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Research Article

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Water Quality and Associated Aquatic Fungi in Selected Wetland Ecosystems in Southern Nigeria: Potential Implications for Food Safety and Public Health

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Abstract

Objective: Seasons, physical, and chemical properties of water bodies influence the diversity and distribution of aquatic mycoflora in wetlands. The study was conducted in March during the dry season of 2022. This study aimed to evaluate the effect of water quality on aquatic fungi in selected wetland ecosystems in southern Nigeria.

Materials and Methods: Physical parameters (temperature, turbidity, pH, and Electrical conductivity (EC)), chemical properties (salinity, hardness, dissolved oxygen (DO), total suspended solid (TSS), chemical oxygen demand (COD), and biochemical oxygen demand (BOD))., heavy metals, and trace elements (Ca, Na, K, Mg, V, Pb, Zn, Cd, Cr, and Ni) constituents were measured. The fungal loads on water and sediment specimens from the wetlands were also assessed using standard analytical and scientific procedures.

Results: The results showed that the temperature, pH, turbidity and EC of the test specimens ranged 27.27±0.35-29.21±0.003 °C, 5.17±0.03-7.30±0.17, 0.59±0.002-2.51±0.08 NTU, and 4.88±0.05-209.40±0.23 µs/cm, respectively. Salinity (7.10±0.06-710±5.77 gCl-/L), hardness (4.80±0.11-18.59±0.35 mg/L), TDS (2.44±0.01-104.70±0.03 mg/L) were below the WHO recommended limits. However, certain heavy metals including Cu (0.021±0.02-0.22±0.01 mg/L), Fe (0.22±0.001-0.33±0.02 mg/L), Pb (0.28±0.01-0.09±0.001 mg/L), Cd (0.05±0.001-0.36±0.16 mg/L), Cr (0.01±0.001-0.03±0.02 mg/L) and Mn (0.21±0.001 mg/L) exceeded WHO recommendations. The remaining elements were within acceptable limits. Most chemical qualities were highest at Ibeno and lowest at Nsit Ibom. *Candida tropicalis, Penicillium citrinum, P. rolfsii*, *Trametes polyzona*, and *Aspergillus* species were isolated from the wetlands.

Conclusion: The concentrations of heavy metals (Cu, Fe, Pb, Cd, Cr and Mn) above regulatory limits, along with the array of potentially pathogenic aquatic fungi, constitute concerns regarding the safety of sea-foods from these wetlands. Thus, a regular assessment of the health of wetlands in the State is warranted.

Keywords Aquatic fungi · Akwa Ibom State · Mycosis · Public health · Wetlands · Water quality

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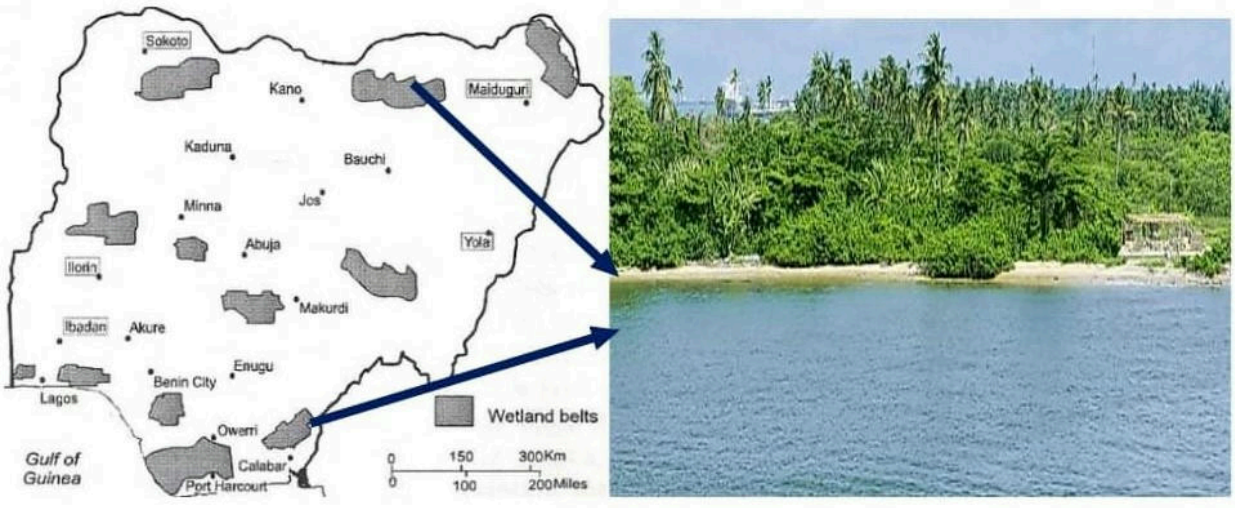
INTRODUCTION

