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Research Article

Assessment of the Physico-chemical Properties in the Muni-Pomadze Ramsar Site and its Catchment in Winneba, Ghana

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Abstract: The study sought to investigate the physico-chemical properties of the Muni Lagoon and its catchment in Winneba, Ghana. This was an onsite study, thus all the data were taken in situ. Parameters which allow for on-field measurements were measured and used in conducting this study. Field observations, field measurements, and recordings of physical parameters in situ were the data collection methods. Data was analyzed using descriptive statistics and presented on bar graphs. The field results were compared to the standards set by the World Health Organization (WHO) and the United States Environmental Protection Agency (USEPA). The field measurements indicated that all the parameters tested within the Muni catchment were within the thresholds provided by the WHO and USEPA. Though parameters were within the acceptable threshold, field observations over the years revealed that there had been a great decline in biodiversity within the catchment, which could be attributed to anthropogenic activities such as encroachment, overfishing, harvesting of mangroves and waste intrusion. It is recommended that there should be constant monthly water quality monitoring of the water bodies within the Muni catchment to inform their status from time to time. The Forestry and Wildlife Commission of the Effutu Municipality should conduct routine community outreach programs on the radio to sensitize people on the effects of their actions on the catchment.

***Keywords*:** physico-chemical, water quality, catchment, socio-economic, assessment, parameters

1. Introduction

Pollution is a major obstacle to long-term water resource management in developing countries. Despite World Health Organization (WHO) and United States Environmental Protection Agency (USEPA) drinking and surface water quality guidelines, pollution from diverse sources has been steadily increasing in most nations. As a result, maintaining water quality must be a priority for both scientists and the general public. Various variables that threaten water quality have been identified by scientists and other researchers. Habitat destruction, invasive species, pollution, and human overpopulation are just a few of the issues that need to be addressed. Several studies have even found that human activities that influence changes in the hydrologic regime, water quality, and biodiversity of water bodies are constantly disrupting and polluting many bodies of water. Wetlands are not truly aquatic because they often contain soil, but they are also not truly terrestrial because they require or contain standing water [1]. They grow on the outskirts of both terrestrial and aquatic settings, possessing traits of both [2].

The Ramzar Convention defines wetlands as areas of marsh, fen, peatland, or water, whether natural or man-made,

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permanent or temporary, with water that is static or flowing, fresh, brackish, or salty, including seawater with a depth of less than six meters at low tide [3]. A report published by the Ramzar Convention in 2005 stated that Ghana became a party to the Ramzar Convention in 1988, and the country now has five Ramsar sites of international significance, namely Sakumo, Densu Delta, Songor, Muni-Pomadze, and the Keta Complex lagoons. All of these areas have been designated as protected areas and have been promulgated as such. According to the Food and Agriculture Organization of the United Nations (FAO) [4], the Mole National Park, Black Volta, Sene, Bia, and Owabi animal sanctuaries are among the various wetlands found inside the forest and wildlife reserves. These are also designated as protected areas. Traditional conservation measures are used in certain wetlands that are not preserved, such as the Ankobra and Pra rivers [4].

In 1988, Ghana ratified the Ramsar Convention, a global treaty dedicated to the conservation of internationally significant wetlands. Wetlands, like lagoons, provide a variety of socioeconomic and ecological services and functions [5]. Wetlands also provide water that is used for both domestic and industrial purposes. Wetland health is constantly deteriorating as a result of poor use and misunderstandings regarding wetlands, casting doubt on their continued existence in the near future [6-8]. However, it is claimed that wetlands have historically been seen as "wastelands" [9], with degradation occurring largely due to dredging, flooding, filling, and excavation for various agricultural and industrial purposes. As a result, the attraction and value of wetlands as key wildlife habitats have been hampered. Coastal wetlands are particularly significant as nutrient-rich spawning and nursery habitats for fish [10]. It is, nevertheless, critical to understand what defines high-quality clean water. Pure water does not occur in nature, so it is extremely unusual to find water that is completely devoid of contaminants [11].

It is very common to find minerals and chemicals in drinking water. Human activities, precipitation and runoff from neighboring land, surrounding flora and wildlife, soil, geologic formations, and the geography of the catchment basin all affect the minerals and compounds found in water [12].

If water quality deteriorates, the consequences for the ecosystem are dire. Similarly, damaged ecosystems have a negative impact on water quality. The viability of the environment on which our livelihoods depend is dependent on water supplies [13]. Despite this, a large portion of the water resources are mismanaged. The Muni-Pomadze Wetland is one of Winneba's most important natural resources, and it is attracting increasing interest from a variety of organizations with the goal of preserving and maintaining it.

The Pratu, Ntakofa, and Ayensu rivers are the principal streams that flow into the Muni Lagoon. Household garbage and other toxins have found their way into some of Ghana's lagoons. In light of this, and considering Muni Lagoon's beneficial effects as one of Ghana's most important coastal wetlands, it has become necessary to conduct a physical and chemical assessment of the lagoon's physical and chemical properties in order to alert stakeholders to reconsider their activities that endanger the natural conditions of such a vital waterbody. The study will help to understand why the uncontrolled discharge and dumping of waste into the lagoon is causing a decrease in the species population in the study area. The study will also serve as a policy document for the government and other international bodies on issues of wetlands management. Moreover, if the management policies and recommendations are implemented, they will assist in restoring the ecosystem to its former state. If life is finally restored to the lagoon and its catchment, this will help the locals revive their income. Finally, the study will contribute to the existing literature on wetland management.

2. Materials and methods

2.1 *Study area*

The Muni-Pomadze Ramsar Site (Figure 1) is found along the coast of Winneba in the Central Region of Ghana. The Muni-Pomadze Lagoon is a closed one, separated from the ocean by a sand bar. It is about 56 km west of Accra, on the south coast of Ghana. The Muni Lagoon (05° 22' N, 0° 40' W) is situated in the southwestern part of Winneba in the Central Region of Ghana. It is a closed lagoon that occasionally opens to the sea, especially during the wet season. The lagoon is usually 3 km^2 in extent but could expand to over 6 km^2 in the wet season. The Ramsar Site encompasses an area of about 94.61 km^2 (9,461 ha) [14], comprising the watershed of the Muni Lagoon. This area is peri-urban, implying a rapid expansion of human activities. The wetland is bounded in its northern section by the Yenku (A) and (B) Forest Reserves and in the south by the Atlantic Ocean (Gulf of Guinea). The Pratu and Ntakofa rivers feed the lagoon with fresh water. In the dry season, there is a continuous deposition of material on the sandbar that separates the lagoon from the sea. As a result, the sand bar is breached intermittently by the locals to allow water into the sea as a way of preventing flooding of the lagoon. The lagoon is characterized by shallow, saline, and semi-closed coastal lines with a surface area of 300 ha. It has iconic floodplains, and marine turtles lay their eggs on the adjacent sandy beaches in the southern part of the site [15]. These locational characteristics make the wetland an attractive site for all sorts of human activities.

