Trends in
Applied Sciences
Research
TASR

Assessment of Selected Groundwater for Fish Culture in Maiduguri Metropolis, Nigeria

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ABSTRACT
Background and Objective: Fish farmers in Maiduguri Metropolis mainly use groundwater boreholes for their farming. However, homestead fish farming has been declining in the area, probably due to water quality issues. This study therefore aimed at investigating the quality of borehole water for fish culture in Maiduguri Metropolis. **Materials and Methods:** Borehole water samples were pristinely collected for three months from five different locations (Bolori Kasua, Ngomari Costain, Gwonge Sabolahi, Mai-Sandari and Umarari) in Maiduguri Metropolis and analyzed using standard methods and procedures for physicochemical and heavy metal contents. Data were analyzed using one-way ANOVA at $p<0.05$. **Results:** The results revealed higher ($p<0.05$) pH, electrical conductivity, alkalinity, total dissolved solids, total hardness and potassium in Gwonge Sabolahi and Mai-Sandari. Ngomari Costain also showed elevated ($p<0.05$) magnesium, sulphate, nitrate, calcium, manganese and zinc levels, however, dissolved oxygen, temperature, cadmium and iron showed marginal variations ($p>0.05$) among locations. The results, however, indicated that the physico-chemical and heavy metal parameters analysed in the study were within the desirable limits for fish culture, except cadmium (0.01 ± 0.00-0.01 ± 0.02 mg L^{-1}) and iron (0.11 ± 0.05-0.20 ± 0.02 mg L^{-1}). **Conclusion:** Hence, water is regarded as good for fish culture. It is however necessary to appropriately remediate those few parameters above the threshold for successful fish culture.

KEYWORDS
Fish farming, groundwater, water quality, heavy metals, Maiduguri

INTRODUCTION
Aquaculture is a yet-to-be-tapped-animal protein source in most parts of Northeastern Nigeria especially Maiduguri due to over-reliance on capture fisheries from rivers and lakes. However, fish supply from capture fisheries has recently been hampered by insurgency hence, the need to look inward for alternative avenues to bridge the gap in fish supply through aquaculture. Aquaculture has the potential to help expand the resource-based, generate more employment and improve the socio-economic status of the farmers. Mondal *et al.*[1], opined that aquaculture can make an important contribution to poverty alleviation, food security and the social well-being of the people. At present, fish farming is largely subsistence in Maiduguri and Nigeria at large making its contributions insignificant.

ISSN: 2151-7908 (Online)
ISSN: 1819-3579 (Print)
https://doi.org/10.3923/tasr.2023.63.70
Received: 23 Dec. 2022
Accepted: 02 Apr. 2023
Published: 30 Jun. 2023

The starting point for conceptualizing aquaculture is land and water availability and suitability[2]. Maiduguri is endowed with a vast land area (105.5 sq km) and is the largest city of Borno State in North-Eastern Nigeria. However, security concerns have impeded access to all open water resources (e.g., Ngadda River, Alau Dam, Lake Chad, etc.) for fish supply from capture fisheries. Hence, an urgent need to ascertain the suitability of available groundwater sources for aquaculture activities to guarantee nutritional security and provide income to the populace. Two criteria have been documented for selecting a good water source for aquaculture[3]. Such sources must be uncontaminated from excessive nutrients, chemicals or heavy metals and must be available in the required quantity for commercial fish farming. Consequently, some groundwater may satisfy the criteria, hence the need for evaluating the contents of the physical, chemical and heavy metal for aquaculture purposes.

The physical and chemical constituents of pond water must satisfy the requirement of fish quality, which is sacrosanct for fish culture since it affects their health, growth and survival in the production systems. The source and quantity of water available are the most important factors to consider when choosing a site for an aquaculture facility. Recently, many gains have been recorded in fish farming development in Maiduguri and its environs due to advocacy and training for youth and women. However, the effort can only be sustained when the area of water quality management for sustainable production is addressed. Ssekyanzi *et al.*[4] affirmed that poor knowledge and practices concerning water quality in aquaculture usually wreck the farmers and hamper fish food production in Sub-Saharan Africa.