Wetlands are natural edaphic ecosystems that remain inundated for most of the year.[1] Besides aesthetic and recreational values, wetlands function as ecological kidneys playing important roles in controlling erosion, protecting coastal shorelines against flooding, sequestering carbon and mitigating global warming, and improving the overall water quality.[2-4] Crabs, fish, shellfish, medicinal plants, a variety of timber plants, and most of all, a broad-spectrum of microorganisms inhabit wetlands.[1] Urbanisation, industrial activities, lumbering, and paddy rice production carried out around wetland ecosystems, and toxic chemical leachates from these activities contribute to wetland water pollution.[5,6] In Nigeria, wetlands scatter the Lake Chad, Sokoto-Rima basins in the north; Benue River lowlands in the middle belt and the Atlantic coast in the Niger Delta areas of the south (Figure 1).[7,8]

Wetland water quality is one of the basic factors that influence biological species composition in aquatic medium.[6] These parameters are, in turn, greatly affected by changes in temperature, pH, turbidity etc. and concentration of ions in a water body.[9] It is also affected by the fallout of anthropogenic activities[10] such as heavy metals from mining, landfills, and dumping sites, effluents from industrial concerns, as well as leachates from fertilisers and pesticides residues accruing from intensive agricultural activities along coastal plains.[1,11] High temperature, turbidity, ions of nitrates, sulphates, mercury, lead, and so on are reported as indications of anthropogenic pollution in wetland ecosystem.[12]

Nitrates and ions of heavy metals negatively affect water quality, taste, odour, and appearance and may lead to reduced oxygen tension and algal blooms.[13,14] In turn, these changes threaten biodiversity and potentially endanger many aquatic species.[15] High concentrations of organic pollutants and heavy metals in aqueous medium has been associated with death of aquatic organisms, while chronic exposure causes diseases such as fin and tail rot, ulcerations, and immune suppression in fish and shellfish.[11,12,16-19] Research indicates that certain heavy metals in fish from regions like the Philippines and Bangladesh exceed safety limits, raising the risk of certain cancers in humans consuming them.[20-22] For example, drinking water contaminated with nitrates and heavy metals has been linked with serious health problems, including, goitre, birth defects, liver and kidney dysfunctions, organ failures, haemoglobin-related disorders, and several kinds of cancers in humans.[23] In the overall, type and concentration of substrates and ions, especially heavy metals, in wetlands have been reported to select for, and narrow the relative abundance of mycotic organisms to pollution-tolerant species.[6,24-26] Fungal diversity and composition therefore are veritable pointers to aquatic ecosystem health.[27]

Aquatic fungi play important roles in organic matter recycling and food web dynamics in wetlands.[28] Species of *Fusarium, Alternaria, Trichoderma, Penicillium, Aspergillius, Curvularia* amongst many others have been isolated from different wetlands.[27,29] High electrical conductivity, turbidity, and concentration of sulphates and arsenic ions correlated with high population density of *Aspergillus*, *Fusarium, Penicillium*, and *Trichoderma* species in Idah River.[26] Organic matter, nitrogen quality, and phosphate loads correlated with high fungal growth, biomass accumulation, and diversity in polluted streams.[25] However, high temperatures support



Source: Olucha and Okeke[7]; World Atlas[8].

Figure 1. Map of Nigeria showing schematic representations of some of her wetlands; and a typical wetland in its Niger Delta area.

fungal growth and diversity, whereas a high acidic profile in water bodies retards same.[24] Therefore, the objectives of this work were to assess the effect of water quality (physical and chemical properties) on the types and distribution of aquatic fungi in selected wetland ecosystems in Akwa Ibom State, Nigeria.

MATERIALS AND METHODS

Study Area

This study was carried out in 4 selected wetlands located in 4 different Local Council Areas namely Uyo, Itu, Ibeno, and Nsit Ibom (Figure 2)[30], in Akwa Ibom State, in the Niger Delta region of southern Nigeria. The coordinates of the locations of the wetlands were: (a) Ibeno wetland (latitude 04°32´27´´N, longitude 008°00´12´´E). (b) The Itu wetland falls within the Eniong Creek segment of the Cross River (Latitudes 05°13´14´´and 05°19´19´´N, and between longitudes 007°56´14´´ and 007°56´59´´E). (c) Nsit Ibom wetland (Latitude 4°53´0´´N and longitude 7°54´0´´E) and, (d) Uyo wetland on (Latitude 5°02´31´´N and longitude 7°56´11´´E).

