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Water quality parameters and fisheries in central river region of the Gambia: Differences between wet and dry seasons

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Abstract

This research was aimed at studying the two seasonal changes in water quality of Central River Region (CRR) of The Gambia to influence fish assemblage. Physicochemical properties were measured in-situ with a portable YSI multiprobe water meter and fish sampling was done using a fishing net of 100 × 4 m. A total of 2,039 fishes, represented by sixteen species totaling to a biomass of 49, 236.3g were caught by seine netting. Laboratory analysis were also done for nitrite, nitrate, ammonia and phosphate in CRR using a spectrophotometer. The water variables were subjected to Principal Component Analysis (PCA) which showed a strong positive correlation between oxygen and pH, conductivity and TDS and negative correlation between oxygen and ammonia and nitrate ($p \leq 0.05$). The research further showed that seasonal variation in environmental conditions have increased and are negatively influencing fish assemblage in CRR, determined from a three-decade time series of rainfall and atmospheric temperatures.

Keywords: Central river region, freshwater fisheries, river gambia, climate change, conductivity

1. Introduction

Freshwater ecosystems are hot spots of biodiversity with disproportionate percentages of species based on surface area. Recently, freshwater biodiversity has declined faster than that of either terrestrial or marine habitats, a situation likely to continue [1, 2]. These losses are a consequence of degradation due to diversion and regulation of river flows, fragmentation, eutrophication, contamination, over-harvesting, invasions of exotics, filling and draining, and alterations to disturbance regimes [2]. Aquatic ecosystems are particularly sensitive to climate change due to the high heat capacity of water and due to indirect effects through changes to catchment processes [2].

Few studies have look at the socio-economic impacts of climate change on freshwater fisheries in the Gambia [4]. The study reveals that artisanal fishers alluded to fisher folk with low capital, and fish utilizing little gear and innovation like canoes, hook and line. The analysis of the effects of temperature changes on shrimp yield and productivity in The River Gambia showed a potential increase of 46% and 13% respectively by the year 2100.

Changes in climate variables such as increase in atmospheric temperature, declining rainfall and prolonged droughts and sea level rise are believed to be major changes in the hydrology of tropical and freshwater fisheries [4, 5]. Many researches have been done and conclusions drawn labelling climate change as the major cause for reduced habitat integrity in both the tropics and subtropics, example in the USA, Australia and Senegal, [6, 7, 8] respectively.

The decline in rainfall during the Sahelian drought in the 1970s, coupled with increasing demand for economic goods and services have led to major ecological changes in West African mangroves and freshwater ecosystems [4, 9], this however is not well documented and therefore there is a need to fill this information gap for countries like The Gambia, where mangroves and freshwater ecosystems support major economic activities including fisheries, agriculture and tourism [10].

The Gambia as a developing country is highly susceptible to the effects of climate change and variability [4, 11] (Examples sea level rise, increase in temperature and seasonal hyper-salinity due to erratic rains and increasing atmospheric temperatures for the past three decades

[12]. Annual rainfall in The Gambia has decreased by 30% between the years 1950 and 2000 alone, remaining at a range of 850 mm to 1200 mm, the bulk of which occurs in August causing floods in some part of the country [13]. In addition, due to the flat nature of the Gambia, sea water intrudes up to 240 km inland during the peak dry season [14], when river discharge becomes very low ($4.5 m^3 s^{-1}$) [15]. This changes in seasonal variations of fresh and marine water discharge can cause drastical change in physicochemical parameters, causing ecological disturbances on fish community and subsequently decline in estuarine and freshwater fisheries [15]. With fish providing more than 50% of the national protein intake [16], freshwater research is a timely intervention area for The Gambia and also in conformity with global climate change adaptation strategies for both coastal and riverine countries [17], describing the River Gambia as slightly exploited by small scale fisheries and not receiving any major pollution from either agriculture or industrial activities. Despite this, the freshwater fisheries in The Gambia continues to decline as the fish assemblage keeps changing with time, both in species number and abundance [18].

Furthermore, the fish assemblage of a given ecosystem is influenced by multiple factors [19]. These factors include floods (depending on force and duration) [13]; change in the balance of physicochemical parameters [20] e.g. conductivity and nutrient influx; presence, abundance and state of mangroves [12] as well as land use/anthropogenic activities occurring on it like infrastructure, agriculture and industry [19]. Species richness in West African estuaries is mainly attributed to hydrological variability between the dry and the flood seasons, due to seasonal intrusion by fish species of marine and continental origin combining and adapting to form an estuarine community [21, 22] attributed overfishing as the main cause for the decline in estuaries. On the other hand, [23] argued that natural habitat degradation as the main culprit. That have been said, information is highly lacking with regard to the spatial and temporal changes occurring in the River Gambia including Central River Region where this study is conducted and how this affects the fish community structure and fish production [24].

The River Gambia is about 11 km wide between Kombo St. Mary and Buniadu Point and about 4 km wide between Banjul and Barra. This narrows down to about 1.5 km at Carrol's Wharf (about 200 km in inland) where this research is conducted. The river is flank on both sides by mangroves and mud flats which are important for fish spawning and as habitat for aquatic species [25]. Central River Region being the rice basket of the country and also as a freshwater ecosystem where the rural poor obtain cheap protein source from the fish they catched, it's important that research is done to serve as a vital tool to both the local fishermen and policy makers in order to fill the information gap. Having this in mind, this research hypothesizes that climate induced seasonal variations in water quality of the River Gambia are the main cause of species drop in diversity and abundance. The aim of this research was to study the seasonal changes in physicochemical parameters and their effects on fish community in Central River Region of the Gambia.

