Water Quality Assessment in the lower reaches of the Belize River – A baseline chemical assessment

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Abstract

Water is one of the most important natural resources known on earth. It is important to all living organisms, ecological systems, human health, food production and for economic development. Without its presence, life would not exist on this planet as it is required for the chemical reaction of photosynthesis and respiration to occur. As such, preserving the quality of water is very important to the environment. The present study tested the quality of the Lower Reaches of the Belize River; thirteen samples were selected spatially along the lower reaches of the Belize River and compared with previous data collected in 2013. Physio-chemical parameters were collected; temperature, pH, dissolved oxygen, and salinity data were collected using a calibrated YSI meter model Professional Series. Nitrates and phosphate were collected and analyzed using the cadmium reduction method, and the ascorbic acid method, respectively. Results showed that there were statistical differences within all physio-chemical parameters P-value ($P < 0.05$) between the 2013 and the present study. The difference between the two years may have been attributed to weather conditions and to the fact that the 2013 data was collected at the beginning of the rainy season. Therefore, the values obtained from the study are within acceptable limits as required by Belize's Department of the Environment for surface water quality and that there were statistical differences between the data collected in 2013 to the present.

Keywords: Physio-chemical, Lower Reaches

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Student ID number: 2014110886

I declare this is my own original work, and that it does not contain material that has already been used to any substantial extent for a comparable purpose.

Name of student: ____________________ Signature: _____________________

Date: ____________________

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List of abbreviations and acronyms

EPA	Environmental Protection Agency
DOE	Department of Environment
WHO	World Health Organization
US EPA	United States Environmental Protection Agency
UNESCO	United Nations Educational, Scientific and Cultural Organization
BAS	Belize Audubon Society

Introduction

Undulating and tumbling from the elevated northeastern highlands of Guatemala where it is called the Rio Mopan, making its entrance into Belizean territory, the Belize River, also known as the "Old River", flows about 290 kilometers (180 miles) through the northeast to the center of Belize into the Caribbean Sea (Perez & Chin-Ta, 2009). Belize is rich in biodiversity and natural resources, in particular, one of the main resources; water. 2.8% of this territory is focused on the protection of water resources (Belize Enterprise for Sustainable development [BEST], 2009); however, the paradox of the never-ending flow of the Belize River presides within the fact that water is a scarce resource that is available merely in a finite amount, thus it is crucial to understand the importance of preserving it.

Belize has 18 principal watersheds that drains off into 16 minor drainages carrying water and sediment eastward to the Caribbean Sea from the mountains and hills of the west. The greatest concentration of freshwater wetlands etc. marshes, swamps and lagoons, is within the northern regions of Belize. The Belize River a total area of 9,434 km2; 69% in Belize, occupies substantially more than Belize's land, dominating the central portion of the country (Esselman, 2001). Many of the wetlands of the northern Belize occur as expansive lagoon systems that has multiple ecosystem type (e.g herbaceous marshes, and open water areas). Crooked tree Lagoon is the most notable among these, a 167 km2 wetland that is connected to the Belize River via two streams (Esselman, 2001).

Although most of Belize's water resources have thus far escaped advanced degradation from development and population pressures, the situation is changing rapidly, fueled by immigration from neighboring countries and expanding industries. Belize is home to approximately 375,000 people and is increasing rapidly (Statistical Institute, 2019). Unfortunately, about 41.3 percent of these people live below the poverty line (Lano, 2018). Though the majority of the country's residents have access to potable water, a significant number (e.g. the Belize River Valley area) lack access to potable water; these residents rely on river, well, and pond water to meet their needs, which leads to a high incidence of gastrointestinal maladies among rural populations (Young, 2008). Population growth rates can exert pressures on the environment which can affect long-term sustainability of natural resources and can also affect the quality of life. The water quality of these rivers is gradually declining due to the changes in the land cover patterns within the watershed as these human activities keep increasing over time. Deforestation, agricultural activities, and urbanization generally modify land surfaces characteristics, alter runoff volume, change water temperature, and generate pollution and decreases concentrations of dissolved oxygen in the water bodies.

Belize is fortunate to have ample water resources with many rivers and streams as well as groundwater, with the highest per capita water resources in the Americas (53.156 m3/annum) (BEST, 2009). But due to Belize's increasing population and expanding economy are placing ground-breaking pressure on its watershed. Although the growth and land use change may be unavoidable in many communities, the way in which the growth is taking place adds additional pressure on water quality. In developing countries such as Belize, the watershed ecosystem services are essential for most of the rural communities, therefore, there is a pressing need to understand the chemical composition that can safeguard these services.

Polluting substances that lead to deterioration of water quality affect most freshwater and estuarine ecosystems (Massoud, 2012). In addition, due to irrigation water that return back to the ground water or surface water may contain pesticides or even have elevated levels of nutrients such as nitrate and phosphates. Groundwater tends to move slowly, and is replenished slowly, so it can remain in aquifers for up to thousands of years. The agricultural sector is by far the biggest user of freshwater. These nutrients can then in turn, contaminate or cause harm to the aquatic environment and life that depend heavily on the return water. A water body require nutrients to nurture its health, however, too much can become detrimental. For example, eutrophication is caused when nutrient fertilizers from agricultural activities finds its way to enter the water body. This can aid in reduction of the dissolve oxygen level and suffocate the fishes. For humans, blue algae may produce toxins that can harm if ingested by humans. Therefore, because of these daily human activities, the deterioration of river water quality can now become a key environmental concern for the sustainability of the watershed.

When examining the changes made to an area of land and the cons that these modified landscapes have on the water quality within a watershed, a correlation is often found. However, with careful planning, a commitment in reducing these pressures to protect the streams, rivers, ground water, better land use practices can be implemented for more sustainable watershed management to ensure the quality of our surface waters. The relationships are important for effective water quality management such as relevant measures to minimize pollutant loadings (Ding et al., 2015). The rate of water quality deterioration is increasing in different regions of the world as a function of rapid demographic growth and socio-economic development (Zeilhofer et al., 2006).