Collection of Wetland Water and Sediment Samples

The water and sediment samples were collected according to the procedures adopted by Toby et al.[31] The Ibeno, Itu, Nsit Ibom, and Uyo wetlands were coded as WLD_1, WLD_2, WLD_3 and WLD_4 respectively. The water samples were collected in March during the dry season of 2022. The samples were collected using sterile bottles that were dipped completely in the water at 3 different randomly selected locations in each of the selected wetlands, opened, filled to the brim, and corked under water (avoiding headspaces) to make them air-tight. Three sampling areas were also randomly selected within each wetland, and three replicate sediment samples were also collected at a depth of 10 cm along the bank of each wetland using sterile scalpels sterilised after each use with 70% ethanol. The water and sediment samples thus collected were then placed in Ziploc bags and sealed; and then bagged in brown envelopes, and immediately transported to the University for analysis. Overall, 3 samples each were collected for water and sediment specimens from the 4 wetlands giving 24 sampling units.

Quantitative Physicochemical Analysis of Water Samples

The quantitative determination of the physicochemical parameters of the water samples was performed using the procedures adopted by Agbeke et al.[32] Phosphate and sulphate ions were determined by spectrophotometric method (Spectrophotometer Model: UV-VI-RS, Labmed USA). Total hardness, calcium hardness, magnesium hardness, chloride ions, and sodium chloride levels were determined using the classical titrimetric method. Digital gravimetric analysis using a digital gravimeter (Model: TR-DH-120M, China) was performed to determine the total solids, suspended solids, and total dissolved solids in the samples. The Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) on the other hand were carried out using the standard analytical protocols as described by APHA.[33] However, records of electrical conductivity, pH and colour of the samples were determined by the method adopted by Toby et al.[31] using a digital conductivity meter (Models: 1152, Emcee



Source: Wikipedia.[30]

Figure 2. Map of Nigeria: Akwa Ibom State is delineated in red; green markers indicate the region studied.

Lab., USA), pH meter (Model: pHCal, Analab Scientific., India), and tintometer (Model: Lovibond Model F, EU). Finally, the heavy metals and trace elementals in the water samples were determined using an atomic absorption spectrometer (AAS) (Model: AA 7000, Schimadzu, Japan), as adopted by Enyiukwu et al.[34]

Determination of Fungal Diversity Using Culture Independent Method

The isolation and molecular identification of fungal species were conducted at the Botany and Ecological Studies Laboratory of the University of Uyo and the Bioscience and Molecular Laboratory of the University of Nigeria, Nsukka, Enugu State, Nigeria. The PDA (Thermo Scientific Oxoid, UK) and SDA (Beena Infotech, India) media used for the isolation of the fungal species from the specimens were prepared based on standard methods as adopted by Nwaneri et al.[35] Isolation of the fungal species was carried out using direct plating and serial dilution methods, as described and adopted by Bello and Ukut[36] and Toby et al.[31] Pure cultures of the isolated fungal organisms were maintained in stock McCartney bottles. A record of the types, frequency of occurrence, colony colour and characteristics of each fungus observed on the respective specimens was taken. The organisms were then preliminarily identified by comparing their spore and colony characteristics with the illustrated genera of imperfect fungi by Barnett and Hunter.[37]

Molecular Characterisation of Isolated Mycoflora

Using hexadecyltrimethylammonium bromide (CTAB), the DNA of the isolated fungi was extracted from 3-day-old cultures of each fungus.[31,38] The concentration and quality measurement of DNA of each of the fungal isolates was then determined by spectrophotometric procedure using Nanodrop (Thermo Scientific, Wilmington, DE). The ITS1F and ITS4 primers were used in the PCR assay to amplify the highly conserved internal transcribed spacer (ITS) regions of the fungal agents isolated from the test specimens. Thereafter, the amplicons of the isolates were purified using an ethanol sodium acetate precipitation protocol, as described in previous studies, and then, sequenced.[39,40]

Statistical Analysis

Data generated from this study were analysed using simple percentages and ANOVA. ANOVA was performed using GenStat Computer Programme (2008). Means were separated and compared at a $p<0.05$ significance level.

RESULTS

Physicochemical Analysis of Water Specimens from Wetlands

Physical Properties

The physical properties of the test water specimens from the four wetland habitats are presented in Table 1.[41,42] The pH of the samples ranged from 5.17 to 7.30, with the lowest at WDL_2 and the highest at WDL_3 wetland. Also, WDL_2 wetland had the lowest temperature value 27 °C, while WDL_4 which recorded 29.21°C was the highest. In terms of colour, a range of 5-17.00 was obtained. The colour profile of the water bodies differed significantly ($p<0.05$) from amongst themselves, with the deepest colour of 17.00±1.15 HU recorded for WDL_1. This result was closely followed by WDL_2 (10.00±1.15 HU) while 5.00±2.8 HU obtained at WDL_4 was the lightest. Turbidity is a measure of clarity, and electrical conductivity refers to the conductance of an electric current through a water sample. The values ranged from 0.59-2.5 and 4.88-209.40 mg/L, respectively, across the studied wetlands. WDL_1 had the lowest values for both parameters. However, WDL_3 had the highest turbidity value, and the electrical conductivity was highest in WDL_4 wetland (Table 1).