2. Materials and Methods

2.1 Description of the study area

The Gambia is a small Sahelian country, bordered by Senegal and extending to the Western Coast of Africa between 13° and 14° N. It covers a total land area of approximately 10,689 sq. km with a length of about 400 km and a width varying between 24-50 Km. According to the 2013 National Population and Housing Census, The Gambia's population is estimated at 1.8 million people with a population growth rate of 2.8 % per annum. The climate of The Gambia is a Sudano-sahelian type of climate, with a short rainy season from June to October and a long dry season lasting from November to May. The River Gambia originating from the Fouta Djallon highland in Guinea has a total catchment area of 78 000 km2 [26], and it flows 1200 km through southern Senegal and The Gambia to the Atlantic Ocean. The lower part of the River Gambia, has a virtually zero drainage gradient over the last 500 km. The average annual rainfall is 900 mm [27]. There has been an average reduction of 27% in the annual average rainfall since 1951 [27]. The mean temperature is 25˚c.

The study area (Figure 1) is located in the Central River Region (CRR) of The Gambia. It is one of the six Regions in the country. The CRR consists of ten local administrative districts headed by a District Chief called Seyfo. According to the 2013 census, 226,018 inhabitants are living in the Central River Region of The Gambia [28]. The area is characterized by good soil structure and fertility and has some vegetative cover compared to the rest of the country especially the Northern part [29].

Rainfall in the Gambia occurs from June to October with August recording the highest. Peak river discharge normally occurs in September with rise and fall declining to almost nil from December to beginning of July [30].

Virtually all residents in the Central River Region depend directly or indirectly on the agricultural sector and poor or failed harvests seriously threaten the food security in the area. Because of its vulnerability (high dependence on agriculture), the Central River Region was chosen as the focus of this case study.

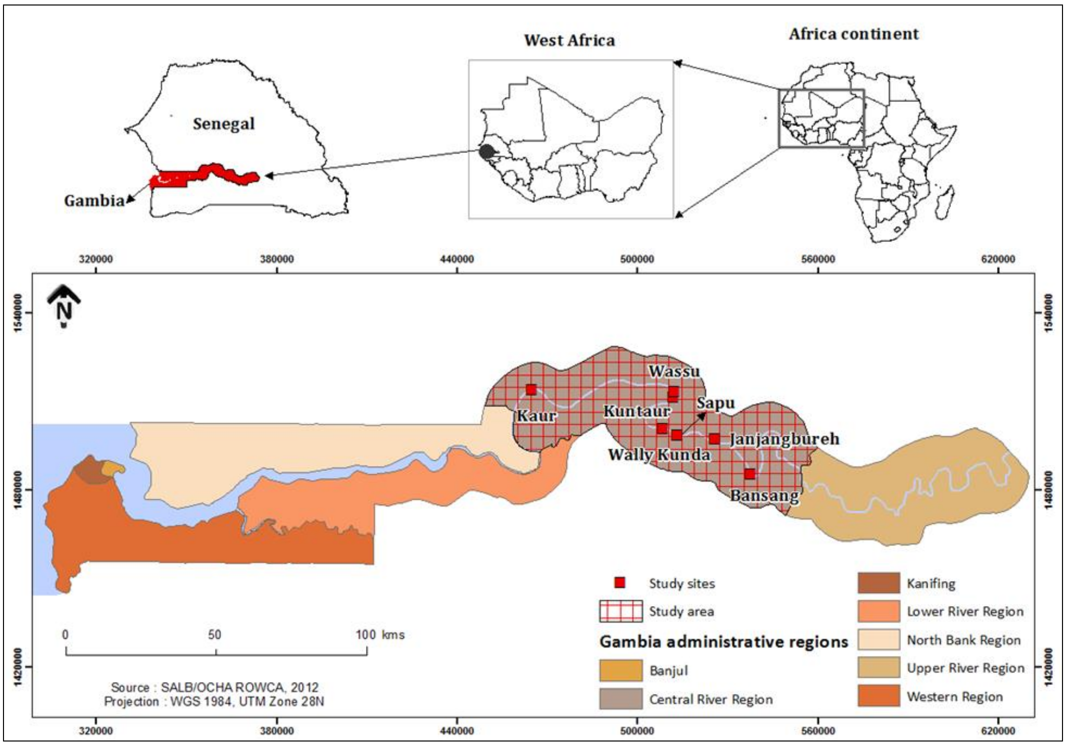


Fig 1: Location of Central River Region (CRR) in The Gambia, with the six study sites marked (red)

2.2 Sampling design

Six sampling sites were identified to be representative of Central River Region (Table 1). Land use types in the study area include Crop lands, Gambia River, Halophytic vegetation, Irrigated crops, Mangrove, Settlement, Shrub/wood savanna and Wooded savanna. To ensure a uniform representation of the hydrological regime of the study area, a straight-line transect method, adapted from [31] was used for sampling water quality parameters at each of the study sites. Three transects were set perpendicular to the water source at each sampling point adapted from [32]. In each transect, three plots were set to give 9 plots per sampling point / village (Figure 2).

Table 1: Sampling sites with GPS coordinates in Central River Region of The Gambia.

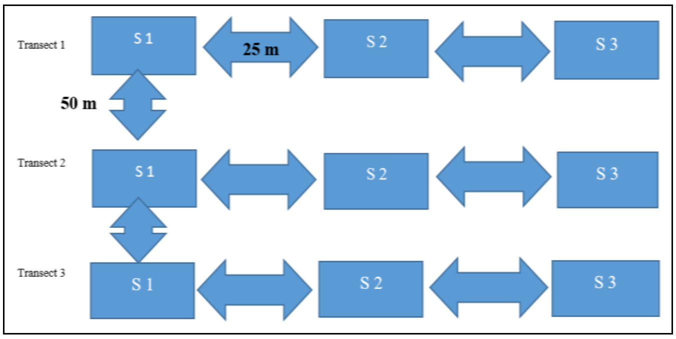
Sampling Sites	GPS Coordinates
Wally Kunda	N 13.57321 W 014.92249
Bansang	N 13.57330 W 014.92294
Janjanbureh	N 13.54368 W 014.76309
Wassu-Darka	N 13.69576 W 014.89130
Kuntaur	N 13.68670 W 014.87980
Kaur	N 13.69271 W 015.32516

2.3 Sampling protocol

2.3.1 Water quality

Three samples were collected from three points in each sampling sites in a diagonal mode (n=27) to ensure uniformity in water samples. All water samples were collected during high tide at a depth of 10-25cm) for measurement of physicochemical parameters since no significant vertical stratification was reported in the River Gambia [17, 33]. Dissolved oxygen, Ph, temperature, conductivity and TDS were measured in-situ using a Multi-probe water meter (YSI Proplus) and turbidity was measured using a HACH turbidity meter (HACH 2100P).Water samples were also collected in clear polyethylene bottles, wrapped in foil and stored in ice boxes for transport to the laboratory for nutrients analysis.

