Title:

MONITORING OF NEARSHORE WATERS IN BARBADOS FROM A MICROBIOLOGY PERSPECTIVE

With Government Analytical Services (G.A.S) Microbiology - Island of Barbados

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Abstract

Barbados, a Caribbean island known for its pristine beaches, is a premier location for visitors from several countries. Tourism is a major industry and the beaches are of great value to tourists and residents alike.

The aim of this research project was to determine the microbial quality of sea water on the beaches in Barbados. Three samples were taken during a six (6) period from June 2019 to August 2019 from sixteen beaches along the South and West coasts. The indicator organisms (IOs) Escherichia coli and Enterococcus faecalis were used to determine the likelihood of the presence of pathogenic organisms in the water. Sampling measurements were taken every fourteen days.

The south coast had mean values of 69.4 colonies/100mL for E.coli and 35.1 colonies/100mL, for E. faecalis. Mean values on the west coast were 21.6 colonies/100ml for E. coli and 33.7 colonies/100ml for E. Faecalis. These are within the EPA acceptable values. No significant difference was found between the number of Escherichia coli and Enterococcus faecalis on both coasts. Among individual beaches, weather and the presence of fish vendoring appeared as the most important factor affecting bacterial count.

1. Introduction

1.1 Background

Barbados is an island country in the Lesser Antilles of the West Indies, in the Caribbean region of the North American continent. It is 34 kilometers in length and up to 23 km in width, covering an area of 432 km^2. The geography of Barbados differs from the mountainous volcanic topography of most Caribbean islands. Barbados was formed as a result of a tectonic collision between Atlantic and Caribbean plates, forming a geologically unique island composed of 85% coral limestone and 15% oceanic clays and chalks. The expansive coral reef composition makes the island a leading destination for snorkeling and diving, while the chalk and clay components constitute the extensive white sandy shores, making Barbados a desirable destination for relaxation holiday travel (Scantlebury, 2016). As such, Barbados has moved from an economy heavily dependent on agriculture to one focused on tourism, making beach quality critical to the economy (Vasquez, 2017). Marine water quality in Barbados can be compromised by pollution from agriculture, industry and urban development. Barbados is a densely populated nation, with an additional high volume of cruise ship passengers docking at the island's ports. The extensive human activity taking place close to shore can impact the quality of shallow ocean water.

On January 16th, 2018, the Barbados Integrity Movement (BIM) stated that the current state of the South Coast sewage system was a looming national health crisis in the making (Holder, 2018). Much of the media reported that there was a steady stream of effluent coming from a number of manhole covers along a 3km stretch of the Barbados South Coast. This led to the closure of tourist oriented and local businesses due to the smell and health concerns (King, 2018). There was a cancellation of an undisclosed number of visitors to the island. The Environmental Protection Department in Barbados had assured the public that rigorous testing was being carried out along the South coast to ensure safe swimming water (Moore, 2016). Since this incident, Barbados beach water quality tests have returned to the World Health Organization's "A" Standard (Springer, 2018). To uphold the reputation of Barbados' beautiful beaches, frequent and reliable test samples are taken from the beaches every month. Based on the information from the Chief Medical Officer's report available data of diarrhoeal illness are not correlated with marine activities on the south coast.

One of the most commonly identified pollutants in recreational waters are fecal coliform coliforms (Curtis, 2003). Bacteria exist naturally in all surface water and are not typically harmful to humans, but certain types of bacteria present in fecal contamination can cause infections in humans (Curtis, 2003). Detecting fecal bacteria is an effective way to determine the likelihood of the presence of pathogenic organisms in water. Pathogens are difficult and expensive to detect, therefore fecal indicator bacteria such as E. coli and Enterococci, are used to determine the presence of fecal waste in surface water (Meays, Broersma, Nordin, & Mazumder, 2004).

1.2 Relevance to tourism industry in Barbados

Tourism is of central importance to the economy of Barbados. The World Travel and Tourism Council (WTTC) statistics quote that direct and indirect tourism activities accounted for 36% of total employment and 85% of the country's foreign exchange in 2014 (Scantlebury, 2016). Barbados as a tourist destination offers the classic Caribbean "sun, sand, and sea" experience, along with numerous attractions and festivals throughout the year (Scantlebury, 2016, p.88). The Encyclopedia of Tourism (Jafari & Xiao, 2016) states that Barbados received 536,000 tourists and 874,000 cruise ship visitors in 2012. As with the rest of the Caribbean region, Barbados is extremely dependent on a consistent flow of tourists to maintain economic development (Mycoo, 2014).

Barbados has become known as a high end travel destination, meaning that visitors are spending significant funds on airfare, accommodation and activities on the island; and thus are expecting top quality for their dollar. Since Barbados classifies as a coastal and marine travel destination, beach and water quality are integral to the touristic appeal of the island. The coast marks departing and returning point for most activities, including cruise ships, scuba diving, sailing, snorkeling and jet skiing (Lueck and Orams, 2016).

Scholars (Schumann 2011; Mycoo 2014; Hall 2011), have predicted that Caribbean Small Island Developing States (SIDS) will be the most at-risk tourism destinations in the coming decades. Risk factors include sea level rise, coastal erosion, tropical storms, biodiversity loss, resource depletion, droughts and flooding. On top of being vulnerable to these challenges, the Caribbean is also poorly prepared to deal with the economic repercussions of climate change (Mycoo, 2014). Climate change and human activity are interconnected and require further interdisciplinary research, for the purpose of this report, we are focusing specifically on microbial bacteria contamination on the popular beaches of Barbados.

Fecal bacteria are microorganisms that inhabit the gastrointestinal tract of humans and most other warm-blooded animals. The primary sources of fecal bacterial contamination in coastal zones are through the discharge of sewage and human waste. Marine fecal contamination is estimated to account for billions of gastrointestinal illnesses globally (Munn, 2005). Infections due to contaminated beach water also include respiratory, eye, ear, nose, throat and skin diseases (Noble, 2004). The impact of pathogenic contamination on human health depends on the susceptibility of the host, the extent of exposure and the strength of the pathogen (Thompson et al., 2005). The relationship between contaminated coasts and human health has two serious implications for tourism in Barbados. Firstly, hotel and real estate development along the coast is becoming increasingly dense, which can adversely affect the quality of the beach water. Secondly, if human health is compromised by swimming or ingesting contaminated water and tourists are coming to Barbados largely for marine recreational purposes, this poses both public health and economic risks (Powell, 2008).

Gharmaratne and Brathwaite (1998) have applied an economic valuation of water quality for touristic appeal in Barbados by interviewing visitors on their perception of beach water quality and willingness to pay for improvements. This study surveyed respondents on south and west coast beach quality, finding that over 92% of respondents ranked the visual quality of the water to be of top importance. The analysis also found that improvements in water quality “accrue significant benefit to users,” referencing a willingness to pay (WTP) of $14.66 US for a 30% reduction in water pollutants, including fecal coliforms (Gharmaratne & Brathwaite, 1998, p.143). To address tourists WTP for improved water quality, Gharmaratne & Brathwaite (1998) suggested the implementation of private paid beach access, as Barbados’ coasts are currently public. There has been a growing concern over the impact of water pollution on the tourism industry in Barbados, however at the time of publication, the report cited that “virtually no research” had been done on the connection between coastal water quality and tourism.

Schuhmann (2011) studied ‘tourist perceptions of beach cleanliness in Barbados’ in relation to their return visitation rate. The key outcome of this study was finding that Barbados has an extremely high rate of return visitation, one of the highest in the Caribbean, largely due to the island's unparalleled beaches. Schuhmann (2011) deduced that the sources of Barbados' water quality concerns (coastal real estate development, cruise ships, extensive marine recreational activities) are a result of the tourism industry. Yet, as nothing leads to believe that the expansion of these industries will decrease, it might lead to a reduction in tourism demand due to overcrowding, pollution and environmental degradation.

1.3 Importance of contamination to marine life

Fecal contamination of recreational waters not only affects the tourism industry, but also has an important impact on marine life and health of the marine ecosystems.

Coral reef communities thrive in clear water, relatively low in nutrients and are affected by poor water quality (Wenger et al., 2016). However, coral reefs are today in severe decline and are amongst the most critically endangered habitats on earth. Recent research on the Caribbean Elkhorn coral by Sutherland et al (2011), highlight the dangers that a human strain of common fecal enteric bacterium, *Serratia marcescens*, has on living corals. The results of this study demonstrate a successful "reverse zoonosis", involving the jump of a pathogen between vertebrate to invertebrate and from terrestrial to marine (Sutherland et al., 2011). Thus, *S. marcescens* isolated from human wastewater causes acroporid serratiosis (APS), a coral disease, in only four days, explicitly verifying that human feces can be a source of a marine invertebrate disease and contribute to coral reef declines (Sutherland et al., 2011). The decline of coral reefs has serious implications for marine ecosystems. Coral reefs are some of the most biodiverse ecosystems and provide many benefits, such as protecting coastlines from damaging effects of storms, providing habitats and shelter for many marine organisms, being a source of nitrogen and other essential nutrients for marine food chains, and assisting in carbon and nitrogen fixing, etc (Burgess, 2006). It is therefore crucial to safeguard coral reefs and ensure these systems are not jeopardized.

The presence of potentially pathogenic bacteria in sea waters does not however always act as a danger to marine life. Under specific circumstances, marine life can rather become a source of contamination whereby certain organisms can help spread pathogenic bacteria in the marine environment (Maugeri et al., 2004). In fact, Maugeri et al. (2004) found that the exoskeletons of some crustaceans are nutrient sources that encourage bacterial attachment and colonization, and therefore showed another association between enterococci with zooplankton by establishing that the latter, as well as similar small marine organisms may provide an over wintering site for enterococci.

The presence of pathogens are important to monitor because they will have severe impacts on marine life, both in the short term and long term. Thus, monitoring water quality is essential to maintaining a healthy marine ecosystem (Kite-Powell et al., 2008).

1.4 Indicator organisms

The use of indicator organisms (IOs) is common to determine the likelihood of the presence of pathogenic organisms in water (Korajkic et al., 2018), indicators being defined as “elements that can be efficiently monitored to approximate the risk of human exposure to a given environment” (Belkins & Cowell, 2006, p.41). Although their sole presence might not cause the disease, “their presence in an environment suggests a high probability of co-occurring pathogens” (Belkins & Cowell, 2006, p.41). In the case the monitoring contamination in water bodies, faecal indicator bacteria (FIB) are widely accepted and used in water quality studies to assess the level of faecal contamination (Garrido-Pérez et al., 2008) (Lamparell et al., 2015).

In order to monitor the quality of marine waters, the two indicator organisms most used worldwide are *Escherichia coli*, a member of the faecal coliform group used for freshwater, and *Enterococcus Faecalis*, used for both freshwater and marine waters (Anderson et al., 2005) – as recommended by the U.S. Environmental Protection Agency (Anderson et al., 2005). Their use allows to infer the presence of other pathogens in recreational waters ; a large amount of the IOs in waters increases the likelihood of other pathogens being present (Noble et al., 2004).

Some studies even suggested that the proportions of the amounts of E. coli compared to enterococci in the water could be used to identify the source of the contamination (human faecal contamination vs. fecal contamination from other warm-blooded animals) (Hanes & Fragala, 1967). In fact, a higher ratio of enterococci compared to fecal coliforms would be found in animal feces, whereas the opposite is true for human feces (Belkins & Cowell, 2006). This is however an outdated method of determining the source of contamination, as it is not always accurate, and as specific organisms associated with human and animal feces can now be used to identify the contamination source.