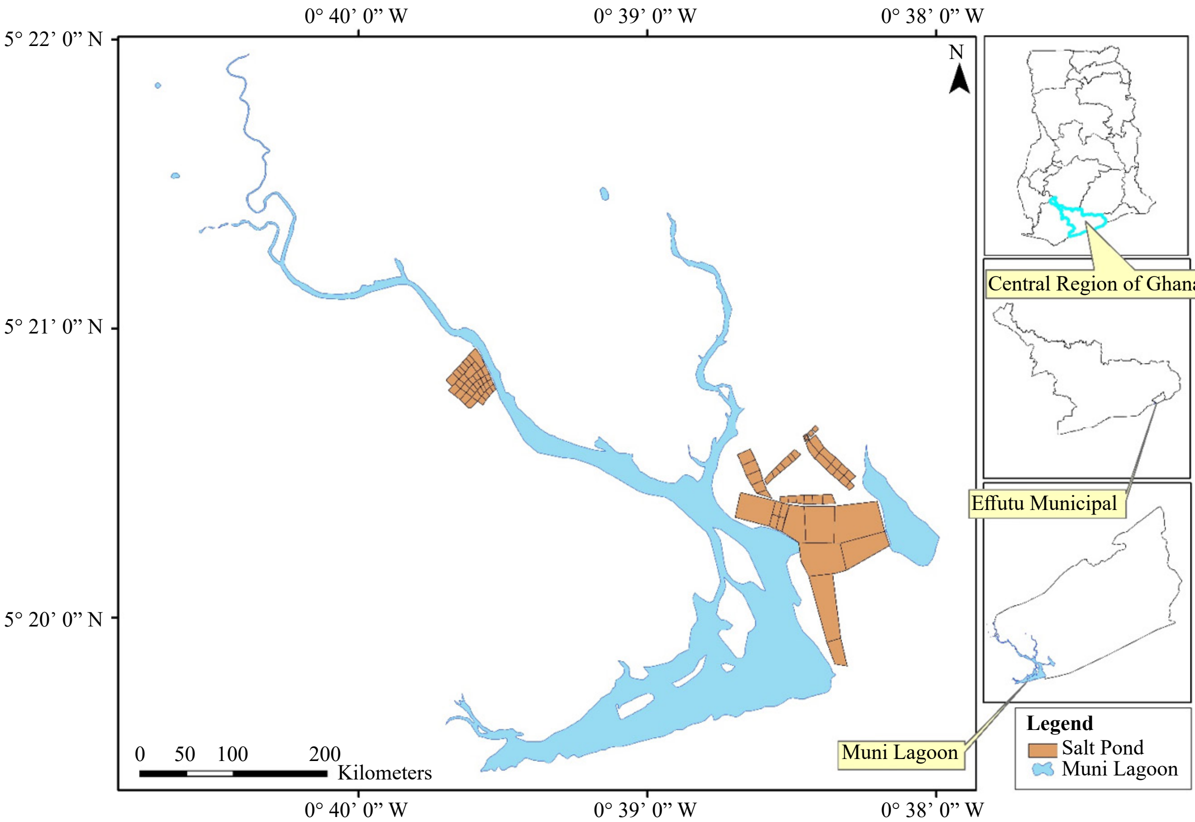

Figure 1. Map of the study area

2.2 *Materials and description of the research process*

Observation was used to get first-hand information on the rate of pollution, degradation, and biodiversity change of the Muni-Pomadze Ramsar Site and its catchment area. A global positioning system called the Garmin 12XL was also used to locate the exact points where samples were taken. The lagoon and the Pratu and Ntakofa rivers were divided into three sections (upper, middle, and lower sections). The PC60 Premium Multi-Parameter Tester was used to test for pH, conductivity, salinity, temperature, and total dissolved solids (TDS). The Dissolved Oxygen Meter Kit 850081DOK was used to test for dissolved oxygen (DO).

2.3 *Site selection*

The Muni-Pomadze Ramsar Site was specifically chosen for the study. This lagoon was chosen because it is one of the few internationally recognized wetlands in Ghana that houses diverse species [16]. It is an area specifically conserved to continually support ecosystem services, hence the need to carefully study and sustain it. The Pratu and Ntakofa rivers were selected because they are the main fresh water sources that flow into the lagoon and because people farm along these rivers.

2.4 *Measurement of physico-chemical parameters*

To measure the parameters, 33 points were located on the lagoon (Figure 2), together with the Pratu and Ntakofa rivers in the wet and dry seasons. The points were located in the body of water's upper, middle, and lower sections. A continuous point sampling method was used in taking measurements of the dry and wet seasons. In the wet season, samples were taken between June and July 2019, while in the dry season, samples were collected from December 2019 to January 2020. These periods were the peaks of the two seasons within the area of study. During the season, twice-monthly measurements were taken and the data was compiled and averaged. In situ field measurements were conducted with 21 points in the Muni Lagoon, five points on the Ntakofa River, and seven points on the Pratu River. Six parameters were examined in total. A systematic sampling technique was used to take water samples. A sampling interval of 100 m was utilized. This interval was used because the whole catchment covers about 3.3 km², and for every 100 m interval, a station was mounted and measurements were taken. This allowed the authors to measure 33 points within the catchment.

Figure 2. Muni catchment sampling points

3. Results and discussion

3.1 *Physico-chemical parameters of the Muni catchment*

3.1.1 *Temperature*

Temperature is one of the most important factors that determines the existence of species. If an organism is exposed to temperatures that are too cold or too warm, it must either adjust to the changes or perish. With respect to biodiversity in and around a body of water, other environmental factors affect the growth of biodiversity more than temperature.

According to the USEPA [17], most aquatic organisms reside or exist within a temperature range of 25 °C to 30 °C. Results from the study indicated some variations in temperature during the period of data collection in the Muni catchment (Figure 3). The Muni catchment comprises the Muni Lagoon, the Ntakofa River, and the Pratu River. The mean temperature of the Muni Lagoon during the wet season was 28 °C, compared to 27.7 °C for the Pratu River and 28.5 °C for the Ntakofa River. At the Muni Lagoon, a maximum temperature of 28.9 °C and a minimum temperature of 27.5 °C were recorded. The maximum and minimum temperatures recorded for the Pratu River were 28.6 °C and 27.1 °C, respectively. Meanwhile, the Ntakofa River recorded 29.8 °C and 27.1 °C as the maximum and minimum temperatures, respectively.

During the dry season, the average temperature of the Muni Lagoon was 30.9 °C, with maximum and minimum readings of 33.2 °C and 29.4 °C, respectively. On the Pratu River, the average temperature recorded during the dry season was 32.3 °C, with a maximum of 33 °C and a minimum of 31.8 °C. The average temperature of the Ntakofa River during the dry season was 31.7 °C, with a maximum temperature of 32.8 °C and a minimum temperature of 30 °C. Temperature is very important for aquatic ecosystems as it affects the organisms as well as the physical and chemical characteristics of the water in which they live [18].

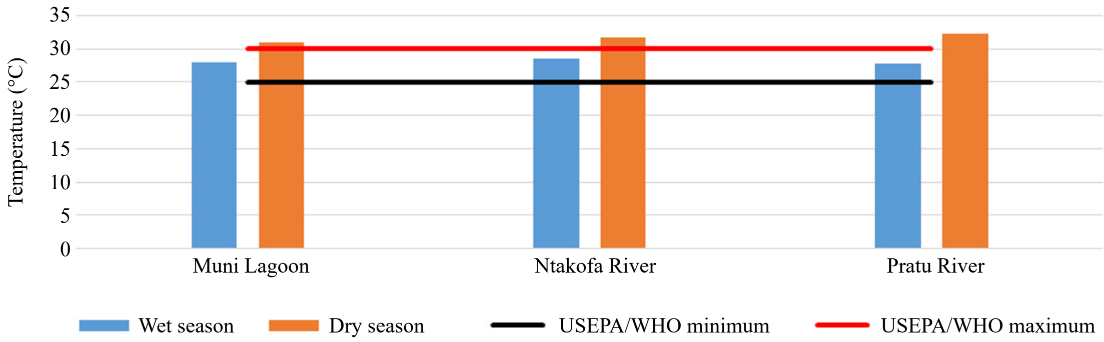

Figure 3. Temperature concentration for two seasons (wet and dry)

During the dry season, temperatures are higher in water bodies; an increase in water temperature is associated with an increase in bacterial numbers that are essential to their growth [19]. This supports the previous hypothesis by Wetzel [20] that algal photosynthesis increases with temperature, though different species have different peak temperatures for optimum photosynthetic activity. This temperature range is favorable for aquatic organisms. According to the results, the highest range or average is 32.3 °C, with a difference of around 2.3 °C between the highest and lowest ranges. This finding is consistent with a study by Tiakor [21] that found the temperature of the Muni Lagoon to be between 29.3 °C and 32.5 °C. This condition will drive the living organisms in that area to adapt to the temperature changes. The more these organisms strive to adapt to the changes, the more energy they release, and at some point, when all their energy reserves are depleted, they perish. Those that cannot adapt to the changes may relocate to locations with more suitable temperatures. Increased evaporation caused by rising temperatures within the catchment would undoubtedly reduce surface and groundwater levels, hence reducing the size of the wetlands. Again, plant species within the catchment will transpire a lot, which will challenge their existence.