Nutrient analyzes were done using a HACH spectrophotometer (DR/2010) with Phos VerR 3 reactive reagent (ascorbic acid method) and Nitra VerR 5 (cadmium reduction method) for phosphate and nitrate. Sampling was done during peak discharge period of the River Gambia (September-December, 2017) and repeated during the peak dry season (April-July, 2018) to represent the seasonal cycle.



Source: Adapted from Kathiresan, 1990 and Louca *et al*., 2008.

Fig 2: Sampling design used. S: sample.

2.3.2 Fish community

Fish sampling was done in the open waters adjacent to transects during the ebb tides to assess seasonal variation based on species abundance and biomass. A seine net of 100 m by 4 m (14mm mesh size) was deployed with three throws at each site with the help of fishermen. Fish caught were measured, weighed and photograph for verification purposes. They were then identified to species level based on morphological characteristics. Fish identification of the fish species caught was verified using Fish base (http://www.fishbase.org) and IRD fish species identification keys for fresh and brackish waters of West Africa. Fish sampling was done during both seasons.

2.4 Data collection

The samples of water were collected from each sampling site immediately before the sampling of freshwater fish. Dissolved oxygen, temperature, conductivity and pH parameters were determined by using "Hach Lange HQ40D Multipara meter" [34] and [35] device during the field studies.

2.5 Data analysis

The data obtained were sorted in basic excel format by site. Presented results were obtained according to several different statistical analyses applied in similar research: descriptive statistical analysis, three-way analysis of variance (ANOVA) to rank the treatments, and Post-Hoc test analysis for independent samples. The post-hoc Scheffe test were applied for definition of difference significance between certain groups. To test the effect of the factors studied, variance comparison tests were carried out. A check of the normality of the data was carried out using the Shapiro test. All data being non-normal, a non-parametric test (Median test) was used to compare median values between treatments. The median values between treatments are statistically different with the probability $p \leq 0.05$ (5%). A Principal Component Analysis (PCA) was also carried out to characterize the sites and seasons according to the physicochemical parameters of the water.

3. Results

3.1 Environmental / water parameters

3.1.1 Temperature and conductivity

Mean seasonal water temperature and conductivity values ranged from 28.52° C to 28.54° C and from 48 (μS/cm) to 66 (μS/cm), respectively. For all sites, the highest temperature were observed during the dry season with the highest temperature value recorded at the Bansang site (29.1˚ C). In rainy season, the median temperature are lower with the lowest temperature value recorded at the Kaur site (29.1˚ C). There were no significant differences in temperatures between seasons (Chi-square test, $p < 0.6303$).However, there were significant differences in conductivity between seasons (Chi-square test, $p < 4.6775$). For all sites, the highest Conductivity were observed during the dry season with the highest conductivity value recorded at the Kaur site (3206 μS/cm). In rainy season, the median conductivity are lower with the lowest conductivity value recorded at the Wassu-Darka site (45 μS/cm). Maximum temperature and conductivity values were registered during dry season, while minimum temperature and conductivity values occurred during rainy season, respectively.

There were no significant differences in temperature between Wallykundanda, Bansang and Wassu Darka in terms of study sites. However, significant differences were observed between these communities and Janjanbureh, Kuntaur and Kaur (Chi-square test, $p < 8.7848$).There were no significant differences in conductivity (Chi-square test, $p < 4.6775$) in all the five communities except Kaur (Figure 3A and B).

3.1.2 Dissolved oxygen and pH

The average DO level differ significantly between the two seasons (Chi-square test, $p < 3.3492$).The DO for the rainy season was 5.000mg/L and the DO for the dry season was 6.425mg/L. For all sites, the highest Dissolved Oxygen were observed during the dry season with the highest DO value recorded at the Kaur site (8.49mg/L). In rainy season, the median Dissolved Oxygen are lower with the lowest DO value recorded at the Bansang site (4.5mg/L). For all sites, the highest pH were observed during the dry season with the highest pH value recorded at the Janjanbureh site (7.63). In rainy season, the median pH are lower with the lowest pH value recorded at the Kaur site (6.8).Similarly the pH level differ significantly between the two seasons (Chi-square test, $p < 1.6158$).The median pH level for the rainy season was 7.00 and that of the dry season was 7.44 (Figure 3C).

The post-hoc paired comparison tests show that statistically the median DO are higher during dry season compared to rainy season for all sites. The Kaur site is characterized by statistically superior median DO compared to others during the dry season sites, whereas the Janjanbureh site dominates compared to others during the rainy season. There were no significant differences between Janjanbureh, Wassu-Darka and Kaur in Dissolved Oxygen (Chi-square test, $p < 3.3492$). However, these communities differ significantly between Wallykunda, Bansang and Kuntaur. Kaur had the highest median DO (7.31mg/L) and Kuntaur had the lowest DO (5.65mg/L).Significant differences were observed in pH in all the study sites (Chi-square test, $p < 3, 8327$) with Janjanbureh scoring the highest (7.63) and Kaur the lowest (6.83) during the research (Figure 3D).

