The Zoologist
2024. Vol. 25: 16-22. http://dx.doi.org/10.4314/tzool.v25i1.3 Print ISSN 1596 972X, Online ISSN 2992-4030

Response of phytoplankton to seasonal changes in some water quality parameters in Anyim River, Ebonyi State, Southeast, Nigeria

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Received: 03 July, 2024
Revised: 24 October, 2024
Accepted: 19 November, 2024
Keywords: Anyim River, Phytoplankton, water pollution, Physicochemical variables, seasonal variation

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Abstract

Anyim River is an important tributary of Cross River that provides water for various purposes to some rural communities in Ebonyi, Benue and Cross River states of Nigeria. However, the river is polluted from anthropogenic and naturogenic sources, which is worrisome. This study assesses the responses of the phytoplankton community to changes in water quality as a preliminary step toward mitigating pollution of the river. Water and plankton samples were collected bimonthly from November, 2017 to September, 2019 and then analysed in the laboratory following standard procedures. The results showed that mean water temperature ($29.97\pm2.34^{o}C$), total dissolved solids (28.00 ± 4.21mg/L), conductivity ($50.00\pm5.28\mu$S/cm), carbon (iv) oxide (8.63 ± 1.10mg/L) and transparency (0.19 ± 0.12m) were higher in the dry season. All the water quality parameters varied significantly ($p<0.05$) between seasons except dissolved oxygen, nitrate and transparency. Cyanophyta (487 cells/L) was the most abundant phytoplankton during the dry season while Bacillariophyta had the highest diversity ($H'=1.84$) and species richness ($d=2.53$) in the wet season. Principal Component Analysis (PCA) revealed that pH, transparency, nitrate and phosphate favoured the abundance and diversity of Bacillariophyta and Cyanophyta during dry season. The dominance of Cyanophyta in dry season was an indication of poor water quality.

Introduction

Tropical rivers are characterized by seasonal fluctuations in water levels occasioned by changes in hydrological regimes (Nwinyimagu *et al* 2018; Petts 2018). Plankton and other aquatic biota show obvious responses to these changes in the physical and chemical variables of freshwater ecosystems owing to changes in meteorological variables (Dias *et al* 2014; Nwinyimagu *et al* 2016) and flood regime (Nwonumara and Okogwu 2013) that occur seasonally. Rivers can support rich ecosystem both in species abundance and diversity (Eyo *et al* 2013), with normal nutrient input from riparian agricultural farmlands. Nutrients drift from agricultural farms through surface runoff into rivers and can stimulate production and consequently increase species abundance thereby enhancing the maintenance of the community structure of an aquatic ecosystem (Glibert and Burford 2017).

In aquatic ecosystems, phytoplankton plays very vital role in building and structuring aquatic food chains. It is suggested that production in any aquatic ecosystem is almost entirely the function of the phytoplankton population (Jasim *et al* 2015; Saravanakumar *et al* 2008). They are usually the first link in the vast aquatic food chain to convert inorganic nutrients through photosynthesis into new organic compounds and transfer same in the form of chemical energy to the successive trophic levels (Saravanakumar *et al* 2008). Phytoplankton have been reported to contribute approximately half of the total global primary production, and strongly influence the water–atmosphere gas exchanges despite their minute sizes (Rost *et al* 2008). Bhat *et al* (2015) also reported that phytoplankton play vital role in nutrient circulation in aquatic ecosystems thereby controlling the ecological processes within such ecosystem.

The abundance and diversity of phytoplankton species in any water body indicates the water quality (Nwonumara 2018). Rost *et al* (2008) reported that the diversity and abundance of any particular planktonic species in any given water body may largely depend on certain complex changes that are common to major environmental factors, which can affect their growth rate, behaviour and the activities of other organisms. They can easily be influenced by spatial and temporal changes in the aquatic environment (Rost *et al* 2008). Meanwhile, phytoplankton species vary in their tolerance to various environmental factors, which suggests why their presence in any aquatic environment can be used for water quality assessment (Essien-Ibok and Ekpo 2015).

