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Influence of Precipitation – Runoff on Oceanographic Parameters in the Gulf of Guinea

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Abstract

The Gulf of Guinea includes a wide expanse of West African coast characterized by upwelling dominated region confronted with climatic pressure and anthropogenic influences. Variations of oceanographic parameters: chlorophyll-a concentration and Sea Surface Temperature along the Gulf of Guinea (GoG) and its relations with hydrological variables were analyzed using remote sensing satellite observations spanning from 2016 – 2019. Copernicus Marine Environment Monitoring Service (CMEMS) chlorophyll-a concentration and Sea Surface Temperature (SST) data, Global Precipitation Climatology Project (GPCP) version 2.3 and National Centers for Environmental Prediction (NCEP) surface runoff data were exploited for the present study. The effects of hydrological variables (precipitation and runoff) were considered on monthly time scale, with analysis carried out on the monthly mean chlorophyll-a concentration and SST. To investigate the exact spatial and temporal contribution of hydrological variables on chlorophyll-a concentration and SST, precipitation data were extracted and cleaved into precipitation over land and precipitation over sea, thereafter referred to as PoL and PoS respectively. Spearman Rank correlation was employed to achieve the objectives of the study i.e. to explore possible relations between hydrological variables and oceanographic parameters along GoG. Results show significant positive correlations between surface runoff and chlorophyll-a concentration, surface runoff and precipitation over land (PoL), Sea Surface Temperature and precipitation over sea (PoS) and significant negative correlation between chlorophyll-a and precipitation over sea (PoS), and between chlorophyll-a concentration and Sea Surface Temperature. Spatial and temporal results show variabilities in chlorophyll-a concentrations as its decreases in the direction of the ocean from the coast i.e. coastal water possess more chlorophyll-a concentrations than the open ocean. Sierra Leonne and Liberia exhibit upwelling properties in boreal spring and winter, with Cote d'Ivoire and Ghana exhibiting upwelling properties in boreal summer. Nigeria coastal water was perceived to be the hottest and contains lesser chlorophyll-a concentration in GoG with mild exceptions in south southern part of the country.

Keywords: Hydrological Variables, Precipitation-runoff, Oceanographic parameters, Chlorophyll-a concentration, Sea Surface Temperature.

INTRODUCTION

Understanding connection between climate induced hydrological variables and oceanography parameters is an important metrics for evaluation of the impacts of climate change on the ocean. Climate change is one of the important global environmental issue because of its impacts on various sectors of life. Climate change affects the variability of the ocean and the atmosphere not only the physical processes (e.g. hydrological cycle) but also the chemical and biological processes in the ocean.

The West African climate, driven by West Africa Monsoon is controlled by two air masses: dry, hot continental air masses arising from Sahara Desert and the cool moist air masses originating from the Atlantic Ocean in the Gulf of Guinea (23). These air masses form two air pressure system (i.e. low-pressure and high-pressure system), interact with one prevailing at a time. This interaction results to West Africa's precipitation regime characterized by latitudinal belts of decreasing rainfall and wet season length from March to October (wet monsoon season), and dusty Harmattan winds over most West Africa states from November to February (dry monsoon season). However, Gulf of Guinea which is the northernmost part of the equatorial Atlantic located off the western coast of Africa is affected by the climate it helps to build.

It is said that coastal states of West Africa receive the highest amount of precipitation because of their proximity to the Atlantic Ocean (2). Precipitation is potentially a large driver of change in the ocean and impacts the ocean significantly but yet frequently overlooked. There are evidences that hydrological variables e.g. (precipitation, runoff etc.) can impact the sea and influence temperature, salinity and nutrient of surface waters. For instance, nutrients in estuaries and coastal ocean waters are majorly sourced from atmospheric wet disposition through precipitation and agricultural runoff (26,7).

Many studies have identified precipitation to positively influenced marine production in low nutrient areas by increasing chlorophyll-a concentration level. (16) studied the Influence of precipitation events on phytoplankton biomass in coastal waters of the eastern United States. It was concluded that precipitation influences increase in chlorophyll-a concentration mostly in the area near the coast especially with complementary effect of strong winds. Similarly, positive correlation between precipitation and chlorophyll has been reported by (14) and a favoring effect of precipitation on chlorophyll has also been suggested in a study by (17) in Cyclades region. Increased chlorophyll-a concentrations have as well been noted over areas affected by high rainfall amounts and in sections of different extreme events ((18). The reason for chlorophyll-a increases after rainfall events could be linked to 1- Atmospheric exposure to anthropogenic soluble irons from such as biofuel and biomass burning particles in the region close to the ocean (10), these particles are deposited in the atmosphere and fall on the ocean in the event of rainfall 2- Agricultural surface runoff (21) flushing nutrients from the farmland to the ocean.