Fig 3: Seasonal variation in Dissolved Oxygen (A), pH (B), Conductivity(C) and Temperature (D) within different study sites in Central River Region of The Gambia: Rainy season: Dry season, Wally Kunda, Bansang, Janjanbureh, Wassu-Darka, Kuntaur, Kaur

3.1.3 Turbidity and TDS

Average turbidity level differed significantly (P value < 0.0014) between the rainy (25 NTU) and dry seasons (30 NTU). For all sites, the highest turbidity were observed during the dry season with the highest turbidity value recorded at the Wassu-Darka site (65 NTU). Again in dry season, the median turbidity were lower with the lowest turbidity value recorded at the Bansang site (5 NTU). Average TDS also differ significantly (P value < 2.2303). The average TDS during the rainy season was 31 and 43 during the dry season respectively. For all sites, the highest TDS were observed during the dry season with the highest TDS value recorded at the Kaur site (2094). In rainy season, the median TDS were lower with the lowest TDS value recorded at the Kuntaur and Wassu-Darka (27.5) sites respectively.

The three-way ANOVA results showed significant differences between the different study sites in turbidity with Wassu-Darka having the highest median turbidity level (60.00 NTU) during the rainy season and Bansang scoring the lowest (5.00 NTU).There were no significant differences in TDS in all the different sites except Kaur. Kaur scoring the highest TDS (1109.0) and Wallykunda the lowest (32.0) during the research (Figures 4A and B).

3.1.4 Ammonia and Phosphate

There were significant differences in ammonia level between the two seasons (P value < 2.5207).The median ammonia level during the rainy season was 0.11mg/L and that of the dry season was 0.72mg/L. For all sites, the highest ammonia were observed during the rainy season with the highest ammonia value recorded at the Bansang (0.88mg/L) site. In dry season, the median ammonia were lower with the lowest ammonia value recorded at the KAUR (0.08mg/L) site. Similarly, significant differences occur in phosphate during the two seasons (P value < 5.3198).The average phosphate level during the rainy season was 0.44mg/L and 1.29mg/L during the dry season. For all sites, the highest phosphate were observed during the dry season with the highest ammonia value recorded at the Bansang (1.71mg/L) site. In rainy season, the median phosphate were lower with the lowest phosphate value still recorded in Bansang (0.17mg/L) site.

There were no significant differences in ammonia between Wallykunda, Janjanbureh, Kuntaur, Wassu-Darka and Kaur (P value < 0.0094). However, there were significant differences in ammonia between these communities and Bansang. There were no significant differences in phosphate between Wallykunda, Kuntaur and Kaur (P value < 1.3971). However, these communities differ significantly between Janjanbureh, Bansang and Wassu-Darka. Bansang scored the highest median ammonia level (0.52mg/L) and Wassu-Darka the lowest (0.11mg/L).The highest phosphate (1.22mg/L) level was recorded in Janjanbureh and the lowest (0.54mg/L) was recorded in Kaur (Figures 4C and D).

3.1.5 Nitrites and Nitrates

Nutrient analysis showed significant differences in nitrates but not nitrite level during the two season. The average nitrite was 0.03 mg/L and nitrate 0.73mg/l respectively during the two seasons. Wassu-Darka scored the highest median nitrite (0.04 mg/L) and Bansang the lowest (0.01mg/L). Kaur scored the highest median nitrate 0.86 mg/L and Janjanbureh and Kuntaur jointly scored the lowest (0.58mg/L) respectively in the two seasons. Both nitrite and nitrate increases from rainy season to dry season with Kaur still scoring the highest in the dry season (Figures 4E and F).

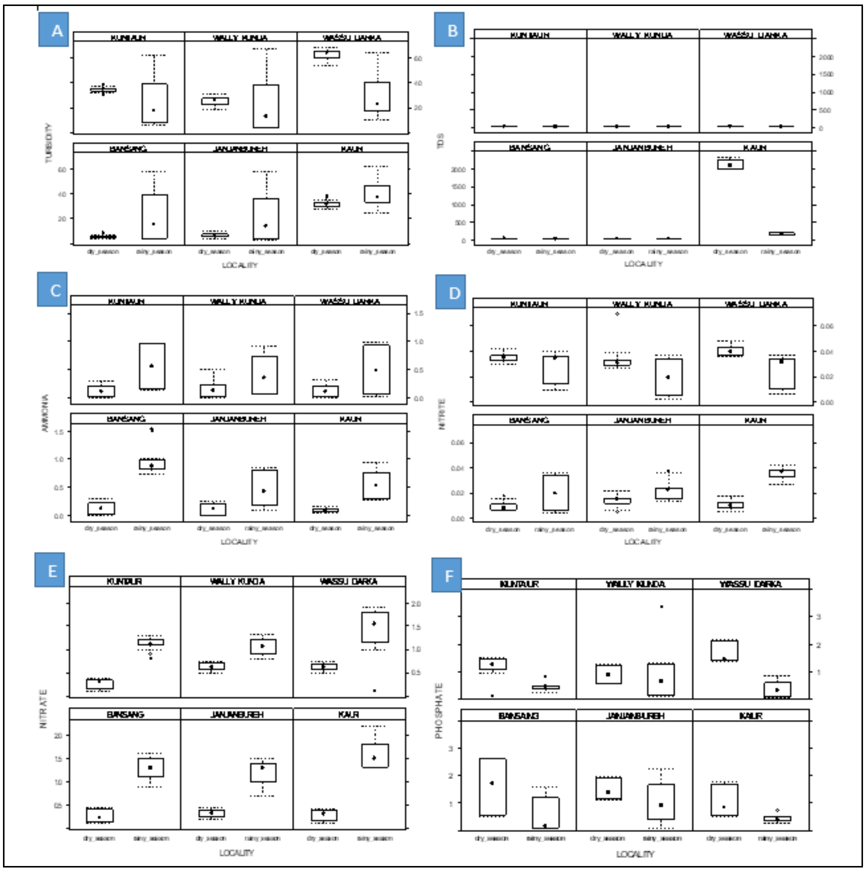


Fig 4: Seasonal variation in Turbidity (A), TDS (B), Ammonia (C), Nitrite (D), Nitrate (E) and Phosphate (F) within different study sites in Central River Region of The Gambia: Rainy season: Dry season, Wally Kunda, Bansang, Janjanbureh, Wassu-Darka, Kuntaur, Kaur.