Further, many of the inland waters used for fish farming are increasingly experiencing heavy metal pollution following growing agricultural and industrial development[5]. The trace and heavy metals at higher concentrations in pond water contaminate the fishes[6], as well as the consumers indirectly through the food chain[7]. Most of the toxic metals such as Pb, Zn, Cu, Hg and Cd, etc., usually found their way into pond water through the release of urban, agricultural and industrial wastewater and dumping of solid waste into the open water channels[8]. Yet, there are relatively few studies relating to heavy metal contamination of pond water in Nigeria[9,10].

Moreover, there is a paucity of information on the physic-chemical parameters and heavy metals contents of groundwater in the Maiduguri Metropolis and how suitable are they for fish farming. Although, few documented reports exist on the physicochemical parameters and heavy metals content of groundwater in Maiduguri, mainly for drinking and irrigation purposes[11-14]. This study, therefore, seeks to investigate the physic-chemical quality and heavy metals contents of groundwater boreholes on their suitability for fish farming in Maiduguri Metropolis, Nigeria. The findings of this study will provide scientific information to the existing and potential fish farmers on the suitability of groundwater quality for fish farming in the Metropolis. The information will also serve as a reference for physic-chemical and heavy metals comparison in pond culture over time.

MATERIALS AND METHODS

Study area: The study was carried out in Maiduguri Metropolis between October, 2018 and December, 2018. Maiduguri (Borno State, Nigeria) is the largest city in the Northeastern Region of Nigeria, with land size covering an area of 543 km^2 Goni *et al.*[15]. The city is located on a geographic grid of Longitude 11°46'18"N to 11°53'21"N and Latitude 13°03'23"E to 13°14'19"E. The Metropolis cut across four Local Government areas which include Maiduguri Metropolitan, Jere, Konduga and some parts of Mafa[16]. It is situated in North-Eastern Nigeria, having a Tropical Savannah climate and sandy loamy soil with mean with a mean annual rainfall of about 300 to 500 mm[17].

Water sample collection: Water samples were collected fortnightly from selected boreholes for 3 months (October and December, 2018). Five sampling locations, which include Bolori Kasua, Ngomari Costain,

Table 1: Sampled water sources, locations and GPS points

		Coordinates	
Sampled location	Sample tag/identification	Latitude	Longitude
Bolori Kasua	BKS	11°51'31"N	11°08'03"E
Ngomari Costain	GCS	11°49'54"N	13°10'53"E
Gwonge Sabolahi	GSS	11°50'06"N	13°10'25"E
Maisandari	MSS	11°49'25"N	13°07'34"E
Umarari	URS	11°52'01"N	13°08'16"E

Gwange Sabon line, Mai Sandari and Umarari areas in Maiduguri were used for the study (Table 1). Water samples were collected directly from the borehole taps into pre-washed polyvinyl polyethylene (PVC) bottles (250 mL) and labeled appropriately and conveyed to Water and Biological Laboratory, NAFDAC Office, Maiduguri.

Physic-chemical analysis: Water temperature, pH, conductivity, total dissolved solids and alkalinity were measured *in situ*. The water temperature and pH were measured using a pH meter (HANNA, HI 98107) while the conductivity and total dissolved solids were measured using an Intelligent meter (AD. 33915). Alkalinity was also recorded using a portable Alkalinity meter (HANNA HI 3811). Other physic-chemical parameters were analyzed in the laboratory following the method used by Akpoveta *et al.*[18].

Dissolved oxygen was measured using Winkler's method, the phenoldisulfonic acid method was used for the determination of nitrate and EDTA titrimetric method for total hardness, calcium and magnesium. The flame photometry method was used for potassium and sodium. Sulphate was estimated using the turbidometric method. Phosphate was determined by the molybdate-ascorbic acid method.

Heavy metals analysis: Heavy metals (lead, zinc, iron, manganese and cadmium) were determined in water samples using a Perkin Elmer Model 306 Atomic Absorption Spectrophotometer at the Analytical Laboratory, NAFDAC Office, Maiduguri, Borno State. All samples were acidified *in situ* with Nitric acid (NHO_3) (5 mL) before transporting them in an ice box in the laboratory. This is to prevent microbial degradation of heavy metals and to ensure sterility.