Figure 4 shows the temperature distribution in the wet and dry seasons. The lowest average temperature recorded during the wet season was 27.7 °C, which is well within the threshold of 25 °C and allows many organisms to survive and grow. All three parts of the river showed a fairly stable temperature regime. Though temperatures in the sampling area fluctuated, this could be attributed to the ambient air temperature at the time of sampling. According to Brown [22] and Fondriest Environmental Inc. [23], heat transfer from the air, sunlight, thermal pollution, or water source has the potential to change the temperature of water.

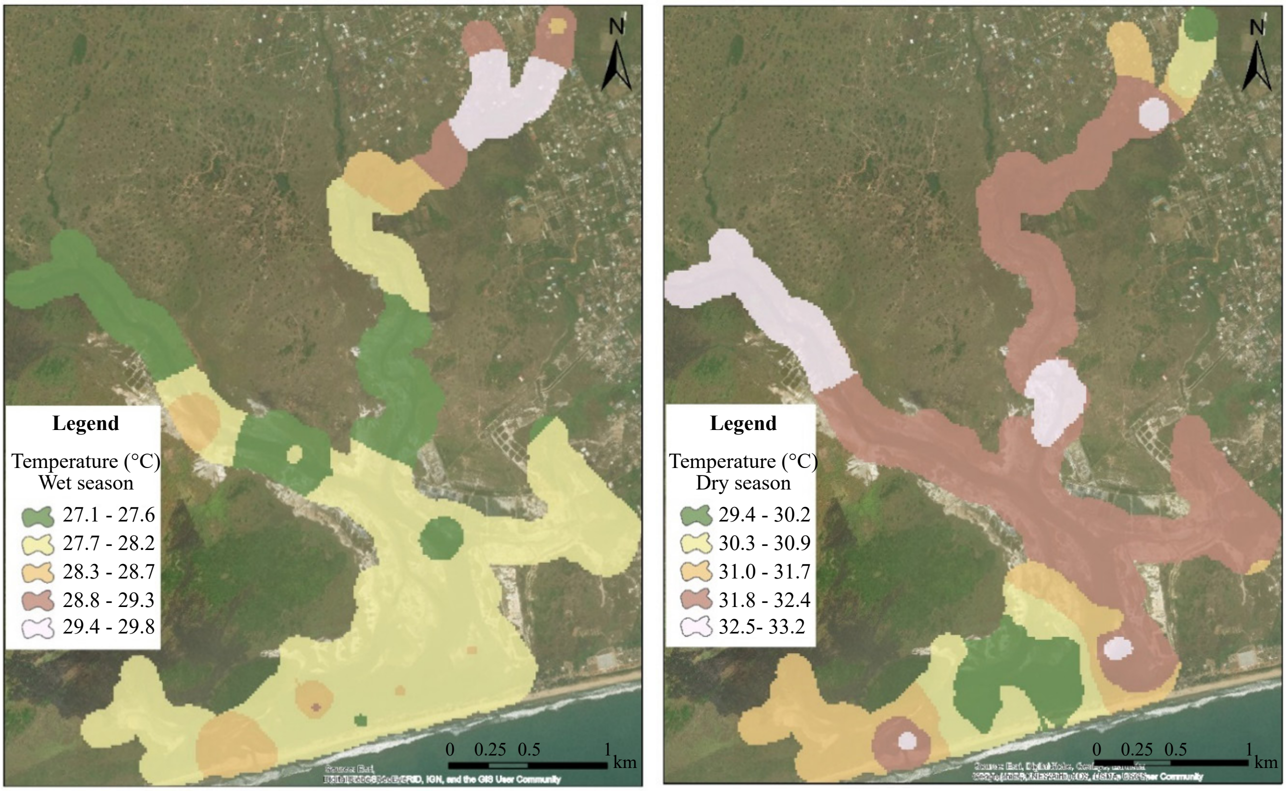

Figure 4. Temperature distribution in wet and dry seasons

3.1.2 *pH*

During the wet season, the average pH of the Muni Lagoon was 8.2, with maximum and minimum values of 8.3 and 8.1, respectively. The Pratu River recorded an average pH of 8.2, with a maximum of 8.2 and a minimum of 8.1. An average pH value of 7.7 was recorded for the Ntakofa River, with 8.3 and 7.2 as the maximum and minimum pH values, respectively. The pH values recorded in these bodies of water were relatively close, with little variation. Nonetheless, all of these pH values were within the thresholds provided by the USEPA and WHO, indicating a reasonably good buffer range for supporting different aquatic life. According to Gallagher [24], pH has an impact on numerous biochemical systems in water, and different organisms have their own optimal pH range within which they may survive. Therefore, anything outside the pH range of 6.5 to 8.5 poses a threat to the aquatic life and organisms in that body of water [25]. This is because the aquatic organisms within that enclave would have to adapt to those living conditions, thereby releasing more energy. If they continue to adjust, at some point they might die or perish, while others may leave for a suitable environment.

The pH of the whole Muni catchment was found to be alkaline since all the mean values were significantly above the minimum threshold of 6.5 and fairly close to the maximum threshold of 9.0. This finding is consistent with the study conducted by Salamatou [26] in the Muni catchment, which recorded a pH range of 7.43 to 8.70 and concluded that the catchment is alkaline in nature. Wurts and Durborow [27] assert that the ideal pH range for aquatic organisms such as fish should be between 6.0 and 9.0 with at least 20 mg/L of alkalinity and recommended calcium carbonate ($CaCO_3$) levels of between 75 mg/L and 200 mg/L. Numerous studies, however, have demonstrated that a pH range of 6.5 to 9 is optimal for preserving fish communities. The pH of bodies of water is determined by the type of underlying rock, the temperature, and the water's source. The USEPA [17] and WHO [28] stated that the normal pH range for surface water should fall between 6.5 and 9.0. According to the United States Geological Survey [29], pH that deviates from this range reduces the biodiversity in the stream because the physiological systems of most of these faunas are stressed and can decrease reproduction. The pH scale measures the acidity or alkalinity of water samples and bodies of water. From the results, it is evident that the water in the catchment is relatively alkaline. Figure 5 shows the pH concentration in the wet and dry seasons.