Chemical Properties

The presence of ions and chemical pollutants in the water are presented in Table 2. Specimens obtained from WDL_1 recorded the highest level of salinity with a value of (710±5.77 gCl^-/L)

Table 1. Physicochemical properties of water samples from the selected study Locations in Akwa Ibom State, Nigeria

		Parameters and Survey Locations				
S/N	**Parameter**	**WDL1**	**WDL2**	**WDL3**	**WDL4**	**WHO/SON Limit**
1	*Potentia hydrogenii* (pH)	6.52±0.01[a]	5.17±0.09[a]	7.30±0.17[a]	6.90±0.06[a]	**6.5-8.5**
2	Temperature (°C)	28.52±0.01[a]	27.27±0.33[a]	28.00±1.15[a]	29.21±0.003[a]	**25.0-30.0**
3	Colour (HU)	17.00±1.15[a]	10.00±1.15[b]	8.00±1.73[c]	5.00±2.89[d]	**Na**
4	Turbidity (NTU)	0.59±0.02[a]	1.60±0.03[a]	2.51±0.58[a]	1.76±0.002[a]	**1-5**
5	Electrical Conductivity (µS/cm)	4.88±0.05[d]	26.90±1.15[c]	41.80±0.03[b]	209.40±0.23[a]	**1400**

*WHO = World health Organization[41] SON = Standard Organisation of Nigeria[42]; Values of means on the same row with different alphabetical superscripts are significantly different. (*p<0.05*)

Table 2. Chemical properties of water samples taken from selected study locations in Akwa Ibom State, Nigeria.

		Parameters and Survey Locations				
S/N	**Parameter**	**WDL1**	**WDL2**	**WDL3**	**WDL4**	**WHO/SON Limit**
1	Salinity (gCl^-/L)	710.00 ± 5.77^a	14.20 ± 0.12^c	7.10 ± 0.06^d	21.30 ± 0.17^b	**250**
2	Hardness (mg/L)	18.59 ± 0.35^a	5.68 ± 0.01^b	4.80 ± 0.11^b	6.10 ± 0.06^b	**500**
3	TSS (mg/L)	0.004 ± 0.001^a	0.002 ± 0.0006^a	0.016 ± 0.001^a	0.018 ± 0.001^a	**Na**
4	TDS (mg/L)	2.44 ± 0.01^b	13.50 ± 1.73^d	20.90 ± 0.03^c	104.70 ± 0.03^a	**500-2000**
5	DO (mg/L)	3.95 ± 0.01^a	3.31 ± 0.58^a	2.78 ± 0.01^a	4.00 ± 1.15^a	**5**
6	BOD (mg/L)	2.42 ± 0.58^a	1.19 ± 0.58^a	0.76 ± 0.001^a	1.96 ± 0.04^a	**6**
7	COD (mg/L)	4.84 ± 0.02^a	2.38 ± 0.01^a	1.52 ± 0.02^a	3.98 ± 0.001^a	**25**
8	THC (mg/L)	1.03 ± 0.58^a	0.51 ± 0.002^a	0.002 ± 0.001^a	0.003 ± 0.002^a	**Na**

*DO (Dissolved Oxygen), BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), THC (Tetrahydrocannabinol), TDS (Total Dissolved Solid), TSS (Total Suspended Solid); *WHO = World health Organization[41] SON = Standard Organisation of Nigeria[42]; Values of means on the same row with different alphabetical superscripts (a,b,c...) are significantly different ($p<0.05$).

which was above the WHO limits, while the minimum value of 7.10 ± 0.06 $gCl^-/L$was observed in the samples from WDL_3 wetland. Regarding hardness, a range of 4.80-8.59 mg/L was recorded for samples with WDL_1 having the peak value. WDL_4 wetland water had the highest level of total dissolved solids (TDS) at 104.7 mg/L, while WDL_1 presenting a value of 2.44 mg/L was the lowest. Among the water samples from the four different wetlands, a range of 0.002-4.84 mg/L was obtained for total suspended solid (TSS), dissolved oxygen (DO), BOD, COD, and tetrahydrocannabinol (THC) (Table 2).