Statistical analysis: Data obtained were subjected to descriptive statistics and one-way analysis of variance at $\alpha_{0.05}$. Fisher's LSD was employed for mean separation to asses any significant difference at the probability level of $p<0.05$ among the studied locations. Statistical analysis was performed using SPSS software statistical program version 20.0 (SPSS Inc., Chicago, IL, United States of America).

RESULTS

Physic-chemical parameters: The physic-chemical parameters from selected boreholes in Maiduguri are presented in Table 2. The GSS had the highest recorded concentrations of dissolved oxygen (5.66±0.25 mg L^{-1}), while BKS had a higher temperature level (25.03±0.47°C). However, the values obtained for dissolved oxygen and temperature were not statistically different ($p>0.05$) between the water samples from the 5 locations studied. Mean electrical conductivity (EC) concentration ranged between 60.00±0.03 to 120.00±0.01 µS cm^{-1} with the lowest in UWS and highest in MSS, respectively. MSS had the highest significant value ($p<0.05$) of 40.22±18.10 mg L^{-1} and the least (30.15±10.14 mg L^{-1}) found in GCS. Marked variations ($p<0.05$) were also observed in alkalinity with MSS had the highest value of 40.22±2.14 mg L^{-1} and the least (30.15±3.70 mg L^{-1}) found in GCS. Also, the significantly highest pH concentrations were obtained in GSS (8.42±0.42) and MSS (8.40±0.45) while the least (6.60±0.07) pH was recorded in UWS. The mean total dissolved solids obtained for GCS (180.00±7.00 mg L^{-1}) were markedly lower ($p>0.05$) than values from other sample locations.

Table 2: Physico-chemical parameters of analyzed borehole water in the Maiduguri Metropolis

	Location					
Water parameter	BKS	GCS	GSS	MSS	UWS	Desirable limits
DO (mg L^{-1})	5.15±0.40[a]	5.62±0.14[a]	5.66±0.25[a]	5.48±0.32[a]	5.32±0.37[a]	5.0-10.0
Temp (°C)	25.03±0.47[a]	24.30±0.40[a]	24.50±0.50[a]	24.70±0.60[a]	24.13±0.60[a]	25.0-32.0
pH	7.11±0.18[b]	6.64±0.07[c]	8.42±0.42[a]	8.40±0.45[a]	6.60±0.07[c]	6.5-8.5
EC (µS cm^{-1})	80.00±0.02[b]	70.00±0.02[b]	110.00±0.01[ab]	120.00±0.01[a]	60.00±0.03[bc]	50.0-500.0
ALK (mg L^{-1})	30.81±12.07[b]	30.15±10.14[b]	35.36±9.57[ab]	40.22±18.10[a]	31.93±11.18[b]	50.0-300.0
TDS (mg L^{-1})	230.00±13.45[a]	180.00±7.00[b]	193.00±11.38[ab]	240.00±5.56[a]	240.00±7.00[a]	30.0-300.0
Mg (mg L^{-1})	0.28±0.03[b]	0.36±0.03[a]	0.12±0.01[c]	0.11±0.01[c]	0.23±0.03[b]	<150.0
SO_4^{2-} (mg L^{-1})	60.00±3.20[b]	83.00±5.45[a]	14.00±1.00[c]	12.00±0.95[c]	18.00±1.39[b]	<400.0
PO_4^{3-} (mg L^{-1})	0.00±0.00[c]	0.02±0.01[ab]	0.01±0.01[b]	0.01±0.00[b]	0.03±0.01[a]	0.12
NO_3^- (mg L^{-1})	0.37±0.03[b]	2.01±0.45[a]	0.32±0.13[b]	0.11±0.01[c]	0.29±0.04[b]	0.1-3.0
TH (mg L^{-1})	39.00±2.80[c]	4.80±0.26[d]	201.33±63.00[a]	61.10±3.10[b]	21.00±1.10[c]	30.0-180.0
Ca (mg L^{-1})	0.84±0.16[ab]	1.08±0.06[a]	0.68±0.35[b]	0.68±0.06[b]	0.69±0.03[b]	75.0-200.0
Na (mg L^{-1})	300.00±10.00[a]	110.00±10.28[b]	103.00±11.84[b]	101.00±6.22[b]	100.00±4.40[b]	<500.0
K (mg L^{-1})	3.90±0.11[bc]	4.80±0.30[b]	5.50±0.50[a]	6.00±7.00[a]	2.10±0.22[c]	0.5-10.0

