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Research Paper

The Status of Surface Water in Linden and Coastal Guyana

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Abstract: *The status of surface water was determined for several selected areas of coastal Guyana. These were Linden, Cane Grove, Botanical Gardens, Non-Pariel, Utvlugt, Turkeyen and No. 62 village. Both physio-chemical properties and the concentration of cation and anion in mg/L were determined. The physical properties determined were temperature, pH, Turbidity, EC, Total dissolved solids, TDS. The pH range from 5.01 ± 0.01 to 6.17 ± 0.02, whereas EC (µs) and TDS (mg/L) was found to range from (26.7 ± 0.26 µs to 484 ± 1.15µs) and (18.7 ± 0.15 mg/L to 343 ± 4.36 mg/L). Dissolved oxygen content (DO) range from (1.0 ± 0.0 mg/L to 5.0 ± 0.0 mg/L), whereas salinity varied from 12.5 ± 0.05 ppm to 233.0 ± 0.1 ppm. All these physical factors with the exception of Turbidity and EC at No. 62 village were below WHO standards. With respect to the cations, there was no detection for cadmium in any of the surface water, with the exception of Cane Grove Surface water, which registered a value of 0.47 ± 0.03 mg/L. There was no detection for Pb, in any of the surface water. Aluminum detection range from (0.2 ± 0.03 mg/L to 0.43 ± 0.03 mg/L). Fe detection range from 0.01 ± 0.002 mg/L to 0.07 ± 0.03 mg/L. Cu detection was found to be constant at 0.01 ± 0.02 mg/L for all Surface water, whereas Zn showed detection in the range (0.04 ± 0.03 mg/L to 0.17 ± 0.03 mg/L). With respect to anions, there was no detection for nitrate, whereas SO_4^{3-} and PO_4^{3-} detection was found in the range (2.93 ± 0.02 mg/L to 20 ± 1.53 mg/L) and (0.06 ± 0.011 mg/L) to 1.10 ± 0.01 mg/L) respectively. All cations concentration, were below WHO standards. For the anions, only chloride at No. 62 village surface water was above WHO standards.*

Keywords: surface water, anions, cations, detection, permissible range.

Introduction

Water is a universal solvent that sustains all life forms. Much of the current concern with regards to environmental quality is focused on water because of its importance in maintaining the human health and health of the ecosystem. Surface water is water on the surface of the planet such as in a stream, river, lake, wetland, or ocean. It can be contrasted with groundwater and atmospheric water[1-7]. Providing sufficient quantities of high quality water to satisfy our domestic, industrial and agricultural needs is an ongoing global problem. Increasing population size, climate change and pollution will only exacerbate the global status. There is no physical shortage of water on the planet earth as it covers 70% of the globe. However, 97% of the world water is saline and is thus non-drinkable, 2% is locked in glaciers and polar ice caps, resulting in 1% to meet humanity needs[7]. Guyana water need continual monitoring to assess the concentration of toxic elements[8].Surface water plays a very vital role in economics and the functioning of ecosystems[9]. In Guyana, surface water is primarily used for agricultural, industrial and commercial purposes. Pollution of surface water due to industrial effluents and municipal waste in water bodies is a major concern in Georgetown, Linden and many other regions in Guyana. The addition of various kinds of pollutants and nutrients through the agency sewage, industrial effluents, and agricultural runoff in to the water bodies results in changes in the physicochemical characteristics of water[10]. For example, the discharge of toxic chemicals and metals from mining and industrial manufacturing, over pumping of aquifer and contamination of water bodies with substance that promote algae growth are some of the today's major cause for water quality degradation[11].

Runoff from urbanized surfaces, municipal and industrial discharges leads to increased loading of nutrients, metals, pesticides, and other contaminants into water bodies resulting in loss of species, loss of biodiversity, loss of amenities that these ecosystems once provided for society, and toxic algal growth in aquatic ecosystems[12]. These impurities may impair the colour, taste, odour, turbidity of the resource and sometimes cause corrosiveness.

Some contaminants of water are visible others, though present in significant quantities are not detected by the average human. Certain metals and microscopic agents in water are undesirable because of the hazardous effects on aquatic lives and human. A common phenomenon observed in Guyana's surface water is eutrophication. Excess growth of algae and plants in the water bodies rob aquatic lives of oxygen resulting in suffocation and death of fishes. Cation and Anion can accumulate in fish tissue and hence in the bodies of consumers[13]. Diarrhoea, a common occurrence for Guyanese, is a major effect of drinking and cooking with surface water, contaminated with fecal coliforms from latrines, municipal sewage, and consumption of seafood from polluted waters[14]. Guyana has not suffered any significant water- related illnesses[15]. However, between 1980 and 2011, over 650 000 people were affected by water borne illnesses[16].

The extensive use of chemical fertilizers for increased crop yield in the production of rice and sugar is significantly affecting the livelihoods of many. Irrigation from fields results in the increased blooming of aquatic plants which raises biological oxygen level demands and endanger aquatic life in the rivers[17]. An article titled "Canje residents forced to drink discoloured contaminated water," residents complained of rice farmers using a lot of chemicals and have been erratically discharging the contaminated water from their rice fields into the Canje River[17].

In addition, mining, an important industry in Guyana is a major source of contamination and degradation of rivers and creeks along the mining districts. The mining operations cause hydrocarbons to be released and increase sediment loading in rivers and creeks. The tailings dam at LINMINE (Bauxite mining) in Guyana's second largest town, Linden, discharges decant water with a pH of 4.5, via the local stream, into the Demerara river[18].Also mining within region one has been one of the major contributing factor of the polluted Port Kaituma creek. The Port Kaituma creek from long has been the residents' main water source for domestic purposes, including drinking[19].

The use of "missile dredges" in the Essequibo River basin, which have had a devastating effect on the forest and river areas in which they operate, causing: destruction of river banks and pollution of rivers from the chemicals used in the extraction process and from the diesel fuel used to run the dredging machines. Such impacts on the Potaro River are threatening the pristine environment of the Kaieteur Falls, the only legally established protected area[20].

There is an ongoing need to determine the concentration of toxic elements in water in view of the fact that some can be toxic amongst other effects[1-7]. Also, to ensure that the concentration of these is below the threshold limit[1-7]. Some cations and anions are toxic beyond their threshold value because of their mobility in living systems and abilities to cross cell membranes. Toxic anions are poisonous and can cause harm or even death via malfunctioning of the organs such as the kidney etc. They enter the body via drinking waters, food, fruits and vegetables, fish and other foods in general, that may have been exposed to such waters. Thus, the levels of concentration of cations/ anions must be controlled in our water bodies[21-22].

All cations and anions investigated in this research have both beneficial and deleterious effects to mankind [1-7, 21-29, 30-34]. For example, lead is a lethal ubiquitous metal. Natural waters seldom contain more than 5 ug/L, even though much higher values have been reported. Lead in water may originate from industrial, mine, smelter discharges or from the dissolution of old lead plumbing[1-7, 21-22]. In Guyana, the deposition of lead batteries may also contribute to the lead been carried to water ways and is also a source of lead poisoning[8]. Other sources include lead based indoor paint, lead in air from the combustion of lead containing industrial emissions, lead glazed pottery, lead dust brought home by industrial workers on their shoes and clothes. Lead has neurological, hematological and renal effects. Amongst these are lethargy, vomiting, irritability, loss of appetite, dizziness and eventual death[1-7, 21-22].