In particular, precipitation is enriched in biologically available forms of nitrogen (NOx, NH4, organic N), because coastal receiving waters are often nitrogen limited and hence sensitive to even small nitrogen amendments (7,26,24,19,4). Nitrogen and its compounds are essential and serve as important source of nutrition to ocean's primary food producer 'phytoplankton' when present in the right proportion and could also constitute nuisance when found in excess in the ocean. Nitrogen accounted for about 57% of world total fertilizer use from early 1960 except for 2009 and 2014 (8), some of which later awash by rainfall from the farmland into the ocean as runoff.

The work of (21) in the Gulf of California titled 'Agricultural runoff fuels large phytoplankton blooms in vulnerable areas of the ocean' robustly established great connections between agricultural runoff and ocean nutrients with much emphasis on Nitrogen flux. However, to the best of our knowledge such research has actually not been done in the Gulf of Guinea surrounded with verse agricultural activities.

Here, GIS methods were used to explore possible influence of hydrological variables (precipitation and precipitation induced surface runoff) on oceanographic parameters: sea surface temperature and chlorophyll-a concentration in the Gulf of Guinea as these parameters determine biological abundance in the ocean. For these objectives, correlations between surface runoff and chlorophyll-a concentration, surface runoff and precipitation over land (PoL), Sea Surface Temperature and PoS, chlorophyll-a concentration and PoS, chlorophyll-a concentration and Sea Surface Temperature will be estimated separately for the four years under study. These calculations will be based on the compilation of robust and concise relevant data sets; these involve monthly mean Copernicus Marine Environment Monitoring Service (CMEMS) chlorophyll-a concentration (2017–2019) and Sea Surface Temperature data and (2016–2019) on $0.083^o x\ 0.083^o$ spatial resolution, monthly mean Global Precipitation Climatology Project (GPCP) precipitation data (1979 to present) on $2.5^o x\ 2.5^o$ spatial resolution and monthly mean National Oceanic and Atmospheric Administration (NOAA) surface runoff data (1948 to present) on $2.5^o x\ 2.5^o$ spatial resolution. Spatial and temporal distributions of these variables with their respective annual and monthly trend for the year under investigation in the Gulf of Guinea shall also be considered.

Study area

Gulf of Guinea (GoG) is the northernmost part of the equatorial Atlantic located off the western coast of Africa as shown in figure 1, extending from Cape Palmas in Liberia to Cape Lopez in Gabon. A number of different rivers drain into the Gulf, these include River Niger in Nigeria and the Volta River in Ghana. The Gulf's coastline includes the Bight of Benin and Bight of Bonny and form the western edge Africa tectonic plate. This region is surrounded by farming activities as agriculture accounts for about 65% of the employment and 35% of Gross Domestic Product (GDP) (World Bank, 2013) in West Africa. Although the use of fertilizers and pesticides remain low, agriculture in West Africa depends mostly on rainfall (5). In the event of rainfall, these chemicals (fertilizers and pesticides) are washed to the neighbor coastal waters as runoff, thereby affecting the biological productivity of the water involved positively or negatively depending on the type and amount of the chemicals.

Figure 1. The study area map

METHODS

Recently, satellite observations have become an important method of data acquisition most especially in oceanography because of its ability to probe remote part of the ocean. In anterior to satellite observations, data acquisition in oceanography studies were basically from infrequent measurements collected from drifter, buoys and ships etc. which are limited to sampling the ocean in a relatively tiny area. Arrival of ocean-observing satellite has sensationalized and revolutionized oceanographic studies such that remote sensed satellite data and modeling techniques enable global mapping and seasonal changes in oceanographic parameters.

Data sources

Chlorophyll-a and SST data

The chlorophyll-a concentration and SST data used in the study were sourced from Copernicus Marine Environment Monitoring Service (CMEMS) at *marine.corpenicus.eu* on NETCDF4 file format. The downloaded data were monthly mean datasets at 0.49-meter depth spanning from January 2016 to December 2019 and January 2017 to December 2019 for SST and chlorophyll-a concentration respectively. CMEMS provides regular and systematic reference information on physical and biogeochemical ocean and sea-ice state for the global ocean and European regional seas. The products are based on the state-of-the-art data processing, advanced modelling and data assimilation techniques. CMEMS architecture includes Thematic Assembly Centers (TACs), modelling assimilation (Monitoring and Forecasting Centers – MFCs) and a Central Information Centers (CIS). There are eight TACs, six of which are satellite TACs that generate ocean variables such as (sea surface topography, ocean color, sea-ice, sea surface temperature, waves and winds), one is in situ TAC e.g. Global Ocean Observing System (GOOS) and the last one, multi-observation TAC (that merges different in situ and satellite data to elaborate high-level products). The products are 3D updated weekly, and are blended in situ and observational global daily and monthly mean analysis on $0.083^{o} x\ 0.083^{o}$ resolution. See (25) for more information and the method used to generate the data. The products uncertainties are subjected to meticulous scrutiny by internationally recognized quality assessment methods (11).