Essien-Ibok and Ekpo (2015) suggested that plankton can often be used as bioindicators for monitoring the pollution status of an aquatic environment. Glauch and Escher (2020) also reported that phytoplankton can be used as a tool for assessing the impact of toxic substances on aquatic environment. As key primary producers in aquatic ecosystem, any change in water quality affects the species composition and diversity of phytoplankton and other organisms in the food chain/web (Nwonumara and Okogwu 2019; Glauch and Escher 2020). Agrochemicals, household and industrial wastes have been reported as the common sources of pollutants to river systems (Chauhan 2014; Egbueri 2023; Ezugwu *et al* 2019). Pollutants could cause changes that are capable of disrupting a balanced ecosystem; leading to significant alteration in its structure and function (Ama-Abasi 2017).

Anyim River is a major tributary of the Cross River system that is of immense economic benefits to the riparian human communities, so there is need to regulate human activities around the ecosystem to reduce pollution (King and Brown 2021). This can be achieved with good knowledge of the water quality and phytoplankton diversity of the river. Several studies have been conducted on some important rivers in Southern Nigeria (Abowei 2010; Imoobe 2011; Evo *et al*. 2013; Essien-Ibok and Ekpo 2015; Nwinyimagu *et al*. 2018; Nwonumara and Okogwu 2021) but none has been reported on the water quality and phytoplankton of Anyim River. Hence, this study will bridge the gap and further provide information that will enhance the understanding of the functionality of Anyim River and the health of the riparian ecosystem. It will also be useful in proposing the appropriate conservation measure that will help to protect the water quality of the ecosystem and its biodiversity.

Materials and methods

Study area

The study was carried out within the middle reaches of the Anyim River Ebonyi State, Nigeria (Figure 1). The study area lies within longitudes 8.10 º E and 8.15 º E and latitude 6.35 º N and 6.45ºN. The study area experience two major seasons namely, the dry (November-April) and wet (May-October) seasons. The vegetation is derived guinea savanna that resulted from intense farming activities as the riparian communities are majorly agrarian. The river flows through the lower Benue trough and passes through swampy rainforest with numerous creeks and empties into Cross River system. So, allochthonous input into the river are mainly agrochemicals from numerous farmlands and sewage from residential houses and hospital located within the reaches of the river. Sand mining also takes place in the river. These activities might alter the water quality and its productivity.

Sample collection

Samples for water quality measurement were collected bimonthly from three sampling points, upstream (A), mid-stream (B) and downstream (C) from November, 2017 to September, 2019. Some water quality parameters namely surface water temperature, conductivity, TDS, and pH were measured *in-situ* using portable Hanna digital thermometer (Model HI 98303), conductivity and TDS meter (Model HI 98303) and pH meter (Model HI 77700P), respectively. Transparency was measured by lowering a seechi disc into the water until it disappeared and the point marked L1. The disc was lifted until it reappeared and the point marked L2. The average of L1 and L2 was taken as the transparency of the water.

Phytoplankton samples were collected concurrently at a depth of 0.15m from the surface water with a plastic bucket of 10-liter capacity from the designated locations and filtered with plankton net of mesh size 45µm and mouth diameter of 0.26m. The filtered plankton samples were emptied into a 1-liter plastic container, preserved with 3 drops of Lugol's solution and transported to the laboratory for identification.

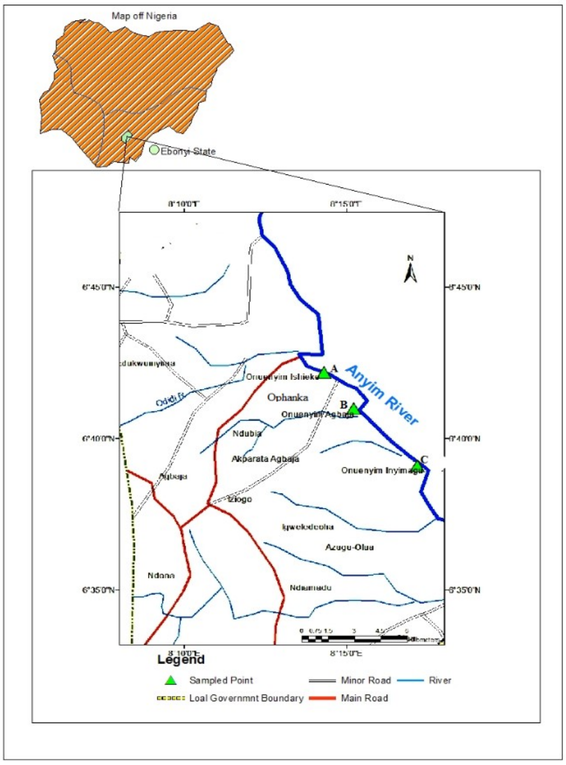

Figure1. Map showing a section of Anyim River and the sampled locations A, B and C.