Phosphates and nitrates need special mention. The phosphate anion (1) is a hypervalent molecule[30-33]. It is the conjugate base of the hydrogen phosphate anion, HPO_4^{2-}, which is the conjugate base of $H_2PO_4^-$, the dihydrogen phosphate ion, is the conjugate base of H_3PO_4, phosphoric acid. Organophosphate (2), Figure 1, is an ester of phosphoric acid, H_3PO_4. Phosphate can also form polymeric ion such as diphosphate (pyrophosphate, $P_2O_7^{4-}$, triphosphate, $P_3O_{10}^{5-}$etc. Metaphosphate ions which are long linear polymers have an empirical formula of PO_3^- and are found in many compounds.

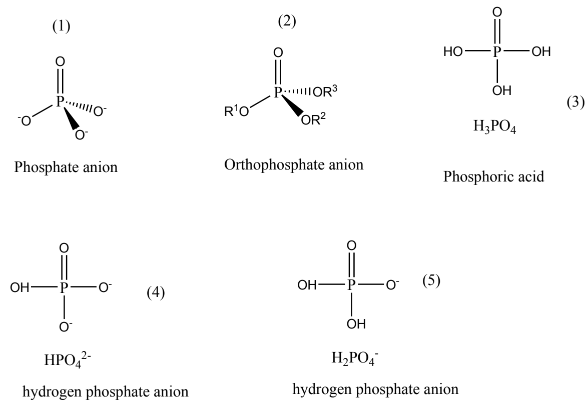


Figure 1: Phosphate ions

Phosphates anion occurs in natural and wastewaters as Orthophosphates, Condensed or acid hydrolysed phosphates (Pyro-, meta-, and other polyphosphates), and organically bound phosphates. They occur in solution, in particles or detritus, or in the bodies of aquatic organisms. These forms of phosphate arise from a variety of sources. Phosphates may also occur in bottom sediments and in biological sludge[1-7].

Biologically, Phosphates are found in the form of Adenosine Phosphates (AMP, ADP and ATP) and in DNA and RNA, Figure 3. Hydrolysis of these results in the release of phosphates. Phosphates are useful as buffering agents in the Biological system. These include Na_2HPO_4, NaH_2PO_4 and the corresponding potassium salts. Phosphates form the structural material of bone and teeth[26-29].

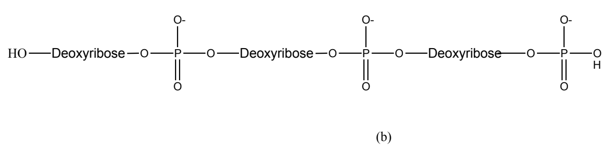


Figure 2: Structure of Adenosine Triphosphate, ATP, (a) and a section of a single strand of DNA

Phosphorus in phosphates is essential for the growth of plants, animal and microorganisms. It is an essential part of the process of photosynthesis and can be the nutrient that limits the primary productivity of a body of water. In instances, where phosphate is a growth-limiting nutrient, the discharge of raw or treated wastewater, agricultural drainage, or certain industrial wastes to that water may stimulate the growth of photosynthetic aquatic micro and macro-organisms in nuisance quantities. Phosphorus is involved in the formation of all oils, sugars, starches etc. It helps with the transformation of solar energy into chemical energy, proper plant maturation, withstanding stress and it also encourages blooming and root growth [30-33].

Nitrates have both beneficial and harmful uses. On the positive side, nitrates (NO_3^-) are essential plant nutrients that are important for protein synthesis [26,33-34]. They are responsible for the growth of plants and nitrogen fixation. Nitrates are found in nature since they are the end product of the aerobic decomposition of organic nitrogenous matter as well as the decomposition of organic micro-organisms. Unpolluted natural waters contain only miniature amounts of nitrate. In surface water, nitrate is a nutrient which is taken up by plants and assimilated into nucleic acid. Nitrates have also been responsible for Eutrophication, the process of enriching water or algal blooms.

The significance of this research is that it serves to assess the quality of surface water in Linden and selected areas of Coastal Guyana by determining their physical, chemical and biological properties. Also, to determine the bacterial contamination of surface water and to compare the analyzed values for water quality and coliform data with the standard permissible values recommended by WHO. This will be useful to initiate steps necessary for remedial actions in the case of polluted water bodies. Water pollution is dangerous to both aquatic and human health. Growing populations may put stresses on natural waters by impairing its quality.

Guyana is a sovereign state on the northern mainland of South America and is also part of the Caribbean region. Guyana (83,000 square miles) is bordered by the Atlantic Ocean to the north, Brazil to the south and southwest, Suriname to the east and Venezuela to the west[35] (Figure 4).

Figure 4: Map of Guyana
www.worldatlas.com/webimage/countrys/samerica/gy.htm

Water samples were taken from the following surface water in the following areas:

Areas where Surface water was taken from	Location	Regions
Linden	Upper Demerara-Berbice Region	10
Cane Grove	Demerara-Mahaica	5
Botanical Gardens	Georgetown	4
Non-Pariel	East-Coast Demerara Region	5
Utvlugt	West Bank Demerara River	4
Turkeyen	Georgetown	4
No. 62 village	Corentyne/Berbice	6

(a)

(b)

Figure 5: Two of the seven areas of coastal Guyana where the surface water was taken and analysed. (a) Botanical surface water (b) Utivugt surface water

Seven sites were chosen for this study: six on the Low Coastal Plain and one in Linden, Region 10. The Low Coastal Plain is populated with 90% of Guyana's population. Agricultural and industrial activities are prominent in this region with the capital city, Georgetown being the center of industrialization[15]. Linden is located on the Hilly Sand and Clay region 107 km inland from Guyana's Atlantic coast, on the east and west banks of the Demerara River. It is the second largest town in Guyana and occupies an area of approximately 140 sq km. This town was developed around bauxite mining industry with a population of approximately 40,000 and is the main population centre of Region 10[16].

There are articles in the literature on the pollution of surface water by metal cation and anions studied in this research [18-19, 37-43]. For example, heavy metals levels (Pb, Cd, Cr, Ni, Mn, Zn and Fe), in different samples (surface water, depth water and therapeutic mud) were collected from seven salt lakes from Romania and were determined by atomic absorption spectrometry (AAS). The results show that heavy metal concentrations were higher in mud samples comparative with water samples. The relationships between physicochemical parameters (pH, conductivity, turbidity, salinity, and TDS) and heavy metal concentrations were assessed as well[37].

A study was conducted in order to investigate amounts heavy metals such as cadmium, lead and chrome in surface water sources in Meshkinshahr region, Iran by using five stations during both high and low rainfall seasons in the year 2013. Results from T-test for high rainfall season showed that mean values for lead and chrome were higher than limits set by WHO and EPA and Iranian standard value, whereas mean value for cadmium were higher from limits set by WHO and EPA, but lower than Iranian standard value. In contrast, during low rainfall season, mean values for chrome and lead were lower than all the standard values; whereas, mean value for cadmium was higher than limits set by WHO and EPA and lower than Iranian standard value[38].

Material and Methods[1-7]

Sample collection

Water samples were collected in new plastic bottles during the day on July 28, 2015 at the seven selected sites previously described. These were stored in a cooler and submitted to GUYSUCO and GWI for physical, chemical analyses and bacterial analyses respectively. Water samples were analyzed within 48 hours using versatile standard methods. Water sample in triplicates were analysed for each parameter.