Heavy Metals and Trace Elements

The presence of heavy metals and elemental pollutant concentrations are presented in Table 3. Calcium levels and magnesium concentrations captured in the water specimens ranged between 4.93-6.13 mg/mL and 1.62-3.3.27 mg/mL respectively. WDL_3 wetland had the lowest concentrations of these ions while WDL_1 had the peak values. The presence of ions and radicals of sodium, lead, chromium, cadmium, arsenic, vanadium, nitrate, phosphate and sulphate amongst many other ions and elements, was detected at varying concentrations in all the test water specimens (Table 3).

Table 3. Heavy metal and trace element constituents of water samples taken from selected study locations in Akwa Ibom State, Nigeria.

		Parameters and Survey Locations				
S/N	**Parameter**	**WDL1**	**WDL2**	**WDL3**	**WDL4**	**WHO/SON Limit**
1	Calcium (Ca) (mg/L)	6.13 ± 0.02^a	5.27 ± 0.001^a	4.93 ± 0.001^a	5.82 ± 0.001^a	**75-200**
2	Potassium (K) (mg/L)	1.82 ± 0.01^a	2.08 ± 0.001^a	1.00 ± 0.001^a	2.18 ± 0.001^a	**55**
3	Magnesium (Mg) (mg/L)	3.27 ± 0.58^a	2.18 ± 0.58^a	1.62 ± 0.001^a	2.02 ± 0.001^a	**30**
4	Phosphate (PO_4) (mg/L)	0.12 ± 0.01^a	1.20 ± 0.12^a	1.11 ± 0.002^a	0.02 ± 0.001^a	**≤200**
5	Sulphate (SO_4) (mg/L)	0.09 ± 0.005^a	0.12 ± 0.002^a	0.02 ± 0.001^a	0.003 ± 0.001^a	**100**
6	Nitrate (NO_3) (mg/L)	0.12 ± 0.02^a	0.02 ± 0.001^a	0.006 ± 0.001^a	0.003 ± 0.001^a	**45**
7	Copper (Cu) (mg/L)	0.22 ± 0.01^a	0.02 ± 0.002^a	0.03 ± 0.001^a	0.21 ± 0.002^a	**0.02**
8	Iron (Fe) (mg/L)	0.33 ± 0.02^a	0.25 ± 0.001^a	0.31 ± 0.001^a	0.22 ± 0.001^a	**0.30**
9	Lead (Pb) (mg/L)	0.28 ± 0.01^a	0.09 ± 0.001^a	0.07 ± 0.07^a	0.03 ± 0.001^a	**0.01**
10	Zinc (Zn) (mg/L)	0.33 ± 0.01^a	0.46 ± 0.001^a	0.54 ± 0.001^a	0.31 ± 0.001^a	**3.0**
11	Cadmium (Cd) (mg/L)	0.27 ± 0.01^a	0.24 ± 0.002^a	0.36 ± 0.16^a	0.05 ± 0.001^a	**0.05**
12	Chromium (Cr) mg/L)	0.02 ± 0.005^a	0.002 ± 0.001^a	0.03 ± 0.002^a	0.001 ± 0.001^a	**0.003**
13	Nickel (Ni) (mg/L)	0.28 ± 0.01^a	0.22 ± 0.001^a	0.02 ± 0.001^a	0.001 ± 0.001^a	**0.02**
14	Vanadium (V) (mg/L)	0.25 ± 0.03^a	0.23 ± 0.002^a	0.001 ± 0.007^a	0.01 ± 0.001^a	**43**
15	Sodium (Na) (mg/L)	1.42 ± 0.01^a	0.99 ± 0.001^a	0.12 ± 0.001^a	0.01 ± 0.001^a	**200**
16	Manganese (Mn) (mg/L)	0.96 ± 0.02^a	0.46 ± 0.001^a	0.21 ± 0.001^a	0.63 ± 0.002^a	**0.02**

*WHO = World health Organization[41] SON = Standard Organisation of Nigeria[42]; Values of means on the same row with different alphabetical superscripts are statistically different ($p<0.05$).

Types and Distribution of Fungal Isolates in Wetland Samples

A total of 10 species of the genera *Penicillium, Aspergillus, Trametes,* and *Candida* belonging to two fungal divisions, basidiomycota and ascomycota, were isolated from wetland water and sediment specimens from the wetlands (Table 4). The results showed that distribution of fungi isolates in WDL_1 sediment was dominated by *Candida tropicalis* (40%) and *Trametes polyzona* (30%). WDL_2 wetland sediments contained 30% each *Aspergillus flavus, T. polyzona, and C. tropicalis*. The fungal population dominance in the WDL_3 wetland was *A. terreus* (60%) and *A. niger* (30%), whereas WDL_4 wetland was dominated by *Penicillium rolfsii* and *C. tropicalis* at 40% apiece.

