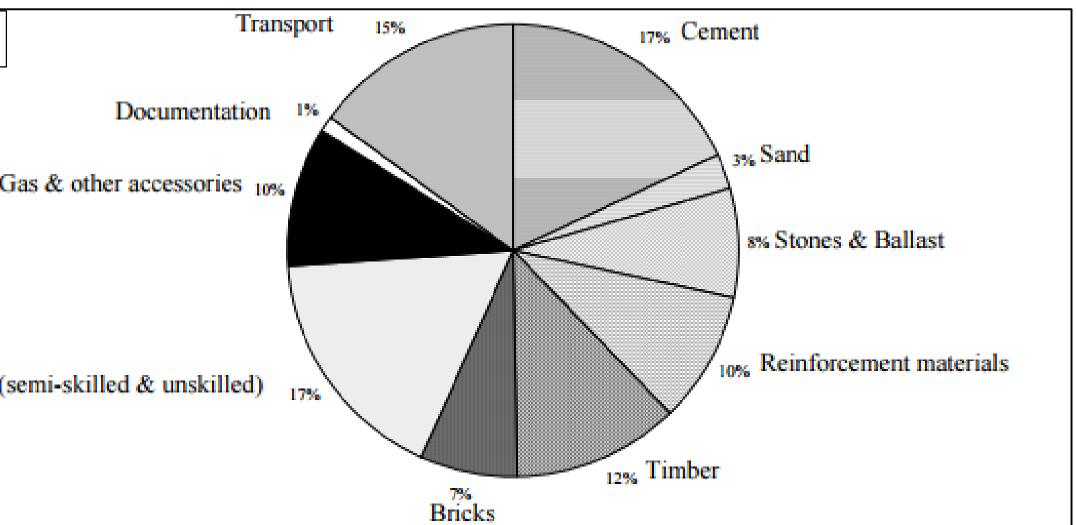


Figure Six: This figure displays the layout of the bio-latrine installed by Practical Action.

A community of 150 could build one of these bio-latrines for roughly $2,000 USD [28]. A project carried out by Practical Action, a charity organization, gave a breakdown of costs for constructing a bio-latrine in Kenya. Their expenses are displayed in the pie chart below (Fig. 7) [28].

Fig. 7



This design can be scaled back to a household sized digester. The MDA gives the initial cost of a digester as roughly $150 per average household [22]. However, the bio-latrine built by Practical Action costs as little as $80 for a household. Daily maintenance for an average unit would take thirty minutes to an hour.

While this solution works in areas that have space and soil for septic tanks, there are areas in Costa Rica that do not have the soil quality or space needed for bio-latrines. A compact above-ground anaerobic digester may be more applicable. The user may need to build two in order to allow the waste to settle to kill the bacteria. The design is simple and inexpensive; it can easily be constructed from recycled items.