1.1 Statement of the problem

The water quality of the Belize River watershed needs to be studied comprehensively because nationally, Belizeans receive many benefits from the natural resources including clean fresh water. Hundreds of families depend on clean water from nearby rivers, creeks and streams for their daily consumption and use. Therefore, water quality should be ensured so that no contaminates exceeds levels that would affect not only human health but also the aquatic ecosystems. Without proper management of the land upstream, these watersheds would deteriorate and affect all systems downstream; including forests, agriculture, villages, coastline and eventually the reef and sea. In addition, pollution sources need to be identified and a map created to illustrate the contaminated sites. The water quality assessment study will be very important to assess the water rescoures management issues in the Belize River watershed. The water quality is a dynamic phenomenon. The proposed study will be a possible way of water quality monitoring activities for the developing master plan of the country.

1.2 Objectives

Main objectives

The main objective of this study is to integrate the physiochemical assessment of the water quality to evaluate the state of the lower reaches of the Belize River.

Specific objectives

1 To compare and contrast nutrient values between the thirteen sites located within the lower region of the Belize River.

2 To describe the water quality change in the lower regions of the Belize River between 2013 and 2019.

Literature Review

Water is an invaluable resource and the benefits to mankind from proper management of this resource as well as the disastrous consequences of its mismanagement are very well known. The public awareness about water quality is at its zenith now but at the same time, the danger signals have not shown any abatement. Nationally, Belizeans receive many benefits from the natural resources including clean fresh water. Hundreds of families depend on clean water from nearby rivers, creeks and streams (Belize Audubon Society, 2013). Therefore, the study of water quality has remained an important pre-occupation with the environmentalist both from the practical and the academic viewpoints. Water from surface runoff incorporates the soluble materials and entrains sediment particles, making the water turbid. The suspended sediments are likely to adsorb ions and other matter. Water infiltrating into the soil will have its quality modified appreciably due to soil-water interactions. During dry periods, evaporative losses will be maximum and the constituents of the sub-surface water will be enriched. The exchange reactions and the chemical equilibria, involving soil and water, have been known to play an important role in determining water quality.

1.1 Water Quality Testing

Water quality is measured by collecting water sample for laboratory analysis by using probes that can record the data at a single point in time, or it can be logged at regular intervals over an extended period (Water and Environmental Regulation of Water, 2017). According to Tuna, Arkoc & Gulez, water quality refers to the physical, chemical, and biological characteristics of water, and it is a measure of condition of water relative to any human need or purpose. The most common testing includes Chemical analysis analysing for many physical, chemical and microbiological contaminants of surface water body to support aquatic life as an ecosystem and this includes freshwater environmental water quality parameters (Wrona & Cash, 1996). These can either be natural and man-made chemical, physical, biological and microbiological characteristics of rivers, lakes and ground-waters these parameters are good indicators of the quality of water. It is highly desirable to put significant effort into selecting indicators. However, for aquatic ecosystems there are a range of generally accepted indicators that are commonly used in most monitoring programs.

Aquatic ecosystem health indicators can be broadly divided into Physico-chemical indicators which are the traditional indicators that most people are familiar with such as dissolved oxygen, pH, temperature, salinity and nutrients (nitrogen and phosphorus) (Department of Science and Environment 2017). The biological indicators are species that can be used as a measure of some aspects of an ecosystem's health. The species' population or health may be a proxy for the ecosystem's health for example in aquatic ecosystem; for example, Escherichia coli (E. coli) and Coliform bacteria (López-López & Sedeño-Díaz, 1970).

1.2 Physico-chemical and Water Quality

It is very essential and important to test the water before it is used for drinking, domestic, agricultural or industrial purpose. The water quality deterioration in reservoirs usually results from acidification, heavy metal contamination, organic pollution, obnoxious fishing practices and excessive nutrient input that leads to eutrophication. According to Mustapha, physico-chemical properties of water quality assessment give a proper indication of the status, productivity and sustainability of a water body. Physico-chemical properties of the water gets varied season wise and in addition, anthropogenic activities such as agriculture, urbanization, domestic sewage, etc. in the catchment area result in the deterioration of water quality (Patel, Maurya & Gamit 2015). Some physical test should be performed for testing of its physical appearance such as temperature, color, odour, pH, turbidity etc. Temperature, turbidity, nutrients, hardness, alkalinity and dissolved oxygen are some of the important factors that play a vital role for the growth of living organisms in the water body. In Addition, Imevbore stated, that as these factor plays its own role, at the same time the final effect is the actual result of the interactions of all the factors. These factors serve as a basis for the richness or otherwise biological productivity of any aquatic environment.

1.3 pH (Potentia Hydrogenii)

Hydrogen ions, which are acidic, as well as hydroxyl ions, alkaline, are the result of the ionization of water. Any change in the concentration of any one of these ions bring about a change in the concentration of the other. Therefore, a single scale of numbers, called the pH scale, measured on a scale of 0-14, is used to measure the acidity or alkalinity of water and the number expresses the concentration of hydrogen ions indirectly (Michael, 1984). The pH changes in water are governed by the amount of free carbon dioxide (CO2), Carbonates and Bicarbonate. These changes are accompanied by the changes in other physicochemical aspects that in turn influence quality of water.

1.4 Nitrite (NO2) and Nitrate (NO3 -)

According to Oram, The Environmental Protection Agency (EPA) has since adopted the 10 mg/L standard as the maximum contaminant level (MCL) for nitrate-nitrogen and 1 mg/L for nitrite-nitrogen for regulated public water systems. Nitrite is an intermediate stage in oxidation of nitrogen, both the oxidation of ammonia to nitrate as well as in reduction of nitrate.

Nitrate is the most highly oxidized form of nitrogen compound commonly present in natural waters. It is a product of aerobic decomposition of organic nitrogenous matter. Significant sources of nitrates are fertilizers, decaying vegetation and animal matter, domestic and industrial effluents and atmospheric fall out. Excessive concentration of Nitrate in drinking water is considered hazardous for infants because in their intestinal tract nitrates are reduced to nitrites, which may cause blue baby syndrome (Meays, 2009). Hence, nitrate levels needs to be maintained in a water body. Nitrate is assimilated by algae and larger hydrophytes. It is reduced to ammonia when molybdenum is provided in the enzyme system associated with the reduction.