Table 4 also shows the fungal dominance profile of the water specimens in the various wetlands. *P. citrinum* and *A. nominus* had 30% occurrence each at WDL_1 while 50% and 30% were recorded for *A. flavus* and *A. nominus*, respectively, in WDL_4 wetland water specimens. *A. flavus* (50%) and *C. tropicalis* (40%) dominated WDL_3 water samples, while *P. citrinum* (60%) and *A. nominus* (30%) dominated WDL3 water samples. Results of this study also indicated that *A. flavus* and *P. rolfsii* were not observed in both water and sediment samples from WDL_1, whereas *T. polyzona, A. terrreus, and A. flavus* were conspicuously absent in Uyo WDL_4 specimens. In water and sediment samples obtained from WDL_2 wetlands, A. *niger, A. aculeatus, A. terreus, P. citrinum, and P. rolfsii* were not isolated. However, the absence of *T. polyzona, A. nominus, A. tamari, P. citrinum, and P. rolfsii* was observed in all WDL_3 samples.

Generally, the trend of the mean dominance of fungal agents across all water and sediment specimens at the 4 wetland locations indicated that *C. tropicalis* recording (18.75%) was the most frequently encountered organism, followed by *A. flavus* (16.25%), while *A. aculeatus* was the least (3.75%). The dominance profile across the wetlands was *C. tropicalis>A. flavus>P. citrinum≥A. nominus>A. terreus>A. niger≥T. polyzona>A. tamari>P. rolfsii>A. aculeatus* (Table 4).

DISCUSSION

Results of the physical properties (pH, temperature, turbidity and electrical conductivity) of the wetlands presented in Table 1 showed that these parameters for all the studied wetlands remained within the WHO recommended values. In Table 2, the results indicated that, with the exception of WDL_1 which had 710.00±5.77 gCl^-/L for salinity, values of this parameter and hardness were within acceptable limits of concentrations by WHO and the Standards Organisation of Nigeria. Similarly, the values of TDS, TSS, COD, BOD, and DO were within the acceptable profiles set for these parameters (Table 2). Findings from this study are divergent and inconsistent with reports from surface and ground waters in Pakistan and Abuja where values of TDS, DO, chloride, and electrical conductivity exceed the acceptable limits.[40,43] Interestingly, data from this study indicated that ions of Ca, K, Mg, Fe, Zn, Na, SO_4^{2-}, PO_4^{2+}, and V across all the studied wetlands in Akwa Ibom State were still below the recommended and permissible limits by the Environmental and Health Agencies (Table 3). On the other hand, data from this study indicated that Ni exceeded the acceptable limits at WDL_1 and WDL_2 wetlands; Cu at WDL_1; and Pb, Cr, and Cd at WDL_1, WDL_2, and WDL_3 wetlands. However, Mn exceeded the permissible limits at all the studied locations. These findings are in strong agreement with the reports of various workers in Africa, the Philippines, and elsewhere where levels of these ions were higher than the recommended values in both ground and surface waters.[21,44-46]

Table 4. Percentage (%) distribution of fungi isolated from sediments and water samples from selected wetlands in Akwa Ibom State, Nigeria.

	WDL1		WDL2		WDL3		WDL4		
Isolated Fungi	**Sed.**	**Water**	**Sed.**	**Water**	**Sed.**	**Water**	**Sed.**	**Water**	**Mean**
Candida tropicalis	40.00	0.00	30.00	20.00	0.00	40.00	40.00	0.00	18.75[a]
Aspergillus niger	10.00	0.00	0.00	0.00	30.00	10.00	10.00	0.00	7.50[e]
Aspergillus aculeatus	10.00	0.00	0.00	0.00	10.00	0.00	10.00	0.00	3.75[h]
Penicillium rolfsii	0.00	0.00	0.00	0.00	0.00	0.00	40.00	0.00	5.00[g]
Penicillium citrinum	0.00	30.00	0.00	0.00	0.00	0.00	0.00	60.00	11.25[c]
Aspergillus tamari	10.00	20.00	10.00	0.00	0.00	0.00	0.00	10.00	6.25[f]
Aspergillus nominus	0.00	30.00	0.00	30.00	0.00	0.00	0.00	30.00	11.25[c]
Aspergillus flavus	0.00	0.00	30.00	50.00	0.00	50.00	0.00	0.00	16.25[b]
Trametes polyzona	30.00	0.00	30.00	0.00	0.00	0.00	0.00	0.00	7.50[e]
Aspergillus terreus	0.00	20.00	0.00	0.00	60.00	0.00	0.00	0.00	10.00[d]

*Sed. = sediment. Values of means in the same column with different alphabetical superscripts (a,b,c...) are statistically different.