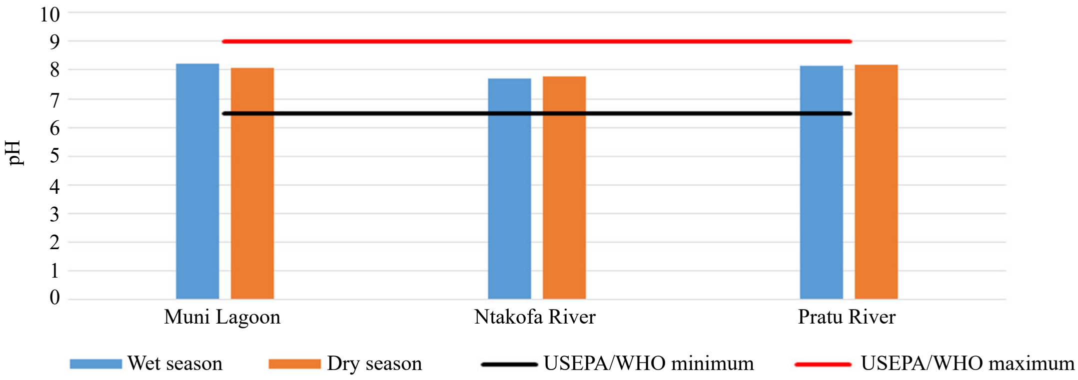

Figure 5. pH concentration in wet and dry seasons

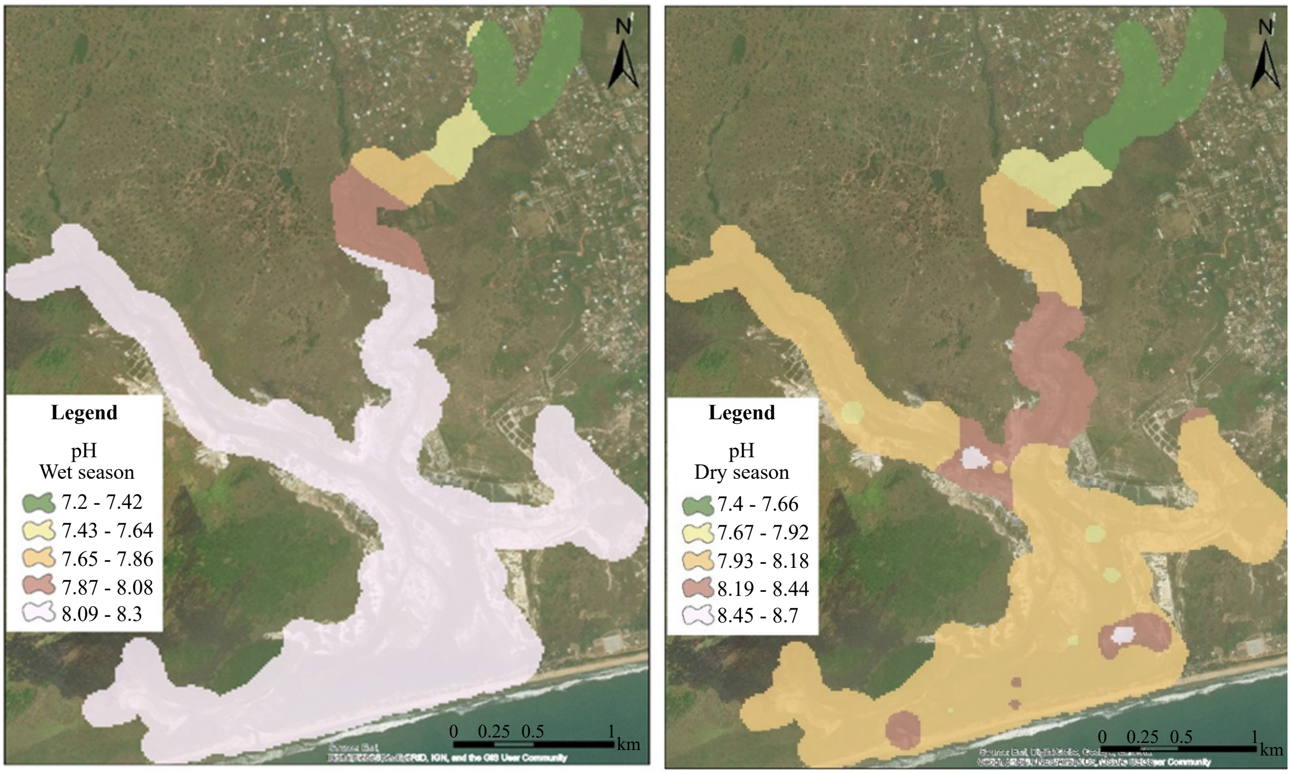

Figure 6. pH distribution in wet and dry seasons

In the dry season, the Pratu River had the highest average pH value of 8.2, followed by the Muni Lagoon at 8.1 and the Ntakofa River at 7.8. The steady increase in the values may be due to the influence of anthropogenic activities occurring around the area. This is due to the fact that a large portion of the rivers flow through densely populated areas, where domestic and agricultural effluents may enter the rivers. The maximum and minimum pH values for the Muni Lagoon were 8.7 and 7.9, respectively. The Pratu River recorded a maximum of 8.6 and a minimum of 7.9, while the Ntakofa River recorded a maximum of 8.4 and a minimum of 7.4.

It is obvious that any aquatic species that lives in conditions with a pH that is too low or too high will perish. When the pH levels exceed the recommended range, animal systems are stressed, which affects hatching and survival rates. If the ranges move further outside the optimum pH values, the mortality rate will be higher. Therefore, changes in pH have a greater impact on more sensitive species. Within the Muni Lagoon, the black-chin tilapia is the predominant fish species. However, Sarikhani et al. [30] stated that these species thrive in a pH range of 7.0 to 8.0. Thus, pH levels outside this range pose a threat to their existence. It is expected that this fish species would flourish in the Muni Lagoon because the pH falls within the acceptable range. Figure 6 shows the pH distribution in wet and dry seasons.

3.1.3 *Total dissolved solids*

Total solids are dissolved solids plus suspended and settleable solids in water. The USEPA recommends an upper limit of 500 mg/L TDS for aquatic life [31], though this is exceeded in some regions with little ill effect. If TDS goes above the range, it means that the body of water is highly polluted. The implication of this is that anything below 500 mg/L means the lagoon is a clean body of water and will favor aquatic organisms. According to Sarikhani et al. [30], TDS also determine the degree of salinity of the water and hence is related to conductivity. This explains how TDS can affect other physico-chemical properties of water, such as salinity and conductivity. Water containing low TDS could be considered "fresh water" and ideal for both consumption and agricultural (irrigation) purposes, as this would not affect the osmotic pressure of the soil solution [32]. TDS concentrations were monitored in the catchment, i.e., Muni Lagoon, Pratu River, and Ntakofa River. Figure 7 shows the TDS concentration in the wet and dry seasons. The highest average TDS value was recorded at the Ntakofa River at 233.8 mg/L with a high average conductivity value of 328.7 mS/cm and a low average salinity value of 1.1 parts per thousand (ppt). This high value was recorded because the Ntakofa River runs through densely populated areas and hence receives uncontrolled domestic and agricultural waste.