1.5 Phosphate (PO4 -3)

Phosphorus plays a major role in biological metabolism. In comparison to other macronutrients required by biota, phosphorus is the least abundant and commonly the first element to limit biological productivity. The deposition of phosphorus into river sediments occurs by mechanisms such as sedimentation of phosphorus minerals imported from the drainage basin, adsorption or precipitation of phosphorus with inorganic compounds, uptake of phosphorus from the water column by algal and other attached microbial communities (Williams and Mayer, 1972; Bostrom et al., 1988; Wetzel, 1990). The quantities of phosphorus entering the surface drainage vary with the amount of phosphorus in catchment soils, topography, vegetative cover, quantity and duration of runoff flow, land use and pollution.

1.6 Temperature

Temperature is a measure of the intensity (not the amount) of heat stored in a volume of water measured in calories and is the product of the weight of the substance (in gms), temperature (ºC) and the specific heat (Cal g - ºC-1). According to Kreger 2004, the measurement of temperature is the most common physical assessment of water quality. Temperature impacts both the chemical and biological characteristics of surface water. It affects the dissolved oxygen level in the water, photosynthesis of aquatic plants, metabolic rates of aquatic organisms, and the sensitivity of these organisms to pollution, parasites and disease. In addition, Human activities affecting water temperature can include the discharge of cooling water or heated industrial effluents, agriculture and forest harvesting (due to effects on shading), urban development that alters the characteristics and path of storm water runoff, and climate change (Regional Aquatic Monitoring Program).

1.7 Dissolved Oxygen and Water Quality

Dissolved oxygen (DO) is the amount of oxygen that is present in water (US EPA, 2016). However, Kemker stated that dissolved oxygen refers to the level of free, non-compound oxygen present in water or other liquids. It is an important parameter in assessing water quality because of its influence on the organisms living within a body of water. Apart from temperature, dissolved oxygen is an essential factor second to water itself. Both plants and animals depend on dissolved oxygen for survival. These organisms use oxygen in respiration, similar to organisms on land (Kemker, 2013). Measuring dissolved oxygen is probably the most significant water quality test to determine the suitability of a stream for fish and many other aquatic organisms.

At levels around 5 mg/l of dissolved oxygen, irrigation water is typically considered marginally acceptable for plant health. Most greenhouse crops, however, will perform better with higher levels. Levels of 8 mg/l or higher are generally considered to be good for greenhouse production and much higher levels, as high as 30 mg/l or more, are achievable and can be beneficial. If the DO levels are below 4 mg/l, the water is hypoxic and becomes very detrimental, possibly fatal, to plants and animals. If there's a severe lack of DO, below around 0.5 mg/l, the water is anoxic. No plants or animals can survive in anoxic conditions. The irrigation water in many greenhouses has surprisingly low levels often in the dangerous hypoxic range (Becker, 2016). Oxygen gets into the water by diffusion from the atmosphere, aeration of the water as it tumbles over rocks and waterfalls, and as a product of photosynthesis. The oxygen content of water will decrease when there is an increase in nutrients and organic materials from industrial wastewater, sewage discharges, and runoff from the land (Kale, 2016); Intensive land uses such as farming produce more nutrients in runoff than native forest; Excessive plant and

Algal growth and decay in response to increasing nutrients in waterways can significantly affect the amount of dissolved oxygen available. Moreover, oxygen affects a vast number of other water indicators, not only biochemical but appealing ones like the odour, clarity and taste (Swanson & Baldwin, 1965). Consequently, oxygen is perhaps the most well-established indicator of water quality.

Methodology

1.1 Description of site

The Belize River, also known as "the Old River", runs 290km through the center of Belize. The river begins where the Mopan River and Macal River join just east of San Ignacio, Cayo, Belize. The River Valley is largely tropical rainforest however, many points along the lower reaches have been stripped of its riparian forest. It is known that the river served as the main medium of commerce and communication between the interior and the coast until well into the twentieth century. Presently, the river is a vital source of water and domestic use for local people living along the river bank.