Sample analysis

Analysis of surface water samples for DO, CO_2, phosphate, nitrate, ammonia and alkalinity were carried out in the laboratory using standard methods according to Association of Official Analytical Chemists (AOAC 2003). Plankton samples collected were carefully decanted and the concentrated portion preserved in 4% formalin. Identification of phytoplankton was done with the aid of Olympus binocular microscope using keys and guides of Komárek and Anagnostidis (2005) and Sahoo and Seckbach (2015). Cell count by drop count method was used for phytoplankton enumeration as described in Verlencar and Desai (2004).

Data analysis

Data collected were summarised using descriptive statistics. Temporal variation in mean water quality parameters and phytoplankton data were compared using One-way Analysis of Variance (ANOVA) and pairedwise t-test, respectively, values were considered significant at $p<0.05$. Species diversity, richness and evenness were estimated using Shannon-Wiener diversity index, Margalet's index and evenness, respectively on Paleontological Statistics software.

Principal Component Analysis (PCA) was used to identify the factors responsible for the observed variations in phytoplankton abundance at the different seasons. Statistical analyses were performed using Statistical Package for Social Science (SPSS) version 22.0 and Paleontolgical Statistics (PAST) 1.0.

Results

Water quality
The result of water quality parameters measured in the river during the study period showed that mean water temperature (29.97±2.34ºC), TDS (28.00±4.21mg/L), conductivity (50.00±5.28 µS/cm), pH (6.76±1.20) and transparency (0.19±1.12m) were higher in the dry season. On the other hand, DO (6.02±0.32mg/L), phosphate (0.08±0.01mg/L) and nitrate (0.08±0.02mg/L) as well as alkalinity (14.57 mg/L) were higher in the wet season.

Seasonal abundance of phytoplankton in the study area
Three Phyla/Divisions: Bacillariophyta, Chlorophyta and Cyanophyta were identified during the study (Table 2). The three Divisions were more abundant during the dry season compared to the wet season. Cyanophyta was the most abundant (487 cells/L**)** among the three Phyla/Divisions with *Oscillatoria* (121 cells/L) as the most abundant genus in the dry season while Bacillariophyta (311 cells/L) was the least abundant. *Gyrosigma balticum* (11.61%) contributed most to the abundance of the Bacillariophyta. However, *Starorustrum rotula* **(**153 ind/L), a Chlorophyta was the most abundant phytoplankton species identified during the study. Bacillariophyta abundance significantly differed between the dry and wet seasons ($p< 0.05$).

Diversity indices of phytoplankton of Anyim River during the study period
Bacillariophyta was the most diverse (H′=1.84) during the wet season and Cyanophyta (H′=1.78) in the dry season (Table 3). Bacillariophyta was also highest in species richness in both seasons with Margalef's indices of 2.53 and 1.74 in wet and dry seasons, respectively. However, Cyanophyta had the highest evenness of 0.86 and 0.85 in the wet and dry seasons, respectively. Seasonal variation in species diversity was significant ($p<0.05$) among the Chlorophyta and Cyanophyta while evenness varied significantly ($p < 0.05$) among the three phytoplankton Divisions. There was no significant differences ($p>0.05$) in the species richness of the three phytoplankton Divisions between seasons.

Relationship between water quality and phytoplankton abundance
The relationship between water quality and phytoplankton abundance is illustrated in Figure 2. The analysis showed that PC1 and PC2 accounted for 95.82% and 4.18% in variations in water quality and phytoplankton abundance in Anyim River. Nitrate and phosphate concentrations controlled the abundance of Cyanophyta (CyA), some species of Bacillariophyta (Diatomella spp, *Gyrosigma balticum,* Synedra spp) and Chlorophyta (*Closterium simplex, Chlorella ellipsoides, Staurostrum rotula*). Water temperature, TDS, conductivity and pH controlled Bacillariophyta abundance, diversity, species richness, Chlorophyta abundance, diversity, species richness, Cyanophyta diversity and species richness in the wet season.