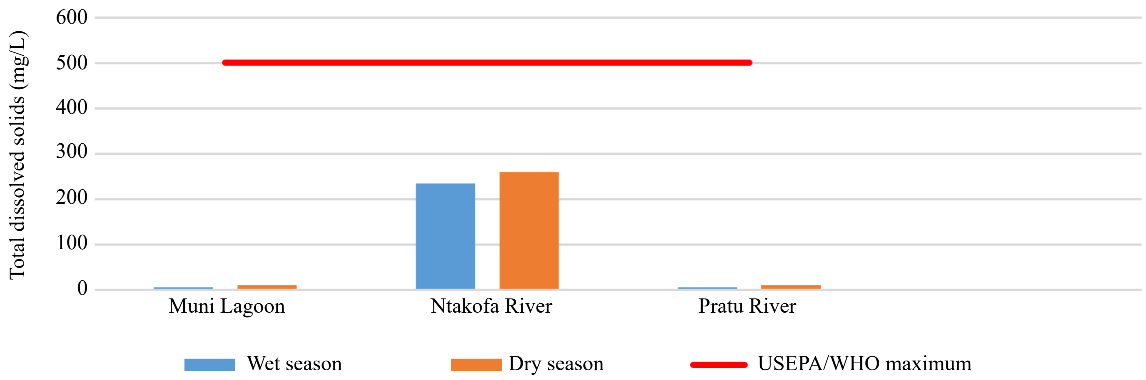

Figure 7. Total dissolved solids concentration in wet and dry seasons

In the dry season, the Ntakofa River had a higher average concentration of 259.5 mg/L, a higher average conductivity of 366.6 mS/cm, and a lower average salinity of 3.5 ppt. The average TDS value for Muni Lagoon and the Pratu River was 10 mg/L and remained constant throughout the period of study. However, the Muni Lagoon recorded an average salinity value of 8.6 ppt, which was relatively above that of the Pratu River, with an average value of 8.3 ppt. The average conductivity of the Muni Lagoon and the Pratu River remained relatively similar at 17.2 mS/cm and 17.3 mS/cm, respectively. A cell may inflate or shrink if the TDS content is outside the typical range. This may have a harmful influence on aquatic life that is unable to adjust to the change in water retention. However, since the average values are less than the recommended threshold, it means it is a clean body of water, which is a good indicator of fish population growth. Figure 8 shows the TDS distribution in the wet and dry seasons.

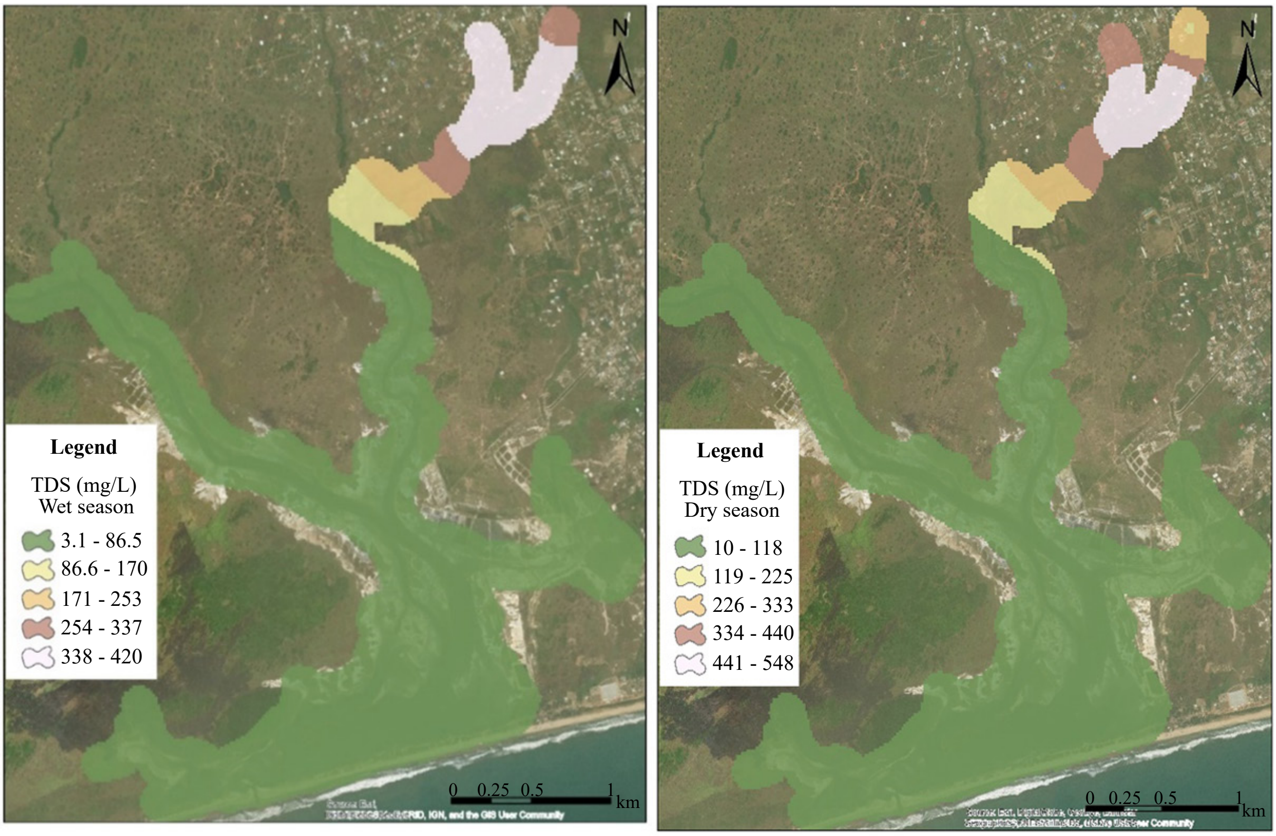

Figure 8. Total dissolved solids distribution in wet and dry seasons

3.1.4 *Conductivity*

Conductivity is a measure of the dissolved ionic component in water and hence an electrical characteristic. It is usually measured in micro or milli siemens per centimeter (uS/cm or mS/cm). It can alternatively be expressed in micromhos/centimeter (umhos/cm) or millimhos/centimeter (mmhos/cm), albeit these are less frequent quantities. The conductivity of most water ranges from 10 mS/cm to 1,000 mS/cm [33]. Dissolved salts and inorganic elements such as alkalis, chlorides, sulfides, and carbonate compounds provide these conductive ions. The conductivity of water increases as the number of ions present increases. Similarly, the fewer ions in the water, the less conductive it becomes. This is similar to a previous study by Perlman [21], claiming that distilled or deionized water might behave as an insulator due to its extremely low (if not non-existent) conductivity value. Seawater, on the other hand, has a very high conductivity. Figure 9 shows the conductivity concentration in the wet and dry seasons. From the results, the highest conductivity of 593 mS/cm was recorded at the water sampling point (WSP) 30 of the Ntakofa River. This was recorded between Klimovic Hospital and Crown Villa Hostel. The average conductivity of the Ntakofa River was 328.7 mS/cm with a minimum value of 4.1 mS/cm in the wet season. These high conductance readings could be due to either industrial pollution or urban runoff from streets, parking lots, or garages. The Ntakofo River passes through the urban centers of Winneba and is therefore subjected to urban runoff and waste deposition. This reflects the high conductance value. The conductance values of the Muni Lagoon and the Pratu River were relatively close. The conductivity value of the Muni Lagoon, was recorded at an average of 4.9 mS/cm, a maximum of 5.2 mS/cm and a minimum of 4.8 mS/cm. This low value of conductance could be due to the fact that the Muni Lagoon at the time of the study had no interaction with the sea. It was cut off from the sea by a sandbar. For the Pratu River, the average value was recorded at 4.9 mS/cm, the same as the Muni Lagoon, with a maximum value of 5.1 mS/cm and a minimum value of 4.5 mS/cm. To a greater extent, the Pratu River exhibits quite similar characteristics to the Muni Lagoon. This is because the Muni Lagoon is able to flow into the Pratu River and mix with it, which flows on a relatively lower slope than the Ntakofa River.