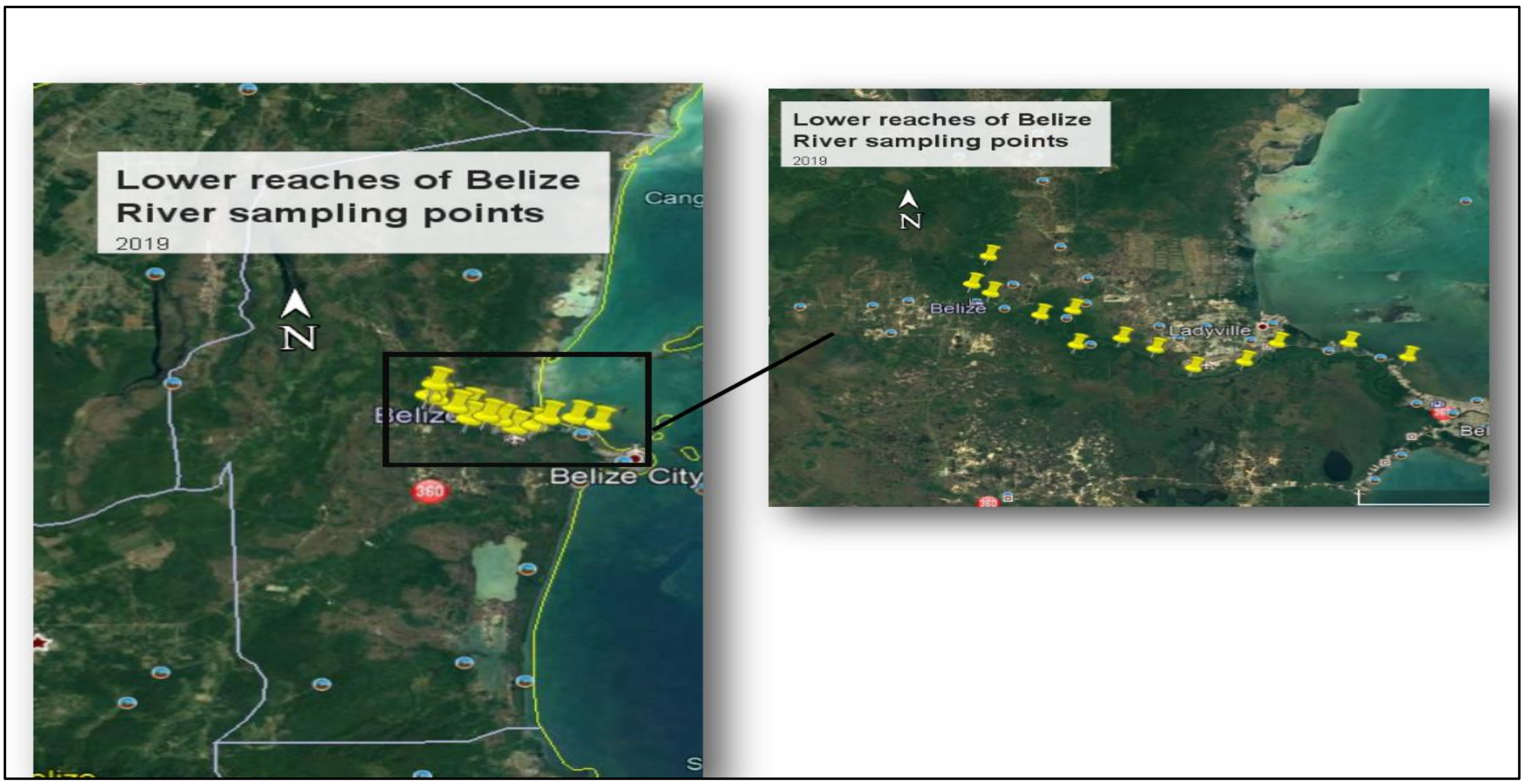

Figure 1. Map of sampling sites along the lower reaches of the Belize River

1.2 Water Quality Parameters

The following physical and chemical parameters that will be measured from the three sampling sites namely: temperature, turbidity, pH, conductivity, dissolved oxygen and nutrients (nitrates and nitrites, ammonia phosphorus). Characteristics of these parameters give either a direct or an indirect indication of the type and occurrence of pollution in water which in turn highlights possible sources of pollution (Kibena, 2012). The collection of these parameters will also provide an over view of the health of the river.

1.3 Sampling and Field Work

Various sampling sites (2.2 kilometers apart) were located at the lower reaches of the Belize River. The distance between samples was tracked using a Garmin GPS. Sampling was carried out in one day, with thirteen sampling sites being located and samples were taken from a fourteen sites. The data collection was conducted in the middle of the river to ensure minimal influence from erosion banks and decomposition hotspots and from the influence of the riparian forests, especially on water temperature. Parameters were taken using the YSI water sampler and water sample was gathered using the Niskin bottle sampler and then poured into sterile 125ml Nalgene bottle, and kept under ice bathe.

Measurements of parameters such as dissolved oxygen, salinity, pH, temperature, ammonia, conductivity and turbidity were done in-situ at the various sampling stations. This data was collected via a comprehensive YSI meter and was stored on a laptop computer. Surface water samples were collected at depths of approximately 1 meters using the YSI and the Niskin Water Sampler. samples were directly stored into sanitized 120ml Nalgene bottles that were thoroughly washed with phosphate free and brought to the laboratory, processed under 24 hours, and under 4°C for further analysis.

1.4 Laboratory Analyses

All analyses were done using the Hach DR 6000 spectrophotometer and Hach reagents. Nitrate levels were analysed using the Cadmium Reduction Method. In this method, cadmium metal reduces nitrates in the sample to nitrite. The nitrite ion reacts in an acidic medium with sulfanilic acid to form an intermediate diazonium salt. The salt couples with gentisic acid to form an amber colored solution. The reagent used in this analysis was the NitraVer® 5 Nitrate Reagent Powder Pillow. Phosphate was analysed using the PhosVer3 (Ascorbic Acid) Method. This method employed the use of the PhosVer® 3 Phosphate Reagent Powder Pillow produced by Hach. In the reaction, orthophosphate reacts with molybdate in an acid medium to produce a mixed phosphate/molybdate complex. Ascorbic acid then reduces the complex, giving an intense molybdenum blue color. Three sample were randomly chosen and analysis was done in duplicate and the mean value was taken.

Results

Table 1. Statistical analysis of environmental parameters of water quality analysis of Belize River lower reaches.

Summary of the water quality analysis done utilizing both the YSI meter model Professional Series, and the HACH DR 6000 spectrophotometer. Values represent the mean of thirteen samples done in each reach of the river.

A t-test was conducted to determine the significant difference between the means of all six parameters for the year 2013 and 2019. It was concluded that all parameters had a significant difference therefore the means were different. The following table shows the mean difference between all parameters for both the researcher A and researcher B.

	Researcher	N	Mean	Std. Deviation	Std. Error Mean
Temperature	researcher A	13	36.2185	2.53509	.70311
	researcher B	13	28.9731	.14739	.04088
Ph	researcher A	13	6.8546	.71554	.19845
	researcher B	13	8.3377	.05570	.01545
Salinity	researcher A	13	.1646	.06253	.01734
	researcher B	13	.2385	.01345	.00373
Dissolve_Oxygen	researcher A	13	5.8323	.72129	.20005
	researcher B	13	3.2638	.43295	.12008
Nitrate	researcher A	13	1.9154	.89800	.24906
	researcher B	13	1.0308	.14367	.03985
Phosphate	researcher A	13	.0508	.03947	.01095
	researcher B	13	.4469	.09810	.02721

*Table 1 Showing difference between parameter means for Researcher A and Researcher B. * Research A is data from 2019 and Researcher B is 2013 data.*

The following graphs shows the comparison between all six parameters gathered from the thirteen sample sites along the lower reaches of the Belize River for the year 2013 and 2019. The summary of the temperature results at the thirteen sampling sites for the year 2013 and2019 is presented in figure 2 below. The mean temperature at the thirteen sampling sites were 36.2 C in 2019 and 28.9 C in 2013. In 2013, the temperature was stable along the river however, in 2019, there was variations in temperature values at different sites which could be attributed to the prevailing environmental condition such as, atmospheric temperature, cloud cover, and availability of the riparian forest cover.

