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GEOSPATIAL ANALYSIS OF MARITAL DISSOLUTION IN NIGERIA

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ABSTRACT
Marital dissolution remains a critical socio-demographic issue in Nigeria, with significant regional disparities in divorce and separation rates across the country's six geopolitical zones. This study employs a geospatial approach to examine the patterns and socio-economic implications of marital dissolution using data from the Nigeria Living Standard Survey (NLSS) 2018/2019 and the Nigeria Demographic and Health Survey (NDHS) 2018. The findings reveal that marital dissolution rates (MDRs) vary significantly by region, with the South-South zone recording the highest MDR (7.2%), while the North-West reports the lowest (1.3%). The study identifies several key factors influencing divorce trends, including educational attainment, economic conditions, cultural practices, and religious beliefs. Divorce is highly stigmatised in the North, where women often face economic hardship and social exclusion. In contrast, in the South-West and South-South, rising financial independence among women and changing gender roles contribute to increased MDRs. The study also highlights the impact of urbanisation, polygamous marriages, early marriage practices, and economic instability in shaping marital outcomes. Based on these findings, the study recommends targeted policy interventions, including legal reforms, economic empowerment initiatives, and public awareness campaigns, to mitigate the adverse effects of marital dissolution and promote stable and equitable marital relationships across Nigeria's diverse regions.

Keywords: Divorce, Separation, Geospatial, Nigeria, Gender Roles, Stability

INTRODUCTION

Marriage, as a fundamental institution of human society, forms the cornerstone for family formation and the transmission of culture, values, and economic resources (Oloyede et al., 2024). However, marital dissolution, commonly referred to as divorce, has emerged as a global phenomenon, challenging traditional family structures and societal norms. Divorce is defined as the legal dissolution of a marriage, which terminates the marital relationship and grants both parties the right to remarry (Stykes and Guzzo 2020). Divorce rates vary significantly across regions, shaped by cultural, economic, and legal frameworks. In high-income countries, individualism, gender equality, and shifting societal expectations are closely tied to higher divorce rates. On the other hand, in developing regions, marital stability is often influenced by patriarchal norms, economic dependencies, and limited access to legal redress mechanisms. This variation underscores the importance of understanding divorce not only as a personal or family issue but also as a spatially embedded phenomenon (Statistics South Africa, 2021).

Africa offers a fascinating context for examining the spatial aspects of divorce. While marriage remains deeply rooted in cultural and religious traditions, the continent has witnessed a gradual increase in divorce rates over the past decades (Corno et al., 2020). Nigeria, Africa's most populous nation, is characterised by profound regional diversity across its six geopolitical zones, each with distinct cultural, religious, and economic attributes. While marriage remains deeply rooted in tradition and religion, MDR have shown notable spatial variation. (National Bureau of Statistics, 2020; Aref et al., 2024). This regional variation in divorce patterns highlights the need for a spatially informed approach to understanding marital stability in Nigeria.

Furthermore, despite the growing body of research on MDR, its spatial dimensions remain underexplored. Many studies (Ntoimo & Akokuwebe, 2014; Gaya, 2017; Killewald et al., 2023) focus on individual or household-level determinants of marital dissolution, including communication, financial stability, and personal values. While these factors are important, they overlook the broader spatial context in which marriages exist and dissolve. Spatial analysis examines the impact of location-specific factors, including economic disparities, cultural norms, and social differences, on shaping patterns of divorce. In Nigeria, the stark contrasts between location-specific factors and geopolitical zones highlight the need for such an approach. Given the above, this study aims to bridge the gap between spatial analysis and research on marital dissolution. By investigating divorce patterns in Nigeria, it explores how spatial factors intersect with cultural and economic dynamics to shape marital stability.

Theoretical Framework

This study applies Bronfenbrenner's (1979) Ecological Systems Theory to examine disparities in divorce rates across Nigeria's geopolitical zones. The theory highlights how interactions between individual, social, economic, and cultural systems shape marital stability. Differences in macrosystem factors, such as religious beliefs, gender roles, and cultural expectations, contribute to regional variations, with divorce being more stigmatised in the North than in the South. Exosystem influences, including economic conditions, employment opportunities, and legal frameworks, vary by zone and affect marital dissolution rates. Additionally, microsystem dynamics, such as family structure and spousal relationships, differ based on socio-cultural contexts. Lastly, the chronosystem accounts for historical shifts, including urbanisation and changing societal norms, that impact divorce patterns across Nigeria's regions.