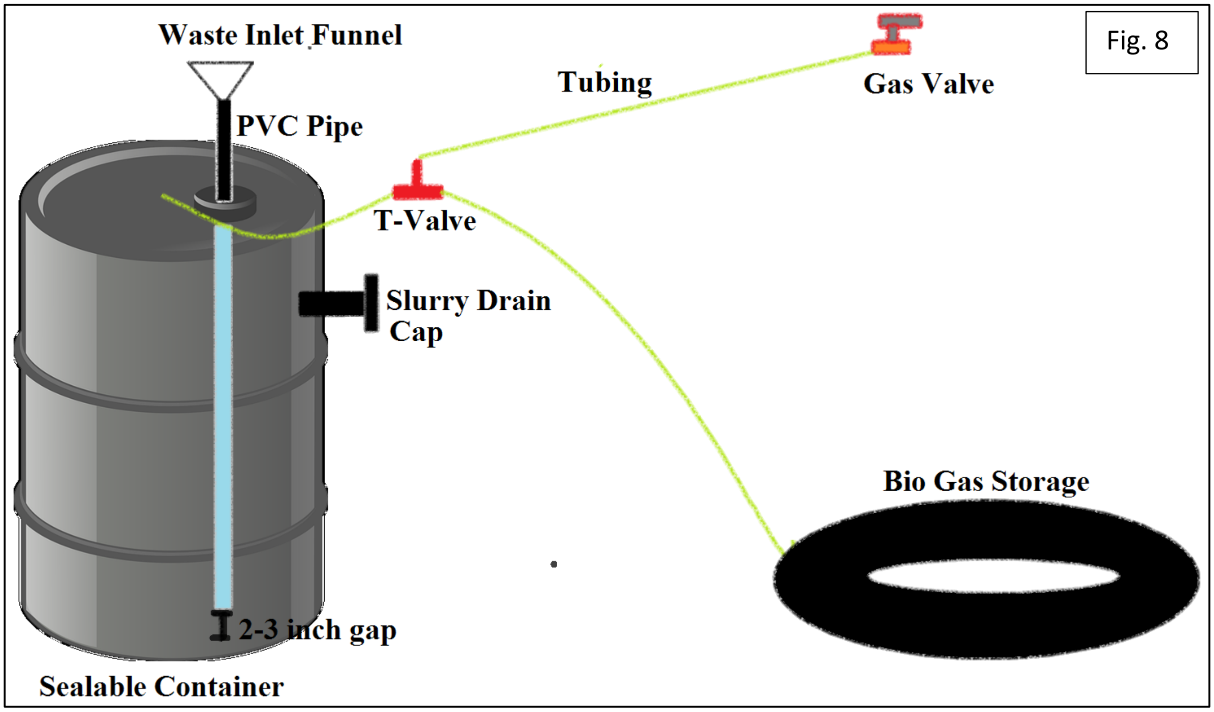


Figure Eight: The above picture depicts a simple anaerobic bio-digester design. The container can be switched out for whatever storage device is available as long as light cannot penetrate it. If needed, the container can be painted black to stop the penetration of light. All pipes and tubes inserted into the container must be airtight to prevent biogas leakage. To store the biogas, an inflatable tire may be used. Weights may be set on the tire to compress the gas.

The anaerobic digester is not new in Costa Rica. Several schools from the United States, such as Penn State College, Georgia University, and Michigan University, have built digesters in Costa Rica. Their digesters--while effective and successful-- focus mainly on agricultural waste disposal rather than human waste disposal. The idea of treating human fecal waste as a resource is less lucrative. Many people may be leery about the collection of their own waste. Familiarization to this idea may need to utilize several different methods, but the methods should be implemented as community interests and not government projects.

A potential route to introduce the AD system into the Costa Rican communities is to promote its use with the Certification for Sustainable Tourism (CST) program. This national program promotes ecotourism with several important goals: the proper use of the natural and cultural resources, improvement of the quality of life of local communities, and economic success that contributes to other national development programs [29].

The participants in the CST program get many benefits, such as priority lodgings and travel news, promotional materials, and inclusion in the Green Travelocity. The CST program is rated on a five "leaf" system. The system of rating is divided into five different areas: interaction with the natural environment, waste management and the saving or energy and water, service management, ability to involve or interest the customer in sustainability, and the capacity of businesses to create jobs and other benefits to the community [29]. The sites that best follow the guidelines ranked as a five leafs. More benefits are given to those who score higher on the five leaf system. The AD system would also help those who participate receive higher ratings as it removes pathogenic bacteria, saves water, and creates renewable energy from waste. An establishment that reutilizes waste also provides a way for all customers to be involved.

Currently, not all toilet systems in tourist accommodations can break down human waste and toilet paper adequately. Most tourist hotels and hostels have guest throw toilet paper away into trash cans instead of flushing in down the toilet. However, anaerobic digesters can handle the toilet paper. Flushing the toilet paper is more appealing to consumers as most consumers view flushing as more hygienic. It is also much more habitual than tossing toilet paper in trashcan. Clients would be more likely to visit the establishments that allowed them to do this.

Introducing them in communal settings would also help promote the idea of recycling human waste. The public schools in Costa Rica could install the AD systems and use the biogas as a source of energy. Biogas could be ignited for light in the classroom or used in food preparation. Schools in rural areas may partially benefit from this as they may not have reliable electricity

In schools, education over anaerobic digesters as well, as riparian buffers, would fall under educational points promoted by the EBBP. The buffer and the digester address proper management of waste, qualify as a social environmental projects, and assists in conservation of energy and water [15]. This is one way to instill more knowledge in the community about the possible ways to help combat poor water quality.

Community involvement is key in getting any idea to become widespread. With the above ideas enacted, riparian buffers and anaerobic digesters can become mainstream in the Costa Rican community. This would positively affect the health of their waters.

Conclusion:

This research project established that the majority of the Costa Rican waters sampled do not meet EPA limits. The results reveal excess amounts of *E. coli* and phosphates in the water. Even the smallest treatment can help reduce containments in the Costa Rican watershed. The previously mentioned ideas are just a few of the several that the community can contribute to this reduction.