The summary of DO concentration at the thirteen sampling sites is presented in figure 3 below. 2019, the dissolved oxygen concentration at all thirteen sampling sites showed an average of 5.8mg/l whilst in 2013, 3.2mg/l. dissolved oxygen concentration showed variations at the different points along the Belize river; this can be attributed to turbulence, temperatures and/or biological activities at the various points.

The summary of pH at the thirteen sampling sites is presented in figure 4 below. The average pH values at all sampling points for year 2013 and 2019 ranged from 6.8 – 8.3, these values are well within the DOE water quality standard (6-9), as well as the US EPA (6-9) standards, and WHO guidelines (6.5-8.5).

The summary of Nitrate concentration at all thirteen sites is presented in figure 5 below. 2019, the nitrate average concentration at the thirteen sampling sites range from 1-3mg/l and ranges from 0.8-1mg/l in 2013. These concentration were all within the DOE standards (0.3-30.0mg/l). There was variations in nitrate concentration at different sites in 2013 which could be attributed to the runoff caused by land use activities such as farming, urban development.

The summary of salinity concentration at all thirteen sites is presented in figure 6 below. 2019, the nitrate average concentration at the thirteen sampling sites range from 1-3mg/l and ranges from 0.8-1mg/l in 2013. These concentration were all within the DOE and US EPA standards (0.02- 2.50). There were variation in phosphate concentration at the different sites in 2019 which could be attributed to farming.

The summary of phosphate concentration at all thirteen sites is presented in figure 7 below. The salinity values were started at an average of 28ppt and gradually got lower due to distance from estuary. These values from year 2013 and 2019 were within WHO standard, US EPA standard and environmental standard.

Water quality parameters along lower reaches

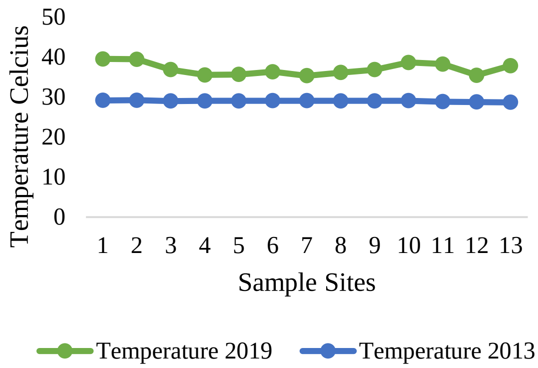

Figure 2 Temperature at different sampling sites

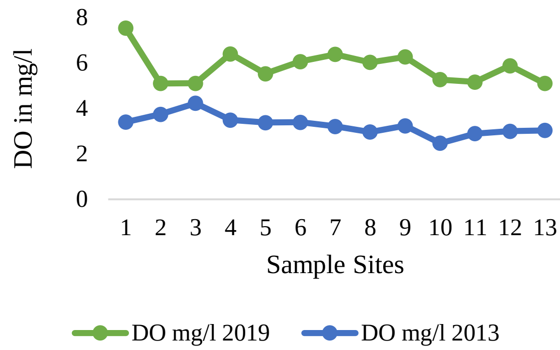

Figure 3 Dissolved Oxygen at different sampling sites

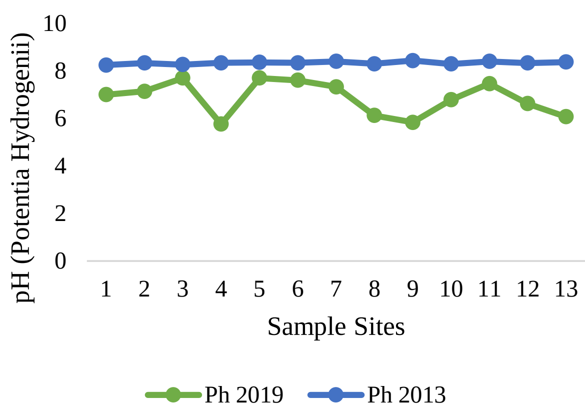

Figure 4 Ph (Potentia Hydrogenii) at different sampling sites

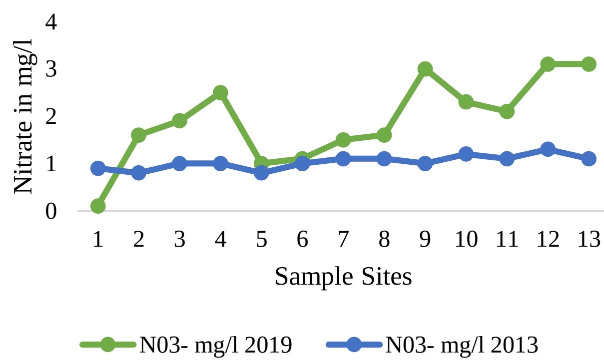

Figure 5 Concentration of nitrate at different sampling sites

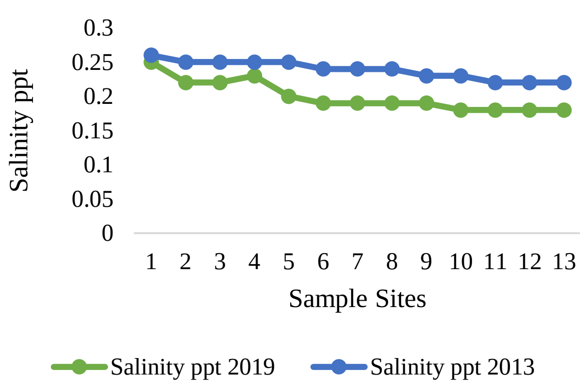

Figure 6 Salinity ppt at different sampling sites

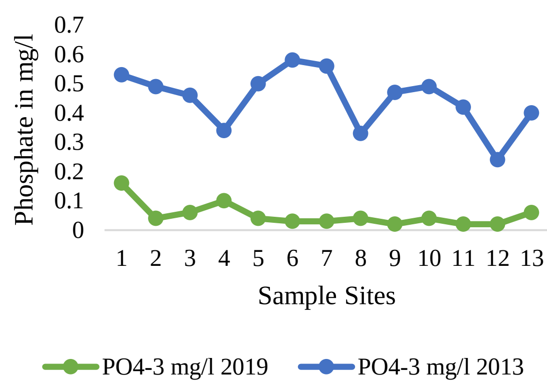

Figure 7 Concentration of phosphate at different sampling sites

Discussion

Chemical Analysis

The temperature of the river is one of the most important characteristics of the aquatic ecosystem affecting number of water quality parameters such as dissolved oxygen levels, chemical processes and the biological processes (Ali et al., 2015). The results if figure 2 show the range of temperatures from all thirteen sampling sites from the lower reaches of the Belize River. The results demonstrate that the temperature of the lower reaches, as shown in figure 2, starts high at 39.5 it gradually goes low and then elevates again and this could be because the river temperature varies due to the environment. According to Hannah & Garner (2015), Water can be heated or cooled through radiation at the surface and conduction to or from the air and surrounding substrate. Climate, shading and elevation all affect water temperature. Therefore, along the lower reaches the estuary had a high temperature due to more exposure of the sun compare to the upper region being cooled by shade and going more to the hills.