Discussion

Variability in the water quality of a natural aquatic ecosystem could be affected by several factors including seasonality, weather conditions and type of soil in the water course or watershed as well as the nature of human activities in and within the reaches of the water body.

These factors play significant role in determining also the biological community and whether the water will be suitable for domestic use or not. In this study, seasonal variation in water temperature was significant and this could be attributed to the difference in the amount of solar radiation that is experienced in the wet and dry seasons in the tropics. Imoobe (2011) and Nwinyimagu *et al* (2016) reported seasonal variations in water temperature across wet and dry seasons in Okhuo and Asu Rivers in Edo and Ebonyi States, respectively, and attributed it to changes in metrological regimes. Eyo *et al* (2013) in their study on the ecology and diversity of the zooplankton of the Great Kwa River in Cross River State reported that the rise and fall in water temperature in the dry and wet seasons, respectively, can be linked to changes in the meteorological variables common in the tropics.

Table 1: Seasonal variations in some water quality parameters during the study period

Water Quality parameters	Mean ± standard deviation Wet season	Dry season	p - values	Acceptable limit for drinking water NSDWQ	WHO
Water temperature (ºC)	27.75±2.21	29.97±2.34	0.01	Ambient	Ambient
DO_2 (mg/L)	6.02±0.32	3.91±0.54	0.08	5.00	4.00
CO_2 (mg/L)	8.38±0,05	8.63±1.10	0.00	NS	NS
TDS (mg/L)	23.00±0.10	28.00±4.21	0.01	500.00	500.00
Conductivity (µS/cm)	32.00±2.50	50.00±5.28	0.03	1000.00	500.00
Water pH	6.56±0.13	6.76±1.20	0.01	6.50-8.50	6.50-8.50
Phosphate (mg/L)	0.08±0.01	0.06±0.02	0.03	NS	6.50
Nitrate (mg/L)	0.08±0.02	0.04±0.10	0.07	50.00	NS
Transparency(m)	0.09±0.02	0.19±0.12	0.10	NS	NS
Alkalinity (mg/L)	14.57±1.14	12.32±1.26	0.02	150.00	100.00

Note: WHO: World Health Organisation, NSDWQ: Nigerian Standard for Drinking Water Quality, NS: No standard

Table 2: Abundance (No. of cells/L) of phytoplankton in Anyim River during the study period

Phytoplankton	Wet season	Dry season	P-values
BACILLARIOPHYTA	**170 (51.05)**	**311 (27.57)***	**0.03**
Aulacoseira granulata	11(3.30)	5(0.44)	0.12
Bacillaria spp.	1(0.30)	0(0.00)	0.50
Bacteriastrum hyalinum	1(0.30)	1(0.09)	-
Cocconeis spp.	35(10.51)	13(1.15)	0.10
Coscinodiscus spp.	5(1.50)	11(0.97)	0.12
Diatomella spp.	13(3.90)	52(4.61)	0.13
Fragilaria spp.	2(0.60)	7(0.62)	0.28
Gyrosigma balticum	7(0.62)	131(11.61)*	0.04
Hemidiscus spp.	1(0.30)	0(0.00)	0.50
Hyalodiscus spp.	2(0.60)	0(0.00)	0.50
Nitzschia spp.	13(3.90)	7(0.62)	0.08
Skeletonema spp.	3(0.90)	1(0.09)	0.29
Surirella linearis	1(0.30)	0(0.00)	0.50
Synedra spp.	11(3.30)	72(6.38)	0.17
Tabellaria spp.	0(0.00)	11(0.97)	0.50
CHLOROPHYTA	**95 (28.53)**	**330 (29.26)**	**0.07**
Ankistrodemus spiralis	2(0.60)	0(0.00)	0.50
Chlorella ellipsoidea	25(7.51)	91(8.06)	0.10
Closterium simplex	7(2.10)	18(1.59)	0.12
Pithophora roetttleri	3(0.90)	0(0.00)	0.50
Schizomeris leibleinii	4(1.20)	2(0.18)	0.20
Spirogyra spp.	0(0.00)	52(4.61)	0.50
Staurastrum rotula	48(14.41)	153(13.55)	0.08
Staurastrum galeatum	0(0.00)	2(0.18)	0.50
Stichococcus nivalis	1(0.30)	1(0.09)	-
Tetraspora spp.	5(1.50)	11(0.97)	0.12
CYANOPHYTA	**68 (20.42)**	**487 (43.17)**	**0.11**
Anabaena spiroides	3(0.90)	5(0.44)	0.11
Anacyctis spp.	13(3.90)	71(6.29)	0.15
Aphanizomenon spp.	11(3.30)	52(4.61)	0.15
Athrospira spp.	21(6.31)	111(9.84)	0.13
Gloeotrichia spp.	0(0.00)	73(6.47)	0.50
Microcystis spp.	5(1.50)	54(4.78)	-
Oscillatoria spp.	15(4.50)	121(10.73)	0.17