Filamentous fungi are the principal decomposers of organic matter in nature, and thus, they function in nutrient recycling and bio-remediation.[47] The findings of the present study (Table 4) showed that *Candida tropicalis, Aspergillus niger, A. terreus, A. aculeatus, A. tamarii, Penicillium citrinum, P. rolfsi, A. flavus, A. nominus, and Tramates polyzona* were observed and identified from wetland water and sediment samples from the test locations. These array of isolated mycotic species are consistent with those previously isolated and identified from some water bodies in the Niger Delta states of Nigeria by other workers.[48-50] It is also in agreement with the fungal species profile listed from a study by Thomas and Thangavel[51] in the Vembanadu wetlands agro-ecosystem of India. Most of these organisms are known plant pathogens that likely get washed-off from arable and paddy agriculture shorelines through manure and crop debris- carrying runoff.[52] The density and diversity of these fungal agents are likely to increase over time if not checkmated.[53] The absence of some fungal organisms in one or both water and sediment samples of the wetlands, as seen in the present study, is in tandem with the report of Chikere et al.[54] from water bodies in the River States, Nigeria.

The present study identified the genus *Aspergillus* as the most commonly encountered genus in wetlands and surface water ecosystems and has been implicated in contributing to the highest mycotic contamination in many water bodies.[55] The outcome of the present study is in line with findings made by previous workers in this regard.[48,54,56] Findings from the present study also agree with outcomes from Mbong et al.[57] and Effiong and Adeyemi[49] where *C. tropicalis* and *A. niger* were the most commonly occurring organisms in water bodies in Akwa Ibom State. However, this result is inconsistent with observations made by Thomas and Thangavel[51], who reported that *A. niger* and *Penicillium* sp. were the most frequently occurring species. Differences in organic nutrients, pH and temperature ranges may explain this disparity. *Aspergillus* spp. and *Penicillium* spp. are notable incitants of bread, postharvest spoilage of crop produce, and sea foods. Outbreak of seafood poisoning is on the rise globally.[49] The presence of microplastics and heavy metals and the strong association of fish, crayfish and shellfish with a variety of medically important plant pathogens[58] such as species of *Aspergillus* and *Penicillium* in water bodies raises enormous concerns about the safety of sea-foods in Nigeria and elsewhere; warranting regular assessment of mycotic loads of water bodies.[46,48,49] In recent times, fungi of the genera *Candida, Peniclillium, Fusarium, Tramates* and *Aspergillus* have been reported as active mycotic agents of human diseases, causing various kinds of allergies, keratitis, asthma and fungal balls in affected humans, especially immuno-compromised individuals.[51,55,57,59-60] Generally, the degree of hydrogen ions in water medium, salinity, TSS, DO nitrate, total organic carbon and temperature affect the relative abundance, richness and diversity of birds and mycotic species in and around wetlands.[14,47,61]

Data from this study indicate that the assayed wetlands were slightly acidic to slightly alkaline. This is in consonance with the observation of Ali et al.[62] and Mustafa et al.[63] that stated that such pH ranges in water bodies effectively support fungal growth, sporulation, and diversity. *Aspergillus* species noted Wheeler et al.[64] exhibits greater tolerance to alkaline pH, whereas *Penicillium* species appear to be more tolerant to acidic pH medium.[31] In fact, high pH has been found to correlate with high presence of potentially pathogenic filamentous fungi in water.[47] Our data are consistent with reports of other workers which say that the distribution of these genera of fungi in various studied wetlands was influenced by pH ranges.[31,65] However, our data is divergent from the observations of Singh et al.[66] where the Kusheshwar Asthan wetlands in India maintain an alkaline profile. Differences in the types of underlying rocks and high ammonium leachate levels from surrounding agro-allied concerns may explain this phenomenon.

Sea temperature, pH, DO, and electrical conductivity are considered the principal factors influencing the geographical distribution of water-inhabiting fungi, birds, and biodiversity.[25,67,68] *Candida* species are tolerant to tropical aquatic climes with moderate to high temperatures and high humidity levels year round.[69] Ali et al.[62] reported that 25-30°C remain optimum temperature range for growth of all fungi. Similarly, Muller[70] and Almiman[71] reported that the growth and sporulation of various genera of *Penicillium, Rhizopus, Fusarium, and Aspergillus* occur at 25-30 ^{o}C. According to this source, high temperature values in aquatic medium and low carbohydrate substrates cause low pigmentation of fungal mycelia. Similarly, increasing water temperature, DO status, and electrical conductivity were associated with increased richness of water birds in Malaysian waterways and channels.[66] Data from this study are in line with the reports of previous workers.