This study aims to analyse the spatial patterns and implications of marital dissolution in Nigeria. This will be achieved by the following objectives which are to: examine the geographical distribution of marital dissolution rates (MDRs) across Nigeria's six geopolitical zones using geospatial analysis, dentify the socio-economic and cultural factors influencing marital stability, and analyse the regional variations in the consequences of divorce, particularly in terms of financial stability, social acceptance, and post-divorce opportunities.

Study Area

Nigeria is situated between latitudes 4°16' and 13°53' North, and Longitudes 2°40' and 14°41' East (Figure 1). It is located in the West African sub-region, bordered by the Republic of Benin to the west, Niger Republic to the north, Chad to the northeast, and Cameroon to the east. The southern boundary is defined by the Atlantic Ocean, which forms an approximately 800-kilometre-long coastline extending from the Badagry inlet in the west to the Rio del Rey, east of the Cross River estuary (Allu & Ochedi, 2015). The country spans 923,769 km², stretching across 36 states from the northern to the southern regions (Onah, 2020).

Nigeria is broadly divided into two main climatic zones. The tropical rainforest area extends from the southern coast to approximately 9°N latitude and includes all southern states, as well as parts of Kwara, Benue, Gongola, and the Federal Capital Territory (FCT). The savannah zone covers the rest of the country, reaching the Nigeria- Niger border in the north (Edokpa et al., 2024).
Nigeria's population is highly diverse ethnically, comprising numerous groups, with the largest

being the Hausa (30%), Yoruba (15.5%), Igbo (15.2%), and Fulani (6%). Other notable ethnic groups include Tiv (2.4%), Kanuri/Beriberi (2.4%), Ibibio (1.8%), and Ijaw/Izon (1.8%), while other smaller groups collectively constitute 24.9% of the population (NBS, 2020).