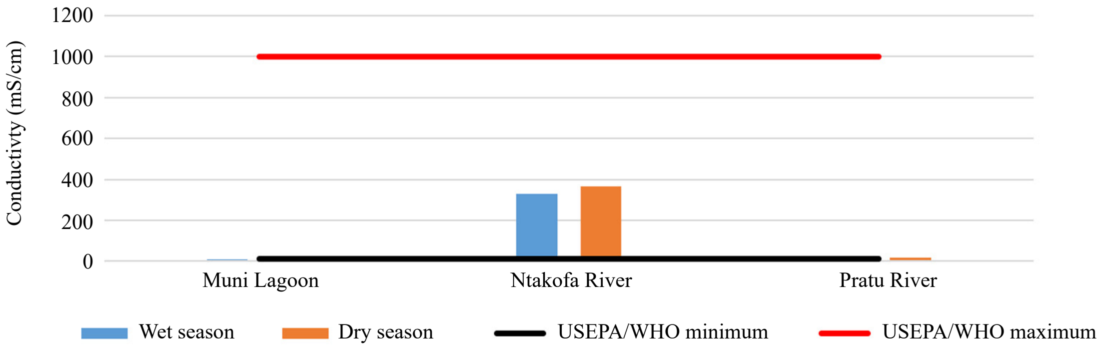

Figure 9. Conductivity concentration in wet and dry seasons

In the dry season, the maximum conductivity value recorded at the Ntakofa River was 771.5 mS/cm, with an average of 366.6 mS/cm. Meanwhile, the minimum value recorded was 16.9 mS/cm. As explained earlier, there was an increase in urban runoff and waste disposal in the absence of rainfall, resulting in a high conductance value. The Muni Lagoon and the Pratu River once again exhibited similar values. However, this time the values recorded were far higher than during the wet season. The maximum conductivity of the Muni Lagoon was 17.6 mS/cm, with an average of 17.2 mS/cm and a minimum of 16.4 mS/cm. The Pratu River recorded an average conductivity of 17.3 mS/cm, with a maximum of 17.9 mS/cm and a minimum of 16.9 mS/cm. This relative increase in values during the dry season was a result of the sandbar being breached to allow the sea to mix with the lagoon, resulting in interaction between them. A rise in temperature is also believed to increase conductivity, so temperature also plays an important role. This was confirmed by Dubrovsky et al. [34], who found that higher water temperatures are known to increase the movement of ions in water and therefore increase conductivity. Figure 10 shows the conductivity distribution in wet and dry seasons.

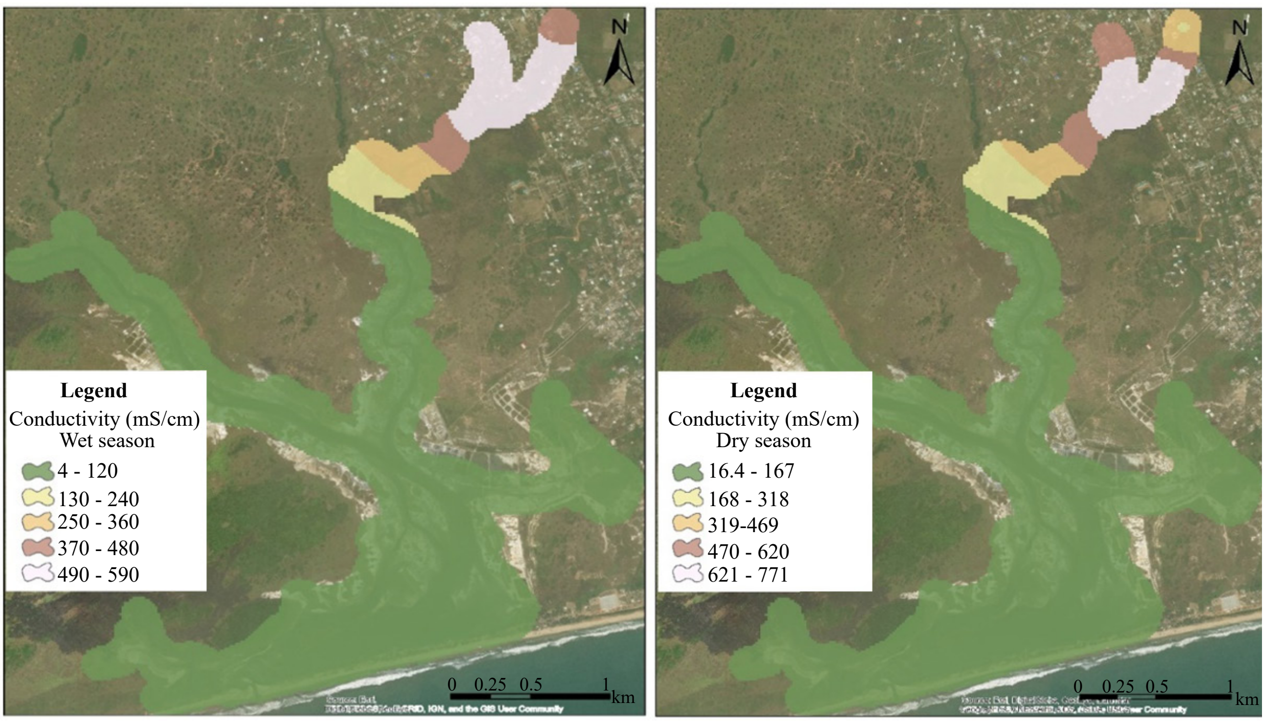

Figure 10. Conductivity distribution in wet and dry seasons

3.1.5 *Salinity*

The concentration of dissolved salt in a given volume of water is called salinity [31]. The salinity should be between 0.5 ppt and 17 ppt for brackish water, but depending on the location and rate of evaporation of the water, some could have higher values. Figure 11 shows the salinity concentration in wet and dry seasons. The maximum value recorded for the Muni Lagoon in the wet season was 2.6 ppt, with an average salinity value of 2.5 ppt. The minimum value was 2.4 ppt. The Pratu River also recorded a maximum salinity value of 2.6 ppt with an average of 2.4 ppt, while the minimum value recorded was 2.1 ppt. These values reflect the fact that the Muni Lagoon at the time of the study had no interaction with the sea because it was cut off by a sandbar. This, coupled with less evaporation and much rainfall, diluted the salt content in the lagoon for the wet season. The Ntakofa River recorded an average value of 1.1 ppt, with a maximum of 2.3 ppt and a minimum salinity value of 0.2 ppt.

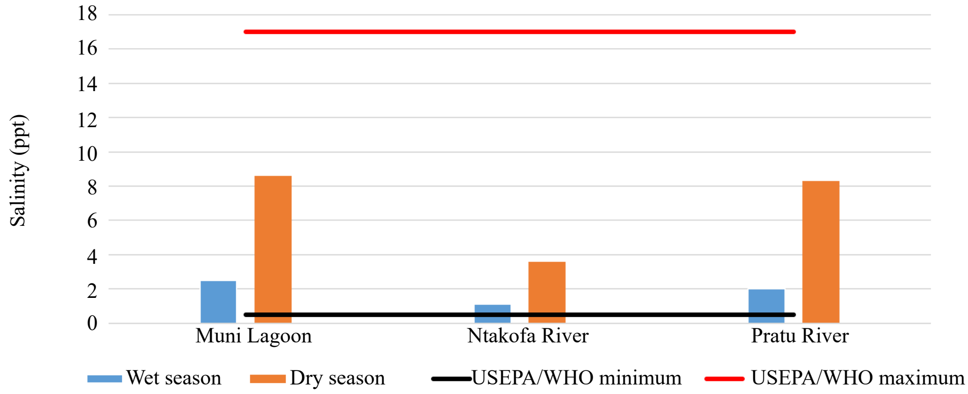

Figure 11. Salinity concentration in wet and dry seasons

In the dry season, however, the Muni Lagoon recorded the highest average salinity value of 8.6 ppt. The maximum and minimum values recorded during the dry season were 8.9 ppt and 8.2 ppt, respectively. Because of the salt pans located at the Pratu River's stretch, the river recorded values that were close to those of the Muni Lagoon. The Pratu River recorded an average salinity value of 8.3 ppt, with maximum and minimum values of 8.5 ppt and 7.5 ppt, respectively. These high values may be the result of the sandbar being breached during the dry season for the sea and lagoon to mix. So, the interaction between the sea and the lagoon could lead to a rise in salinity levels. Secondly, these rises could be attributed to the high levels of evaporation coupled with salt pans in the area. The Ntakofa River recorded an average salinity of 3.5 ppt at WSP 31, with a maximum of 8.5 ppt and a minimum of 0.2 ppt, which was recorded between 100 m and 150 m from the lagoon.