Water Sample Analysis

Physicochemical analyses of different surface water

Surface water collected from Linden and selected areas of Coastal Guyana were subjected to the following basic physicochemical analyses: Temperature, pH, Salinity, Electrical Conductivity, Total Dissolved Solids, Dissolved Oxygen and Turbidity. The following methods were used for the analysis of physicochemical parameters.

Temperature and pH

The temperature and pH of the samples were tested on site during collection step. This was done using the Temperature and pH meter from Hach 2559833 Surface Water Test kit and was in accordance with Standard protocol [1-5].

Total Dissolved Solids (TDS), Electrical Conductivity, and Salinity

For Turbidity measurement, the equipment used was the 2100N Laboratory Turbidimeter**.**

Dissolved Oxygen Test

The dissolved oxygen in the samples was tested using Model OX-2P, Drop Count Titration Kit 146900 (0.2 to 4 and 1 to 20 mg/L O_2) and using standard methods [1-5].

Cation and Anion Analysis

Cation and Anion analyses were done according to standard procedure[1-5].

Bacterial Analysis [45]

Bacterial Analysis was conducted at the Guyana Water Inc (GWI) via the Membrane Filtration Method [45]. In this technique, the filter used has a pore size of 0.45 micrometers and serves to retain indicator bacteria present in samples. Indicator bacteria are too large to pass through these small pores and are caught on the surface of the membrane. Each plating technique allowed indicator bacteria colonies to grow, while restricting the growth of non-target bacteria. Pour Rite ampules were used in this method. Pour Rite Ampules contain prepared selective media. This eliminates the measuring, mixing and autoclaving needed when preparing dehydrated media. The ampules are designed with a large unrestrictive opening that allows media to pour out easily.

Total Coliform (m-Endo), method 8074

First, the work desk was disinfected with dilute bleach solution. A pair of forceps was sterilized by dipping in alcohol and flaming in a Bunsen burner. A sterile absorbent pad was placed in a sterile petri dish using the sterilized forceps. An m-Endo Broth Pour Rite Ampule was inverted 2to 3 times to mix the broth. The ampule beaker was used to break open the ampule and the contents were carefully poured evenly over the absorbent pad. The petri dish lid was replaced. Steps 1 and 2 were repeated for each petri dish prepared. The Membrane Filter assembly was set up. A membrane filter grid side up was placed into the assembly. The sample was then inverted for 30 seconds to mix. Vacuum was applied and the sample was filtered. The vacuum was released. The funnel walls were rinsed with 20 to 30 mL of sterile buffered dilution water. Vacuum was reapplied. Rinsing was repeated 2 more times. The vacuum was turned off and the funnel top was lifted off. The vacuum was released when the filter was dry so as to prevent damage to the filter. Using sterilized forceps, the filter was immediately transferred to the absorbent pad in the previously prepared petri dish, grid side up. The petri dish lid was replaced. The petri dish was incubated in an inverted position at 35± 0.5 ºC for 24 hours. After incubation, a 10 to 15 X microscope was used to count the red colonies. Red colonies are representative of total coliform.

The inoculating loop was sterilized by passing it over the Bunsen burner flame. The sterilized loop was used to swab the entire surface of the total coliform-positive membrane filter (colonies grown on m-Endo Broth). The loop was placed in an EC Medium Broth tube and swirled to transfer the colonies collected from the filter. Steps 1 – 3 were repeated for the other broth media. The loop was removed from the medium. The tubes were inverted to eliminate any air bubbles trapped in the inner vial. The tubes were incubated at 44.5± 0.2 ºC. After 1 hour, the tubes were inverted to removed any trapped air in the inner vial followed by continued incubation. After 24 ± 0.2 hours, the inner vials were checked for gas bubbles. Growth and gas bubbles in the EC Medium Broth confirmed the presence of fecal coliforms. Fecal coliforms are blue in colour.

Results/ Statistical Analysis

The results of the various parameters tested in the samples collected from the selected areas are presented in tables. These were statistically analysed[46-53]. Corresponding graphs are also shown below.

Table 1: The basic physio-chemical parameter values in triplicates

Sample Area	Sample No.	Temperature (°C)	pH	Turbidity (NTU)	EC (µs)	TDS (mg/L)	DO (mg/L)	Salinity (ppm)
Linden	S1	28.9	5.01	3.3	33.9	24.6	5	16.0
	S2	28.9	5.02	3.4	33.6	23.8	5	16.0
	S3	28.8	5.02	3.7	33.5	24.3	5	16.1
Cane Grove	S1	28.9	5.48	4.0	26.9	18.9	3	12.5
	S2	28.7	5.49	4.1	26.8	18.7	3	12.5
	S3	28.0	5.49	3.8	26.4	18.6	4	12.6
Botanical Gardens	S1	29.2	6.18	3.9	149	107.3	4	71.7
	S2	29.1	6.19	3.9	151	106.7	4	71.8
	S3	29.2	6.16	4.2	153	106.1	5	71.8
Nonpareil	S1	29.1	6.02	2.3	379	263	2	178.0
	S2	29.1	6.02	2.4	375	265	2	178.0
	S3	29.0	6.01	2.0	372	267	2	177.9
Uitvlugt	S1	29.1	5.96	5.90	190	147	1	135.0
	S2	29.1	6.24	6.20	187	147	1	135.0
	S3	29.0	6.25	6.10	186	147	1	135.0
Turkeyen	S1	29.2	6.07	4.3	241	171	2	112.0
	S2	29.2	6.07	4.3	237	165	2	112.1
	S3	29.3	6.07	4.4	236	163	3	111.9
No. 62 Village	S1	29.0	5.96	455	484	338	2	233.2
	S2	29.3	5.96	455	484	346	2	233.0
	S3	29.4	5.97	451	486	345	1	233.0

Table 2: The Mean Concentration± Standard Deviation of Physico-chemical parameters in selected surface waters (mg/l) in comparison with the permissible limits recommended by WHO. A low standard deviation was observed for each parameter tested, which implies that the data obtained from the triplicates did not deviate much from the mean

Sample Area	Temperature (°C)	pH	Turbidity (NTU)	EC (µs)	TDS (mg/L)	DO (mg/L)	Salinity (ppm)
Linden	28.9 ± 0.06	5.01±0.01	3.4±0.21	33.6±0.21	24.2 ± 0.40	5.0±0	16.0 ± 0.05
Cane grove	28.9 ± 0.47	5.49±0.01	3.9±0.15	26.7±0.26	18.7± 0.15	3.3±0.58	12.5 ± 0.05
Botanical Gardens	29.2± 0.06	6.17±0.02	4.0±0.17	151 ±2	106.7± 0.6	4.3±0.58	71.7 ± 0.05
Non pariel	29.1± 0.06	6.01±0.01	2.2±0.21	375±3.51	261± 2	2.0±0	178.0 ± 0.05
Uitvulgt	29.0± 0.06	6.15±0.16	6.1±0.15	187±2.08	147± 0	1.0±0	135.0 ± 0
Turkeyen	29.2± 0.06	6.07±0	4.3±0.01	238±2.65	166.3±4.16	2.3±0.58	112.0 ± 0.1
No. 62 village	29.1± 0.21	5.96±0.01	455±2.31	484± 1.15	343± 4.36	1.6±0.58	233.0 ± 0.1
WHO standard		6.5-8.5	5	1800	500	5	