Bacterial growth and survival can be influenced by both biotic and abiotic factors. These abiotic factors include mostly environmental parameters such as salinity, temperature, nutrients, which influence bacterial populations by a direct effect on their growth rates and deaths, or indirectly by ecosystem interactions (Belkins & Cowell, 2006). Other abiotic factors affecting their survival and inactivation in recreational waters include pH, temperature, irradiation, predation, osmotic stress, nutrient deficiencies, particulate levels, turbidity, oxygen concentration and microbial composition (Belkins & Cowell, 2006). Temperature has often been described as the factor having the biggest role to play in their survival (Noble et al., 2004). Various studies have reported bacterial populations to decrease with higher salinity, high temperature (approximately above 25 °C) and high solar radiation, whereas elevated levels of nutrients and particles in the water has been associated in laboratory studies with a higher survival of marine contaminants and of various enteric bacteria, including E.coli and Enterococci (Belkins & Cowell, 2006). However, this relationship between nutrient levels and growth rates have not been shown as often in a natural environment. Still, a study conducted by Lopez-Torres et al (1988) (Belkins & Cowell, 2006) showed an increase in survival of E.coli populations at a site contaminated by rum distillery effluent (nutrient-rich). The E. coli population numbers dropped as soon as the source of contamination (the discharges) was stopped, indicating the importance of organic matter and nutrient-rich effluents in promoting the growth of bacterial pathogens.

Sunlight has repeatedly been shown to be a major source of bacterial inactivation, mainly because of phototoxic damage. Indeed, one day of sunlight exposure would be sufficient to reduce the fecal coliform counts by up to 5 orders of magnitude. For seawater/sewage mixes, enterococci expressed a higher sunlight resistance than fecal coliforms, although it is still very affected by the radiation as well (Figure 1)(Belkins & Cowell, 2006). Sunlight represents the most important influence on bacterial populations in clear, well-mixed sea-water especially. This mechanism is part of the reason why bacterial survival rates are higher in sediments: they are protected from sunlight. The other reason for increased growth in sediments is due to the higher presence of organic matter, which helps by providing nutrients, a protective layer and other useful compounds (Belkins & Cowell, 2006). Supporting this, other studies (Elliot & Colwell, 1985) revealed that bacteria were not uniformly distributed in a body of water: while most are found at the surface, their numbers are reduced as depth increases, although the highest amount is found on marine bottom deposits, because of the sunlight protection provided by the sediments.

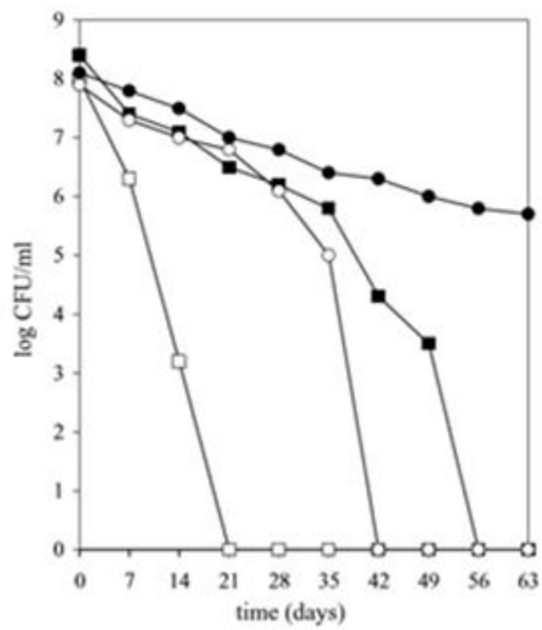


Figure 1. “Cells decline of E. faecalis in artificial seawater” (Belkins & Cowell, 2006).

High temperatures give the range have also consistently been reported to increase inactivation rates in bacteria, although the reason for this is not as clear as for the other factors, and might mainly be due to the often co-occurrence of high temperatures and high solar radiations. Cold temperatures (5-15 °C) are however also resulting in high inactivation rates.

Biotic factors affecting their growth are often factors inducing biotic stresses, such as the natural seawater microbiota – competition for the limited nutrients available – which relates to some of the abiotic factors.

1.5 Potential sources of contamination

Many different sources can lead to fecal contamination, such as storm water runoff, municipal wastewater, and sewage effluent from treatment plan. As previously mentioned, associations between marine pathogens and surface marine animals, phytoplankton, sediments and suspended detritus are frequent and can lead to a perpetuation or amplification of a contaminant once it has already been introduced (Belkin & Colwell, 2006). The level of contamination found in marine waters is enhanced by water temperature, higher than 15ºC, which appears to have a positive effect on the abundance of human invasive pathogens, as fecal bacteria grow under mesophilic conditions (Thompson et al., 2005). Additional factors that have been related to an increased risk of contracting disease from seawater include swimmer density, eutrophication and thermal pollution. Pollution from aquaculture environments is correlated to an increased presence of Vibrios (salt water bacteria) in underlying sediments, which can contaminate seafood (La Rosa et al., 2001). Untreated sewage has been attributed to the introduction of norovirus and rotavirus into marine environments (Hellmér et al., 2014). In Barbados, the Marine Pollution Control Act (1998) was designed to establish discharge standards for all waste water into the groundwater as well as the marine environment. Domestic and commercial properties along the coast should dispose of their sewage via septic tanks, well or earth pit while the effluent from the treatment plant is allowed into the sea after primary treatment (Carter & Singh, 2010).

Boehm et al. (2002) have shown that “coastal Enterococci levels are enriched by bird activity in adjacent estuaries,” pointing to birds as an additional contamination source. Boats and vessels were also reported as having a potential impact on water and sediment contamination. According to the International Convention for the Prevention of Pollution from Ships, of which Barbados is a signatory, raw sewage can be released at least 12 nautical miles from the nearest coast line (International Convention for the Prevention of Pollution from Ships’ 1978) . Various studies (La Rosa et al 2001; Thompson 2006; Belkin & Cowell 2006) demonstrated that the concentrations of fecal coliforms in marine water were positively correlated with increasing boat occupancy, and that the overboard disposal of sewage could explain this relationship (Belkin & Colwell, 2006). As mentioned, fecal contamination has often been connected to human activities and density: “The presence of pathogens in the environment mainly depends on the density of the coastal urban and animal population” (Belkin & Colwell, 2006). High levels of human activities impact the levels of water contamination, as they represent a constant input, either direct (sewage treatment plant) or indirectly (wastes from agriculture and runoff). In accordance with this, the levels of fecal contamination increased drastically along with the rapid population growth (Belkin & Colwell, 2006).

Tourists come to Barbados to enjoy the beaches and marine activities and as such it is important to keep the marine environment within international standards, Faecal indicator bacteria (FIB) are widely accepted as a tool used in water quality studies to assess the level of fecal contamination in water bodies (Garrido-Perez et al., 2008). Studies have shown that tourism-related earnings, as a percent of total earnings, are concentrated within forty km of the shore (Klein et al., 2004). According to WHO, recreational water quality and protection of public health are best accounted for by a combination of sanitary inspection and microbial water quality assessments. Urban activities in particular are highlighted as one of the major causes of contamination in surface water bodies in Asian countries (Dada et al., 2012). In Barbados, according to the Barbados Tourism Marketing Inc (BTMI) there are thirty (39) hotels, forty four (44) apartments, thirteen (13) guest houses and one (1) yacht club on the south coast between Drill hall, St. Michael and Miami Beach in Christ church, a distance of 12 kilometers. On the West coast, there are 20 hotels, 19 apartments, 5 guest houses and one (1)yacht club over 15 kilometers between Almond bay beach in Speightstown and Hot Pot beach in St. Michael.

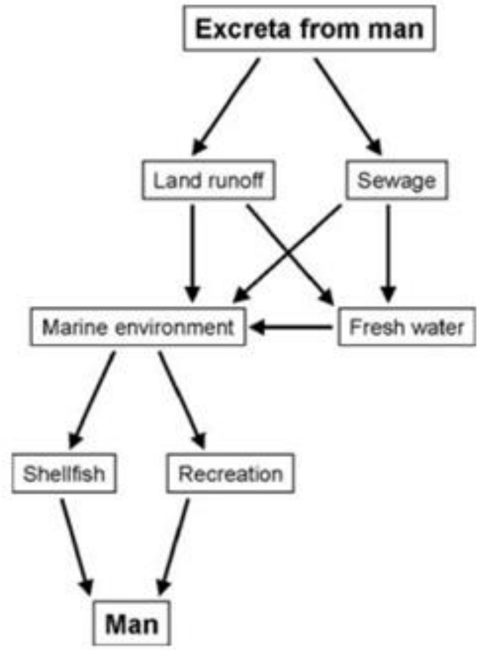


Figure 2. “Routes of transmission of enteric viruses to become contaminants in the marine environment.”

2. Objectives and hypothesis

The objective of this research is to monitor the quality of ocean water on the south and west coast beaches and assess possible variables leading to differences in the sample results from the two popular sides of the island. On top of monitoring the water quality, we aim to provide consistent and reliable data on the quality of Barbados beach water for the Government Analytical Services (G.A.S) Microbiology lab.

It is hypothesized that more fecal coliforms and Enterococci will be found on beaches on the south coast compared to the west coast, due to the higher population density and human activities, such as boat rides, snorkeling tours, commercial freight, cruise ships and fishing boats docking on the south coast.

3. Methodology

Standard microbiology beach sampling protocols were used (Standard Methods 21st Edition, 2005 and 22nd Edition 2012) to test the water quality on 16 swimming beaches on the island of Barbados; eight on the South Coast and eight on the West Coast. Each beach was sampled a total of three times throughout the project, at fourteen-day intervals between June 17th and July 22nd, 2019. Samples were always collected between 10am-12pm each week to ensure consistent data collection for analysis. Sample bottles were then taken to the G.A.S lab directly after collection to be analyzed by membrane filtration technique. Results were read and documented twenty-four (24) hours after incubation. Beach sampling and inoculation was conducted on Mondays, followed by reporting and analysis on Tuesdays. Mondays' procedure included labeling petri dishes, analysis-checking of pipettes and performing control tests for the air, diluent and filtration environment. The data collected was used by G.A.S microbiology lab for the Ministry of Agriculture and Food Security's 2019 records. To ensure confidentiality, location names were given numeric codes. In the final presentation of the results, numeric sample codes were used rather than public beach names.

Sterile collection bottles were labeled before sampling. The water samples were collected in waist deep water, with the collection bottle neck submerged elbow deep with sea current flowing away from the body. Once the bottle was filled, water was poured out until the water level was at the sample bottle`s neck. Sample bottles were stored and transported in a cooler at 4ºC to the G.A.S. where the membrane filtration method was used for bacterial identification. Membrane filtration apparatus was set up and tests were conducted to check the sterility of the water filtration apparatus and the diluent used. Membranes were placed into the apparatus and 100mL of water sample was filtered through the membrane in duplicates of 10ml and 100mL. One membrane was placed on mFC (selecting for fecal coliforms) medium and the other on mEI (selecting for enterococcus) medium. The mFC medium was incubated at 44.5ºC for 24 hours and mEI medium at 35ºC for 24 hours. For both types of plates, the colony forming unit (colonies)/100 mL was calculated, using plates with a colony count ranging between 20-60 colonies.

4. Results

Table 1. Amount of ***Escherichia coli*** colonies per dilutions, calculated and average CFU (colony-forming unit) and standard deviation for the 16 beaches sampled on both South Coast (S1→ S8) and West Coast (W1→ W8).