DO: Dissolved oxygen, Temp: Temperature, EC: Electrical conductivity, ALK: Alkalinity, TDS: Total dissolved solid, Mg: Magnesium, SO_4^{2-}: Sulphate, PO_4^{3-}: Phosphate, NO_3^-: Nitrate, TH: Total hardness, Ca: Calcium, Na: Sodium, K: Potassium, Values are Means±SD and Means across the same row differently superscripted differ significantly $p<0.05$

Table 3: Concentration of heavy metals in water samples from selected boreholes

	Location					
Parameter	BKS	GCS	GSS	MSS	UWS	Desirable limits
Cd (mg L^{-1})	0.01±0.00[a]	0.01±0.01[a]	0.01±0.00[a]	0.01±0.00[a]	0.01±0.02[a]	0.005
Fe (mg L^{-1})	0.20±0.02[a]	0.11±0.05[a]	0.15±0.03[a]	0.18±0.06[a]	0.15±0.02[a]	0.003
Mn (mg L^{-1})	0.10±0.03[b]	0.19±0.04[a]	0.15±0.03[ab]	0.15±0.04[ab]	0.15±0.03[ab]	0.5
Pb (mg L^{-1})	-0.25±0.030[b]	-0.21±0.034[b]	0.01±0.00[a]	-0.12±0.010[b]	-0.24±0.036[b]	0.1
Zn (mg L^{-1})	0.20±0.026[b]	0.12±0.026[a]	0.25±0.03[b]	0.16±0.020[ab]	0.12±0.010[a]	15

Cd: Cadmium, Fe: Iron, Mn: Manganese, Pb: Lead, Zn: Zinc, values are Means±SD and means across the same row differently superscripted differ significantly $p<0.05$

Further, magnesium concentration is notably higher ($p<0.05$) in GCS (0.36±0.03 mg L^{-1}) as compared to other locations. The (83.00±5.45 mg L^{-1}) sulphate concentration ($p<0.05$) was recorded in GCS, followed by BKS (60.00±3.20 mg L^{-1}), while the least value of 12.00±0.95 mg L^{-1} was observed in MSS. Phosphate (0.03±0.01 mg L^{-1}) was significantly ($p<0.05$) higher in UWS. The GSS had the least phosphate values 0.01±0.01 mg L^{-1}. However, no phosphate was observed in water samples from BKS.

Nitrate concentrations ranged from 0.11±0.01 in MSS to 2.01±0.45 mg L^{-1} in GCS. Significant ($p<0.05$) higher values of 2.01±0.45 (GCS), 0.37±0.03 (BKS), 0.32±0.13 (GSS) and 0.29±0.04 mg L^{-1} (UWS) were recorded. The total hardness concentrations varied significantly ($p<0.05$) with the highest value recorded in GSS (201.33±63.00 mg L^{-1}) while the least value of 4.80±0.26 mg L^{-1} was obtained in GCS. Calcium contents were statistically ($p<0.05$) similar in GSS (0.68±0.35 mg L^{-1}), MSS (0.68±0.06 mg L^{-1}) and UWS (0.69±0.03 mg L^{-1}) but notably highest ($p<0.05$) in GCS (1.08±0.06 mg L^{-1}) and BKS (0.84±0.16 mg L^{-1}). The sodium level was significantly higher (300.00±10.00 mg L^{-1}) in BKS compared to the other locations. Potassium concentrations differed significantly ($p<0.05$) between MSS (6.00±7.00) and GSS (5.50±0.50 mg L^{-1}).

Heavy metal contents: The heavy metals concentration in borehole water in Maiduguri is given in Table 3. It showed that the cadmium (0.01 mg L^{-1}) contents were statistically similar ($p>0.05$) among the entire locations. The iron concentrations showed slight differences ($p>0.05$) in all locations and varied between 0.11±0.05 in GCS and 0.20±0.02 mg L^{-1} in BKS. Manganese contents significantly ($p<0.05$) varied from a minimum of 0.10±0.03 in BKS to a maximum of 0.19±0.04 mg L^{-1} observed in GCS. The lead concentration showed significantly ($p<0.05$) higher (0.01 ± 0.00 mg L^{-1}) values in GSS compared to other locations. Zinc was markedly highest ($p<0.05$) in GSS (0.25 ± 0.03 mg L^{-1}) followed by 0.20 ± 0.026 mg L^{-1} observed in BKS, but did not vary significantly ($p>0.05$) among other locations.