Table 3: The concentration of cation and anion in triplicates of water samples

Sample Area	Sample No.	Cation(mg/L)						Anion (mg/L)			
		Cd	Al	Fe	Pb	Cu	Zn	NO_3^-	SO_4^{3-}	Cl^-	PO_4^{3-}
Linden	S1	Nd	0.28	0.01	Nd	0.009	0.03	Nd	10.0	3.55	0.06
	S2	Nd	0.27	0.009	Nd	0.008	0.02	Nd	11.0	3.55	0.06
	S3	Nd	0.32	0.041	Nd	0.013	0.07	Nd	8.0	4.25	0.05
Cane Grove	S1	0.48	0.31	0.009	Nd	0.009	0.03	Nd	5.45	106	0.22
	S2	0.49	0.30	0.008	Nd	0.008	0.02	Nd	5.29	105	0.24
	S3	0.44	0.35	0.013	Nd	0.013	0.07	Nd	5.25	107	0.25
Botanical Garden	S1	Nd	0.32	0.01	Nd	0.009	0.03	Nd	2.92	Nd	0.09
	S2	Nd	0.31	0.009	Nd	0.008	0.02	Nd	2.95	Nd	0.09
	S3	Nd	0.36	0.041	Nd	0.013	0.07	Nd	2.93	Nd	0.06
Nonpareil	S1	Nd	0.38	0.009	Nd	0.009	0.05	Nd	20.0	185	0.06
	S2	Nd	0.39	0.008	Nd	0.008	0.04	Nd	21.0	183	0.06
	S3	Nd	0.43	0.013	Nd	0.013	0.09	Nd	18.0	184	0.07
Uitvlugt	S1	Nd	0.42	0.05	Nd	0.009	0.05	Nd	4.77	43	0.33
	S2	Nd	0.41	0.04	Nd	0.008	0.04	Nd	4.66	42	0.32
	S3	Nd	0.46	0.09	Nd	0.013	0.09	Nd	4.72	44	0.30
Turkynen	S1	Nd	0.38	0.05	Nd	0.009	0.03	Nd	2.51	85	1.11
	S2	Nd	0.39	0.04	Nd	0.008	0.02	Nd	2.50	78	1.10
	S3	Nd	0.43	0.09	Nd	0.013	0.07	Nd	2.48	85	1.10
No. 62 Village	S1	Nd	0.14	0.06	Nd	0.009	0.18	Nd	3.02	1064	0.14
	S2	Nd	0.15	0.05	Nd	0.008	0.19	Nd	2.98	1064	0.14
	S3	Nd	0.19	0.10	Nd	0.013	0.14	Nd	3.01	1064	0.15

Table 4: The Mean ± Standard Deviation Concentration of Cation and Anion in selected surface waters (mg/L) in comparison with the permissible limits recommended by WHO

Sample Area	Cd mg/L	Al mg/L	Fe mg/L	Pb mg/L	Cu mg/L	Zn mg/L	NO_3^- mg/L	SO_4^{3-} mg/L	Cl^- mg/L	PO_4^{3-} mg/L
Linden	Nd	0.29 ± 0.03	0.02 ± 0.02	Nd	0.01 ± 0.002	0.04 ± 0.03	Nd	Nd	Nd	
Cane grove	0.47± 0.03	0.32 ± 0.03	0.01 ± 0.002	Nd	0.01 ± 0.002	0.04 ± 0.03	Nd	5.33 ± 0.11	106 ± 1	0.23 ± 0.02
Botanical Gardens	Nd	0.33 ± 0.03	0.02 ± 0.02	Nd	0.01 ± 0.002	0.04 ± 0.03	Nd	2.93 ± 0.02	Nd	0.08 ± 0.02
Non pariel	Nd	0.40 ± 0.03	0.01 ± 0.002	Nd	0.01 ± 0.002	0.06 ± 0.03	Nd	20 ± 1.53	184 ± 1	0.06 ± 0.01
Uitvulgt	Nd	0.43 ± 0.03	0.06 ± 0.03	Nd	0.01 ± 0.002	0.06 ± 0.033	Nd	4.71 ± 0.05	43 ± 1	0.31 ± 0.02
Turkeyen	Nd	0.40 ± 0.03	0.06 ± 0.03	Nd	0.01 ± 0.002	0.04 ± 0.03	Nd	2.49 ± 0.02	83 ± 4.04	1.10 ± 0.01
No. 62 Village	Nd	0.2 ± 0.03	0.07 ± 0.03	Nd	0.01 ± 0.002	0.17 ± 0.03	Nd	3.00 ± 0.02	1064 ±0	0.14 ± 0.01
WHO Standard	**0.005**	**0.75**	**0.3**	**0.1**	**1**	**3**	**5**	**200**	**250**	**5**

Table 5: The number of Total and Fecal Colony Forming units in triplicates in water samples

Sample Area	Sample No.	Total Coliforms (CFU)	Fecal Coliforms (CFU)
Linden	1	49	6
	2	49	6
	3	52	6
Cane grove	1	63	3
	2	65	3
	3	67	6
Botanical gardens	1	TNTC	2
	2	TNTC	3
	3	TNTC	4
Nonpariel	1	TNTC	10
	2	TNTC	11
	3	TNTC	12
Uitvlugt	1	TNTC	14
	2	TNTC	21
	3	TNTC	25
Turkeyen	1	90	2
	2	85	3
	3	77	1
No. 62 village	1	TNTC	28
	2	TNTC	29
	3	TNTC	33

Table 6: Table showing the number of Total and Fecal Colony Forming Units in selected surface water in the form of Mean ± Standard Deviation where TNTC = > 200. A low standard deviation was observed for both total and fecal coliforms, which implies that the data obtained from the triplicates did not deviate much from the mean

Sample Area	Total Coliforms (CFU)	Fecal Coliforms (CFU)
Linden	50 ± 1.7	6 ± 0
Cane Grove	65± 2	4 ± 1.4
Botanical Gardens	TNTC	3 ± 1
Non Pariel	TNTC	11 ± 1.2
Uitvlugt	TNTC	20 ± 5.5
Turkeyen	84 ± 6.5	2± 1
No. 62 Village	TNTC	30 ± 2.4
WHO Standard		200
EPA Standard		

Table 7: The correlation and regression values, depicting the relationship between each physical and chemical parameter. The correlation and regression coefficient between each parameter was computed by using the mean values

Parameters	Correlation	F value	P value	Significance
EC vs TDS	0.99	2302.8	$7.4 * 10^{-8}$	Significant
Salinity vs DO	-0.77	7.53	0.04	Significant
Salinity vs TDS	0.99	176.7	$4.3*10^{-5}$	Significant
Salinity vs EC	0.97	107.0	$1.4* 10^{-4}$	Significant
Temperature vs pH	0.68	4.50	0.08	Not Significant
Temperature vs Salinity	0.71	5.06	0.07	Not Significant
Temperature vs Turbidity	0.37	0.78	0.41	Not Significant
pH vs Turbidity	0.13	0.08	0.78	Not Significant
Temperature vs EC	0.70	4.84	0.08	Not Significant

Parameters	Correlation	F value	P value	Significance
Temperature vs TDS	0.70	4.93	0.08	Not Significant
Temperature vs DO	-0.38	0.84	0.40	Not Significant
pH vs EC	0.58	2.50	0.17	Not Significant
pH vs TDS	0.59	2.68	0.16	Not Significant
TDS vs DO	-0.69	4.60	0.08	Not Significant
EC vs DO	-0.67	4.01	0.10	Not Significant
pH vs DO	-0.64	3.52	0.12	Not Significant
Salinity vs pH	0.64	3.39	0.12	Not Significant
Turbidity vs EC	0.70	4.90	0.08	Not Significant
Turbidity vs TDS	0.70	4.81	0.08	Not Significant
Turbidity vs DO	-0.35	0.68	0.44	Not Significant
Turbidity vs Salinity	0.67	4.11	0.10	Not Significant