With the values obtained for both seasons, most marine species could thrive in this body of water. This is because most aquatic organisms can only tolerate a specific salinity range. The salinity of each species' surrounding habitat determines its physiological adaptation. The majority of fish species are stenohaline, which means they can only live in fresh or salt water. However, there are a few organisms that can adapt to a wider range of salinities. Figure 12 shows the salinity distribution in wet and dry seasons.

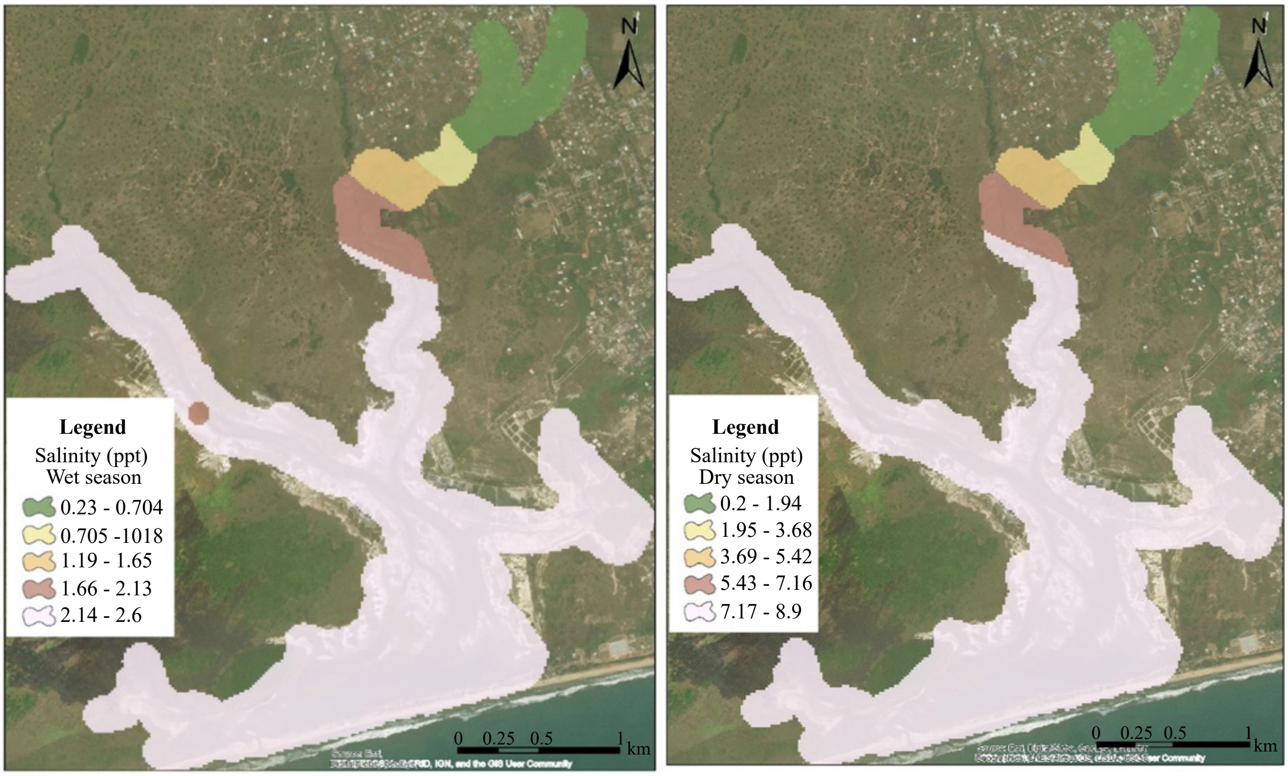

Figure 12. Salinity distribution in wet and dry seasons

3.1.6 *Dissolved oxygen*

According to Talib and Amat [35], DO is oxygen measured in its dissolved state. DO is the most important indicator of the health of water bodies and their capacity to support a balanced aquatic ecosystem of plants and animals. Cunningham and Saigo [36] assert that the DO should not be less than 2 mg/L. This means it should be 2 mg/L or more. So, if DO is below the expected range, organisms will perish. The National Science and Technology Council [37] stated that when oxygen concentrations are less than 2 mg/L, the water is defined as hypoxic or aquatic hypoxia. Hypoxia kills many organisms that cannot escape, and thus the hypoxic zone is informally known as the "dead zone". Figure 13 shows the DO concentration in the wet and dry seasons. From the results obtained, the average DO for the Muni Lagoon in the wet season was 6.9 mg/L, far above the threshold set by previous studies [36, 37]. The minimum and maximum values recorded at the Muni Lagoon during the period of study were 6.6 mg/L and 7.4 mg/L, respectively. These values were far above the threshold. In the wet season, the Pratu River recorded an average of 7.2 mg/L with a maximum value of 7.4 mg/L and a minimum of 6.7 mg/L. The values obtained for the Ntakofa River during this period did not show any significant change. The maximum value recorded for the Ntakofa River was 7.7 mg/L, with an average of 6.2 mg/L, while its minimum was recorded at 5.0 mg/L. Consequently, all of these values were above the recommended threshold, which indicates well for biological productivity in the lagoon and its catchment. This was not surprising as fish ponds were spotted on some sections of the Pratu River.

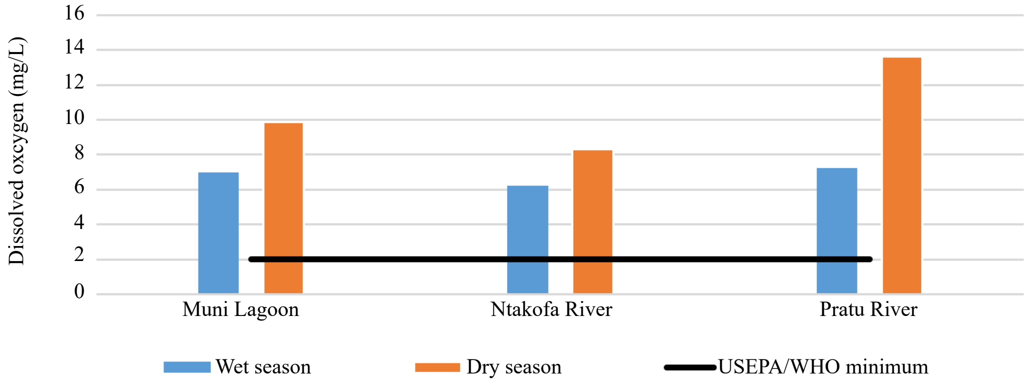

Figure 13. Dissolved oxygen concentration in wet and dry seasons

In the dry season, some changes were observed. In the Muni Lagoon, the maximum and minimum DO values recorded were 14 mg/L and 6.5 mg/L, respectively, with an average of 9.9 mg/L. The highest average recorded during the period of study was 13.6 mg/L at the Pratu River, with a maximum and a minimum value of 13.9 mg/L and 12.5 mg/L, respectively. All these recorded values enhance the biological productivity of organisms. The Ntakofa River recorded an average value of 8.3 mg/L with a maximum and minimum value of 8.4 mg/L and 2.4 mg/L, respectively. The values could be attributed to the aerating action of winds and, more importantly, to the photosynthesis of phytoplankton, algae, seaweed, and other aquatic plants [38]. Figure 14 shows the DO distribution in the wet and dry seasons.