Precipitation and Surface runoff data

Present study used monthly mean reanalysis Global Precipitation Climatology Project (GPCP). GPCP datasets are merged data from rain gauge stations, satellite and sounding observations on $2.5^{o} \times 2.5^{o}$grid resolution spanning from 1979 to present. The spatial details of the GPCP data covers both the ocean and land on a global scale with the estimation of uncertainties embedded in the newest version (V2.3) of the products used in the study. GPCP product is available at global scale (*https://www.esrl.noaa.gov/psd/data/gridded/data.cmap.html*), the processes and methods of the data generation contain therein (1). The surface runoff data is also a reanalysis monthly mean data from National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) project, otherwise known as NCAR – NCEP Reanalysis. It's also a blended data modelled from both in situ and satellite observations available on $2.5^{o} \times 2.5^{o}$grid resolution spanning from 1948 to present. The data is accessible at *http://www.esrl.noaa.gov/psd/data/gridded/data.ncep*.

Data Analysis

Monthly mean hydrological variables and oceanographic parameters data previously described were subjected to series of different analysis to achieve the objectives of the study. In other to determine spatial and temporal pattern of SST and chlorophyll-a concentration, downloaded four-year CMEMS data SST and chlorophyll-a were grouped into monthly mean (i.e. January – December). The grouped data were introduced into a particular GIS software analysis, the data together with the shapefile of the study area were visualized, georeferenced and gridded. The spatial organization of precipitation and surface runoff data were on (0 – 360) degree longitude instead of the conventional degree west and degree east arrangement i.e. (-180 to 180). This arrangement automatically cut some part of our study area off, hence a need to re-grid precipitation and surface runoff data to be in spatial conformity with SST and chlorophyll-a. This was successfully done with a SciPy software code, with spatial and temporal variables of the study area were extracted from the two datasets afterwards. The variables were also grouped into monthly mean as it was done for SST and chlorophyll-a before visualization. In the process of the analysis, differences in precipitation over the sea and that of the land were noticed, therefore, PoS and PoL were extracted separately. Bilinear interpolation method was employed to fill the missing numbers as there was need to plot the temporal trend of the extracted variables for the four parameters under study. As stated with their respective months in the introductory part of the study, West Africa has two seasons (Wet monsoon and Dry monsoon). In order to avoid ambiguities and recurrences, seasonal analysis was left out as that shall be taken care of by the monthly mean analysis. For detecting possible relations between the hydrological variables and oceanographic parameters, Spearman rank correlation coefficient were computed separately for the variables involved. The choice of Spearman rank correlation coefficient for detecting possible relationship were born out of the fact that not all the datasets were normally distributed and Spearman rank correlation coefficient is quite not aff ected by such differences in the data distributions. It is understood that correlations do not ensure a cause–eff ect relationship, but they can be used together with other findings to reach useful conclusions. For this reason, significance of the results was tested using student's t-test at confidence level >95%, results are presented in the results section of the study.

RESULTS

Ocean biological productivity largely refers to production of microscopic marine algae "phytoplankton," suspended plants in the ocean, most of which are unicellular. These organisms are indispensable in marine ecosystem as they are the primary producers of marine food webs. Remote sensing has however, enables researchers to detect the phytoplankton fluorescence from spectral absorption of chlorophyll otherwise known as glow. Spatial and temporal changes in monthly mean chlorophyll-a in the Gulf of Guinea as depicted in figure 3.1 shows temporal and spatial variabilities in chlorophyll-a concentrations as its decreases in the direction of the ocean from the coast. Boreal winter (December, January, February) and spring (March, April, May) upwelling