Table 8: The correlation and regression values depicting the relationship between the cation and anion in water samples

Parameter	Correlation	F value	P value	Significance
Al vs Zn	-0.73	5.84	0.06	Not Significant
Al vs SO_4^{2-}	0.27	0.40	0.55	Not Significant
Al vs Cl^-	-0.78	7.76	0.03	Significant
Al vs PO_4^{3-}	0.38	0.86	0.40	Not Significant
Fevs Cu	0	0	1	Not Significant
Fe vs Zn	0.58	2.65	0.16	Not Significant
Fe vs Al	-0.18	0.17	0.70	Not Significant
Fe vs SO_4^{2-}	0.57	2.5	0.17	Not Significant
Fe vs Cl^-	0.53	2.0	0.23	Not Significant
Fe vs PO_4^{3-}	0.50	1.67	0.25	Not Significant
Cu vs Zn	-0.22	0	1	Not Significant
Cu vs Al	0	0	1	Not Significant
Cu vs SO_4^{2-}	0	0	1	Not Significant
Cu vs Cl^-	0	0	1	Not Significant
Cu vs PO_4^{3-}	0	0	1	Not Significant
Zn vs SO_4^{2-}	-0.16	0.13	0.72	Not Significant
Zn vs Cl^-	0.96	137.5	$7.92* 10^{-5}$	Significant
Zn vs PO_4^{3-}	-0.20	0.22	0.65	Not Significant
SO_4^{2-} vs Cl^-	-0.16	0.14	0.72	Not Significant
PO_4^{3-}vs Cl^-	-0.15	0.11	0.75	Not Significant
SO_4^{2-} vs PO_4^{3-}	0.41	1.03	0.35	Not Significant

Table 9: Table showing the correlation and regression values between Fecal coliforms and cation and anion; and fecal coliform and physical and chemical parameters tested in water samples

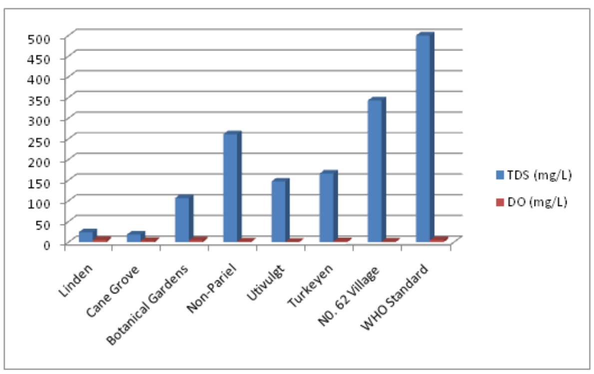
Parameter	Correlation	F value	P value	Significance
Turbidity vs FC	0.81	9.2	0.02	Significant
EC vs FC	0.69	4.65	0.08	Not Significant
TDS vs FC	0.72	5.2	0.07	Not Significant
DO vs FC	-0.66	3.78	0.11	Not Significant
Salinity vs FC	0.78	7.6	0.04	Significant
Zn vs FC	0.89	19.6	0.006	Significant
Cl vs FC	0.80	9.17	0.02	Significant
Fe vs FC	0.62	3.18	0.13	Not Significant

Table 10: Statistical analyses of cation and anion concentration between the study areas

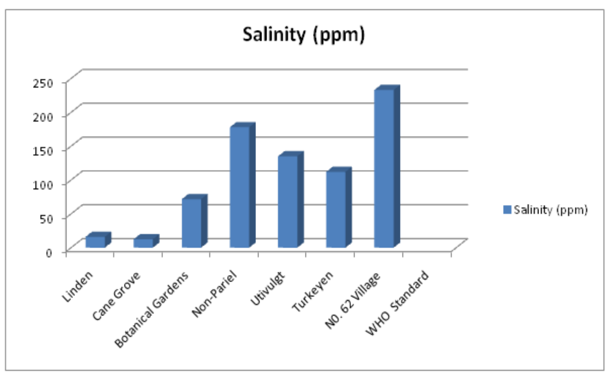
Sample Areas	F value	P-value	F critical
Turkeyen vs Cane Grove	1.21	0.29	5.11
NonPariel vs Cane Grove	1.40	0.27	5.11
Cane Grove vs Uitvlugt	1.03	0.33	5.11
Uitvlugt vs Linden	0.73	0.41	5.11
No.62 Village vs NonPariel	0.95	0.35	5.11
Linden vs Cane Grove	0.91	0.36	5.11
Cane Grove vs Botanical Gardens	1.06	0.33	5.11
NonPariel vs Uitvlugt	1.24	0.29	5.11
Turkeyen vs No. 62 Village	0.99	0.34	5.11
Linden vs Botanical Gardens	1.98	0.19	5.11
NonPariel vs Linden	1.12	0.32	5.11
Linden vs No. 62 Village	0.98	0.34	5.11
No.62 Village vs Uitvlugt	0.99	0.34	5.11
Linden vs Turkeyen	0.82	0.38	5.11
No.62 Village vs Cane Grove	0.99	0.34	5.11
NonPariel vs Turkeyen	1.36	0.27	5.11
Botanical Gardens vs NonPariel	1.21	0.29	5.11
Botanical Gardens vs Uitvlugt	1.11	0.32	5.11
Botanical Gardens vs Turkeyen	1.01	0.33	5.11
Botanical Gardens vs No.62 Village	1.00	0.34	5.11
Uitvlugt vs Turkeyen	0.92	0.36	5.11

Table 11: Anova: Two-Factor without Replication for Cation and Anion Analysis of the Water sample

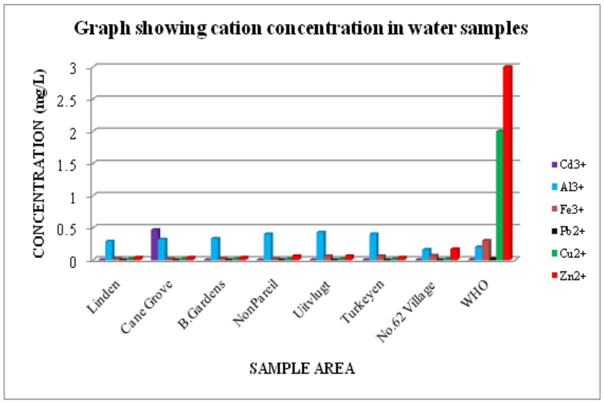
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	281069.2	9	31229.91	2.148249	0.040727	2.05852
Columns	86647.11	6	14441.19	0.993383	0.439192	2.271989
Error	785018.4	54	14537.38			
Total	1152735	69				



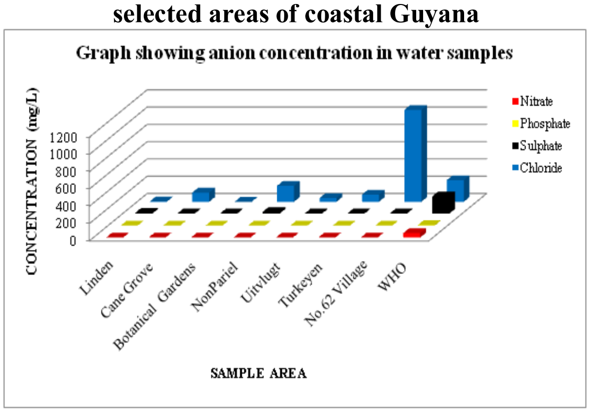
Graph 1: A Plot of Total Dissolved Solids (mg/L) and Dissolved Oxygen (DO) (mg/L) versus area Selected Area Surface Water