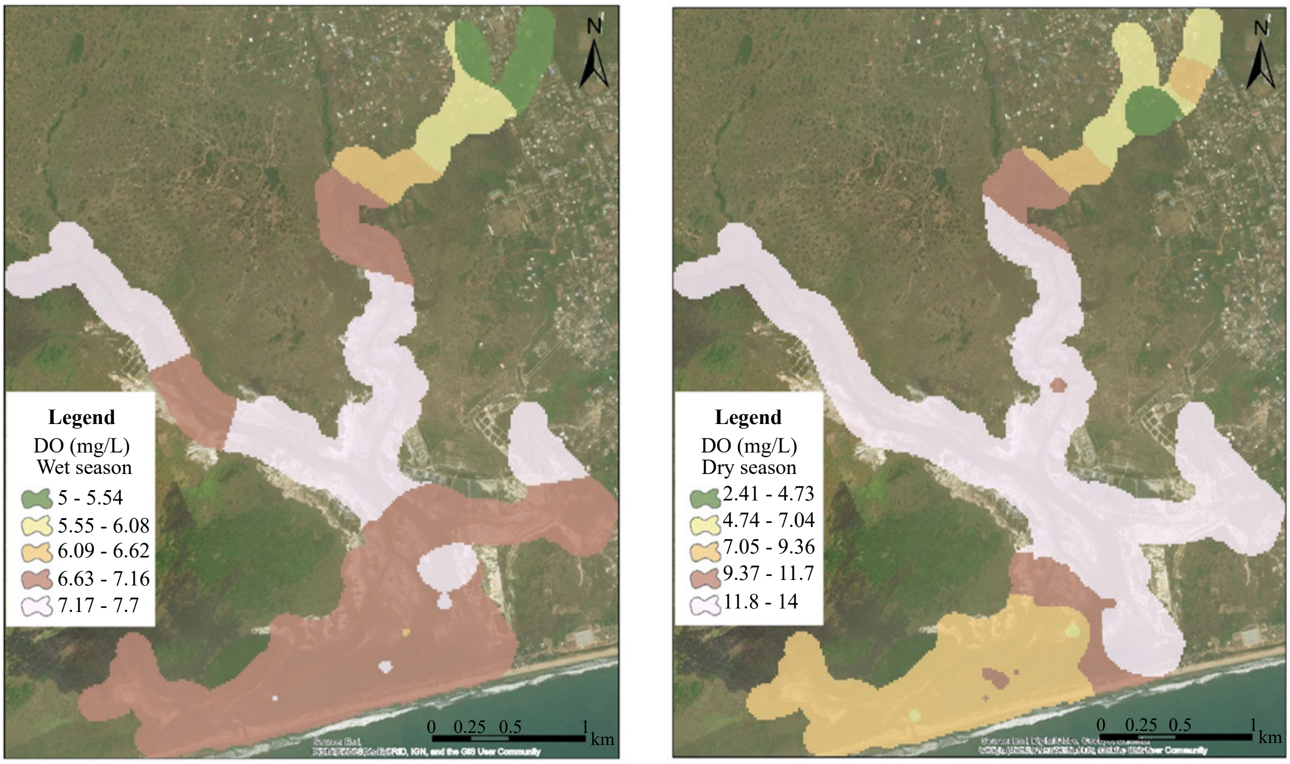

Figure 14. Dissolved oxygen distribution in wet and dry seasons

3.2 *Physico-chemical parameters and biodiversity within the Muni catchment*

The study connected the results of the physico-chemical properties to changes observed in the catchment. The authors found a decline in flora and fauna over time, as evidenced by a decline in fish catches, lower fish sizes, and siltation of the Muni Lagoon. Looking at the results of the physico-chemical parameters and the changes in the catchment, it can be said that these changes are purely anthropogenically induced.

In fact, all of the investigated water quality parameters were well within the threshold, with some minor deviations. This implies that aquatic life and all forms of life within the Muni catchment should be blooming, but this is not the case. It was observed that human activities within the catchment posed a significant danger to biodiversity. Human-induced issues that impact the Muni Lagoon and its catchment area include, among others, the discharge of domestic waste into the lagoon, farming activities, logging, encroachment, illegal fishing, and illegal fishing gear.

It was observed that people who were engaged in fishing used unprescribed nets. This captures all types of fish, including fingerlings, and regular fishing activities eventually result in a dwindling fish catch over time. However, the majority of people in the Muni catchment rely heavily on fish for their livelihood, and as the quantity of fish caught has greatly reduced, their income level is affected. This is due to the fact that the fishermen are unable to catch enough fish to feed their families, let alone sell them for a profit.

Moreover, encroachment is on the rise within the catchment in the form of residential structures and agricultural activities. People fill portions of the feeder streams of the lagoon, resulting in sedimentation and a subsequent reduction in the area covered by the lagoon.

In order to prevent flooding during the rainy season, it was also revealed that the villagers had piled trash in a portion of the lagoon to construct a barrier. This kind of activity leads to an increase in waste within the lagoon, which subsequently affects organisms.

4. Conclusion

Based on the findings of the study, the following conclusions could be drawn: The parameters of the water quality analyzed did not exceed the threshold provided by the USEPA and WHO. However, the closure and breaching of the sea to the lagoon and its catchment had a great effect on the results obtained during the period of study. Therefore, it can be said that the values of the parameters and the health of the Muni Lagoon and its catchment area are dependent on the sea to some extent. Nevertheless, there were some slight changes that, if not monitored, will have a greater effect on biodiversity than what we currently experience. The deteriorating status is a gradual process and could have significant effects on flora and fauna within the Muni catchment for some years to come if not monitored carefully.

It can be concluded that, while nature has some role in influencing the nature of lagoons, anthropogenic activities greatly determine the biodiversity status of the study area.

5. Policy recommendation

In view of the research findings, it is recommended that there should be a thorough and continuous monthly water quality assessment of the Muni Lagoon and its catchment in order to clearly ascertain the progress of pollution in the Muni catchment. This can be done by researchers from higher institutions of learning such as universities and related institutions like the Ghana Hydrological Services and Ghana Water Resources Commission. This will help to make an informed and cogent decision on the right measures to adopt in conserving the quality of the Muni catchment. Moreover, the lagoon should be opened to have access to the sea to ensure consistency of parameter results and create conditions to bring salt and fresh water together to help the mangrove forest grow. In this way, a structure can be constructed to allow water from the lagoon to enter the sea during high precipitation, and water could also enter the lagoon during high tides. The closing and opening of the gates on either side should correspond to the conditions that prevail in the sea and in the lagoon. In consultation with other stakeholders, the Effutu Municipal Assembly may establish an annual dredging and breaching program for the lagoon in conjunction with other stakeholders.

Buffer zones or zoning should be done with strict and constant monitoring. The laws that are meant to protect the wetland should be applied strictly, together with public education, to ensure compliance with its conservation. This can be done in close collaboration among the Effutu Municipal Assembly, the Forestry Commission, and the Effutu Traditional Council.

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Conflict of interest

The authors declare no conflict of interest.

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