When comparing the mean temperature from 2019 to 2013 there was a significance difference between the values. As shown in figure 1, researcher B had a mean value of 28.97 whereas research A had mean value of 36.21. The difference in mean could have been due to climate change. The 2013 assessment mentioned that it was cloudy when the research was carried out compared to research A having a sunny say. As Ficklin et al., 2013, reported Warmer temperatures are expected to raise mountain stream temperatures, affecting water quality parameters, in particular, dissolved oxygen.

The dissolved oxygen reveals the changes occur in the biological parameters due to aerobic or anaerobic phenomenon and signifies the condition of the river/streams water for the purpose of the aquatic as well as human life (Gupta et al., 2017). The dissolve oxygen concentration shown in figure 3 had little variation. The highest value of dissolved oxygen concentration was 7.53 mg/l which was obtained at the first sampling site, while the lowest value of 5.1 mg/l was obtained at the thirteen (last) sampling site. Dissolved oxygen is one of the important parameter for water quality assessment because it is an important factor for the aquatic environment. According to Dirican, the minimum dissolved oxygen may not be less than 5.0 mg L–1 for aquatic life. In addition, Abowei, J. (1970) reported that at high temperature, which is usually observed in dry season, the solubility of oxygen decreases while at lower temperature (wet season) it increases. When comparing researcher B mean value 3.26 mg/l to researcher A mean value 5.83 mg/l it is clear that there is a significant difference. Researcher B having a value of 3.26mg/l and he explained that during the sampling of the lower reach, the exposure of the river to the sun was minimal as it was cloudy most of the time and hence, the temperature of the water would have been around normal, not adversely affecting oxygen solubility. However, the problem of low dissolved oxygen levels is magnified by the fact that the metabolic rates of aquatic plants increase as water temperature rises, thus increasing their biochemical oxygen demand. Low dissolved oxygen levels leave aquatic organisms in a weakened physical state and more susceptible to disease, parasites, and other pollutants. In 2019, the dissolve oxygen concentration increased up to acceptable standards.

Salinity is the concentration of salt in water, usually measured in parts per thousand (ppt) (Dirican et al., 2009). The salinity values ranging from 0.25 ppt at sampling site 1 to becoming stable at 18 ppt (sampling site 13), showed gradual decrease of salinity values from the downstream sampling sites to higher elevation sampling sites along the Belize River. This trend could be attributed to effluent water discharges from several industrial establishments, farms and domestic activities that are prevalent along the lower regions area of the river. Highest salinity value (0.25 ppt) recorded during the dry season was with in the estuary and the lowest (0.18 ppt) was recorded going towards to upper reaches of the river. The months of June to November in Belize usually coincide with the rainy season when high volumes of freshwater are discharged into coastal or estuarine waters that lower or dilute the water. Similarly, NOAA 2014 reported in estuaries, salinity levels are generally highest near the mouth of a river where the ocean water meets, and lowest upstream where freshwater flows in. in addition, salinities vary throughout the tidal cycle, however. Therefore, in the lower reaches of the Belize River the salinity levels usually rise during the month of December to May when higher temperatures increase levels of evaporation in the estuary. According EPA 2019, inland waters below 0.5 mg/l are considered fresh water, therefore the lower reaches having an average of 0.20 mg/l is categorized as fresh water.

In water quality assessment, pH is one of the most important parameter of any aquatic ecosystem because it indicates the fertility or potential productivity of water. If the pH value falls in below 4 or above 9 everything is dead (Gaspar & Lakshman 2012). Figure 4 shows the different pH value at the thirteen site of the lower reaches of the river ranging from 5.75 to 7.7 units. All thirteen sampling sites had a pH value between 5 to 8 units. Site 3 and site 5 had the highest value of pH being 7.7. According to the USEPA (1980), accepted water quality criteria indicate a pH of less than 6.5 units may be harmful to many species of fish. Therefore, the pH range of 6.5-9.0 units would be suitable for the protection of aquatic habitats. Therefore it can be concluded that the lower reaches of the Belize River reaches are normal in pH levels.

Nitrate is a less serious environmental problem; however when nitrate concentrations become excessive and other essential nutrient factors are present, eutrophication and associated algal blooms can be become a problem (Sarda & Sadgir 2015). In the present study, nitrate content among the sampling sites showed a wide variation. The highest value of nitrate with 3.1 mg /l was recorded at the last sampling site, while the lowest value of 0.1 mg/l was recorded at the first sampling site (figure 5). It is suggested that the sampling site that have high nitrate level were the area that were used for farming or land clearing. However, the mean value for the nitrate concentration in the lower region of the Belize River is 1.92 mg/l. The U.S. Public Health Service adopted drinking water standards and set the recommended limit for nitrate-nitrogen at 10 mg/L Oram (2014). Therefore, the nitrate level is within standard limit.

Phosphate is a major source of concern for surface waters because small amounts may lead to eutrophication of lakes and rivers. The results as shown in figure 7 indicate that there was a wide variation in phosphate level. The highest concentration of phosphates was at the first sampling site with a value of 0.16 mg/L. The lowest concentration was observed at site 5 having a value of 0.1 mg/l. While these levels may seem low, according to the US EPA (1986), a phosphate level as low as 0.01mg/L can have detrimental effects on aquatic ecosystems by causing severe algal blooms. According to the criteria set by the US EPA (1986), a water body such as the Belize River, should not exceed phosphate levels of greater than 0.01 mg/L. the overall mean of the phosphate level was 0.05 which is still over the acceptance level. When comparing the present result to 2013; 2013 had a mean of 0.45 mg/l which mean the river was at risk of eutrophication (a reduction in dissolved oxygen in water bodies caused by an increase of mineral and organic nutrients). This could have been due to the rain the previous day before the research had taken place and soil erosion could have been a major contributor of phosphorus to river. The bank erosion occurring during floods could have transported a lot of phosphorous from the river banks and adjacent land into the water body.