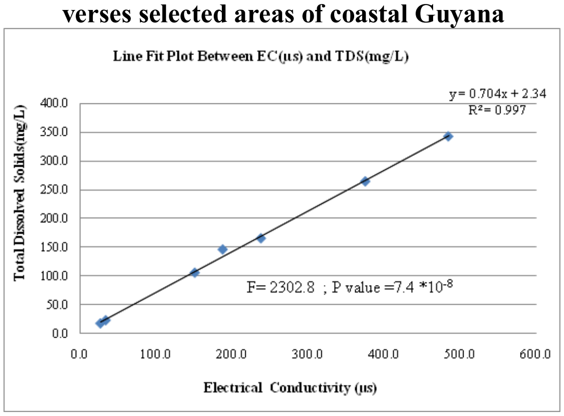
Graph 2: A Plot of Salinity (ppm) versus Selected Area Surface Water of Coastal Guyana



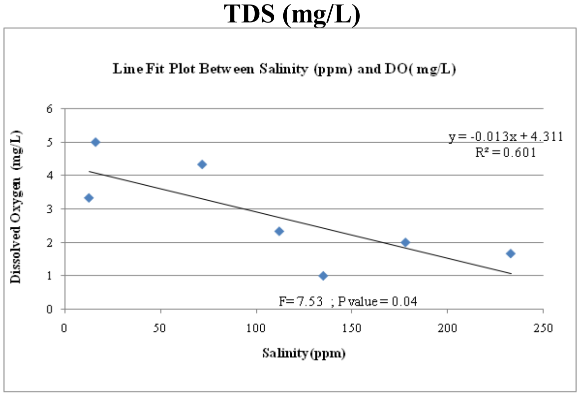
Graph 3: A plot of cation concentration (mg/L) vs selected areas of coastal Guyana



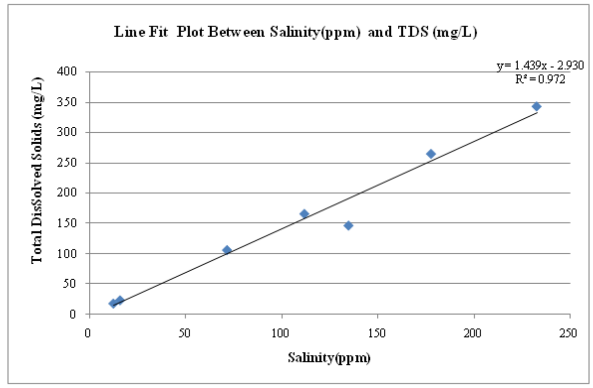
Graph 4: A plot of anion concentration (mg/L) verses selected areas of coastal Guyana



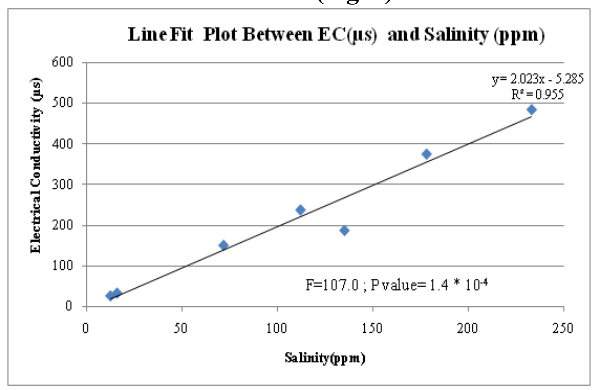
Graph 5: Correlation Plot between EC (µs) and TDS (mg/L)



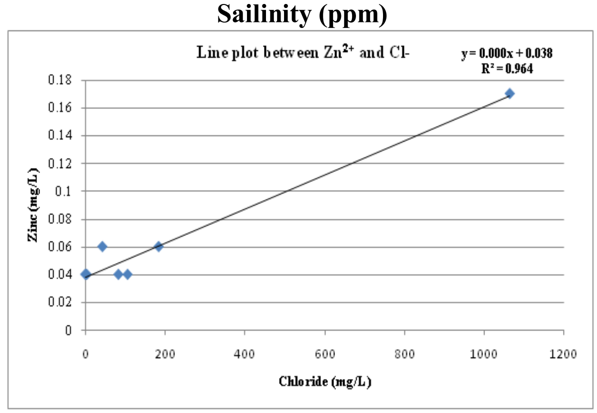
Graph 6: Correlation Plot between Salinity (ppm) and DO (mg/L)



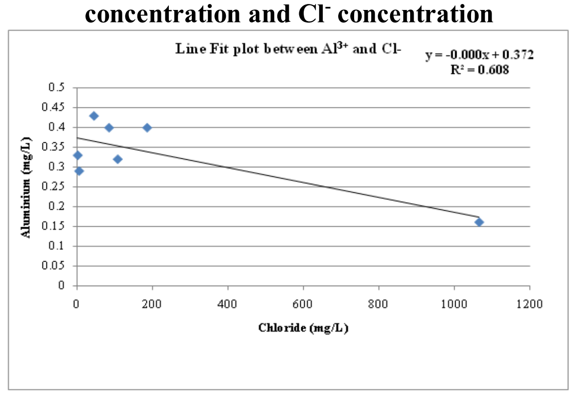
Graph 7: Correlation Plot between Salinity (ppm) and TDS (mg/L)



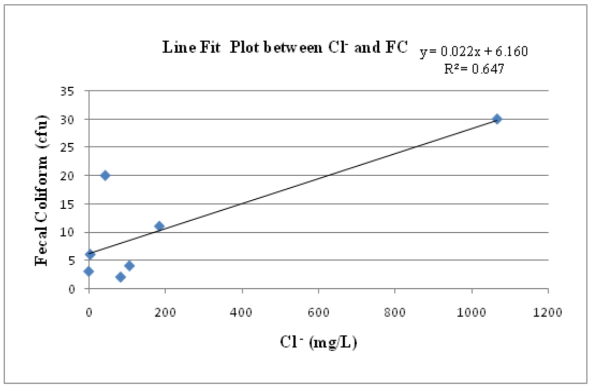
Graph 8: Correlation Plot between EC (µs) and Salility (ppm)



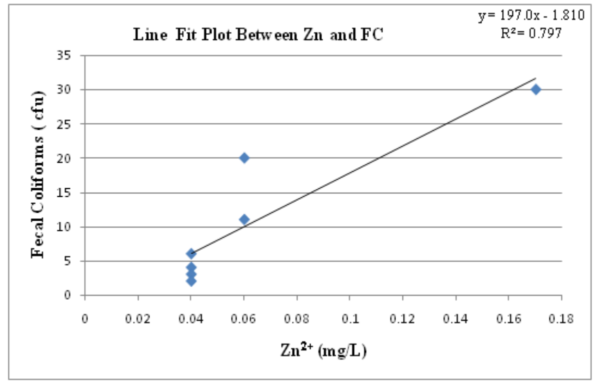
Graph 9: Correlation Plot between Zn^{2+} concentration and Cl^- concentration