Values in parenthesis = percentages (%); percentages on the same row with asterisk varied significantly (p<0.05)

Table 3: Seasonal diversity indices of phytoplankton encountered in Anyim River in the wet and dry seasons

Division/Diversity indices	Wet Season	Dry Season	p-values
Bacillariophyta			
Number of species	14	11*	0.03
Number of individuals	170	311*	0.03
Shannon-Wiener diversity (H′)	1.84	1.65	0.06
Margalef's index (d)	2.53	1.74	0.15
Evenness (E′)	0.45	0.47*	0.01
Chlorophyta			
Number of species	8	8	-
Number of individuals	95	330	0.07
Shannon-Wiener diversity (H′)	1.42	1.35*	0.04
Margalef's index (d)	1.54	1.21	0.23
Evenness (E′)	0.51	0.48*	0.02
Cyanophyta			
Number of species	6	7*	0.02
Number of individuals	68	487	0.11
Shannon-Wiener diversity (H′)	1.64	1.78*	0.04
Margalef's index (d)	1.19	0.97	0.61
Evenness (E′)	0.86	0.85*	0.02

Values on the same row with asterisk varied significantly (p<0.05) using pairwise comparison (t-test)

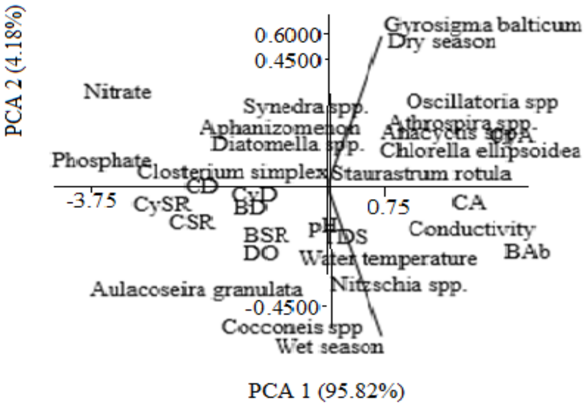

Figure 2: The Principal Component Analysis showing response of phytoplankton data to water quality in Anyim River.

Key: BAb – Bacilariophyta abundance, BD – Bacilariophyta diversity, BSR – Bacillariophyta species richness, CA – Chlorophyta abundance, CD – Chlorophyta diversity, CSR – Chlorophyta species richness, CyA – Cyanophyta abundance, CyD – Cyanophyta diversity, CySR – Cyanophyta species richness.

Values recorded for all the variables measured were within the Nigeria Standard for Drinking Water Quality (NSDWQ) and WHO acceptable limits for drinking water except the DO level in the dry season. The physicochemical parameters varied significantly between seasons ($p<0.05$), except for DO, nitrate and transparency.

Higher surface water temperature recorded in the dry season could be responsible for the observed decline in the dissolved oxygen level of the river, which was below the Nigerian Standard for Drinking Water Quality (NSDWQ) and WHO acceptable limits for drinking water, as high water temperature is known to reduce the dissolution of oxygen in surface water. Abowei (2010) reported an inverse relationship between temperature and dissolved oxygen in aquatic ecosystem, which agreed with the finding of this study. This study recorded an increase in the concentration of CO_2 in the surface water in the dry season and this could be due to higher microbial activity, which utilize oxygen and release more CO_2 as a product of the breakdown of decayed organic matter. This could be responsible for the decrease in water pH recorded in the dry season as CO_2 reacts with water to form carbonic acid with a consequent decrease in the water pH. Total dissolved solids and conductivity varied significantly between seasons which could be due to higher rate of transpiration that lead to surface water loss and increase in the concentrations of dissolved ions in the water column in the dry season. The concentrations of nitrate and phosphate recorded during the study were higher in the wet season and it could be linked to the washing off of NPK fertilizer used on riparian farmlands on the river watershed into the river.