Sources of Error

Turbidity, ammonia was not taken for the YSI meter model professional series was not able to measure these parameters.

Conclusion and Recommendation

It is suggested that the land use around the riparian system influences the nutrients input in the aquatic ecosystem. This was confirmed when results showed that only areas that are occupied by land use activities such as farming and urban development had high levels of nutrients even when compared to the data obtained from 2013. From these finding it was concluded that the lower reaches of the Belize River is relatively ok since all parameter means are within standard from. The results of this study can provide scientific reference for the local land use optimization and water pollution control and assist in the formulation of policies and regulations.

Based on the results of this study, recommendation for future research includes, to continue an intensive water quality monitoring program on the Belize River and to further investigate the delivery of nutrients from the river into the coast. Also, the previous study have indicated that their landscape diversity has an impact on the water quality within the watershed and therefore add some ecological indicators and analyse their influence on the water quality. The Belize River is very crucial to the lives of the residents along the river banks, therefore it is essential to measure some water quality parameters (as indicators) regularly. The parameter selected are to indicate pollution sources and the safety of drinking water.

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Appendices

Appendix 1. Standards for drinking water

Characteristics	ICMR	WHO	CPCB	BIS – IS: 10500 – 2012	CCME
pH (pH units)	7.0–8.5	7.0–8.5	Class A – 6.5–8.5 Class B – 6.5–8.5 Class C – 6.5–9.0	Class A – 6.5–8.5 Class B – 6.5–8.5 Class C – 6.5–8.5 and Permissible – no relaxation	6.5–8.5
TDS (mg L^{-1})	500	500	–	Class A – 500 mg L^{-1} Class B – 500 mg L^{-1} Class C – 1500 mg L^{-1} and Permissible – 2000 mg L^{-1}	500
Temperature (°C)	–	–	–	–	15
Turbidity (NTU)	5	2.5	–	Desirable – 05 NTU Permissible – 10 NTU	5
NO_3-N (mg N L^{-1})	20	45	–	Class A – 20 mg L^{-1} Class B – 20 mg L^{-1} Class C – 50 mg L^{-1} and 45 mg L^{-1} (permissible)	10
o-PO_4-P (mg P L^{-1})	–	–	–	–	0.3
BOD (mg L^{-1})	–	–	Class A – 2 mg L^{-1} Class B – 3 mg L^{-1} Class C – 3 mg L^{-1}	Class A – 2 mg L^{-1} Class B – 3 mg L^{-1} Class C – 3 mg L^{-1} and No relaxation (permissible)	3
DO (mg L^{-1})	–	–	Class A – 6 mg L^{-1} Class B – 5 mg L^{-1} Class C – 4 mg L^{-1}	Class A – 6 mg L^{-1} Class B – 5 mg L^{-1} Class C – 4 mg L^{-1} and No relaxation (permissible)	5

Appendix 2. Standards for water quality assessment.

Sr. No.	Parameters	ID	Units	BIS (10500-2012) Acceptable Limits	BIS (10500-2012) Permissible Limits	WHO (2004)
1	Temperature	Temp.	$^{\circ}C$	--	--	15-35
2	Potential of Hydrogen	pH	--	6.5-8.5	No relaxation	6.5-8.5
3	Electrical Conductivity	EC	mic.mho/ cm	----	---	300
4	Total Dissolved Solids	TDS	mg/l	500	2000	1000
5	Alkalinity	Alk.	mg/l	200	600	---
6	Total Hardness	TH	mg/l	200	600	---
7	Calcium	Ca	mg/l	75	200	---
8	Magnesium	Mg	mg/l	30	100	---
9	Chloride	Cl	mg/l	250	1000	250
10	Sulphate	SO_4	mg/l	200	400	400
11	Dissolved Oxygen	DO	mg/l	4	6	
12	Biochemical Oxygen Demand	BOD	mg/l	---	---	5
13	Chemical Oxygen Demand	COD	mg/l	---	---	10
14	Nitrogen	NO_3	mg/l	45	---	---
15	Nitrogen as Ammonia	NH_3– N	mg/l	0.5	No relaxation	1.5
16	Nitrogen as Nitrite	NO_2-N	mg/l	---	---	---
17	Nitrogen as Nitrate	NO_3-N	mg/l	45	No relaxation	10

Appendix 3. Statistical results comparing p-value (>0.05) between research A and research B.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temperature	Equal variances assumed	7.805	.010	10.287	24	.000	7.24538	.70430	5.79179	8.69898
	Equal variances not assumed			10.287	12.081	.000	7.24538	.70430	5.71200	8.77877
Ph	Equal variances assumed	36.530	.000	-7.451	24	.000	-1.48308	.19905	-1.89391	-1.07225
	Equal variances not assumed			-7.451	12.145	.000	-1.48308	.19905	-1.91620	-1.04995
Salinity	Equal variances assumed	16.674	.000	-4.163	24	.000	-.07385	.01774	-.11046	-.03723
	Equal variances not assumed			-4.163	13.107	.001	-.07385	.01774	-.11214	-.03555
Dissolve_Oxygen	Equal variances assumed	3.536	.072	11.008	24	.000	2.56846	.23332	2.08691	3.05001
	Equal variances not assumed			11.008	19.653	.000	2.56846	.23332	2.08121	3.05571
Nitrate	Equal variances assumed	17.294	.000	3.507	24	.002	.88462	.25223	.36404	1.40519
	Equal variances not assumed			3.507	12.614	.004	.88462	.25223	.33801	1.43122
Phosphate	Equal variances assumed	8.584	.007	-13.508	24	.000	-.39615	.02933	-.45668	-.33563
	Equal variances not assumed			-13.508	15.786	.000	-.39615	.02933	-.45839	-.33392