3.2 Correlation levels of water variables in central river region

Pairwise student's t-tests of water variables of the different study sites during the two seasons showed no significant differences for temperature and nitrite but there was significant differences in dissolved oxygen, pH, conductivity, turbidity, TDS, ammonia, nitrate and phosphate as can be seen in table 2.

Table 2: Summary of water variables and their significance levels during the rainy and dry seasons in Central River Region of The Gambia in 2017/2018.

Parameters[1]	seasons		Pr > F
	Dry season	Wet season	
DO(mg/L)	6.425a	5.000b	3.3492
PH	7.435a	7.000b	1.6158
COND. (µS/cm)	66a	48b	4.6775
TEMP. (˚C)	28.54a	28.52a	0.6303
TURB. (NTU)	30a	25b	0.0014
TDS	43a	31b	2.2303
TAN(mg/L)	0.72a	0.11b	2.5207
NO_2-N(mg/L)	0.0310a	0.0245a	0.0672
NO_3-N(mg/L)	1.300a	0.365b	8.4512
$PO4^{2-}$(mg/L)	1.29a	0.44b	5.3198

Values are means of three replicates. Means in the same row of the same main effect without a common superscript are significantly different ($p \leq 0.05$).

[1] TAN=total ammonia nitrogen, NO_2-N=Nitrite, NO_3-N=Nitrate, DO=Dissolved Oxygen, COND =Conductivity, TEMP=Temperature, TURB=Turbidity, TDS=Total Dissolved Solid, $PO4^{2-}$=Phosphate

The spearman correlation matrix among water variables showed weak non-significant one during the two seasons. However, there was a strong positive correlation between oxygen and pH, conductivity and TDS ($p \leq 0.05$) and negative correlation between oxygen and ammonia and nitrate ($p \leq 0.05$) as shown in table 3.Moreover, conductivity and TDS and phosphate shows positive correlation ($p \leq 0.05$) and negative correlation between conductivity and ammonia and nitrate. Temperature and nitrite shows positive correlation ($p \leq 0.05$).Turbidity and Ph shows weak negative correlation ($p< 0.05$).Ammonia and nitrate shows a positive correlation ($p \leq 0.05$) and negative correlation between nitrate and phosphate ($p \leq 0.05$), table 3.

Table 3: Correlation between mean values of water quality parameters for the rainy and dry seasons in Central River Region of The Gambia in 2018.

	Dry season									
Wet season	**DO**	**PH**	**Conductivity**	**Temperature**	**Turbidity**	**TDS**	**Ammonia**	**Nitrite**	**Nitrate**	**Phosphate**
DO	1.00									
PH	0.45	1.00								
Conductivity	0.74	0.14	1.00							
Temperature	-0.23	-0.02	-0.24	1.00						
Turbidity	-0.03	-0.55	0.20	-0.09	1.00					
TDS	0.74	0.13	0.98	-0.26	0.23	1.00				
Ammonia	-0.64	-0.35	-0.39	0.38	0.15	-0.41	1.00			
Nitrite	-0.11	-0.24	0.10	0.18	0.68	0.09	0.35	1.00		
Nitrate	-0.77	-0.43	-0.52	0.00	0.20	-0.52	0.66	0.30	1.00	
Phosphate	0.46	0.26	0.26	0.14	0.12	0.26	-0.22	0.26	-0.46	1.00

3.3 Species richness

Sixteen fish species, belonging to 13 families, were recorded during this study as can be seen in fish species present/absent (Table 4) and some families were represented by a single species. The average number of species per family was low (1.18). This ratio was lowest during rainy season (September-December) and highest in the dry season (April-July). The species with the highest species diversity were *Oreochromis niloticus, Clarias senegalensis, Mugil cephalus and Polydactylus quadrifilis.* The species richness per survey remained relatively stable throughout the seasonal cycle at between 7(rainy season) and 9 species (dry season). Family richness was also lower in the rainy season.

Table 4: Presence/absence of fish species caught during the rainy and dry seasons in Central River Region of The Gambia in 2018.

#	Species	Rainy Season	Dry Season
1	*Bagrus bayad macropthalus* (Forsskål, 1775)	0	1
2	*Citharinus citharus* (Geoffroy Saint-Hilaire, 1809)	1	1
3	*Chrysichthys spp.* (Geoffroy Saint-Hilaire, 1809)	1	1
4	*Clarias senegalensis* (valenciennes, 1840)	1	1
5	*Cynoglossus senegalensis* (Kaup, 1858)	1	1
6	*Ethmalosa fimbriata (S. Bowdich, 1825)*	1	1
7	*Fonticulus elongatus (Bowdich, 1825)*	1	1
8	*Gymnarchus niloticus* (Cuvier, 1829)	1	1
9	*Labeo coubie* (Ruppell, 1832)	0	1
10	*Mugil cephalus* (Linnaeus, 1758)	1	1
11	*Oreochromis niloticus* (Linnaeus, 1758)	1	1
12	*Polydactylus quadrifilis* (Cuvier, 1829)	0	1
13	*Polynemidae spp.* (Linnaeus, 1758)	1	1
14	*Pseudotolithus elongatus* (Bowdich, 1825)	0	1
15	*Pseudotolithus senegalensis* (Valenciennes, 1833)	1	1
16	*Sphyraena afra* (Peters, 1844)	1	1
Total		12	16

O: Absent and **1:** Present

Fish community parameters (number of fish, species richness, diversity, through Shannon-Wiener index, and biomass) were compared between seasons.