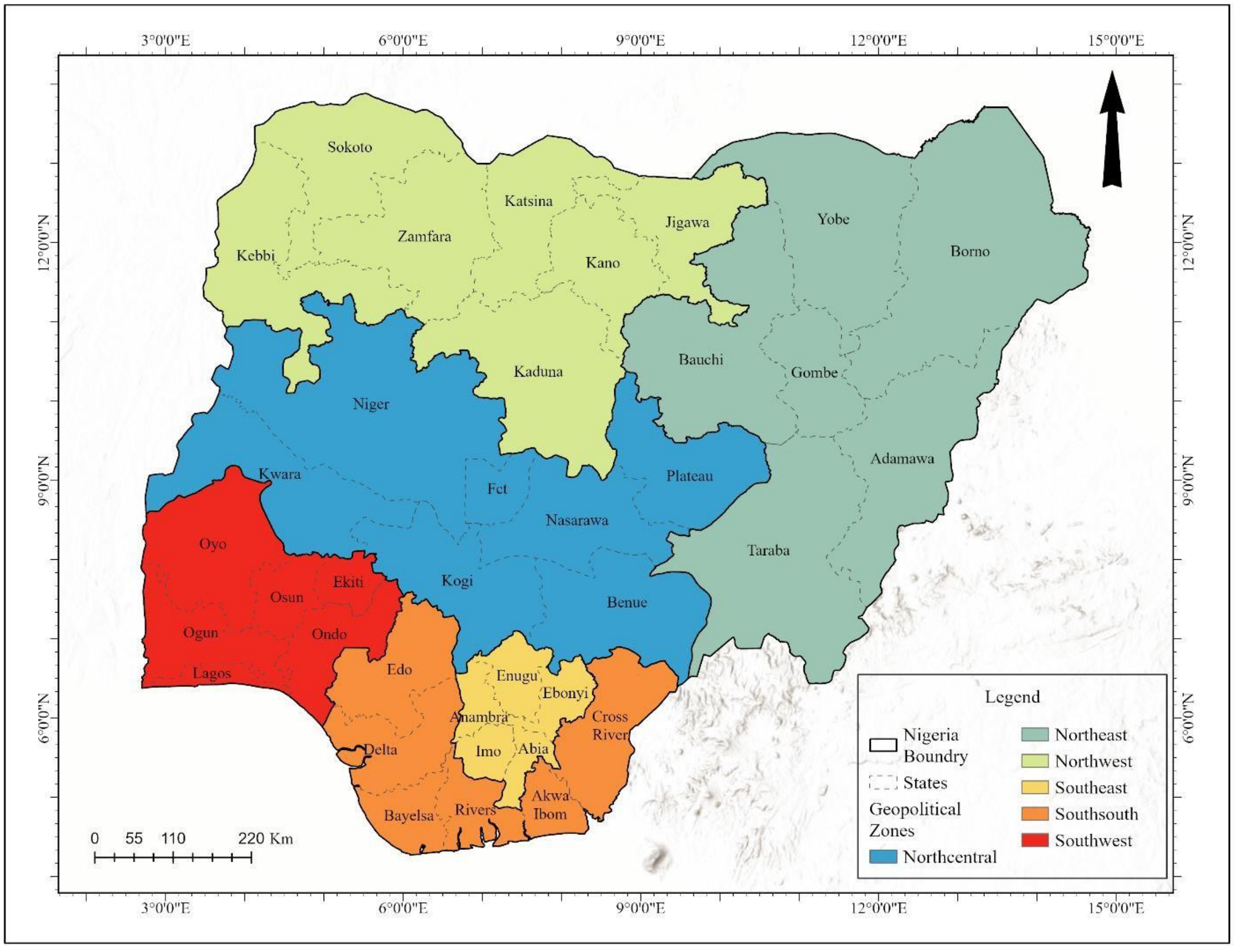

Figure 1: Nigeria Showing Geopolitical Zones
Source: Adapted from Administrative Map of Nigeria.

The official language of Nigeria is English, reflecting its colonial history. Religiously, the population is predominantly Muslim (53.5%), followed by other Christian denominations (35.3%) and Roman Catholics (10.6%). Additionally, 0.6% adhere to other religions (Akindele et al., 2022).

Nigeria's population has experienced significant growth over the years, and this trend is projected to continue. In 2016, the population exceeded 186 million, and it is projected to reach 392 million by 2050, making Nigeria the fourth most populous country in the world (Abubakar & Dano, 2018).

Materials and Methods

A mixed-methodology approach was employed in this study to ensure a comprehensive understanding of the factors influencing marital stability across different geopolitical zones in Nigeria. This methodological framework combined qualitative and quantitative data analysis with spatial mapping techniques to provide a nuanced examination of the subject. To analyse spatial

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patterns and contextual factors, Geographic Information System (GIS) analysis and thematic analysis methods were utilised.

GIS analysis was particularly instrumental in visualising the distribution of divorce rates across the geopolitical zones, allowing for a clear identification of regional disparities. The document review method facilitated the integration of relevant secondary data sources, ensuring the study's findings were grounded in robust and reliable datasets.
In addition to these methods, twelve (12) in-depth interviews, two (male and female) from each of the six geopolitical zones, were conducted to obtain qualitative data on the socio-economic implications of divorce. These interviews provided valuable insights into how divorce affects individuals and communities, particularly in terms of financial stability, social networks, and overall well-being.

The primary data for MDRs were sourced from the 2018/2019 Nigeria Living Standard Survey (NLSS). This dataset was selected because it provides the most recent and comprehensive information on divorce rates segmented by geopolitical zones.

Additionally, data on spatial factors influencing marital stability were obtained from the 2018 Nigeria Demographic and Health Survey (NDHS). The NDHS dataset was particularly valuable for its detailed demographic and health indicators, which are crucial for understanding the broader socio-economic and cultural dynamics that affect marital stability. The rationale for adopting the NLSS 2018/2019 and NDHS 2018 datasets lies in their unique capacity to capture both the crude divorce rate and associated demographic and health data, disaggregated by geopolitical zones. These datasets represent the most reliable and authoritative sources available for such analysis, ensuring that the study’s findings are both valid and representative.

Advanced analytical tools were employed to process and analyse the data. ArcGIS Pro software was utilised to generate spatial visualisations of crude divorce rates. This enabled the creation of maps that highlighted regional patterns and potential hotspots of marital instability.

RESULTS AND DISCUSSION

Distribution of Marital Dissolution in the Study Area

The marital dissolution rates across Nigeria's geopolitical zones reveal significant spatial variations in marital stability. These variations are shaped by diverse socio-cultural, economic, and demographic factors unique to each zone. This is revealed in Figure 2.