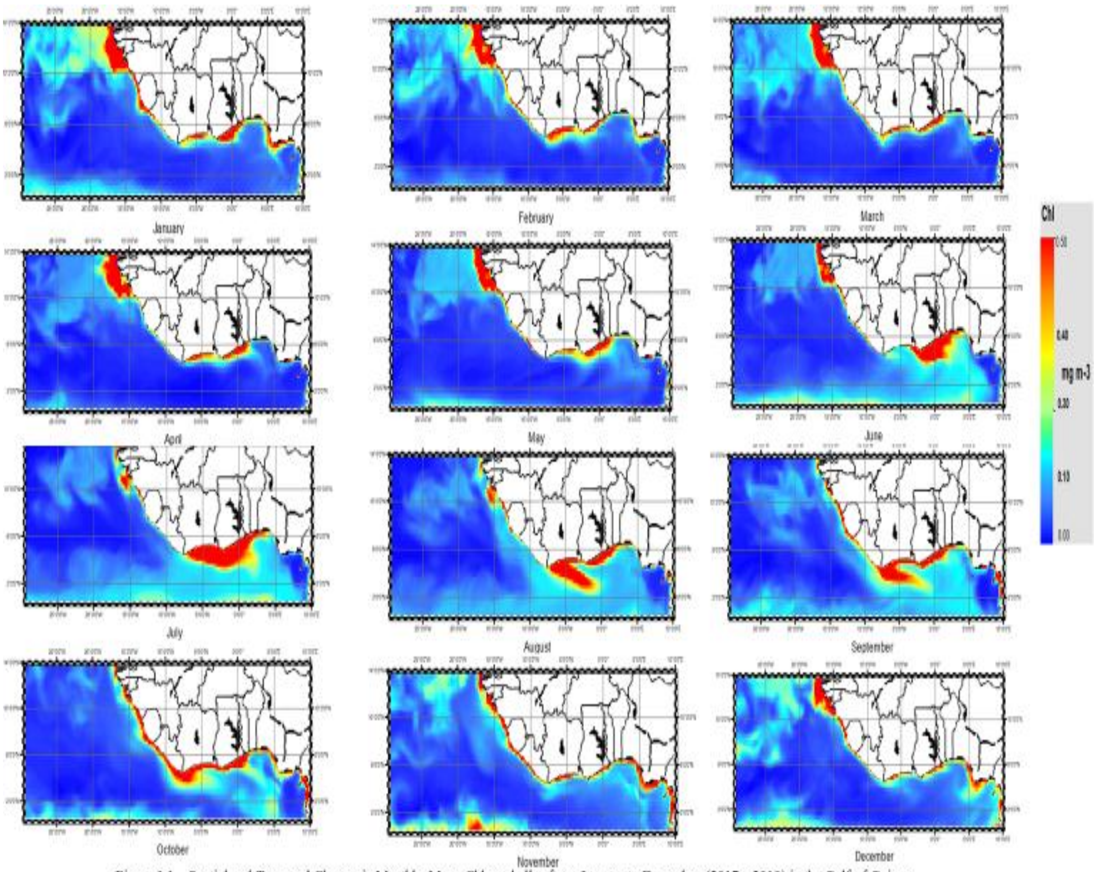

Figure 3.1. . Spatial and Temporal Change in Monthly Mean Chlorophyll-a from January to December (2017 – 2019) in the Gulf of Guinea

properties were noticed in Sierra Leone and Liberia coasts as high chlorophyll-a concentrations values were recorded during these periods. As against Sierra Leone and Liberia coasts, high chlorophyll-a concentrations values were recorded in the summer (June, July, August) periods in Cote d'Ivoire and Ghana coast, suggesting boreal summer upwelling condition in these regions. These results agree with (12). Although, Togo and Republic of Benin coasts recorded a reasonable amount of chlorophyll-a concentrations in June with Nigeria coast recorded lesser throughout. On the other hand, Sea Surface Temperature converses chlorophyll-a concentrations almost in all respect as shown in figure 3.2. Low SSTs were noticed in boreal spring and winter periods in Sierra Leone and Liberia as against high chlorophyll-a concentrations in the same period of the year. Also, low SST were recorded in Cote d'Ivoire and Ghana coast in boreal summer. Nigeria coastal water was perceived to be the hottest water in the Gulf of Guinea with 24.6^oC as the lowest SST recorded in September at an average SST of 27.3^oC, this feat was well reflected in chlorophyll-a concentrations in Nigeria coastal water with mild exceptions in south southern part of the country. The trend plots in figure 3.4 indicates low chlorophyll-a concentrations and high temperature recorded in the boreal winter. Conversely, high chlorophyll-a concentrations and low temperature were recorded throughout the boreal summer in the entire region within the year under investigation. On monthly averages, highest chlorophyll-a