❖ *Researcher A (2019) are the top values; Researcher B (2013) are the bottom values*

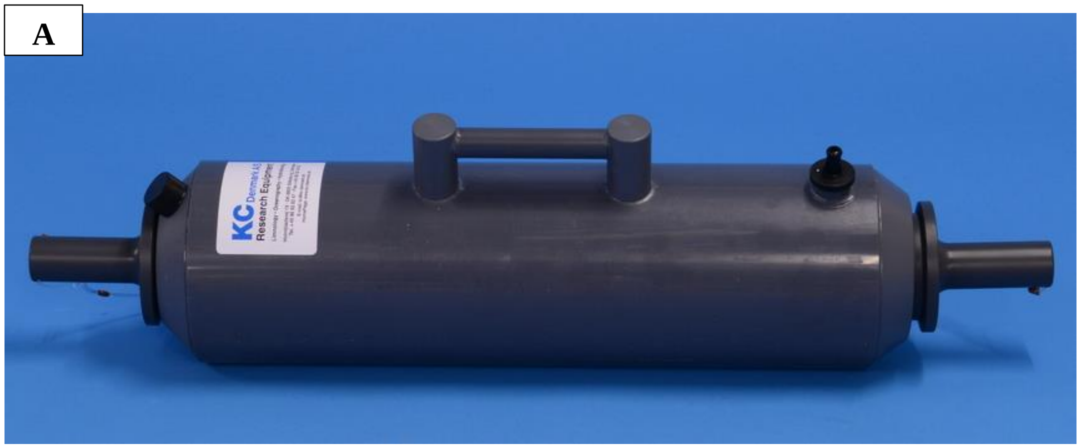
Appendix 4. Sampling data sheet from YSI meter model professional series and spectrophotometer.

Date	Time	Site (BR)	Temperature	Ph	Salinity ppt	DO mg/l	N03- mg/l	PO4-3 mg/l
May 5, 2013	0.663889	1	29.13	8.24	0.26	3.4	0.9	0.53
May 5, 2013	**0.680556**	2	29.16	8.33	**0.25**	3.74	0.8	0.49
May 5, 2013	0.697917	3	28.97	8.26	0.25	4.23	1	0.46
May 5, 2013	0.7125	4	29.03	8.34	0.25	3.49	1	0.34
May 5, 2013	0.729167	5	29	8.36	0.25	3.38	0.8	0.5
May 5, 2013	0.729167	6	29.06	8.34	0.24	3.39	1	0.58
May 5, 2013	0.739583	7	29.04	8.4	0.24	3.21	1.1	0.56
May 5, 2013	0.739583	8	29	8.3	0.24	2.96	1.1	0.33
May 5, 2013	0.752083	9	29	8.43	0.23	3.24	1	0.47
May 5, 2013	**0.752083**	10	29.05	8.29	**0.23**	2.47	1.2	0.49
May 5, 2013	0.763889	11	28.8	8.4	0.22	2.89	1.1	0.42
May 5, 2013	0.776389	12	28.75	8.33	0.22	3	1.3	0.24
May 5, 2013	0.790972	13	28.66	8.37	0.22	3.03	1.1	0.4
	Minimum		**28.66**	**8.24**	**0.22**	**2.47**	**0.8**	**0.24**
	Maximum		**29.16**	**8.43**	**0.26**	**4.23**	**1.3**	**0.58**
	Average		**28.97**	**8.34**	**0.24**	**3.26**	**1.03**	**0.45**

Date	Time	Site (BR)	Temperature	Ph	Salinity ppt	DO mg/l	N03- mg/l	PO4-3 mg/l
Apr-19	10:00	1	39.5	7	0.25	7.53	0.1	0.16
Apr-19	12:45	2	39.4	7.14	0.22	5.1	1.6	0.04
Apr-19	10:25	3	36.8	**7.7**	0.22	5.11	1.9	0.06
Apr-19	01:12	4	35.5	5.76	0.23	6.4	2.5	0.1
Apr-19	10:40	5	35.6	7.7	0.2	5.53	1	0.04
Apr-19	10:50	6	36.3	7.6	0.19	6.06	1.1	0.03
Apr-19	10:58	7	35.3	7.33	0.19	6.38	1.5	0.03
Apr-19	11:10	8	36.1	6.12	0.19	6.03	1.6	0.04
Apr-19	11:20	9	36.8	5.83	0.19	6.27	3	0.02
Apr-19	11:36	10	38.6	6.78	0.18	5.27	2.3	0.04
Apr-19	11:48	11	38.2	7.46	0.18	5.16	2.1	0.02
Apr-19	11:55	12	35.4	6.62	0.18	5.88	3.1	0.02
Apr-19	12:05	13	37.8	6.07	0.18	5.1	3.1	0.06
	Minimum		**35.3**	**5.76**	**0.18**	**5.1**	**0.1**	**0.02**
	Maximum		**39.5**	**7.7**	**0.25**	**7.53**	**3.1**	**0.16**
	Average		**37.02**	**6.85**	**0.20**	**5.83**	**1.92**	**0.05**

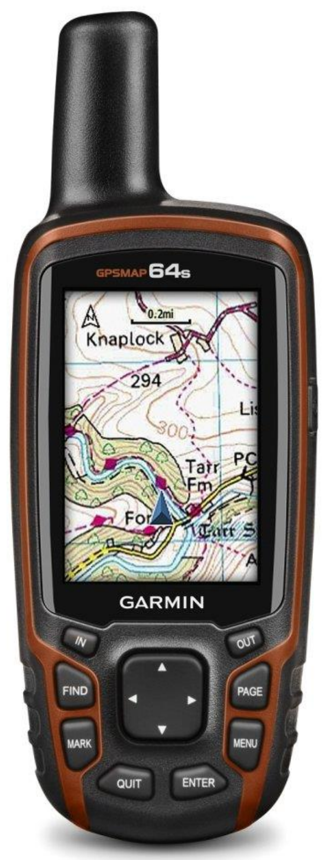
Appendix. 5 (A) Niskin Water Sampler, (B) YSI meter model professional series, (C) Garmin GPS.

A



B

C



Appendix 6. Pictures showing (a) land clearing, (b) pollution, (c) burning of the riparian forest.