According to comparisons of the community parameters, dry seasons (April-July) could be classified as periods with the greatest diversity and biomass of the fish community, compared to wet seasons (September-December).

Percentage species richness was significantly higher in Kaur than at all other sites (60% of the 16 species caught). The lowest percentages in species richness were recorded at Wally Kunda, Bansang and Janjanbureh (20%, 19% and 22% of the total number of species caught respectively). There was no significant difference in the percentage species richness in Wassu-Darka and Kuntaur sites (40% and 42 % respectively) (Figure 5).

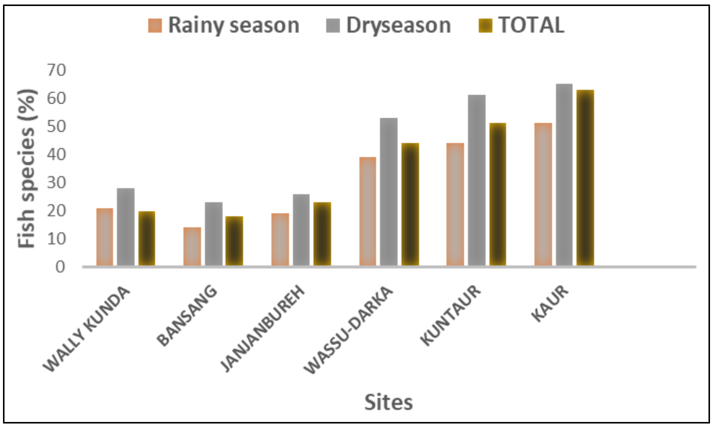


Fig 5: Percentage species richness for rainy and dry seasons at different sampling sites in Central River Region of The Gambia in 2018.

The taxonomic, abundance, morphometric data and Bio-ecological categories of fish community caught by seine netting from September 2017 to June 2018 in Central River Region of The River Gambia can be seen in table 5.This shows the species caught, their number by rankings, numbers, total weight in grams, percentage contributions to total catch, length range, mean length and percentage of occurrence frequency. As can be observed, the four most common species caught during the two seasons were *Oreochromis niloticus, Clarias senegalensis, Mugil cephalus and Polydactylus quadrifilis* respectively. This accounted for 16 species richness, 2,039 number of fish catch and a total of 49,236.3 g biomass of fish catch during the research period in Central River Region.

Categorizing these species based on West African estuarine fish communities methods [19], yielded 6 out of the 8 Bio-ecological categories reported for the River Gambia estuary. These include Em: Estuarine species of marine origin; Es: strictly estuarine species; Ma: Marine species accessories in estuaries; Co: Continental species, occasional in estuaries; Ce: Continental species from estuarine origin and ME: Marine estuarine species (Figure 6).

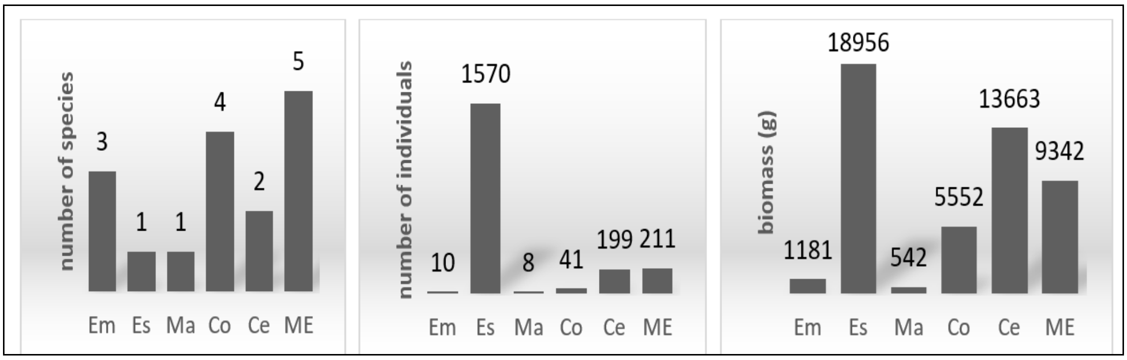


Fig 6: Distribution of fish species by bio-ecological category in Central River Region of The Gambia in 2018 (Em: Estuarine species of marine origin; Es: strictly estuarine species; Ma: Marine species accessories in estuaries; Co: Continental species, occasional in estuaries; Ce: Continental species from estuarine origin and ME: Marine estuarine species): (a) number of species, (b) number of individuals, (c) biomass (g)

The “Strictly estuarine species” (Es) formed the largest bio-ecological categories in terms of number (1570) and biomass (18, 956 g). This represented 77% and 38.5% of total number of catch and biomass of the Cichlid (*Oreochromis niloticus).* The second largest bio-ecological categories was the “Marine estuarine species “(ME) representing a total number of 211 and biomass of 9,342 g, which is 10.3 % and 18.5 % respectively. The “Continental species from estuarine origin” (Ce) formed the third largest category representing 199 in number and 13, 663 g of biomass. This represented 9.8 % and 27.8 % of number and biomass respectively of which *Mugil cephalus* formed the largest number 146 (7.2%) and biomass 4,431g (9%).The fourth largest category was the “Continental species, occasional in estuaries” (Co).This category consist of 41 in number (1.9%) and 5,552 g of biomass (10.8%) of which *Bagrus bayad macropthalus* formed the largest number 24 (1.2%) and biomass 4,431 g (9%).Other minor Bio-ecological categories included the “Marine species accessories in estuaries” Ma and the “Estuarine species of marine origin”(Em) (table 5).In terms of the number of species, Marine estuarine species (ME) has the highest (5 species); followed by the Continental species, occasional in estuaries (Co) with 4 species; Estuarine species of marine origin (Em) came third with 3 species and Continental species from estuarine origin (Ce) with 2 species forming the fourth largest (Figure 6).