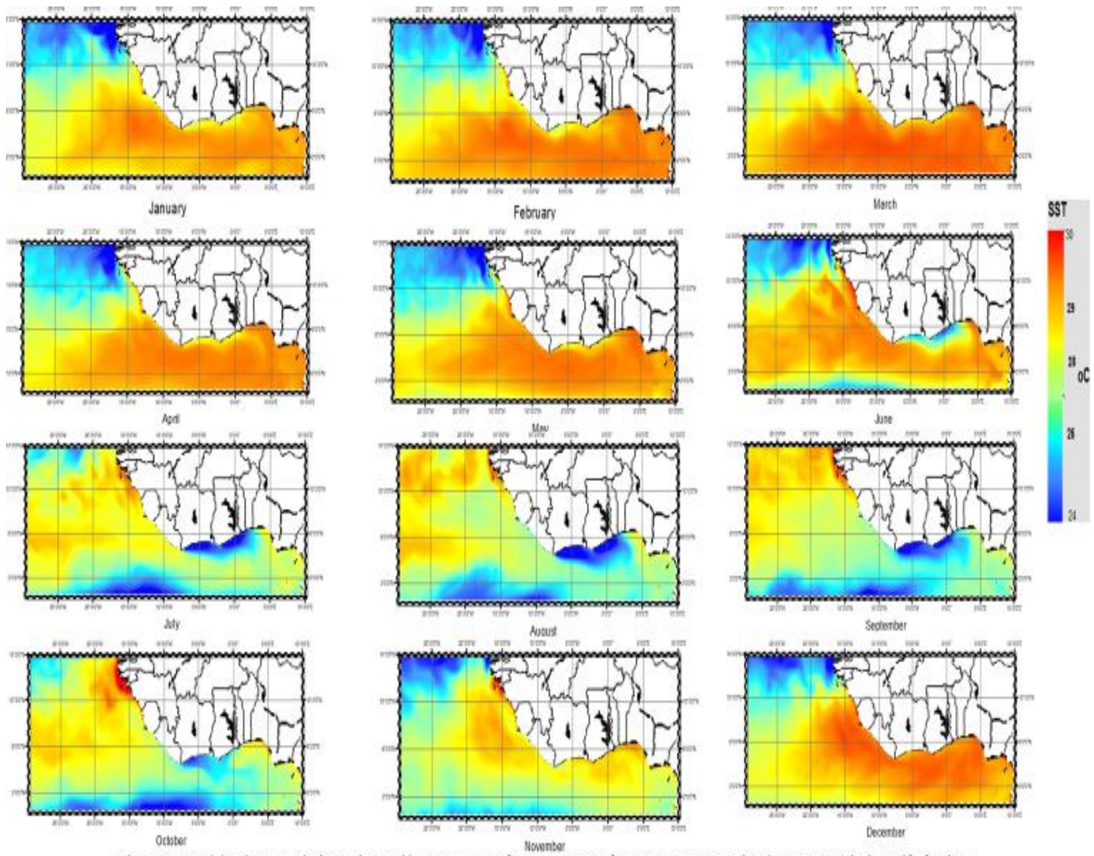

Figure 3.2. Spatial and Temporal Change in Monthly Mean Sea Surface Temperature from January to December (2016 – 2019) in the Gulf of Guinea

concentrations were recorded in July 2019 as opposed to 2017 and 2018 which recorded their respective highest chlorophyll-a concentrations in August, with 2017, 2018 and 2019 recorded their lowest chlorophyll-a concentrations in February, November and March respectively. Contrarily, highest SST values were recorded in March throughout the year under study with their respective lowest values recorded in August. Figure 3.3 shows spatial distribution of precipitation, it could be noted that precipitation was not uniformly distributed as clear differences could be noted between PoS and PoL. Although PoL follows the normal monsoonal pattern as its highest values recorded in September with its lowest in February throughout the year under examination. Whereas PoS seen recorded its highest values in May with its lowest recorded in February all through the year under investigation. Interestingly, surface runoff follows the same pattern with PoL as it is understood that surface runoff is induced by precipitation over the land. Surface runoff exhibits monsoonal patterns as its records zero value throughout the dry monsoon period and records highest values at the peak of wet monsoon periods in the region in September throughout the year under examination.