DISCUSSION

Physico-chemical parameters: In the current investigation, the range values obtained for physical and chemical parameters were in consonance with the standard recommended limits for optimum growth, reproduction and survival of fish[19], except total alkalinity and calcium. The variations in congruent with the observation, of Khatri and Tyagi[20], who noted that water quality and quantity vary from place to place and are affected by environmental factors such as soil and air quality. The dissolved oxygen values observed in this study were within the optimum range (4.6-6.8 mg L^{-1}) reported by Mustapha[21] in different culture systems. In contrast to this finding, Getso *et al.*[22] reported lower dissolved oxygen of (3.0-3.6 mg L^{-1} borehole water in Kano, Nigeria.

The temperature (24.13 ± 0.60-25.03 ± 0.47°C) discerned in the study is tolerable to tropical fish culture, though fell within the optimum recommended ranges (25.0-32.0°C) only in boreholes in Bolori Kasua areas. The water temperature observed in this study is within the range (20.0-30.0°C) of what Mustapha[21] however, reported. The temperature values observed in this study varied from (26.6-30.0°C) reported by Isa *et al.*[14] who recorded a higher temperature range of underground water in Maiduguri, Nigeria. The variance in the results could be attributed to differences in the location and period of study.

Hydrogen iron (pH) values recorded in the current study are within the optimum limits and concurred with the findings of Isa *et al.*[14] in Maiduguri Metropolis, Borno State, Nigeria. Similar observations have also been reported in Maiduguri urban areas[12], Hausari, Mairi and Maisandari[11], all in Maiduguri Metropolis, Nigeria. Meanwhile, Boyd (1998) affirmed that pH values less than 5.0 and more than 10.0 is lethal to fish. The electrical conductivity of all borehole water studied is in accordance with FEPA[23] and Anita and Pooja[19] standard range of 50-500 μS cm^{-1} for tropical fish culture. Contrary to this finding, high conductivity values of borehole water in Maiduguri Metropolis have been documented by Isa *et al.*[14] and Musa *et al.*[12]. The variations in water conductivity values could be due to variations in sampling locations.

The total alkalinity of the borehole water samples observed in this study is below the recommended limits for fish production by Anita and Pooja[19]. The water from the boreholes sampled can be categorized as soft water since its total hardness was less than 120 mg L^{-1} Hori *et al.*[24]. This problem can however be remediated to suit fish culture through the application of lime. The TDS concentrations for all the borehole water studied (180.00 ± 7.00 and 240.00 ± 7.00 mg L^{-1}) fell within the Anita and Pooja[19] recommended limits of 30.0 to 200 mgL^{-1} required by aquatic life.

The borehole water in the study area is suitable for fish farming except in the Gwonge Sabon line where water is hard and higher than the maximum limit (180 mg L^{-1}) suggested by Anita and Pooja[19]. The high total hardness by borehole waters observed in this study is similar to those reported by Adeiza *et al.*[25] in Kano Metropolis. Calcium and magnesium are the major constituents in total hardness and they are essential elements for fish growth. The magnesium contents in the water were within the acceptable level for fish farming[19]. The magnesium contents of groundwater observed in this study were significantly lower than those reported by Bakari[26] in borehole water in Moduganari and Gwange area of Maiduguri, Nigeria. Similarly, the magnesium levels observed in this water differed from the findings of Bashir *et al.*[17] who found 2.6-5.0 mEq L^{-1} in tube wells in irrigation areas in Maiduguri, Nigeria.