North West Zone

The North-West zone comprises states such as Kano, Kaduna, and Sokoto. Figure 2 shows that this region has the lowest MDR of 1.2. This report, according to the NDHS, is in stark contrast to reality, which may be a result of various factors, such as the non-documentation of divorce cases and the fact that most divorcees hardly remain single for long before getting remarried.
In reality, this zone has one of the highest divorce rates in the country. Kano State, in particular, has been labelled the "divorce capital" of Nigeria, with reports indicating that around 32% of marriages end within three to six months (Suleiman, 2021). Several factors, including Islamic Law, influence the high prevalence of divorce in this region. According to Yahaya (2019), under Islamic jurisprudence, men can easily divorce their wives by pronouncing "*talaq*" three times, making the dissolution of marriages relatively straightforward. Another major contributor to high MDR is economic hardship**.** Abubakar (2020) established in his study how financial instability

contributes to strained relationships, leading to higher MDRs, particularly among low-income families. Another factor is the practice of polygamy, which is common in this region and has been pointed out as a major player in MDR. In his research, Bello (2018) stated that many men who enter polygamous unions struggle to maintain fairness among wives, leading to marital dissatisfaction and eventual separation.

North-East zon

This includes States such as Borno, Adamawa, and Yobe. Figure 2 shows that the MDR in this region is 3.2. This is slightly higher than the National MDR average of 3.0. Factors influencing marital instability in this region include: conflict and displacement, which were spearheaded by the insurgency, have led to significant displacement, causing family separations and increased divorce rates (Aliyu, 2022). The Northeast region practices early marriage, which often results in failed unions due to a lack of maturity and preparedness for marital responsibilities (Allen & Adekola, 2016). Also, similar to the North-West, Islamic traditions influence divorce rates, with men able to dissolve marriages easily (Abdulhameed & Mohammad Sanusi, 2016)

The North-Central zone

This includes states such as Benue, Kogi, and Plateau, which have a moderate MDR. According to Figure 2, the MDR of the North Central Zone is 2.6. This is slightly lower than the National average, with some factors contributing to marital dissolution peculiar to this region, including urbanisation and Western Influence. Okeke (2021) revealed that the growing influence of Western ideals about marriage and gender equality has led to increased MDRs, especially in urban centres. Inter-ethnic and inter-religious marriages are common in this region due to its diversity. These marriages, however, sometimes lead to conflicts due to differences in traditions, customs, expectations and religious beliefs (Ojo, 2010; Adebayo, 2020).

The South-West zone

According to Fig. 2, this has an MDR of 6.5. This is one of the highest marriage dissolution rates in the country, more than doubling the national average. This region, dominated by the Yoruba ethnic group, has witnessed increasing divorce rates, particularly in cities such as Lagos and Ibadan. The high figure of the MDR also signifies a good documentation of the status of legal marital unions. According to research, some reasons fueling a high MDR in the region include a cultural acceptance of marriage dissolution; according to Adaki and Wajim (2024), in the Yoruba culture, divorce is not heavily stigmatised, and individuals who are unhappy in their marriages often choose separation as a viable option. This region is also recognised as having infidelity and domestic abuse as primary reasons for divorce (Adetunji,2020). Many women from the southwestern region are highly educated and have achieved financial independence; therefore, they are less inclined to remain in unhappy marriages (Akinyemi, 2021).