Beach code	1st sampling			2nd sampling			3rd sampling			Mean CFU	Standard deviation
	colonies/10 mL	colonies/100 mL	CFU	colonies/10 mL	colonies/100 mL	CFU	colonies/10 mL	colonies/100 mL	CFU		
S1	2	19	**19**	18	> upper limit	**180**	20	> upper limit	**200**	**133.0**	99.2
S2	0	3	**3**	0	2	**2**	3	31	**31**	**12.0**	16.5
S3	1	4	**4**	0	2	**2**	1	9	**9**	**5.0**	3.6
S4	0	5	**5**	0	27	**27**	5	60	**60**	**30.7**	27.7
S5	1	1	**1**	0	0	**0**	0	4	**4**	**1.7**	2.1
S6	0	1	**1**	0	2	**2**	4	28	**28**	**10.3**	15.3
S7				1	> upper limit	**10**	0	15	**15**	**12.5**	3.5
S8				6	> upper limit	**60**	> upper limit	> upper limit	**640**	**350.0**	410.1
W1	3	9	**9**	0	1	**1**	0	3	**3**	**4.3**	4.2
W2	0	4	**4**	1	0	**9**	2	18	**18**	**10.3**	7.1
W3	0	19	**19**	5	62	**62**	2	17	**17**	**32.7**	25.4
W4	0	4	**4**	0	13	**13**	2	28	**28**	**15.0**	12.1
W5	19	>upper limit	**190**	8	> upper limit	**80**	0	14	**14**	**94.7**	88.9
W6	0	6	**6**	0	19	**19**	0	1	**1**	**8.7**	9.3
W7				0	9	**9**	0	0	**0**	**4.5**	6.4
W8				0	5	**5**	0	1	**1**	**3.0**	2.8

Table 1 shows the number of **E. coli** colonies counted for each beach, at each sampling episode and for each dilution used. Each beach was sampled 3 times, except for S7, S8, W7 and W8, which were only sampled 2 times. A lot of variability of E. coli contamination levels between each sampling episodes and between each beaches within the same coasts. S1 and S8 were the most contaminated beaches for E. coli when looking at the mean (133.0 and 350.0, respectively). The most E.coli contaminated beach within the west coast was W5 (CFU of 94.7). The E.coli levels for all the beaches on the south coast were higher on the 3rd sampling episode (for south coast only) than the levels recorded on previous days.

Table 2. Amount of ***Enterococcus Faecalis*** colonies per dilutions, calculated and average CFU (colony-forming unit) for the 16 beaches sampled on both South Coast (S1→ S8) and West Coast (W1→ W8).

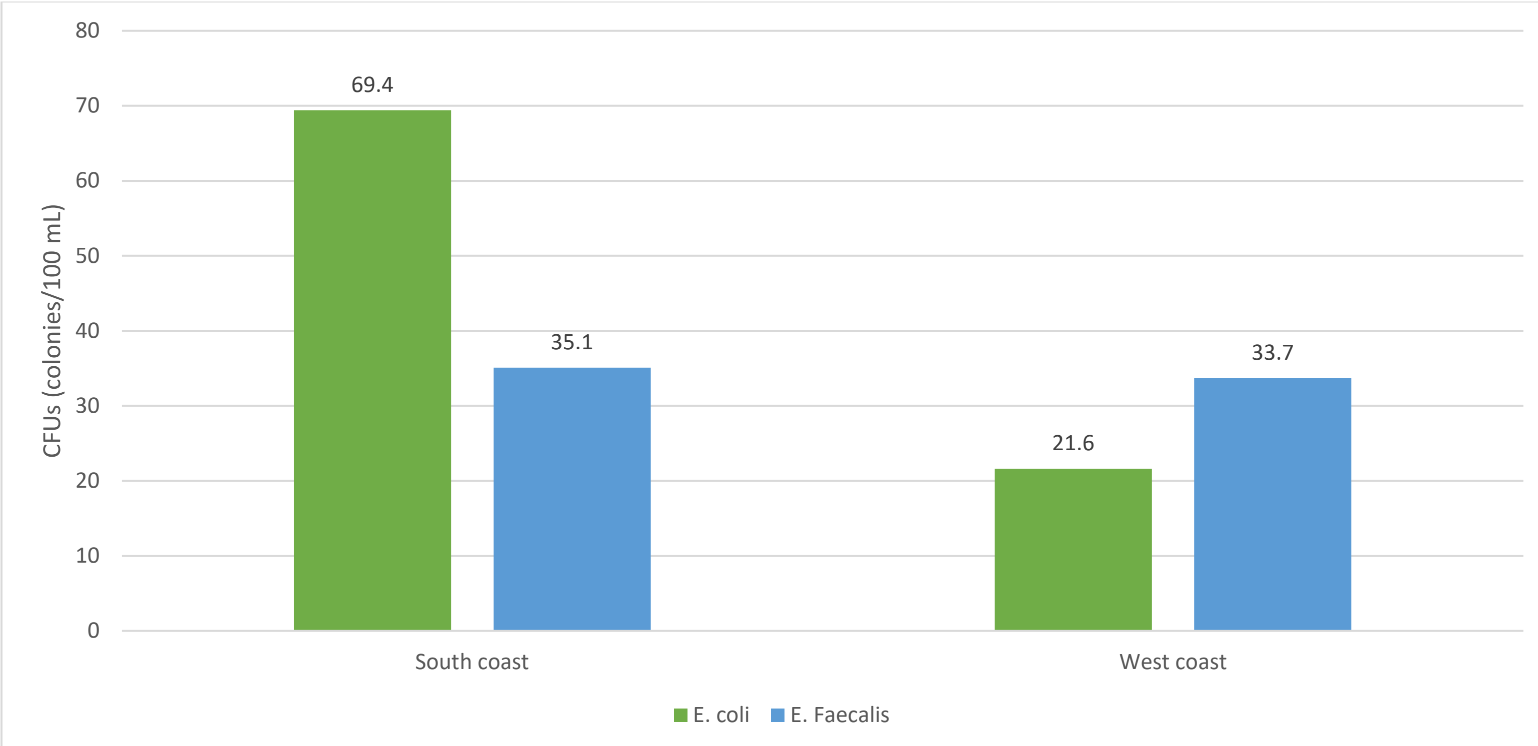
Beach code	1st sampling			2nd sampling			3rd sampling			Mean CFU	Standard Deviation
	colonies/10 mL	colonies/100 mL	CFU	colonies/10 mL	colonies/100 mL	CFU	colonies/10 mL	colonies/100 mL	CFU		
S1	0	4	**4**	8	> upper limit	**80**	20	> upper limit	**200**	**94.7**	98.8
S2	0	1	**1**	1	2	**2**	3	12	**12**	**5.0**	6.1
S3	0	0	**0**	0	0	**0**	0	6	**6**	**2.0**	3.5
S4	0	2	**2**	1	1	**1**	1	27	**27**	**10.0**	14.7
S5	0	1	**1**	0	2	**2**	2	3	**3**	**2.0**	1.0
S6	0	0	**0**	0	0	**0**	14	45	**45**	**15.0**	26.0
S7				1	8	**8**	3	16	**16**	**12.0**	5.7
S8				4	> upper limit	**40**	24	> upper limit	**240**	**140.0**	141.4
W1	0	4	**4**	0	3	**3**	1	8	**8**	**5.0**	2.6
W2	0	1	**1**	0	13	**13**	0	5	**5**	**6.3**	6.1
W3	0	6	**6**	6	50	**50**	1	8	**8**	**21.3**	24.8
W4	0	6	**6**	8	> upper limit	**80**	1	2	**2**	**29.3**	43.9
W5	16	> upper limit	**160**	9	> upper limit	**90**	1	4	**4**	**84.7**	78.1
W6	0	0	**0**	10	59	**59**	0	2	**2**	**20.3**	33.5
W7				14	> upper limit	**140**	0	0	**0**	**70.0**	99.0
W8				7	63	**63**	0	2	**2**	**32.5**	43.1

Table 2 shows the number of **Enterococci** colonies counted for each sampling episode, beach and dilution tested. The beaches S1, S8, W5 and W7 had the highest levels of E. Faecalis contamination. The enterococci levels were also exceptionally high on the south coast's third sampling episode (especially for beaches S1 and S8). There was no sampling of beach S7, S8, W7 and W8 on the first sampling episode of each coast.

Table 3. Average CFUs for E. coli and E. Faecalis per coast, standard deviation of each average and p-values obtained by student t-test comparing south coast and west coast levels.

	E. coli CFUs	Standard Dev.	E. Faecalis CFUs	Standard Dev.
South coast	69.4	121.3	35.1	52.4
West coast	21.6	31.0	33.7	22.0
t-test	*p=0.299*		*p=0.948*	

Table 3 shows the average CFUs levels of E. coli and E. Faecalis per coast, as well as the standard deviation of each these means. The p-value for the Student t-test comparing south coast and west coast average levels of E. coli and E. Faecalis is shown (p=0.299 and p=0.948, respectively). The levels of E. coli and Enterococci are therefore not significantly different on the west coast than on the south coast.



Graphic 1. South coast and west coast average E. coli and E. Faecalis CFUs (colony-forming unit).

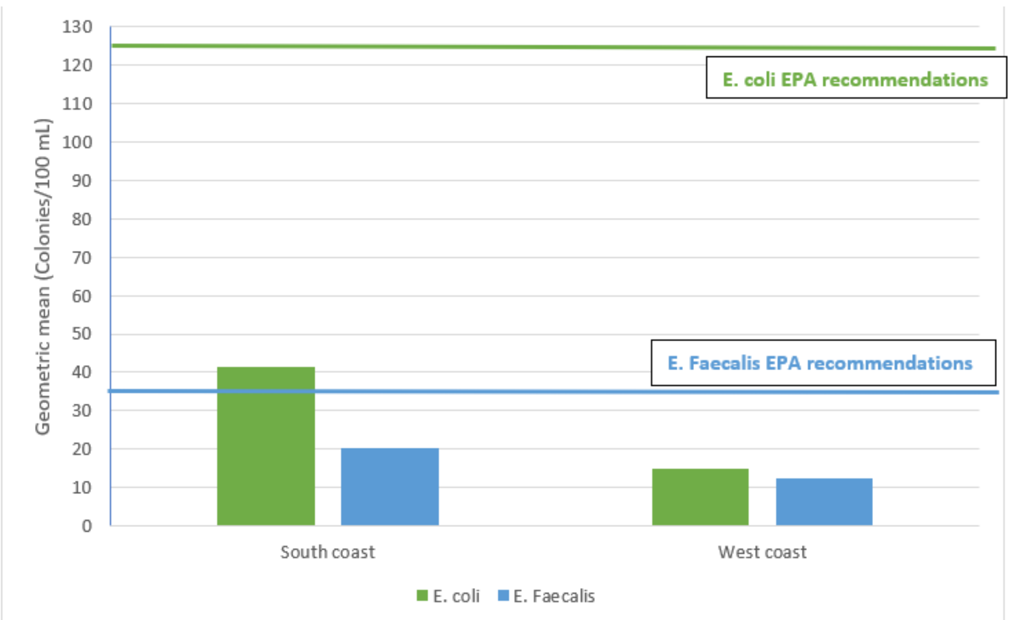
Graphic 1 illustrates the average colony-forming units (colonies/100 mL) for E. Coli and E. Faecalis grouped per coast (south coast and west coast). E. coli levels are a lot higher on the south coast average than west coast (69.4 compared to 21.6 colonies/100 mL), whereas there is not a big difference between the E. Faecalis levels between the south coast average and the west coast average (35.1 compared to 33.7 colonies/100 mL).