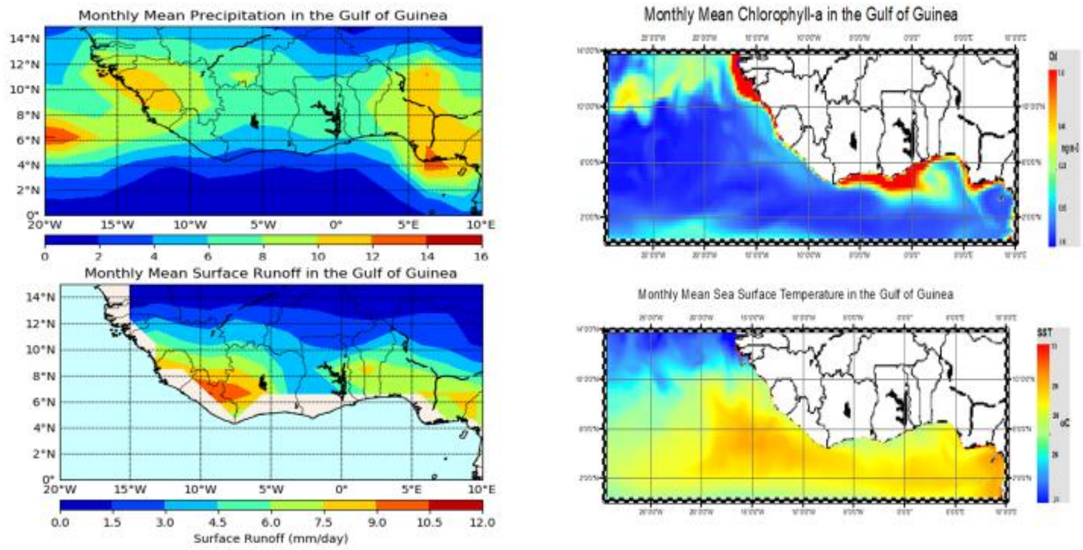

Figure 3.3 . Spatial and Temporal Change in Monthly Mean Chlorophyll-a from January to December (2017 – 2019) in the Gulf of Guinea

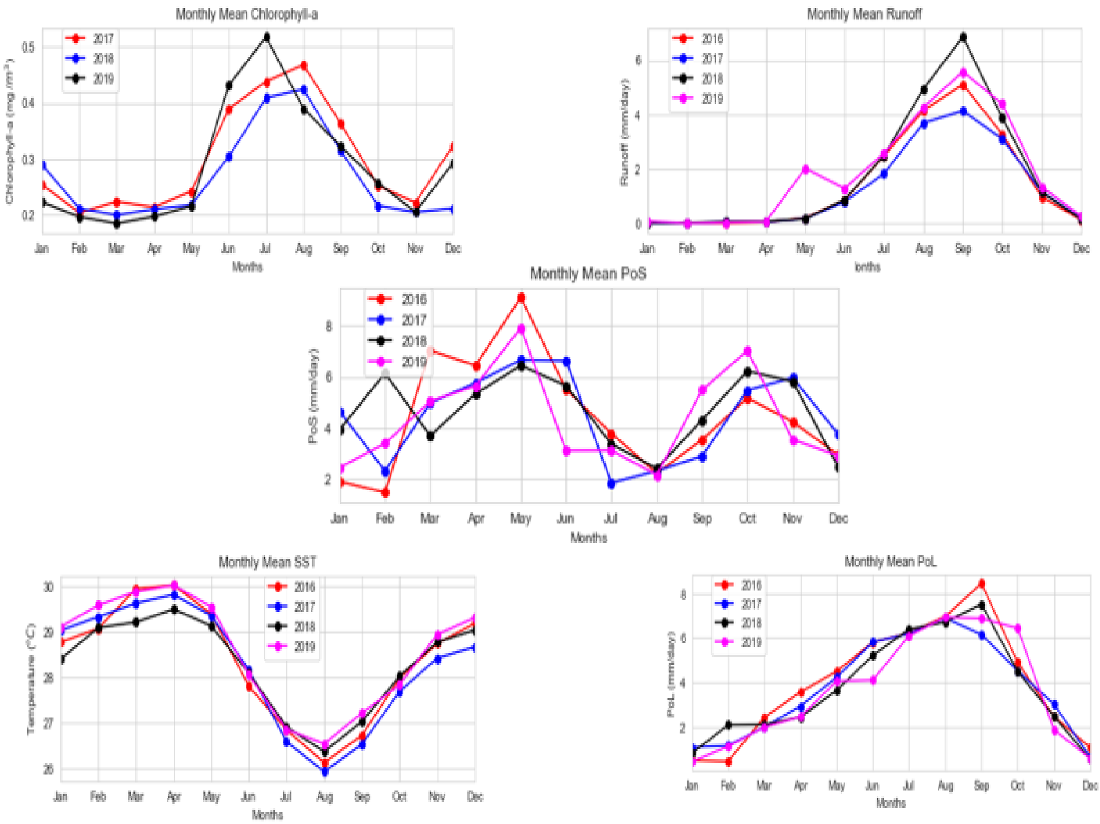

Figure 3.4. Temporal trend of Monthly Mean Chlorophyll-a, SST, PoS, PoL and Surface Runoff (2016 – 2019) in the Gulf of Guinea

DISCUSSION

Surface runoff presents a significant direct relationship with Chlorophyll-a concentration with Spearman's ranked correlation coefficient (Rs = 0.572, < 0.01) in the Gulf of Guinea as shown in figure 4.1. To the best of our knowledge, no literature could be found in respect to this particular finding in the Gulf of Guinea, but it could be corroborated with the work of (21) in the Gulf of California where relationship between Agricultural runoff and phytoplankton blooms were studied. It was reported that the periods of greater irrigation are significantly correlated with high chlorophyll levels with Spearman's ranked correlation (Rs = 0.47, P < 0.001). In hydrological cycle of the earth, there is continuous exchange of water between three earth reservoirs (Atmosphere, Ocean and Underground) in the presence of some physical processes e.g.