The promotion of riparian buffers and an anaerobic digester systems to treat waste can help reduce the amounts of these contaminants in the water. Location 1, 6, 8, 10, 12, 13 all had small (5ft or less) riparian zones. These locations specifically would benefit from rejuvenating the riparian buffer. The AD could be applied in the locations that were closer to animal based operations and human populations, such as location 1, 4, 6, 8, 13, 14, 15, 16. The AD and riparian zone restoration methods are low in cost and do not required much skilled labor for their upkeep. They can also be economically beneficial for those who choose to implement them. The methods can be taught to the community through the EBBP, and made widespread by the CST program.

Reflection:

With any research project, there are many things that could potentially go wrong. I would like to address the following issues that occurred during my experiment. One of the first issues we encountered while in the field was an issue with the incubator.

Our incubator was not meant to be run using a car charger. We discovered this after plugging the incubator in and almost immediately smelling burning plastic. Luckily, we had travelled down with two incubators. We retired the inoperable incubator and used the second incubator we brought along.

As a result of the improper electricity supply, we were unable to run the incubator while we traveled. However, we kept the incubator heated whenever we arrived at our accommodations. During travel times, we opened it a minimal amount to preserve the heat. While heat is not needed to grow the colonies, it does help expedite the process.

Another issue we faced when collecting data was the large amount of rain. We visited during an El Niño year. According to our tour guide, this causes certain regions of the country to experience up to 30% more rain, while the other sections get 30% less. As a result, there were durations of the trip were I was unable to sample due to lack of water sources, or constant rain.

If I were to conduct this experiment again, I would elect to go during a different time period where I could have collected samples at more locations.

Another barrier to obtaining more samples was no ability to access the water. There were several locations with flowing water that I would have liked to sample, but were too steep to scale down or had no path to the water. The one specific location I would have thoroughly enjoyed a sample from was the Rio Grande De Tarcoles. The Costa Rican government had passed a law to prevent dumping into the river, and I was curious to determine the water quality. However when we arrived at the location, there was roughly thirty crocodiles scattered around the bridge. No sample was taken as a direct result. In hindsight, I would bring a rope to lower a container down to sample areas with these types of problems.

If I were to conduct a more in-depth examination of the Costa Rican watershed, I would extend my stay in Costa Rica to collect more samples. I would also add enjoy testing the drinking water quality in the communities near my sample sites. I would like to see if the areas with poor water quality had that reflected in their drinking water source. If I attained the finical resources, I would also like to identify the type of *E. coli* present, as it can be a human or animal strand. This would help determine if it was a leaky waste system or agriculture that was impacting the water quality. This would be an excellent continuation of the project.

One of my personal reflections over conducting this experiment is the absolute necessity of waste management. Many of the cities we visited had trash and litter piled into communal dumps and along sidewalk. There was no little tidy green buckets or dumpsters to be picked up weekly, instead there was little mountains of waste build on empty lots or street corners. It was very eye opening for me to see their need of an organized waste removal system.

This research trip also has motivated me to start trying to learn Spanish in my free time. Many times I wanted to ask a local about a water source or how to find one, I had to ask our guide to translate for me. While the guides and the locals tried their best to be helpful, the language barrier was diffidently a challenge. This inability to effectively communicate made it difficult to locate several sample sites.

There also were some ideas that are in use in Costa Rica that I think would be beneficial to implement in the United States. One of those things is sustainable tourism. Environmentally conscious hotels would be an amazing trend, especially near or around natural parks or scenic areas. I believe that hotels that participate in a sustainable tourism program will grow in popularity as the green initiative becomes stronger.

I would also like to see more strides in renewable energy in the U.S. The Costa Ricans have harness hydropower, wind power, and even heat from their volcanos to help power their communities. While we have the technology and the man-power to harness our own resources, the U.S. as a whole is not promoting carbon-neutrality or conservation of energy as much as the Costa Rican government is.

Overall, I really enjoyed visiting Costa Rica. I would not discourage people from visiting the country based on any of the data I collected. However, I would discourage them from drinking or wading in these sources. The locations that were swimming or rafting attractions both passed EPA standards, as they were kept cleaner than the other sources. I believe strongly that Costa Rica will continue to strive for greener energy, and that the country will make great strides as it works towards improving its waste management. Pura Vida!

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