Table 4. CFUs geometric means of E. Coli and E. Faecalis for each beach 16 beaches sampled and geometric mean averaged per coast compared to the EPA recommended levels, and F-value obtained by each ANOVA performed to compare contamination variation between beaches of a same coast.

		E. Coli		E. Faecalis	
		Geometric mean	**EPA recommendation**	**Geometric mean**	**EPA reccommendation**
South coast	**S1**	88.1	126	40.0	35
	S2	5.7	126	2.9	35
	S3	4.2	126	1.8	35
	S4	20.1	126	3.8	35
	S5	1.6	126	1.8	35
	S6	3.8	126	2.4	35
	S7	12.2	126	11.3	35
	S8	196.0	126	98.0	35
	Mean	**41.5**	**126.0**	**20.3**	**35.0**
	F value	***2.37**		***2.21**	
West coast	**W1**	3.0	126	4.6	35
	W2	8.7	126	4.0	35
	W3	27.2	126	13.4	35
	W4	11.3	126	9.9	35
	W5	60	126	38.6	35
	W6	4.8	126	4.9	35
	W7	3.0	126	11.8	35
	W8	2.2	126	11.2	35
	Mean	**15.0**	**126.0**	**12.3**	**35.0**
	F value	***2.20**		**1.03**	

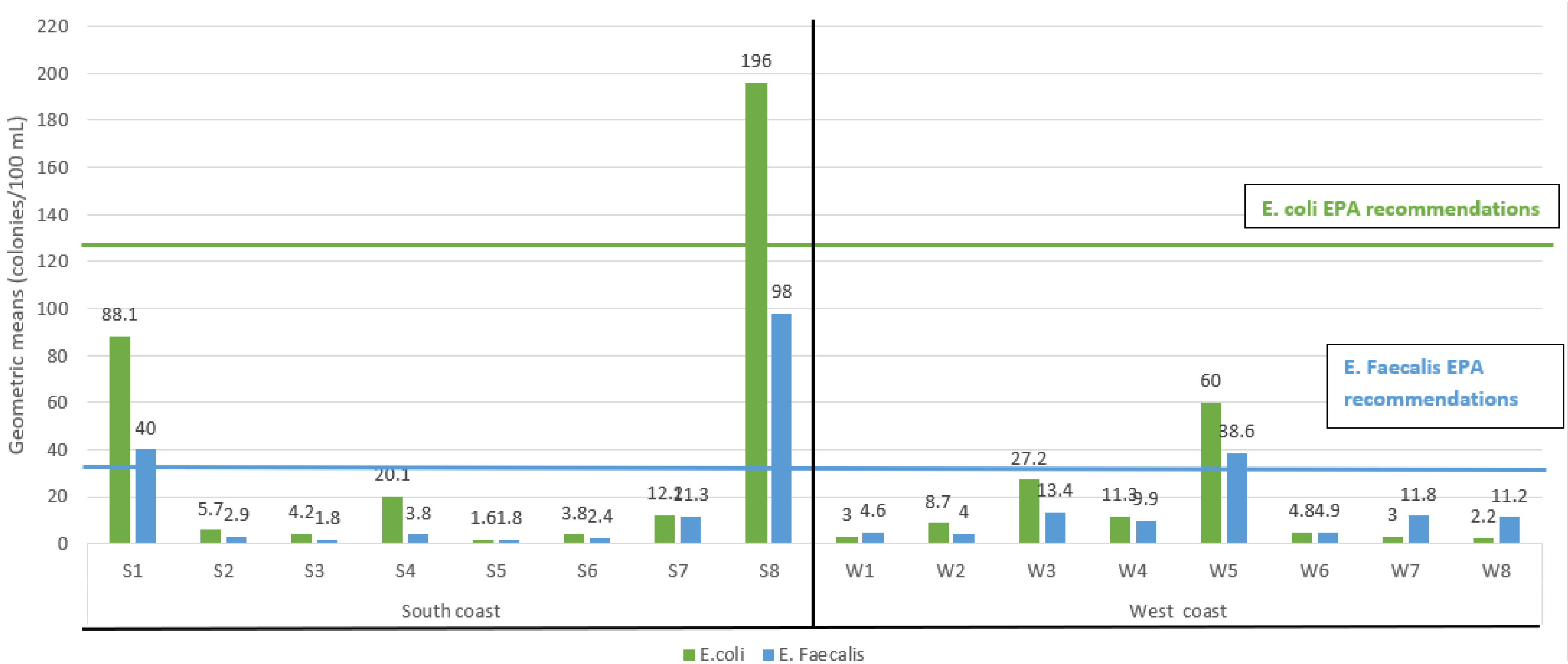
F critical value for alpha = 0.05 is F > 2.76. **
F critical value for alpha = 0.10 is F > 2.19*

Table 4 shows the CFUs levels calculated in a geometric mean (See Appendix B – explanation of geometric mean calculation) for each beach and per coast compared to the EPA recommended levels (United States Environmental Protection Agency) (EPA, 2012). None of the average geometric mean per coast is above the EPA recommendations (126 colonies/10 mL for E. coli and 35 colonies/100 mL for E. Faecalis), as shows Graphic 2. However, by looking at the levels per beach, E. coli levels appear to be above the EPA recommendations for beach S8 only (196.0 colonies/100 mL)), whereas levels of E. Faecalis are above the recommended levels for beaches S1, S8 and W5 (40.0, 98.0 and 38.6 colonies/100 mL, respectively), as shows Graphic 3. ANOVAs were performed to compare the variation of the contamination levels between each beach of a same coast for both E. coli and E. Faecalis, for a total of 4 ANOVAS. None of the F values obtained were significant below a p-value of 0.05. For $p<0.10$ however, both coasts obtained a significant F value for E. coli, whereas only the South coast obtained a significant F-value for E. Faecalis.



Graphic 2. South coast and west coast geometric means for both E. coli and E. Faecalis levels in comparison to the EPA recommendations.

Graphic 2 shows the average geometric means calculated per coast (south coast and west coast) compared to the EPA levels recommended. As seen, none of the coast average levels of E. coli and E. Faecalis are above the maximum recommended levels.



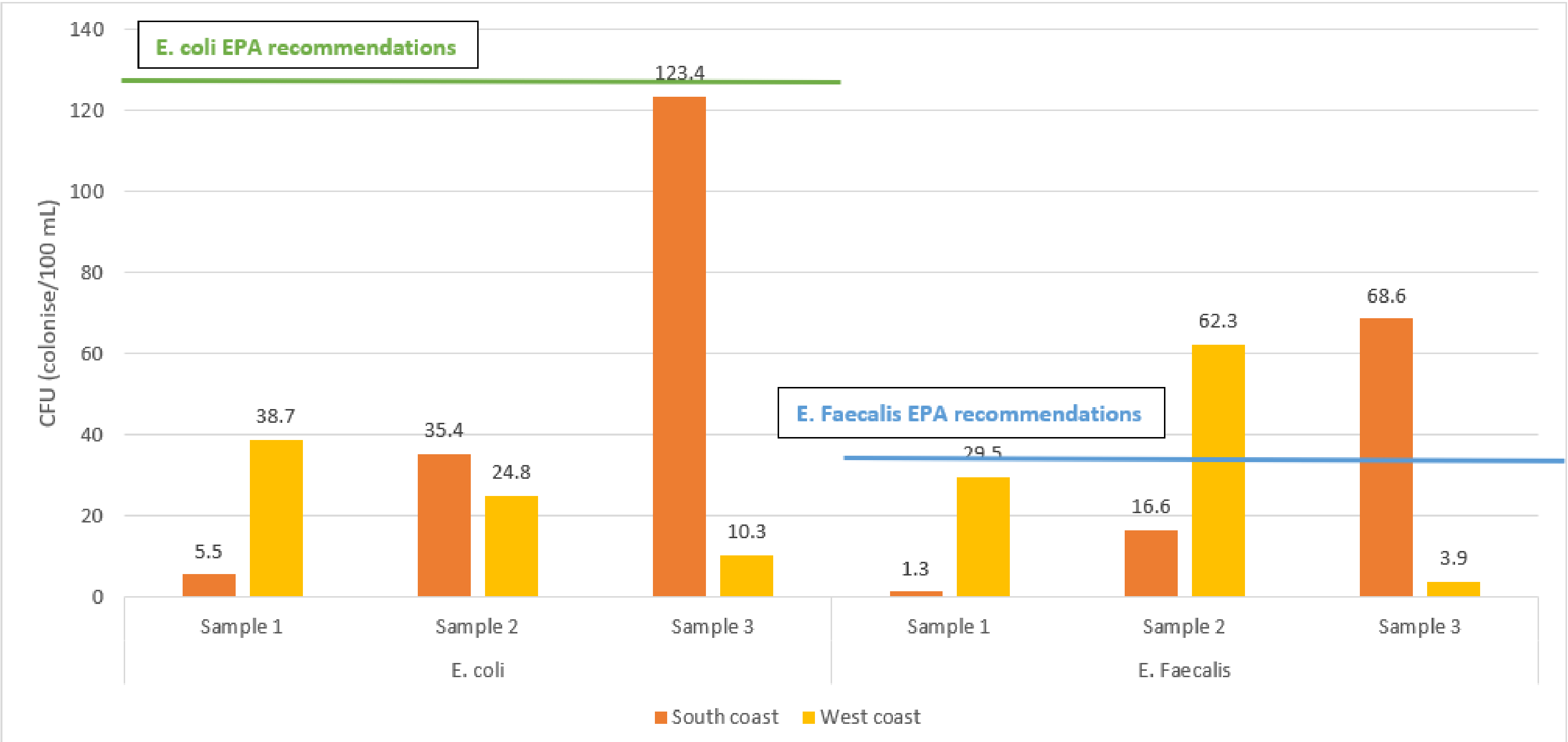
Graphic 3. E. coli and E. Faecalis geometric means for each of the 16 beaches sampled compared to the EPA recommendations.

Graphic 3 shows the geometric means calculated at the beach level, for the 16 beaches sampled, in comparison to the EPA recommendations. S8 is the only beach having E. Coli levels above the EPA standards, whereas the E. Faecalis levels are over the EPA recommendations for beaches S1, S8 and W5.

Table 5. Average E. Coli and E. Faecalis levels recorded (CFUs) recorded on south coast and west coast at each sampling episode.

	E. coli			**E. Faecalis**		
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
South coast	5.5	35.4	123.4	1.3	16.6	68.6
West coast	38.7	24.8	10.3	29.5	62.3	3.9

Table 5 shows the average levels of E. coli and E. Faecalis recorded for each coast, however separated by sampling episode. Both E. coli and E. Faecalis levels recorded were above the EPA recommendations on the 3rd sampling episode for the South Coast. Only E. Faecalis levels were above the recommendations on the west coast's second sampling, as seen on Graphic 4.



Graphic 4. Average E. coli and E. Faecalis mean levels recorded on south coast and west coast at each sampling episode.

Graphic 4 illustrates average E. coli and E. Faecalis levels recorded on each at each sampling episode, compared to the EPA recommendations. Sampling on south and west coast occurred at different days: Sample 1 on South coast did not occur the same day as sample 1 on west coast. Both E. coli and E. Faecalis levels recorded were above the EPA recommendations on the 3rd sampling episode for the South Coast. Only E. Faecalis levels were above the recommendations on the west coast's second sampling.