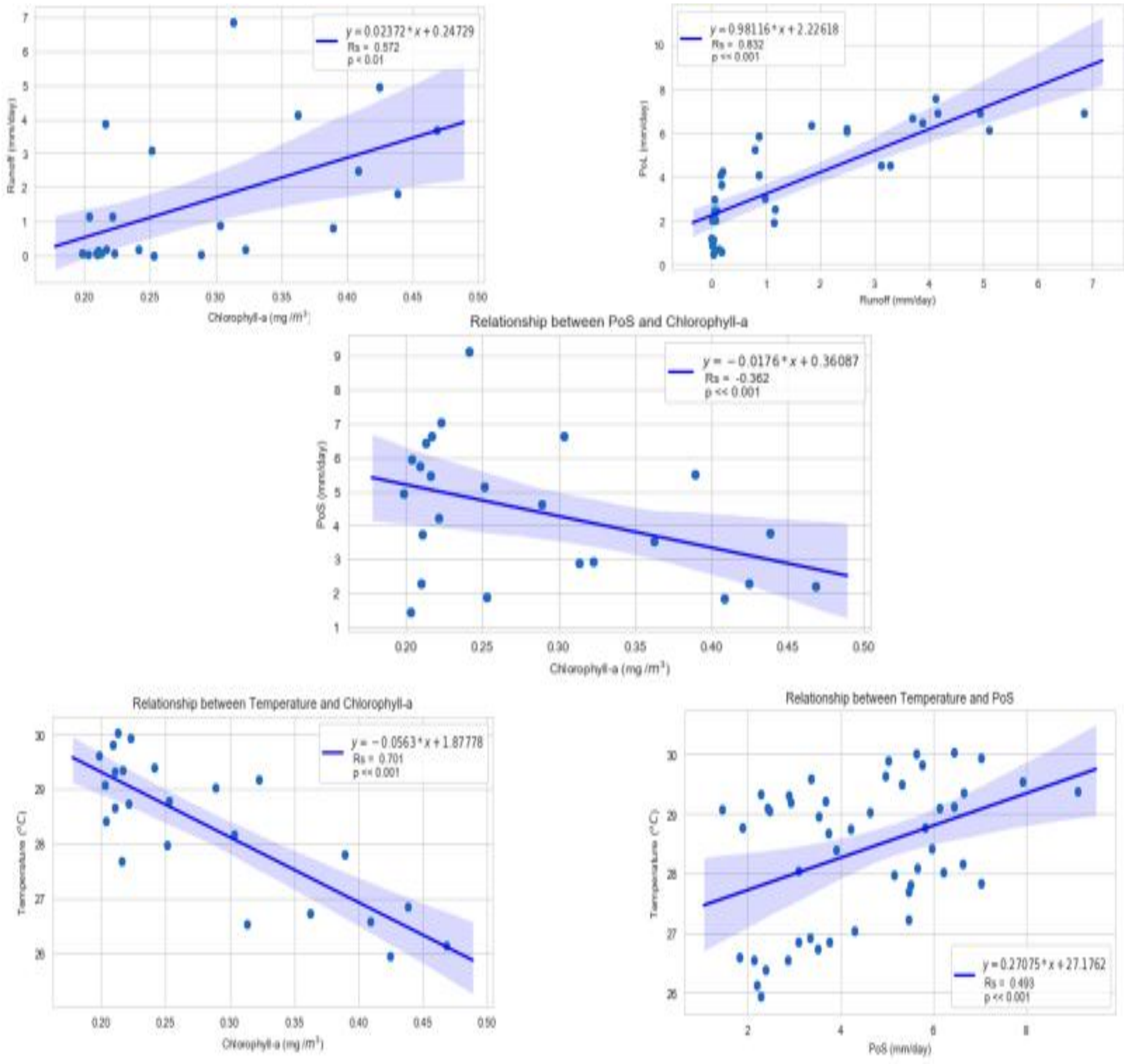

Figure 4.1. Magnitude of connection between Runoff and Chlorophyll-a, Temperature and Chlorophyll-a, PoL and Runoff, PoS and Temperature in the Gulf of Guinea

evaporation, condensation, percolation, precipitation and infiltration. At some point, in the presence of continuous precipitation, when the retentive power of soil becomes very low otherwise known as low percolation rate, overland flow becomes more active, leading to surface runoff. Surface runoff from the farm contribute largely to the ocean nutrient flux e.g. (Nitrogen and Phosphorus from fertilizer) and also Phosphate from detergent and sewages, most of which got stuck in the coastal waters. This explains why chlorophyll-a concentrations in our result decreases in the direction of the ocean from the coast, making the coastal sea more fertile than the open ocean. When these nutrients are oversupplied to the ocean, they become nuisance, leading to aggressive algae growth and oxygen depletion, a process known as eutrophication. Eutrophication is dangerous and harmful to marine ecosystem, hence a need to constantly monitor surface runoff discharge to the ocean.