The colour and turbidity profiles of water bodies are indications of degree of light penetration in aquatic medium. These represent some important parameters affecting the abundance and diversity of fungi in wetlands. Data from this study (Table 1) indicated that the turbidity of the test wetlands was within the WHO standard of 5 NTU. Chang et al.[72] noted that luminous intensity was strongly correlated with growth, biomass accumulation, and phytase activity in aquatic fungi. Unlike white LED light, which enhances fungal growth, these

workers posited that strong fluorescent luminance, consisting of several wavelengths, inhibited growth of *Aspergillus ficuum* in a trial. Similarly, high light intensity disfavoured hyphal growth and branching of *Rhizoctonia solani*.[73]

Generally, freshwater and terrestrial fungi grow, germinate, and sporulate better at lower salinity ranges than at high salinity profiles. Fungi of the divisions ascomycetes and basidiomycetes are salinity-tolerant group of fungi, known to play an important role in leaf litter breakdown in wetland ecosystems.[74] Findings from this study agree with the reports of other workers in which basidiomycetes and ascomycetes were frequently occurring fungal divisions in some studies.[47,75,76] Salinity may in part explain the reason basidiomycetes and ascomycetes were commonly isolated fungal divisions in this study. Based on redundancy analysis, Cudowski et al.[77] noted that fungal species abundance and diversity in a Polish canal were significantly affected by changes in water quality, particularly changes in chloride ions, sulphate ions and electrical conductivity. These factors may to certain extents have supported or influenced the presence and dominance of basidiomycetes and ascomycetes in the assayed wetlands.

Most fungi use nitrate, which is first reduced to nitrate and then to ammonia. They also use ions of sulphur, phosphorus, magnesium, and potassium in their salt form. Nearly all fungi require other elemental nutrients, including iron, copper, manganese, and zinc, as enzyme cofactors for optimal metabolism.[65] The affinity and strong bonding of *A. nominus*, *A. flavus*, and *A. terreus* to nitrate, phosphate, manganese, sodium, manganese, and calcium was reported by Toby et al.[31] However, heavy metals such as Zn, Cu, Ni, Cr, and Cd have been reported to inhibit sporulation and retard hyphal elongation of *Heliscus* sp. and *Tricladium* sp., both aquatic hyphomycetes[78] and the rising presence of other members of the basidiomycetes and ascomycetes in the wetlands, on the other hand, may be attributed to their ability to tolerate, trap, immobilise and adsorb these heavy metal ions in their mycelia. This study revealed that physicochemical properties influenced the species diversity of basidiomycetes and ascomycetes in wetland ecosystems. The result supported the submissions of other workers that wetland contamination with nitrates, heavy metals, and other ions from industrial xenobiotics due to anthropogenic activities selected for potentially tolerant pathogenic fungal groups.[55] Pathogenic fungal organisms can disrupt ecological health, and the entire delicate balance in the wetland food web in several ways. They are reported, for example, to directly infect, prey, and kill aquatic wetland flora and fauna (fish, crabs and other shell fishes), and thus alter the ecosystem's structure of a water body to tilt to their own favour. This, in turn, results in the loss of habitat for other wetland-dwelling organisms that depend on the affected biota for food, shelter, or breeding grounds. In addition to harming aquatic biota, they could affect the health of humans downstream, who depend on such polluted wetlands for irrigation, drinking water, and sea foods.[23,52] These views therefore raise huge concerns about the functioning of wetland ecosystems in the presence of these pathogenic mycoflora.[23,31,76-82]

CONCLUSION

This study revealed that the water quality (physical and chemical properties) of the 4 test wetlands differ in varying degrees among the wetland locations. This study also identified aquatic fungal organisms associated with selected wetland ecosystems in Akwa Ibom State. The fungal organisms isolated from the water and sediment samples from the wetlands belong to the genera *Penicillium, Aspergillus, Trametes, and Candida*. The study also showed that the water quality influenced the occurrence, types, abundance, and distribution of potentially pathogenic aquatic mycoflora in wetland ecosystems. It is recommendation that: (1) Adequate awareness programmes should be organised in order to control wetland pollution, which if not controlled could lead to endangering public health. (2) Disposal of agricultural wastes from intensive farming concerns near wetlands into water bodies should be disallowed and strongly discouraged. (3) Mining and industrial activities around wetlands should be properly and strictly regulated while industrial effluents, should be properly inspected, and stringently controlled to global best practices, by regulatory agencies. (4) Campaigns to grow trap plants that can absorb and clean up the heavy metals and xenobiotic contaminants from around wetlands and shoreline sediments, to make for safe sea-foods and public health should be mounted, and grossly intensified.

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