Table 6. Weather recorded at each sampling episode and corresponding E. coli and E. Faecalis levels (CFUs).

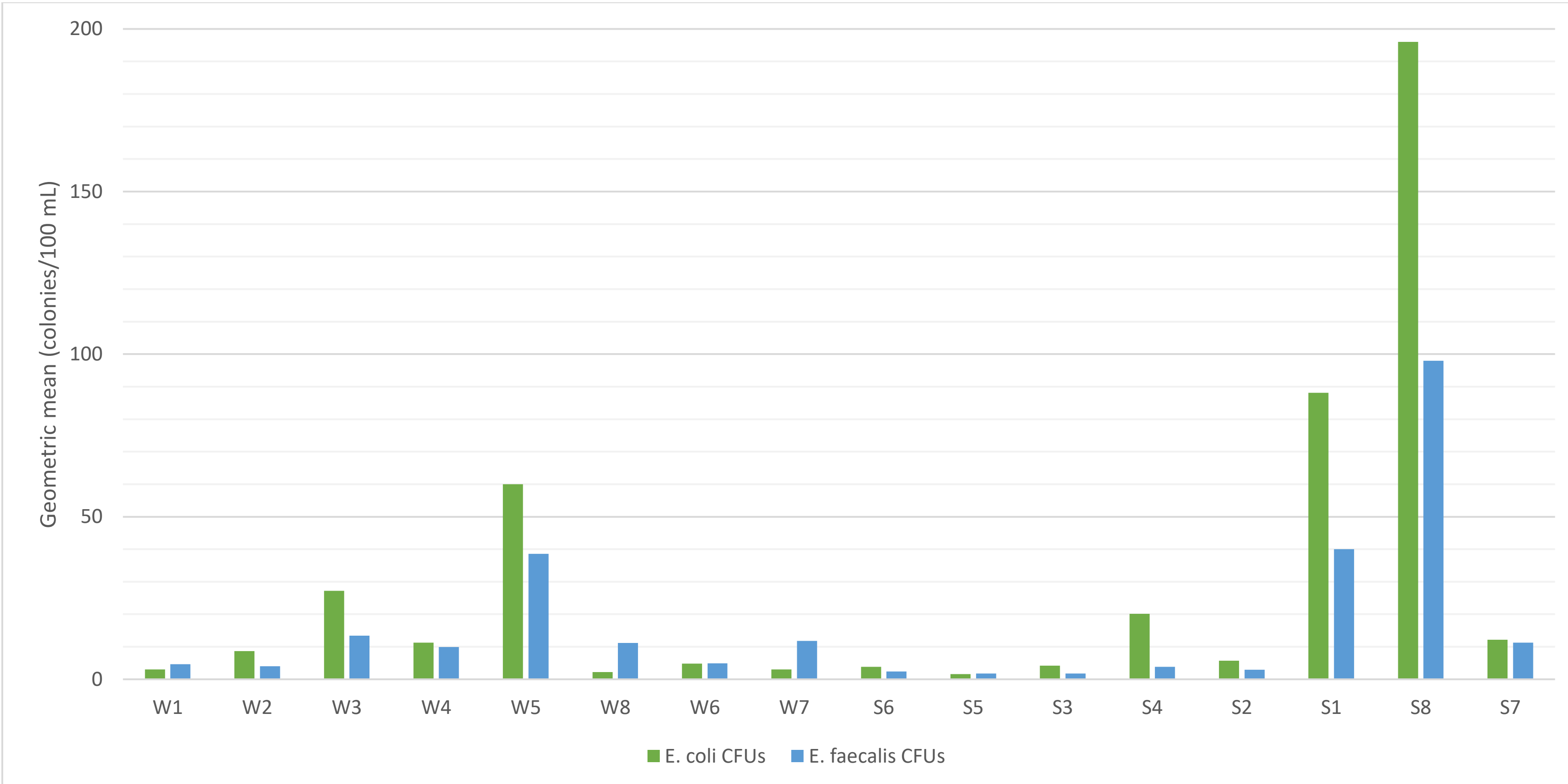
Sampling episode	Coast	Date	Rain-previous day?	Rain - 2 previous days?	Temperature (°C)	Sun-clouds	Wind speed (km/h)	Wind direction	E. coli CFU	E. Faecalis CFU
1	South	June 17th	No	No	31	Cloudy	44	E	5.5	1.3
	West	June 24th	No	No	31	Sunny	36	E	38.7	29.5
2	South	July 1st	No	No	31	Cloudy	34	ESE	35.4	16.6
	West	July 8th	No	Yes (heavy rain)	30	Cloudy	28	E	24.8	62.3
3	South	July 15th	Yes (heavy rain)	Yes (heavy rain)	30	Cloud-sun	37	E	123.4	68.6
	West	July 22nd	No	No	30	Sunny	25	E	10.3	3.9

Table 6 puts in relation the recorded E. coli and E. Faecalis levels for each date to the weather events occurring at this date or the previous days, as the rain, temperature, sunshine levels, wind speed and wind direction. The most outstanding factor appearing for the sampling episodes on July 8th and July 15th appears to be a heavy rain occurring in the 2 days prior to the sampling. This event corresponds with the abnormally high levels of E. Faecalis, whereas a rain occurring the day right before sampling corresponds to high levels of E. coli and E. Faecalis recorded the next day.

Table 7. E. coli and E. Faecalis levels calculated by geometric means (colonies/100 mL) per beach, ordered geographically from the norther beach (W1) of the west coast to the southern beach (S7) sampled.

	E. coli CFUs	E. faecalis CFUs
W1	3	4.6
W2	8.7	4
W3	27.2	13.4
W4	11.3	9.9
W5	60	38.6
W8	2.2	11.2
W6	4.8	4.9
W7	3	11.8
S6	3.8	2.4
S5	1.6	1.8
S3	4.2	1.8
S4	20.1	3.8
S2	5.7	2.9
S1	88.1	40
S8	196	98
S7	12.2	11.3

Table 7 and Graphic 5 both illustrate the E. coli and E. Faecalis levels (by geometric means) of each beach, ordered by geographical order, from the Northern point of the west coast (W1) to the southern point of the south coast (S7), to put the contamination levels in relation to the location of each beach.



Graphic 5. E. Coli and E. Faecalis levels (colonies/100 mL) calculated by geometric mean, ordered by geographic location from the Northern part of the west coast (W1) to the southern part of the south coast (S7) sampled.

Table 8. Tourist accommodation density (per km) on the south and west coast of Barbados

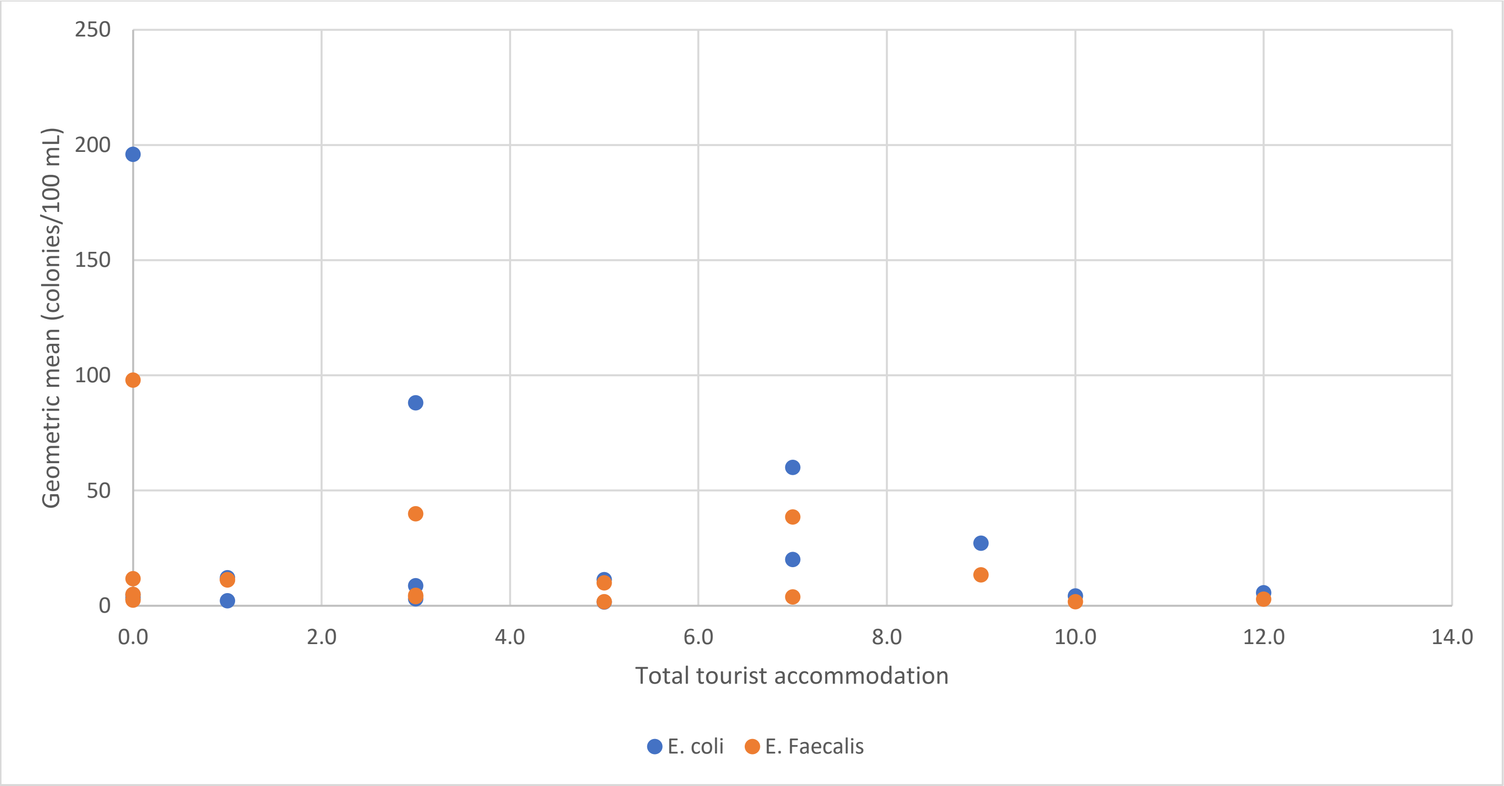
	Hotels	Apartments	Guesthouses	Total
South coast (12 km)	3	4	1	8
West coast (15 km)	1	1	<1	3

Table 8 shows the density of diverse tourist accommodations (amount/km) as well at the density of all the tourist accommodation types combined. South coast has a higher density of tourist accommodations than the west coast (8 compared to 3).

Table 9. Distribution of tourist accommodation within sampling areas in relation to E. coli and E. Faecalis geometric means recorded for each area (Barbados Tourism Marketing INC, 2019).