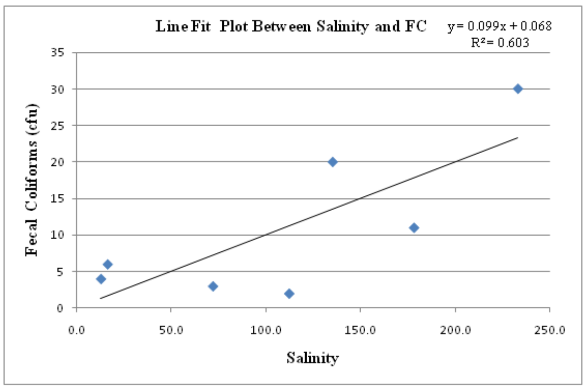
Graph 10: Correlation Plot between Al^{3+} and Cl^-



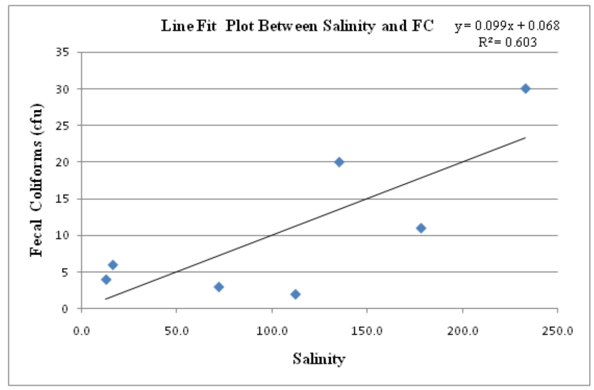
Graph 11: Correlation Plot between Cl^- concentration and Fecal Coliform



Graph 12: Correlation Plot between Zn^{2+} concentration and Fecal coliform



Graph 13: Correlation Plot between Salinity and Fecal coliform (FC)



Graph 14: Correlation Plot between Turbidity and Fe

Discussion

Cations and anions are naturally occurring elements in soils and water. However, from time to time, these elements are loaded into surface water bodies by natural and anthropogenic processes. Cations, anions and physical parameters such as temperature, pH, Turbidity, Electrical conductivity, EC, Total Dissolved Solids, TDS, Dielectric constant and salinity were investigated for the selected areas of coastal Guyana: Linden, Cane Grove, Botanical Gardens, Non-Pareil, Utvlugt, Turkeyen and No.62 Village. For each determination, experiments were done in triplicates. Table 2.0 shows that the temperature range from a minimum of 28.9 ± 0.06 ºC to a maximum of 29.1 ± 0.21ºC . The pH range from a minimum of 5.01± 0.01 to a maximum of 6.17 ± 0.02. The highest pH of 6.17 ± 0.02 was noted for the Botanical Gardens and the lowest of 5.01± 0.01 for Linden. Turbidity (NTU) range from a minimum of 2.2 ± 0.21 to a maximum of 455 ± 2.31. The latter was noted for No. 62 village, whereas the former was noted for Non-Pariel. The turbidity observed at No. 62 Village is far above the WHO accepted value of 5 NTU (Nephelometric Turbidity Units). High turbidity level are often linked with high number of pathogenic microbes which cause diseases such as diarrhea, vomiting and abdominal cramps. High turbidity also interferes with chlorination and helps to shield bacteria. Suspended particles and solids also serve as a place for attachment for bacteria. The electrical conductivity, EC which gives an indication of dissolved salts, range from a minimum of (26.7 ± 0.26) to a maximum of (484 ± 1.15). The latter was obtained for No. 62 village, whereas the former was obtained for Cane Grove Village. The maximum value of (484 ± 1.15) is above the WHO accepted value for EC (µs) which is 1800. The Dissolved Oxygen, DO range from 1.0 ± 0.0 to 5.0 ± 0.0 mg/L. The latter was noted for Linden whereas the former for Utvlugt. The WHO recommends a Threshold value of 5.0 mg/L for aquatic life. Values below that will not sustain aqaquatic life. Table 2.0 shows that Cane Grove, Non-Pariel, Utivulgt, Turkeyen and No.62 village whose DO is below 5.0 will have problems supporting aquatic life. The water from Linden, whose DO is 5.0 ± 0.0 should be perfect for the sustainance of aquatic life.

The Total Dissolved solids, TDS (mg/L) range from a minimum of (18.7 ± 0.15mg/L) to a maximum of 343 ± 4.36 mg/L. The latter was obtained for No. 62 Village and the former for Cane Grove Village. Dissolved oxygen (DO) in mg/L range from a minimum of 1.0 ± 0.0 to a maximum of 5.0 ± 0.0 mg/L. The latter was obtained for Linden Surface water. The former was obtained for Utvulgt Surface water. Graph 1.0 shows a plot of TDS and DO (mg/L) verses selected sample areas. The salinity (ppm) range from a minimum of (12.5 ± 0.05ppm) to (233.0 ± 0.1 ppm). The latter was obtained for No. 62 Village, whereas the former was obtained for Cane Grove Village. Graph 2.0 shows a plot of salinity (ppm) verses selected sample areas. Table 3.0 and 4.0, shows the concentration for the cation (mg/L) and anion (mg/L) for the selected surface water in the selected areas. Cations determined were Cd, Al, Fe, Pb, Cu and Zn. Anions determined were NO_3^-, SO_4^{3-}, Cl^- and PO_4^{3-}.

It was noticeable for all areas, with the exception of Cane Grove, there was no detection for cadmium. Cane Grove showed an average detection of magnitude 0.47 ± 0.03 mg/L which is higher than the WHO Threshold Limit of 0.005 mg/L. For lead, Pb, there was also no detection. The concentration of Al was found to be in the range (0.2 ± 0.03mg/L) to (0.43 ± 0.03 mg/L). The latter was noted for Utvulgt and the former for No. 62 Village. The highest value is below the WHO Threshold Limit of 0.75 mg/L. Fe detection range from (0.01 ± 0.002 mg/L) to (0.07 ± 0.03 mg/L). The latter was noted for No. 62 village, whereas the former for Cane Grove and Non-Pariel. The highest value is below the WHO Threshold Limit of 0.3 mg/L. Copper showed the lowest level of detection. A constant value of 0.01 ± 0.02 mg/L was noted for all the regions and this is below the WHO Threshold accepted value of 1.0 mg/L. Zn^{2+} concentration range from 0.04 ± 0.03 mg/L to 0.17 ± 0.03 mg/L. The latter was noted for No. 62 village, whereas the former for Turkeyen, Botanical Gardens, Cane Grove and Linden Surface water. The highest value is below the WHO Threshold value of 3.0 mg/L. Graph 3.0 shows a plot of cation concentration (mg/L) verses selected areas. As seen, the concentration of the dissolved metal ions is area dependent.

Nitrate, NO_3^- showed no detection in any of the surface water. The WHO Threshold Limit for Nitrate in Surface Water is 5mg/L. The concentration of SO_4^{3-} detected in the surface water range from (2.49 ± 0.02 mg/L) to (20.0 ± 1.53 mg/L). The latter was detected for Non-Pariel water, whereas the former for Turkeyen H_2O. There was no detection for SO_4^{3-} in Linden surface water. None of the selected surface water exhibit concentration of SO_4^{3-} greater than that of the WHO Threshold Limit of 200 mg/L. Cl^- ion concentration detection range from (43 ± 1.0 mg/L) to (1064 ± 0.0 mg/L).The latter was noted for the surface water at No. 62 village whereas the former was noted for Utvulgt surface water. There was no detection for Cl^- ion for Linden and Botantical Surface water. Only one surface water from No. 62 Village exhibit chloride anion concentration, greater than 250 mg/L. The concentration of PO_4^{3-} range from (0.06 ± 0.01 mg/L) to (1.10 ± 0.01 mg/L). The latter was obtained for the Turkeyen surface water, whereas the lowest of 0.06 ± 0.01 mg/L was obtained for Non-Pariel Surface water. None of the selected surface water, exhibited phosphate level, PO_4^{3}-, greater than the WHO Threshold Limit of 5 mg/L. Graph 4.0 shows a plot of anion concentration (mg/L) versus selected sample area. Here again, concentration of the anion detected is area dependent.