Further Multi-Dimensional Scaling ordination of these clusters with environmental variables determined which variables had the greatest influence on fish species abundance for the rainy and dry seasons and six sampling sites in Central River Region. For both seasons, conductivity had the strongest influence on the decline in species abundance at all level. In terms of sampling efficiency, the area sampled/sampling effort could have been the reason for the slightly lower number of species than those reported in the literature for the River Gambia estuary. For instance, increasing sampling points might have led to the capture of a couple of more species (Figure 7).

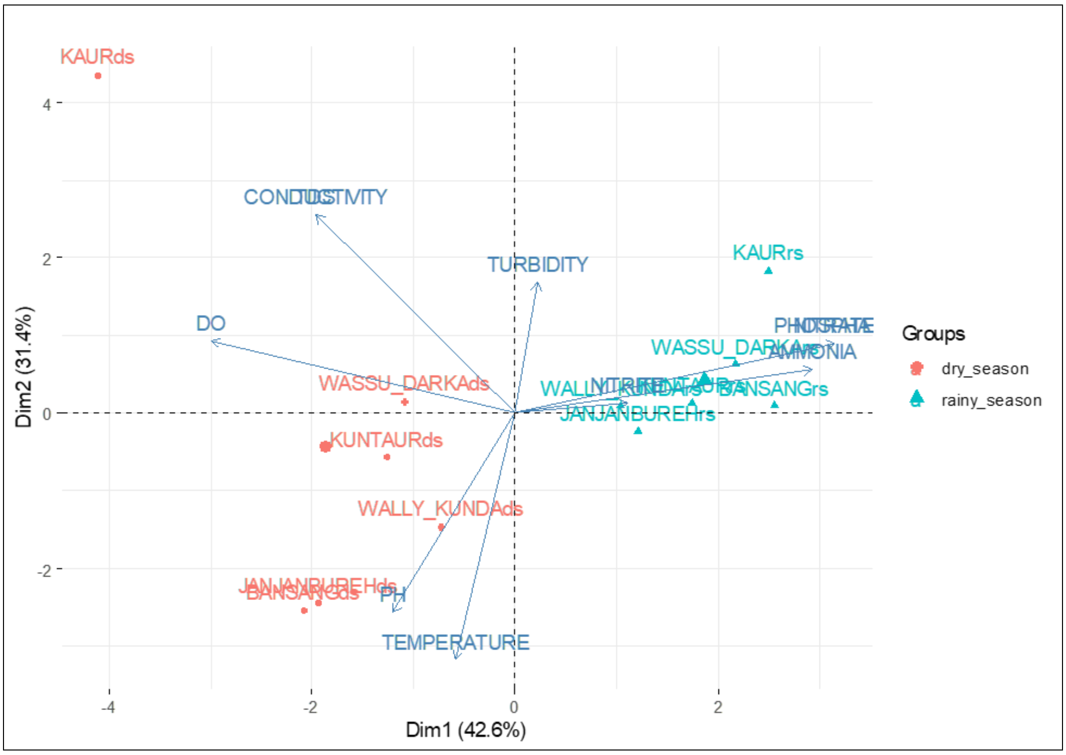


Fig 7: Multi-Dimensional Scaling ordination of percentage species abundance for the 6 study sites over 2 seasons in Central River Region (CRR) of The Gambia in 2018. Red colour: Dry season, Green colour: Rainy season. 1: Kuntaur, 2: Wally-Kunda, 3: Bansang, 4: Janjanbureh, 5: Wassu-Darka, 6: Kaur.

Table 5: Taxonomic, abundance, morphometric data and Bio-ecological categories (Bio. Cat.) of fish community caught by seine netting from September 2017 to June 2018 in Central River Region of The River Gambia in 2018, (R, rankings by abundance; N, numbers; g, grams; %, percentage contributions to total catch; LR, length range; ML, mean length; % OF, percentage of occurrence frequency), Em: Estuarine species of marine origin; Es: strictly estuarine species; Ma: Marine species accessories in estuaries; Co: Continental species, occasional in estuaries; Ce: Continental species from estuarine origin and ME: Marine estuarine species.

Species Bio. Cat.	**Number of Fish**	**Biomass of Fish**	**Total length (mm)**	**% OF**
	R N %	**R g %**	**LR ML**	
Oreochromis niloticus Es	1 1570 77	1 18,956 38.5	10-60 30	98
Clarias senegalensis Ce	2 183 9	2 13,294 27	10-40 32	76
Mugil cephalus ME	3 146 7.2	3 4,431 9	25-100 54	41.3
Polydactylus quadrifilis ME	4 41 2	5 3,693 7.5	45-200 99	27.4
Bagrus bayad macropthalus Co	5 24 1.2	4 4,431 9	20-110 55	17
Gymnarchus niloticus Ce	6 16 0.8	10 369 0.75	40-165 82	13
Fonticulus elongates ME	7 14 0.7	6 591 1.20	12-44 23	11
Citharinus citharus Co	8 12 0.6	8 566 1.15	15-58 25	8
Pseudotolithus senegalensis Ma	9 8 0.4	9 542 1.10	21-113 56	7
Sphyraena afra ME	10 8 0.4	11 369 0.75	55-105 52	7
Cynoglossus senegalensis Em	11 4 0.2	12 295 0.60	24-66.5 33	7
Ethmalosa fimbriata Em	12 3 0.1	13 295 0.60	20-35 26	6
Labeo coubie Co	13 3 0.1	14 295 0.60	16-74 37	6
Pseudotolithus elongates Em	14 3 0.1	7 591 1.20	14-47 24	6
Chrysichthys spp. Co	15 2 < 0.1	15 260 < 0.60	20-65 31	5
Polynemidae spp. ME	16 2 < 0.1	16 258.3 < 0.60	12-28 14	4
Species richness	16			
Total number	2,039			
Total biomass		49,236.3		

***Source*:** (Adapted from Gurdek & Acuña-Plavan, 2017 [49])

4. Discussion

The impact of seasonal change on water quality has been extensively documented and has attracted widespread attention in recent years [37-38]. Seasonal changes like rising temperatures reduce dissolved oxygen levels in surface water. Scanty rainfall leads to less dilution of pollutants whereas frequent heavy spells of rainfall produces more pollution and sedimentation in river due to surface runoff. Additionally, anthropogenic and animal activities affect water quality [37-39]. Furthermore, the geology of the area, the soil condition, and contamination through seepage also contribute to alterations in the quality and availability of water [37-40].