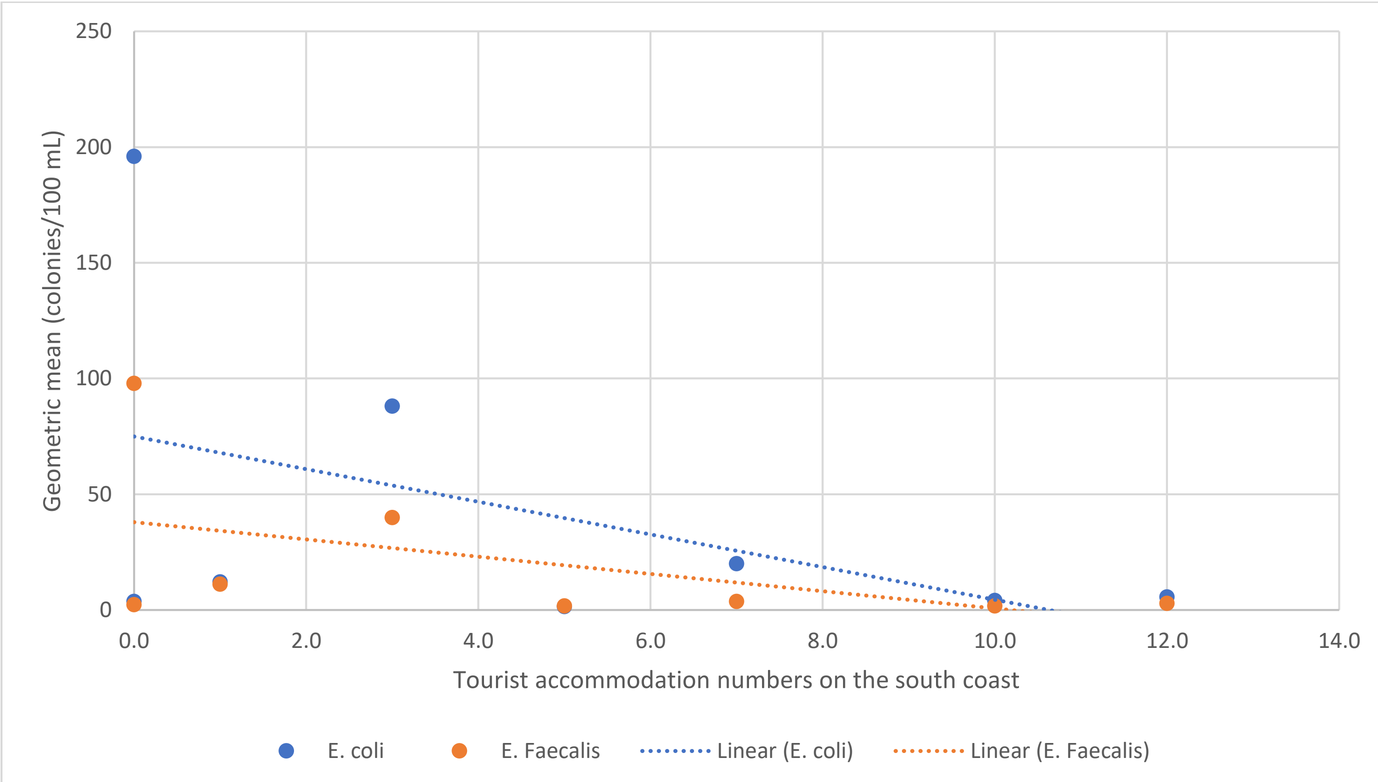
Beach code	Hotels nearby	Appartments nearby	Guesthouses nearby	Total	E. coli geometric mean	E. Faecalis geometric mean
S1	2	0	1	3	88.1	40
S2	5	4	3	12	5.7	2.9
S3	7	3	0	10	4.2	1.8
S4	3	4	0	7	20.1	3.8
S5	4	1	0	5	1.6	1.8
S6	0	0	0	0	3.8	2.4
S7	0	1	0	1	12.2	11.3
S8	0	0	0	0	196	98
W1	1	2	0	3	3	4.6
W2	0	2	1	3	8.7	4
W3	7	1	1	9	27.2	13.4
W4	1	4	0	5	11.3	9.9
W5	3	3	1	7	60	38.6
W6	0	0	0	0	4.8	4.9
W7	0	0	0	0	3	11.8
W8	0	1	0	1	2.2	11.2

Table 9 puts in relation the E. coli and E. Faecalis geometric means with the amount of different tourist accommodations nearby each of them. Beaches S2 and S3 are the ones with the highest amount of tourist accommodations on the south coast (12 and 10, respectively), whereas W3 and W5 are the beaches of the west coast with the highest amount of tourist accommodation nearby (9 and 7, respectively).



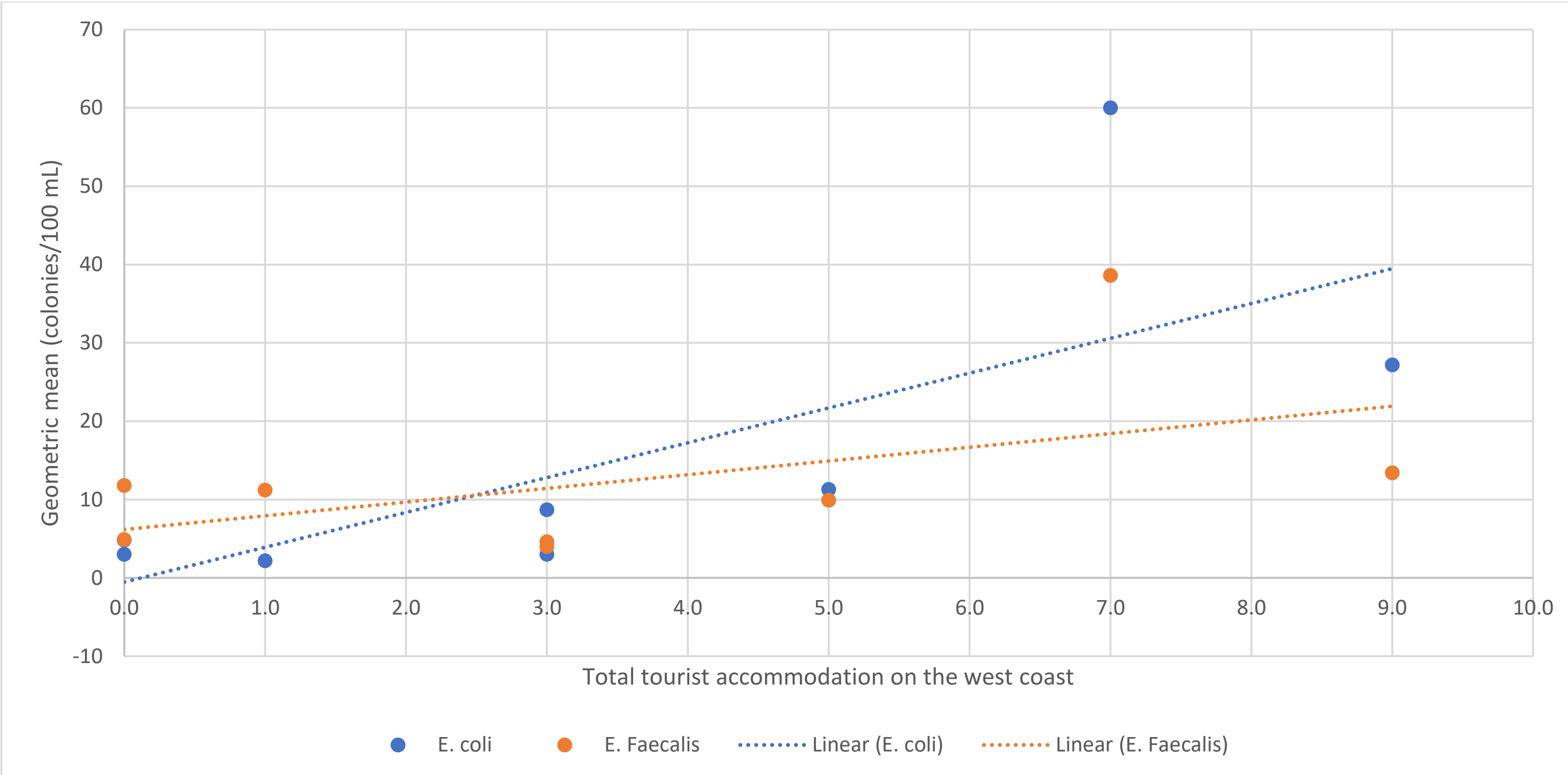
Graphic 6. E. coli and E. Faecalis levels on all 16 beaches in relation to number of tourist accommodation for the area.

Gaphic 6 illustrates the E. coli and E. Faecalis contamination levels put in relation to the corresponding numbers of tourist accommodations found near each beach, for both coasts combined. No obvious trend appears.



Graphic 7. E. coli and E. Faecalis levels on the *south* coast beaches in relation to the number of tourist accommodation found near each one.

Graphic 7 illustrates the E. coli and E. Faecalis contamination levels on beaches of the **south** coast in relation to the corresponding numbers of tourist accommodations found near each beach. Although the trend is not obvious, a negative correlation could be estimated.



Graphic 8. E. coli and E. Faecalis levels on the *west* coast beaches in relation to the number of tourist accommodation found near each one.

Graphic 8 illustrates the E. coli and E. Faecalis contamination levels of the **west** coast beaches in relation to the corresponding numbers of tourist accommodations found near each beach. Although the trend is not obvious, a positive correlation could be estimated.

Table 10. E.coli and E. Faecalis contamination levels in relation to the installations found nearby, such as fish markets, restaurants, hotels and others.

Beach code	Geometric mean		Near:			
	E. coli	**E. Faecalis**	Fish market?	Restaurants?	Hotel?	Other?
S1	88.1	40	600 m **north** of fish market			
S2	5.7	2.9	---	---	---	---
S3	4.2	1.8		Yes		
S4	20.1	3.8		Yes	Yes	
S5	1.6	1.8				Race track
S6	3.8	2.4				yacht club
S7	12.2	11.3	650 m **south** of fish market			
S8	196	98	100 m			
W1	3	4.6	1.4 km north of fish market			
W2	8.7	4			yes	
W3	27.2	13.4				
W4	11.3	9.9	1.3 km north of fish market			
W5	60	38.6	100 m			
W6	4.8	4.9				Near rum distillery, power plant, sewage treatment facility, water treatment plan
W7	3	11.8		Yes		Near flour mill
W8	2.2	11.2		Yes	Yes	

Table 10 puts in relation the geometric means of E. coli and E. Faecalis with the different type of nearby installations and buildings types found nearby.

5. Discussion

5.1 Explanation of results

To first test the hypothesis that the south coast would have higher E. coli and enterococci contamination levels, t-tests were performed in order to compare the difference between the two coasts (Table 3). Although the coast average of E. coli seemed higher on the south coast than on the west coast (69.4 colonies/100 mL compared to 21.6 colonies/100 mL) (Graphic 1), the t-test revealed a p-value of 0.299 for the E. coli levels, and a p-value of $p=0.948$ for E. Faecalis, which doesn't allow a rejection of the null hypothesis (H0= the two coasts have same levels of contamination). Thus, the hypothesis of a different level of contamination between the average of the west coast beaches and that of the south coast beaches can't be confirmed.

The mean colony-forming units per beach and per coast were also calculated by geometric mean, in order to be able to compare the levels to the EPA recommendations (United States Environmental Protection Agency) (Table 4). By averaging the geometric mean at coast level (south and west), although it appears that the south coast has higher levels of E. coli contamination (but not statistically significant), both coasts have an average amount of E. coli and E. Faecalis below the EPA recommendations (recommended levels of 126.0 for E. coli and 35.0 for E. Faecalis) (Graphic 2).

A look at the geometric mean calculated by beach rather than by coast (Table 4 and Graphic 3) however, indicates that one beach (S8) has E. coli levels (196.0 colonies/100 mL) over the maximum recommended levels, and that the beaches S1, S8 and W5 had E. Faecalis levels above the EPA recommendations (40.0, 98.0 and 38.6 colonies/100 mL, respectively). This representation of the results also illustrated a high variability of the contamination levels between the beaches of the same coast, which is supported by the very high standard deviations obtained for the coast averages (Table 3). This would indicate that grouping the E. coli and E. Faecalis levels by a coast average might lead to a major loss of information.