All the samples showed the presence of bacteria, Table 5.0.Total coliform, CFU concentration in the study areas ranged from 50 to more than 200 CFU/100mL, TNTC, while fecal coliform concentration in the study areas ranged from 2 to 30 CFU/100mL.The highest single fecal coliform concentrations were observed at No. 62 Village (30 CFU/100mL) and Utvlugt (20 CFU/100mL), which are predominantly agricultural areas.

In statistics, correlation is a measure that indicates the mutual relationship between two or more variables. There is a positive and negative correlation. A positive correlation shows the extent to which two variables increase or decrease in parallel, while a negative correlation indicates the extent to which one variable increases as the other decreases[51]. Correlation graphs are shown for Graph 5.0 to Graph 14.0. Each graph has a regression line, which is of the best fit nature. Also, each correlation graph is presented with a correlation coefficient, r (R). When R or r = 1 or R^2 =1, all the points are in a perfect straight line. In short, r (R) is the degree of linearity between x and y. As seen, R^2 varied from 0.608 to 0.9978. In statistics, regression analysis is a statistical tool that is used for estimating the relationship amongst variables[52].

Table 7, shows the correlation and regression values, depicting the relationship between each physical parameters. These are reflected in graphs 5 to graph 8. As computed, no significant difference existed between the computed values for most of the physical parameters. Significance difference existed for physical parameters EC vs. TDS, Salinity vs. DO, Salinity vs. TDS and Salinity vs. EC. Table 8.0 shows the correlation and regression values, depicting the relationship between each cation and anion in H_2O samples. These are depicted in graph 9 to graph 11. As shown, there wasn't significant difference between the cation and anion tested with the exception of Al vs Cl^- & Zn vs Cl^-. Table 9 shows the correlation and regression values between Fecal coliforms, cation and anion and physical and chemical parameters tested in H_2O samples. There is no significance difference between the parameters tested, with the exception against Turbidity vs FC, Salinity vs FC, Zn vs FC and Cl vs FC. Table 10 shows non-significant statistical analysis of cation and anion concentration between the study areas. The Anova Two Factor without replication analysis at $P < 0.05$ showed that the F value was less than the F critical, indicating there were no significant differences between the study areas with respect to cation and anion concentration.

Graph 5 shows the Correlation Plot between EC (µs) and TDS (mg/L). The regression line fit plot shows a significant positive relationship (p value ≤0.05) between TDS and EC in all the water samples. This plot indicates as the number of total dissolved solids increases in water, so does the ability of water to conduct electricity increases. Graph 6 is a Correlation Plot between Salinity (ppm) and Dissolved oxygen, DO (mg/L). The regression line fit plot shows a strong significant negative relationship (p value ≤ 0.05) between salinity and dissolved oxygen. The plot indicates an inverse relationship between the two parameters. As salinity increases, the amount of oxygen dissolved in the water decreases and vice versa. Graph 7 is a Correlation Plot between Salinity (ppm) and Total Dissolved Solid (mg/L). The regression line fit plot indicates a strong significant positive relationship (p value ≤0.05) between salinity and total dissolved solids. Both parameters increase in the presence of each other. Graph 8 is a Correlation Plot between EC (µs) and salinity (ppm). The regression line fit plot indicates a strong significant positive relationship (p value ≤0.05) between salinity and EC; as salinity increases, water adopts an increased ability to conduct electricity. Graph 9 is a Correlation plot of Zn^{2+} cation and Cl^{-}anion in the water samples. The regression line fit plot indicates a significant positive relationship (p value ≤0.05) between Zn^{2+} and Cl-. Both parameter either increase or decrease in the presence of each other. Graph 10 is a Correlation Plot between the Al^{3+} cation and Cl^{-} anions The regression line fit plot shows a strong significant negative relationship (p value ≤ 0.05) between Al^{3+} and Cl^{-}. The plot indicates an inverse relationship between the two parameters. Graph11 is a Correlation Plot between fecal coliform and Cl^{-}. The regression analysis at P ≤ 0.05 showed a strong relationship and indicates a positive correlation. Graph 12 is a Correlation Plot between fecal coliform and $Zn^{2+.}$ The regression analysis at P≤ 0.05 showed a strong relationship and indicates a positive correlation. Graph 13 is a Correlation Plot between fecal coliform and salinity. The regression analysis at P≤ 0.05 showed a strong relationship and indicates a positive correlation. Graph 14 shows a Correlation Plot between fecal coliform and turbidity. The regression analysis at P≤ 0.05 showed a strong relationship and indicates a positive correlation.

Anova factor with two replication was used to assess whether there is significant difference in the cation and anion concentration in the water samples for the selected areas and amongst the different cations and anions. The Anova Two-Factor without replication analysis at P < 0.05 showed that the F value (0.99) was less than the F critical value (2.27), indicating that there was no significant difference in cations and anions concentration for the different areas, P value > 0.05 (0.439) and F = 0.99 < F critical (2.27), column entries. However, there was significant difference between the concentration of cations and anions that were tested since the F value (2.14) is greater than the F critical (2.06) and p value (0.040) is less than 0.05, rows entries.

Conclusion

The status of surface water was determined for several selected areas of coastal Guyana. These were Linden, Cane Grove, Botanical Gardens, Non-Pariel, Utvlugt, Turkeyen and N0. 62 village. The pH range from 5.01 ± 0.01 to 6.17 ± 0.02, whereas EC (us) and TDS (mg/L) was found to range from (26.7 ± 0.26 µs to 484 ± 1.15 µs) and (18.7 ± 0.15 mg/L to 343 ± 4.36 mg/L). Dissolved oxygen content (DO) range from (1.0 ± 0.0 mg/L to 5.0 ± 0.0 mg/L), whereas salinity varied from 12.5 ± 0.05 ppm to 233.0 ± 0.1 ppm. All these physical factors with the exception of Turbidity and EC at No. 62 village, were below WHO standards. With respect to the cations, there was no detection for cadmium in any of the surface water, with the exception of Cane Grove Surface water, which registered a value of 0.47 ± 0.03 mg/L. There was no detection for Pb, in any of the surface water. Aluminum detection range from (0.2 ± 0.03 mg/L to 0.43 ± 0.03 mg/L). Fe detection range from 0.01 ± 0.002 mg/L to 0.07 ± 0.03 mg/L. Cu detection was found to be constant at 0.01 ± 0.02 mg/L for all Surface water, whereas Zn showed detection in the range (0.04 ± 0.03 mg/L to 0.17 ± 0.03 mg/L). With respect to anions, there was no detection for nitrate, whereas SO_4^{3-} and PO_4^{3-} detection was found in the range (2.93 ± 0.02 mg/L to 20 ± 1.53 mg/L) and (0.06 ± 0.011 mg/L) to 1.10 ± 0.01 mg/L) respectively. All cations concentration, were below WHO standards. For the anions, only chloride at No. 62 village surface water was above WHO standards. Samples collected at once may not be representative of the surface water source in the future. The concentrations of parameters may vary seasonally or from day to night or in response to some activity of man or animals. Thus, constant monitoring of surface water is necessary.

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