Farming was one of the major human activities within the watershed of the river and may have contributed to the significant increase in the nitrate concentration of the river water. Nigatu (2010) and Nwinyimagu *et al* (2016) in their studies in Geffersa Reservoir, Ethopia and Asu River in Ebonyi State, Nigeria, respectively made similar observations and attributed the increase in nitrate concentration of their study sites in the wet season to runoffs from agricultural lands, slaughter houses, residential and industrial discharges and decomposition of nitrous organic matter.

However, low nitrate concentration recorded in the dry season may be due to increased utilization by phytoplankton and other aquatic plants as reported by Kadam *et al* (2014) and Okogwu and Ugwumba (2012). Ammonia was also at low concentration in the dry season during the study and this could be associated with the regular conversion to trioxonitrate (v) ions and nitrogen (iv) ions by nitrifying bacteria as reported by Ekubo and Abowei (2011). Lower transparency recorded at the study sites in the wet season was attributed to increased siltation due to overland flow from the riparian farmlands during precipitation. Low transparency possibly reduced the amount of light passing through the water columns in the wet season thereby decreasing phytoplankton production in line with the report of Kozak (2005).

The phytoplankton community of Anyim River was represented by three Divisions; Bacillariophyta, Chlorophyta and Cyanophyta during the study. Nwonumara and Okogwu (2021) reported similar Divisions in four rivers in Ebonyi State. The dominance of Cyanophyta during the study could be due to reduced phytoplankton flush-out as a result of reduced water flow velocity and increased water residence time. Cyanophyta are not palatable food to most microcrustaceans so reduction in their consumption might enhance the abundance. Their characteristic proliferation in nutrient enriched water also makes them good indicators of pollution, hence an indication that the river was under pollution pressure and may continue to deteriorate if regulatory measures are not put in place. However, higher diversity and species richness of Bacillariophyta recorded in the wet season showed that the nutrients fluctuate with water level and that was beneficial to more species of Bacillariophyta to proliferate in the wet season.

Water quality–phytoplankton relationship showed that some physico-chemical parameters of Anyim River variously controlled the abundance, diversity and species richness of phytoplankton in the river during the study. The abundance of Cyanophyta was positively correlated with nitrate and phosphate in the dry season which showed that nitrate and phosphate concentration of the river supported the proliferation of this harmful group of phytoplankton. On the other hand, the species diversity and richness of Bacillariophyta and Chlorophyta were higher in the wet season which differ with the findings of Nwonumara and Okogwu (2021) that recorded higher species diversity and richness of the same phytoplankton Divisions in the dry season. Meanwhile, the diversity of phytoplankton Divisions in both season was low with reference to McDonald (2003) who stated that Shannon-Wiener diversity index between 1.50 to 3.40 indicate low diversity while 3.50 and above indicates high diversity. This implied that the river was possibly under pollution stress. So, human activities in and around Anyim River should be regulated to improve the water quality for domestic use, enhanced productivity and efficient ecosystem services.

Conclusion

This study assessed the water quality and phytoplankton of selected areas in Anyim River and the results showed that there were significant variations in some of the water quality parameters measured between seasons. The dissolved oxygen concentration of the river was slightly below the acceptable standard according to NSDWQ and WHO. Changes including higher nutrient concentrations and lower dissolved oxygen affected the phytoplankton species composition by supporting the proliferation of Cyanophyta that are indicators of pollution. It is therefore suggested that there should be regular monitoring of the water quality of the river to help regulate human activities that will undermine its importance for productivity and domestic use.

Acknowledgments

The authors are grateful to Prof. I. C. Okoye, Professor Onyisi and Dr. G.C. Nwosu of the Department of Zoology and Environmental Biology, University of Nigeria, Nsukka, Enugu State, Nigeria for their support and encouragement during the study.

Conflict of interest

The authors declare no conflict of interest

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