ANOVAs were conducted to determine if this impression of intra-coast beach variability could be confirmed. In fact, an ANOVA would highlight if at least one beach within the same coast is different from the others (which would therefore confirm that the beaches within same coasts are statistically different). One ANOVA was performed to compare E. coli levels of the south coast beaches, one to compare E. coli levels of the west coast beaches, and two more were conducted for the E. Faecalis levels, on each coast, for a total of 4 ANOVAs (Table 4). For an alpha value smaller than 0.05, the F-critical value was 2.76, meaning that the F-value obtained by the test had to be higher than 2.76 to be able to confirm an intra-coast difference. None of the ANOVAs performed reached this criteria, indicating that none of the coasts have beaches with different E. coli and E. Faecalis levels at a certainty of $p<0.05$. However, 3 of the F-values obtained were above the critical F-value of 2.19 for an alpha of 0.10 : The south coast for E. coli and E. Faecalis ($F= 2.37$ and $F=2.21$, respectively), and the west coast for E. coli levels ($F=2.20$). This difference that is statistically significance at $p<0.10$ but not at $p<0.05$ for the 3 groups mentioned would imply that there might be a real difference in contamination between at least one of the beaches of the groups, but that the variability within groups (between the different sampling episodes of the same beach) would be too high compared to the variability between groups (between the beaches) in order to be able to confirm intra-coast beach variability at a certainty level of $p<0.05$. This within group between beaches is also supported by the very high standard deviations obtained for each E.coli and E. Faecalis average per beach (Table 1 and 2).

This previous finding highlighted a need to look at what happened to the contamination levels between each sampling episode. By sorting the results by sampling episodes (Table 5), two sampling days appeared to have had much higher levels of contamination than the others : the 3rd sampling of the south coast for E. coli and E. Faecalis, and the 2nd sampling of the west coast had especially high levels of E. Faecalis. These results were put in relation to the recorded weather events for these dates in Table 6 in the hope of finding some trends that could explain this variability. By doing so, it was observed that the only common characteristic between these two sampling days (and that was exclusive to these days), was a heavy rainfall event recorded within the 2 days prior to sampling. Moreover, it appeared that the rain increased both E. coli and E. Faecalis levels on the south coast, whereas it only increased E. Faecalis levels on the west coast.

However, as this is only based on 2 samples (one per coast), it would be difficult to draw any conclusions based on this observation.

The high level of variation between each beach and each sampling episode suggests that it might be more appropriate to explore individual geographical and temporal factors that could affect E. coli and E. Faecalis contamination rather than grouping them by coast, which will be examined in the following sections.

5.2 Weather

Previous microbial water studies (Edwards, 2003; Coulliette, 2007) have demonstrated that weather has a significant impact on FIB (Fecal Indicator Bacteria) levels in marine waters. As such, the beach sampler would record the weather at the time of sampling. Weather data was also gathered for 48 hours prior to sampling. Over the course of the experiment, the weather was usually sunny or cloudy, with isolated incidences of heavy rainfall (Table 6; July 8 and July 15).

Sunshine: A relationship was found between clear sunshine or sparsely cloudy days and lower coliform counts. This link was even stronger if there were clear sunny days 48 hours prior to sampling (Table 6; June 17 and July 22). Background research on Belkins & Cowell *Oceans and health* (2006) highlighted the ability of sunshine to reduce coliform counts. The relationship between sunshine and fewer fecal indicator bacteria (FIB) could be partially due to the disinfecting qualities held in UV rays (Edwards, 2003).

In contrast, sunshine also increases the water temperature, which has been shown to aid the growth of fecal organisms in marine water (Thompson et al., 2005; Belkins & Cowell, 2006). Perhaps the heating of waters by sunshine did not influence results significantly because samples were always taken in the morning before the water reached peak temperature. However, it is not possible to confirm with the present results whether water temperature influenced coliform count because water temperature data were not recorded. It has however been observed during sampling that generally, clear sunny days also had very still and clear waters, so low turbidity and high translucence could also have influenced the low bacterial counts on these days. The possible positive correlation between low coliform counts and clear sunny days would be beneficial for swimmers public health because people tend to visit the beach when the sun is out, rather than on rainy days.

Wind: Previous research (Edwards, 2003) also found wind to be an influential factor on marine coliform counts. Wind can increase FIB counts by creating turbulence in the water and lifting contaminated sediments up from the sand (Lyimo, 2009). On one incident (July 1st, south coast) red flags were present on two of the beaches (S7 & S5), indicating high wind and choppy waters. However, upon interpreting the results, the wind did not appear to increase contamination levels on this day. S5 had 0 E. coli colony counts and 2 E. Faecalis colonies. S7 had an increase in E. coli counts from the first sampling episode (5.5 to 35.5 CFU) but was still significantly below the EPA limit and less than the third sampling episode, demonstrating that wind did not appear to be an influential factor. The absence of obvious link between wind and contamination might suggest that bacteria is likely not located in the sand sediments in Barbados (as if it was, the mixing of waters and sediments on windy days would increase the coliform counts). On July 1st there was also a greater presence of seaweed in the nearshore water, possibly blown in by the wind, which has also been attributed to releasing suspended bacteria in previous literature (Lyimo, 2009). Yet, the absence of significant change in contamination levels on this day indicates that seaweed is also not the primary pollutant source.

Rainfall: The strongest relationship found between weather and marine water contamination was the incidence of heavy rainfall within 48 hours of sampling. Such correlation is strongly supported by previous research (Coulliette, 2007; Belkins & Cowell, 2006; Edwards, 2003). Rainfall increases marine bacterial contamination by activating runoff from nearby contamination sources, such as sewage, agriculture and industry. Rainfall is also negatively correlated with sunshine, which reduces coliform counts (Edwards, 2003). The two incidences of rainfall within 48 hours of sampling had the highest recorded coliform counts (July 8 and July 15), as seen in Table 6. It is interesting that rainfall on the west coast correlated with increased enterococcus contamination, whereas rainfall on the south coast corresponded to increased E. coli levels. This relationship could be due to the runoff contamination source. As previously noted in the literature review, enterococcus has been attributed in the past to animal feces, whereas E. Coli has been attributed more to human waste (Hanes & Fragala, 1967). If this relationship holds true to Barbados, it would appear that rainfall increases runoff from human fecal contamination sources on the south coast, whereas animal feces would be increased by rainfall on the west coast. This trend is reflected overall, as more E. Faecalis than E. coli were found on the west coast, while the opposite trend is true for the south coast (more E. coli than E. Faecalis), as seen on Graphic 1.

Error: Weather related variables would be more certain if additional parameters such as water temperature, salinity, tidal range and ocean currents had been measured. Due to the time constraint of the project, access to resources and the scope of study, the results were limited to indicator organisms. Tides would be extremely relevant to study in relation to marine bacterial contamination; previous studies have demonstrated a strong positive correlation between high tides and increased FIB in marine waters (Lyimo, 2009; Edwards, 2003). While this report can give an idea of bacterial contamination sources, the above mentioned limitations prevent a definitive assessment of all aspects of marine water pollution.

5.3 Runoff Sources

Although the results appeared to demonstrate a positive correlation between rainfall and FIB, some beaches still consistently showed higher levels of E. coli and E. Faecalis than others, rainfall or not (Table 1 and 2). This points to the fact that rainfall could not the single factor responsible for the variability of the contamination levels in the results. The results were therefore organized according to their location and proximity to diverse installations (Table 10). By doing so, there appeared to be a strong positive correlation between high contamination levels and close geographical distance to fish markets. As seen in table 10, this relationship was not reflected for all contamination sources, as restaurants, industrial plants, yacht clubs and sewage plants did not demonstrate a similar impact on the beach contamination levels.

This relationship between fish markets and contamination was an unexpected finding and would require further research and sampling to validate. However, the preliminary results of this study pointed towards both runoff from fish markets and rainfall events to be the strongest correlations with single beach contamination in Barbados. While the connection with fish markets is still relatively unexplored by scholars, it is important for marine and human health. Fish markets attract humans, animals, birds and rodents, due to preparing and consuming food in open areas. At the fish market located closest to S8, rats were noted on multiple occasions. There is also a high density of human activity taking place close to the ocean, thus sewage and other sources of pollution could be improperly disposed into the water. At the market, there is only one public toilet, which is used mainly by customers, therefore fishers and vendors could be using the beach as a toilet facility, potentially increasing E. Coli levels. The shallow marine water in this area is extensively used for fishing and boat anchoring, where untreated sewage could be offloaded into the water.

The fish market located at W5 is much smaller in size, however runoff was noted by the sampler streaming from the parking area all the way onto the beach. W5 beach is also very close in proximity to a busy highway, so the runoff could be coming from multiple sources.

In order to find out the extent of the effect that the presence of a fish market has, the beaches were furthermore ordered geographically (Table 7 and Graphic 5), from the northern part of the west coast to the southern part of the south coast.This allowed to compare geographic proximity of each beach to the prominent fish markets. In this manner, a trend seemed to appear, where the beaches located north of the fish markets (left side of W5 and S8 on Graphic 5) had higher levels of E. coli and E. Faecalis than those located south of the same markets. This relationship suggests that currents travel South-North up Barbados, bringing contamination up the coast. We found this correlation to be the strongest for beaches less than 1km North of the contamination source, as beach W1 and W4, located respectively at 1.3 km and 1.4 km north of a fish market, don’t show higher levels of contamination than beaches located far from fish markets (Table 10). As mentioned, data on tides and current couldn’t be obtained for this report, yet the findings still suggest this Northward pattern.

5.4 Sewage

Much of the previous literature suggested sewage was the primary factor responsible for beach water contamination (Hellmér et al., 2014). On several accounts it was reported that there was a high correlation between high contamination levels of E.coli and enterococci at beaches near sewage outfalls. Along the sampled coasts, there were five main sewage outfalls nearby ; three on the south coast (near beaches S2, S5 and S6) and two on the west coast (near W6).

However, based on the present results, beaches near the sewage outfalls showed among the lowest contamination levels. A possible explanation could be the result of a 2018 sewage crisis on the south coast. In fact, the Minister of Energy and Water Resources, Wilfred Abrahams, said “increased monitoring and adjusted operations have provided a better sewage system on the south coast” post sewage crisis 2018. However, there is no data on E.coli and enterococci levels in the water prior to the crisis that could support this theory. Thus, the relation predicted by the literature between E. coli or E. Faecalis contamination levels and proximity to sewage outfalls hereby can’t be confirmed, and although this could be due to the reaction to the sewage crisis, further research or access to historical data on contamination would be required to confirm this.

5.5 Agricultural Runoff

Previous literature noted a relationship between agricultural runoff (water sent from farm fields due to irrigation or rain) and marine contamination. Agricultural-runoff water can contain fertilizer, pesticides, soil particles and animal waste which can enter the nearshore beaches where people swim and bathe. Despite growing literature on agricultural-runoff being a major concern for water contamination, present findings suggest it may not be a significant source of contamination in Barbados. In fact, the agriculture industry is being concentrated inland of the country and along the East and North coasts (Appendix C - Land use in Barbados). Thus, it is difficult to establish a link between agricultural runoff and water contamination along the West and South coast based on this research.