In The Gambia, differences in water quality of the River Gambia estuary has been reported by [33]. Variations in Central River Region are less due to its distance from the coast. Variation in conductivity declined as one moved away from the coast and toward the riverine end during both seasons similar to findings of [17]. This indicates a deficit in water budget caused by long-term imbalances in rainfall and atmospheric temperature, leading to a negative runoff and enabling seawater to intrude the river and become concentrated by evaporation. Such an occurrence has been reported previously for the estuaries of Sine-Saloum and Cassamance in Senegal [5]. The high conductivity values encountered principally reflect increased salinity, associated with tidal influences, low rainfall and low river discharge.

Average water temperatures for the rainy and dry seasons in Central River Region during this research were 28.52 and 28.54 °C respectively suggesting considerable increase and lesser cooling effect from river flow. Such combination of changes in environmental factors are enough to cause huge declines in riverine fisheries, as important life processes such as migration, reproduction timing and spawning success of various fish species get interrupted [8]. Pollution and excessive nutrient loading have also been reported to cause eutrophication and anoxic conditions unsuitable for supporting marine life in many estuaries surrounded by human activities such as agriculture and industry Ceesay *et al.* 2017 cited [41]. Nutrient levels recorded in Central River Region were way below the critical point (>1 mg l−1) [42], ruling out pollution as an ecosystem destabilizer for Central River Region. Ruling out excess nutrients being released from land use, also points to a possible nutrient deficiency, which would have great implications for vegetation and in turn fish species that depend on the ecosystems services such as DO regulation.

Over the study period the lower portion/ southern part of Central River Region namely Wally Kunda, Bansang and Janjanbureh presented a low number of fish species, compared to the upper portion/northern part namely Kaur, Kuntaur and Wassu-Darka. Fish studies done during the two seasons in Central River Region recorded lower number of fish compared to other studies carried in River Gambia. Most scientists agree that The River Gambia estuary should have more diverse fish communities [17], given the presence of diverse hydrological situations and the existence of extensive mangrove vegetation lining the river and its creeks [19]. These are considered favorable grounds for nursery purposes of many diadromous fish species and a refuge from predators [21]. This is however countered by the extreme seasonal variability as the suitable physicochemical conditions do not last long enough for the successful colonization of the estuary by any given group of fish; be it of marine or continental origin [17, 19].

Fish species diversity in Central River Region of the River Gambia seen in this research progressively declines towards those lower sites of the river where seasonal variability (in particular conductivity) decreases. These findings thus make past scientific predictions, which did not account for spatio-temporal variability of fish diversity, seemingly insufficient. For instance, [19] reported a total of 89 fish species for the River Gambia estuary, and 70 species in 2004 [17], while [43] reported 67 species. However, most of the research mentioned above was done in the open channel of the River Gambia estuary, thus leaving out most of the inland which are areas of large conductivity gradients and intensive human activities; thereby excluding anthropogenic impacts in the riverine and as a result overestimating the overall species richness and abundance for the River Gambia estuary.

The total number of fish species (16) caught during this research differ with findings of [9] who reported a total of 47 fish species from 26 families within the creeks of the River Gambia estuary different from the 16 species and 13 families caught during this research in CRR. This is acceptable, given the small size of the current study site. In addition, [45] reported 49 fish species for the middle part of the River Gambia, where multiple habitats were found. Our lower number of fish species may be due to climate change especially anthropogenic activities. The overwhelmingly higher species abundance of the fish families such as the *Oreochromis niloticus, Clarias senegalensis and Mugil cephalus* in this research might have been as a result of their ability to withstand higher temperatures and their hardy nature [46] or fishing gear (seine net) used which tends to under-sample the fast swimmers [47].

It is safe to say that seasonal changes in environmental variables are the main drivers for the decline in species diversity in Central River Region; in this case conductivity emerged the strongest driver instead of the commonly held notion of human activities. Of course human activities such as the use of pesticides in agriculture serve as strong stressors that exacerbate the effects of seasonal variability on aquatic ecosystems, just as stipulated by [48] in the Florida bay. However, nutrient levels were not high enough to be suggestive of eutrophication. In addition, flow rate of the river Gambia is said to be as high as 1500m3 s−1 during the rainy season and as low as 4.5 m3 s−1 during the peak dry season [43]. This explains the high variation in conductivity during the two seasons and the corresponding decline in fish species abundance and biomass at all sampling sites.

5. Conclusion

Rural communities/fishermen in Central River Region are becoming increasingly aware of the impacts of their activities. Despite this, freshwater fisheries continues to fall drastically due to some anthropogenic and natural factors. The findings in this study showed that both human and natural factors have influenced on the major environmental variables (e.g. conductivity and temperature) affecting fish assemblage in Central River Region. Therefore concrete efforts including good and sustainable fishing methods and restoration of the plant cover are necessary to combat this fisheries decline. The species abundance reported in this study is lesser than those reported for the estuary of the River Gambia [17]. This could have a negative implications on the local fishermen since they depend on the river for their livelihood activities. That being said, it is important to raise awareness about the ecological changes occurring on the freshwater for proper adaptation to seasonal variation and climate change. Further research is necessary on the effects of the decline in fish stock in Central River Region on fishermen incomes. Similarly, more research is needed to investigate the long-term changes in water variables and how they impact on the freshwater fisheries.

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