The calcium levels observed in this study coincide with the findings of Hyeladi and Nwagilari[13], who reported 1.12 mg L^{-1} calcium in treated domestic water from Alau Dam, Maiduguri, Nigeria. The calcium

level observed in the borehole water in this study was found to be below the recommended limits (75-200 mg L^{-1}) for aquaculture by Anita and Pooja[19]. Bashir *et al.*[17], however, reported a calcium content of 2.6-5.2 mg L^{-1} in tube well water around Maiduguri. The sulphate, phosphate and nitrate levels observed in this study are in congruence with the findings of Igwemmar *et al.*[27] and Hyeladi and Nwagilari[13] for boreholes in Abuja Metropolis and Maiduguri Metropolis, respectively. Sulphate, phosphate and nitrate levels found in this study were within the optimum level for fish culture.
The cadmium levels in water samples in the study area were lower (0.04±0.001 and 0.07±0.02 mg L^{-1}) than the values obtained by Kolo and Waziri[28] in borehole waters of selected motor parks in Maiduguri, Nigeria. However, the cadmium levels recorded in this study were above the desirable limit recommended for aquaculture[29]. Iron content observed during this study was incongruence with the recommended limit (0.003 mg L^{-1}) for a safe and healthy water for fish culture[29]. However, Musa *et al.*[12] and Haruna *et al.*[30] reported iron contents between 0.010 and 0.036 mg L^{-1} in wash and deep boreholes in Maiduguri Metropolis. The difference could be due to the deterioration condition of the old galvanized pipes that rusted and leached into the water.

Manganese concentrations in all the water samples observed in this study were in trace quantities that are below the detection limit of 0.5 mg L^{-1} Meride and Ayenew[29]. This is an indication that the manganese level of the borehole's water is within the acceptable levels for fish culture. Sabo and Christopher[31] did not observe magnesium in borehole water in Bauchi (0.00 mg L^{-1}), while Musa *et al.*[12] reported 0.02-0.2 mg L^{-1} in Maiduguri and Garba *et al.*[32] documented 0.03-1.0 mg L^{-1} in boreholes in Jigawa State. The lead concentrations in this study were within regulation limits of 0.065 mg L^{-1} for fish culture by Sultana *et al.*[33]. This finding is in line with the reports of Haruna *et al.*[30] who obtained lead concentrations range of 0.010-0.030 and 0.013-0.036 mg L^{-1} for wash and deep boreholes respectively, in Maiduguri Metropolis. However, the variations in lead concentrations as found in this study and previous studies could be linked to the geology of the soil in different areas as well as lead pipe, water tap and plumbing fixtures.

Zinc levels documented in this study were within the WHO[34] acceptable limit of 15 mg L^{-1} for aquaculture. In contrast to this finding, Kolo *et al.*[35] report a higher mean zinc contents (1.0-3.26 mg L^{-1}) while Musa *et al.*[12] observed lower (0.02-0.08 mg L^{-1}) zinc concentrations in all the borehole water samples from Maiduguri Metropolis, Nigeria.

Aquaculture development in Maiduguri is growing fast due to increasing demands for its products and non-accessibility to fishing grounds due Boko Haram insurgency. However, requisite good water supply and management are critical to this important progress that has been made. Thus, research into groundwater condition for fish farming is crucial as poor-quality water usually affect the health, growth and survival of the fish[36]. The findings in this study seem satisfactory except for a few parameters that are not within the threshold limits for successful aquaculture. Though, the major drawback of the study is tied to inadequate finance, which is responsible for the limited duration and sample size of the research. The study ought to span one year (12 months) to reflect seasonality with more samples covered if there is adequate funding. Further studies are however recommended to explore the seasonality effect on the appropriateness of this water for fish culture. This will also facilitate the monitoring of long-term trends of this selected groundwater for effective management in fish farming.

CONCLUSION

In this study, most of the physicochemical parameters and heavy metals investigated from borehole water samples conform with the optimum standard recommended range for aquatic life, except alkalinity, calcium, cadmium and iron, hence regarded as good for fish culture. It is, therefore, necessary to take appropriate remediation measures for the few parameters that are not within the recommended ranges for successful fish culture in Maiduguri Metropolis.

SIGNIFICANCE STATEMENT

This is the first study to assess and provide crucial data on the suitability of groundwater boreholes for fish farming in the Maiduguri Metropolis. The study found the borehole water suitable in terms of physical and chemical quality. However, the cadmium and iron concentrations in these waters call for concern. The study will be an opener to researchers and other stakeholders in fisheries, which will require thorough findings on causes/sources of metals in these boreholes. It will also lead to suggestions of possible solutions to this problem in Maiduguri Metropolis.

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