5.6 Accommodations

Part of the reason why it was hypothesized that the south coast had higher contamination levels than the west coast was due to the higher volume in hotel density (Table 8). As this hypothesis couldn’t be confirmed, it is therefore not possible to confirm the relationship between contamination levels and the contamination based on coast averages that had been mentioned in previous studies (Powell, 2008).

Looking at the accommodation distribution by beach rather than by coast (Table 9) still doesn’t point towards the existence of relationship between their number and the contamination levels, as is highlighted by Graphic 6. In fact, the beaches with the highest contamination levels (S1, S8 and W5), have very different numbers of accommodation nearby (3, 0 and 7 tourist accommodations, respectively), which would indicate the absence of a relationship between the two variables.

However, some trends appear by looking at this relationship for each coast. In fact, on the south coast, while S1 and S8 have the highest contamination levels on the island, the accommodation numbers nearby are among the lowest on the coast (3 and 0, respectively), whereas S2 and S3, the two beaches with the highest number of accommodations have among the lowest contamination levels, both for E. coli and E. Faecalis (Table 9). This would indicate that if there was an existing relationship between number of tourist accommodation on the south coast and contamination levels, it would be a negative correlation rather than the positive correlation expected (Graphic 7).

The opposite trend seems to appear by looking at this relationship for the beaches of the west coast only. In fact, as shown in Table 9, the two beaches on the west coast with the highest E. coli and E. Faecalis contamination levels (W3 and W5) are also the two beaches with the highest number of tourist accommodation on the coast (9 and 7, respectively). Although it is not an obvious correlation, the results would tend to show that if any relationship existed indeed between number of tourist accommodations on west coast and contamination levels, it would be a positive correlation (Graphic 8).

The south coast having a heavy urban density and low level of tourist accommodation near a beach could possibly indicate a high level of other buildings, such as restaurants, markets, etc. Therefore, this negative correlation found on the south coast may simply be an indication of another positive correlation between a different type of buildings and E. coli or E. Faecalis levels, although this should be further investigated.

Based on observations only, it was noted that the west coast seemed mostly occupied by tourist accommodation compared to other buildings (although the density of tourist accommodations is still lower than that of the south coast) (Table 8). Although an evaluation of the density of other infrastructures on the west coast should be conducted, a positive correlation between number of tourist accommodation and contamination numbers would make sense if the lack of tourist accommodation means a higher level of parks and vegetation (as opposed to corresponding to a higher level of restaurants and other buildings on the south coast). Further research on this relationship should however be conducted with accurate numbers of all buildings types near every beach.

5.7 Boat Density

It has been reported in previous studies that boats and vessels have a potential impact on sediment contamination in the water (La Rosa et al., 2001; Thompson, 2006; Belkin and Cowell, 2006). Indeed, these studies demonstrated a positive correlation between concentrations of fecal coliforms in marine water and increased boat occupancy. Observations made during the sampling episodes led to suspect a higher E.coli and enterococci counts on the south coast, as the main ports for cruise ships, boats and heavy boat traffic lie on this coast. However, due to confidentiality, information regarding registered boats in the area could not be adequately gathered. Thus, it was not possible to confirm or deny the link made in the literature between boat density and contamination levels in the water.

5.8 Limitations

The inconsistency of the weather of the days prior to sampling led to a high variability of the results, and limited the ability to extract significant trends from the data obtained. As mentioned in previous sections (5.2), sampling the water following a night of heavy rainfall would increase runoff into the ocean and create major disturbances in the water, moving many sediments around. Thus, having a larger number of sampling episodes would help to better control this variable, by allowing the exclusion of these rainfall events, or to better compare the effects of drought or rainy season on the beach water contamination levels.

Furthermore, the results obtained allow us to note the presence of contamination on certain beaches. However, the organisms chosen can’t differentiate accurately enough between the different sources of contamination to be able to identify them. Future research should therefore examine the same beaches, but for specific organisms that indicate better where the contamination is coming from rather than the indicator organisms used in this study, which would allow a better understanding of the sources and of the actions that can be put into place to solve it.

6. Conclusion

To summarize, our results did not allow us to confirm the hypothesis that the south coast was more contaminated than the west coast, as t-tests performed for both E. coli and E. Faecalis did not show a statistical difference between our groups (south coast and west coast). Moreover, when the averages of E. coli and E. Faecalis levels per coast were calculated by geometric mean, they both revealed to be lower than the maximum levels established by EPA recommendations. However, when looking at the geometric means per beach, one beach (S8) had E. coli levels over the recommended standards, whereas three beaches (W5, S1 and S8) had E. Faecalis levels exceeding the EPA recommendations.

A geographical analysis of the beach and area surrounding them showed that the three beaches with the highest levels of contamination (W5, S1 and S8) were the beaches located closest to fish markets, indicating that runoff from these markets could be a major source of recreational water contamination. Furthermore, by putting in relation the contamination levels recorded per sampling episode with weather events recorded these days and previous days, a relationship was found between heavy rainfall events within 2 days prior to sampling and contamination levels recorded at sampling. No relationship could be established between contamination levels and sewage outfalls, agricultural runoff, tourist accommodation density or boat density.

The complexity and high variability of the results between beaches of a same coast and between the different sampling episodes suggest that it might be better to analyze results by beach and by individual factors affecting contamination levels rather than by grouping them by a coast average, as this led to a high degree of information loss and a poor representation of reality.

Beyond the factors mentioned above, we further learned important practises that are essential to conducting a legitimate research project. Several protocols have to be learned and studied in order to obtain reliable results. Thus, all group members had to learn and understand basic lab protocol, in order to remain safe in the lab. All lab members were also educated on how to conduct standard protocols for beach sampling. Furthermore, all members of the group had to learn the membrane filtration technique, as it was an important method in the lab for obtaining key results. Finally, learning how to calculate the geometric mean was a fundamental step, as it allowed us to make better comparisons between EPA standards and the results obtained from the samples.

As mentioned under sources of error, accounting for tides and currents and other parameters such as salinity, pH and water temperature would give a more clear idea of contamination sources and influences. Additionally, in future studies, sampling fewer beaches but collecting samples from both coasts in one day and at more regular intervals instead. This study gave a good idea of which beaches require further attention and analysis. In the near future, sampling regularly following heavy rainfall events will give more data to further understand the issue. Marine bacterial contamination, particularly in close proximity to fish markets, is important to analyze further for public safety. It was noted that both W5, S1 and S8 are more popular for local swimming than tourists, thus it is critical for Barbados' citizens health. Enterococci has been attributed to gastrointestinal illnesses and antimicrobial resistance in fish and thus presents a risk for human ingestion, therefore we recommend further research and resources allocated to prevent fish market runoff (Lyimo, 2009). This is especially important considering that membrane filtration for FIB takes upwards of 24 hours before results can be read, making it difficult to post a timely public service announcement to prevent swimming in contaminated waters after a rainfall (Colford 2012). As such, efforts should be made in advance to stop the contamination source. Further research should also be conducted about the relationship between the type of urban installations other than tourist accommodations (such as restaurants) and the nearby beach contamination levels in order to help identify the source of contamination.

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APPENDIX

A. List of Abbreviations

CDC	Center for Disease Control
CFU	colony forming unit
FIB	fecal indicator bacteria
GM	geometric mean
ml	milliliter
RWQC	recreational water quality criteria
STV	statistical threshold value
WHO	World Health Organization
WQS	water quality standard(s)

B. Geometric mean calculations (Wikihow, no date)

Geometric Mean (Three or More Numbers)

$$\boldsymbol{Mean = (a_1 \times a_2 \times \cdots\ a_n)^{1/n}}$$

$$a = a\ number\ in\ the\ group$$

$$n = quantity\ of\ numbers\ in\ the\ group$$

Example:

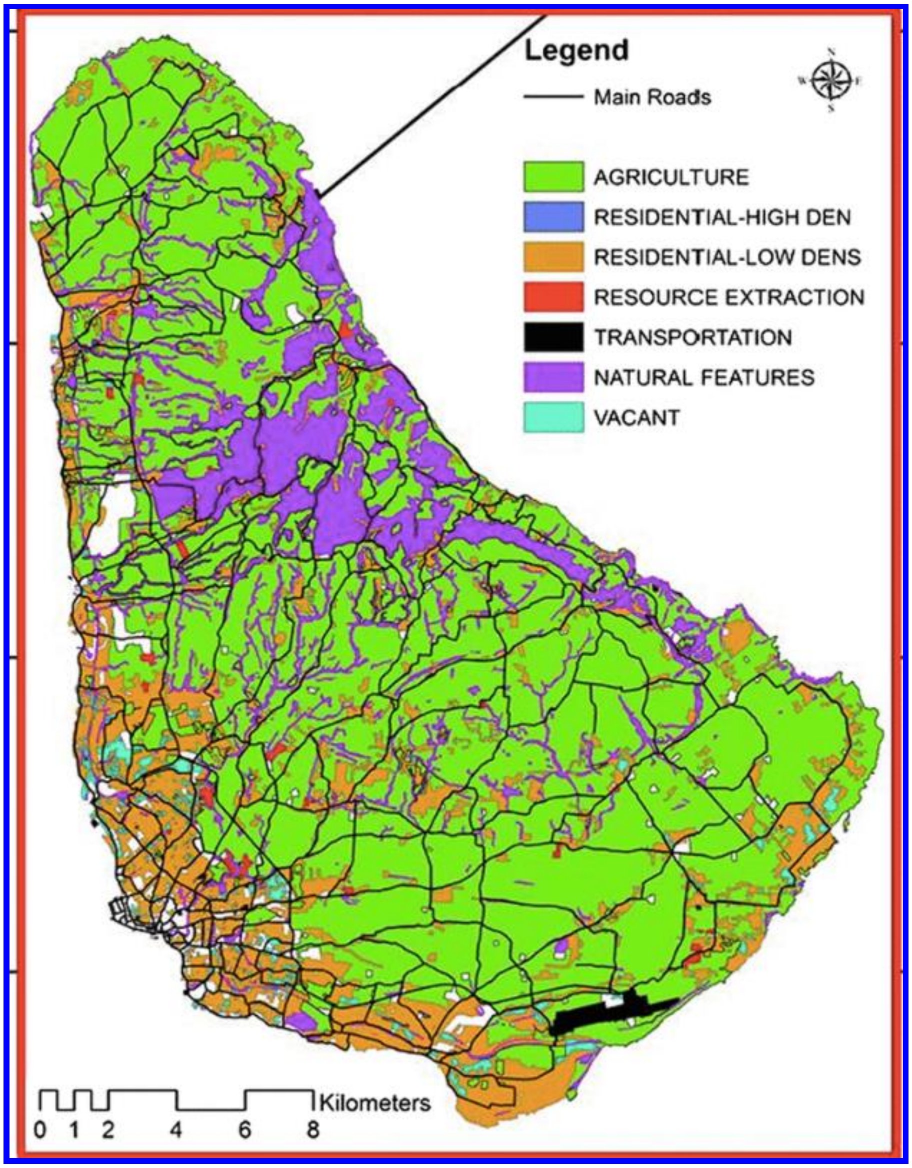
$a_1 = 10$

$a_2 = 15$

$a_3 = 20$

$$\begin{aligned} M &= (a_1 \times a_2 \times \cdots\ a_n)^{1/n} \\ &= (10 \times 15 \times 20)^{1/3} \\ &= (3000)^{1/3} \\ &= \sqrt[3]{3000} \\ &= 14.42 \end{aligned}$$

C. Land use in Barbados (Gohar et al., 2019)



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