Analysis of relationship between chlorophyll-a and Sea Surface Temperature presented a significant inverse relationship with Spearman's ranked correlation coefficient (Rs = -0.701, $p << 0.001$) in the Gulf of Guinea. This correlation agrees with the work of (12). The study titled 'Variability of Chlorophyll-a concentration in the Gulf of Guinea and its relation to physical oceanographic variables,' reported that cold SST with negative Sea Level Anomaly (SLA) and moderate wind favors Chlorophyll-a concentration and upwelling conditions. It should be noted that, such an inverse relationship was anticipated between SST and chlorophyll-a or net primary production for the larger part of the oceans (9, 20) as high SST is known to deplete dissolved oxygen in the ocean.

Correlation between chlorophyll-a concentrations and precipitation over sea (PoS) shows a significant negative relationship with Spearman's ranked correlation coefficient (Rs = -0.402, $p << 0.001$) in Gulf of Guinea. Cloud cover can result in a major reduction in amount of direct-beam solar radiation with a total elimination of sun patches and flecks. The negative correlation between Chlorophyll-a and PoS could be attributed to cloudy atmosphere that gives rise to precipitation, occluding direct radiation on the surface of water, and as such, this could inhibit the growth of phytoplankton that highly depend on sunlight to photosynthesize. Although the work of (22) reported low availability of chlorophyll-a concentration in an intense and extended precipitation day in coastal waters of the eastern United States, this research finding has not also been reported in the Gulf of Guinea.

The world Ocean and the Atmosphere are open systems that continuously interact, this interaction brings about exchange in mass (water, sea salts, precipitable water etc.), momentum (water vapor) and energy (heat transfer) in the presence of physical processes. When radiation from the sun hits the surface of the ocean through the earth atmosphere, water molecules move and vibrate in respond to the incoming radiation so quickly that they escape into the atmosphere in form of water vapor, SST becomes high in respond to the solar heating. It is estimated that 90% of water in atmosphere are sourced from evaporation from the Ocean (22), the water condenses and precipitate back to the surface mostly as rainfall, snow etc. Sea Surface Temperature has been reported by many authors to have a positive correlation with precipitation e.g. (2) studied Sea Surface Temperature Trends and its Relationship with Precipitation in the

Western and Central Equatorial. Strong positive correlation value of 0.627 were reported for both Spearman ranked correlation coefficient and Poisson correlation coefficient in Western Equatorial Africa (WEA). Here, correlation between Sea Surface Temperature and Precipitation over Sea (PoS) shows a significant with Spearman's ranked correlation coefficient (Rs = 0.493, $p << 0.001$) in GoG.

Surface runoff i.e. overland flow water in the face of excess stormwater, show a very strong and significant positive correlation with precipitation over land (PoL) with Spearman's ranked correlation coefficient (Rs = 0.832, $p < 0.01$) in the study area. The strong positive correlation is understood as though surface runoff does not only depends on precipitation over an area but with surface condition, slope, soil types and land features of the area.

CONCLUSIONS

The Gulf of Guinea includes a wide expanse of West African coast, stretching from Cape Palmas in Liberia to Cape Lopez in Gabon, estimated approximately to $2350000km^2$. It is a distinctive and productive system confronted with climatic pressure and anthropogenic influences and so, it is imperative to understand the response and variations in biological productivity to climate induced hydrological variations in its coastal regions. This research work contributed to that effect by holistically analyzing and establishing statistical relationship between chlorophyll-a, SST and hydrological variables. The success of this analysis tied on the availability of satellite remote sensing products describing the major hydrological variables on potential interest to understand chlorophyll-a and SST variability as these parameters determine biological abundance in water. Spearman's rank correlation coefficient is an important and a handy statistical tool used by many researchers to summarize the strength and direction of a relationship between two variables. It was applied to quantify the magnitude of association between hydrological variables and oceanographic parameters: chlorophyll-a concentration and Sea Surface Temperature. Results of this work show significant positive correlations between surface runoff and chlorophyll-a concentration, surface runoff and precipitation over land (PoL), Sea Surface Temperature and precipitation over sea (PoS) and significant negative correlations between chlorophyll-a and precipitation over sea (PoS), and chlorophyll-a concentration and Sea Surface Temperature.

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