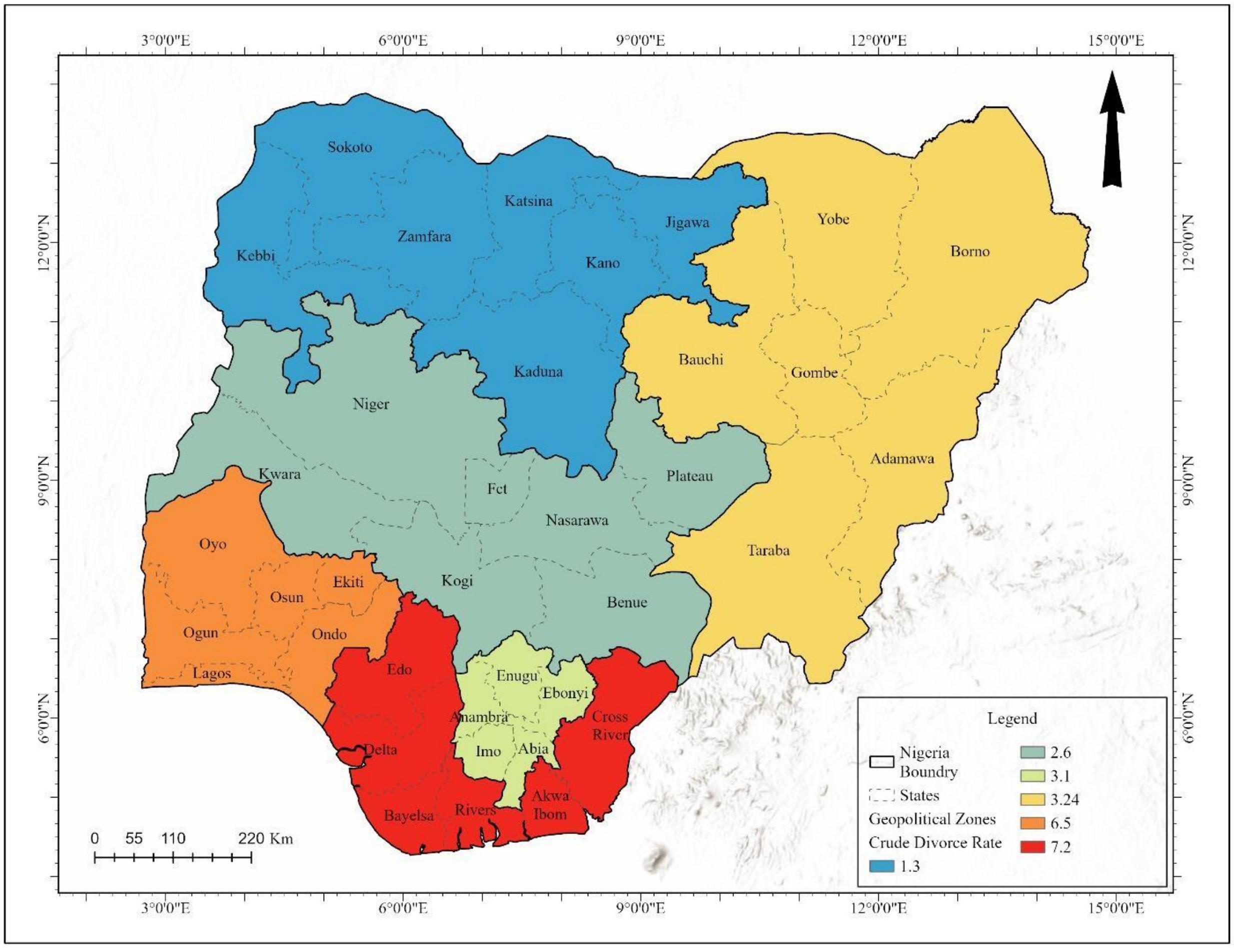

Figure 2: Distribution of Divorce Rate in Nigeria
Source: Adapted from NLSS 2018/2019

The South-East zone

Home to the Igbo ethnic group, records some of the lowest divorce rates in Nigeria. The MDR, as shown in Fig. 2, is 3.1. Apart from the commendable documentation of marital status in the region, other reasons for this MDR include strong traditional values, as Igbo culture places a high premium on marriage and divorce is often discouraged (Nwosu, 2019). Little wonder that the high bride price system makes divorce economically burdensome, deterring couples from separating (Umeh, 2020). Other structures in place to preserve marital unions within this region include the extended family system, which plays a significant role in mediating conflicts and thereby preventing marital breakdown (Obi, 2021). However, recent studies suggest an increase in divorce rates in urban Igbo areas due to modernisation and changing gender roles (Ajao & Olatunji, 2024)

The South-South zone

The South-South geopolitical zone of Nigeria, comprising states such as Rivers, Delta, and Bayelsa, has the highest divorce rates in the country, with a Marital Dissolution Rate (MDR) of 7.2. Several interrelated socio-cultural and economic factors contribute to this trend. Ekpenyong and Ingiabuna (2017) note that marriage inherently involves a mix of stress, disappointments, and occasional success, and when these challenges become overwhelming, they can destabilise the union. In this region, such pressures are often intensified by additional strains, including economic hardship and shifting family dynamics.

Moreover, infidelity and domestic violence have been identified as some of the most common triggers for divorce in the area (Esang, 2020). The growing autonomy of women—particularly in terms of financial independence and education—has also reshaped traditional marital dynamics. As seen in the South-West, women in the South-South are increasingly empowered to challenge patriarchal norms and are more willing to exit unfulfilling or abusive relationships (Ntoimo, 2022). This shift towards greater gender assertiveness, combined with persistent marital challenges and social tensions, has significantly contributed to the region's high rate of marital dissolution.

Implications of Marital dissolution in the study area

The thematic analysis revealed shared challenges and experiences of divorce in the north-west and north-east, reflecting the deeply ingrained socio-cultural and economic realities of these regions. In both zones, divorce is heavily stigmatised, rooted in conservative traditions and patriarchal norms that dominate societal expectations. Participants reported that divorced women often face severe social exclusion and limited opportunities for remarriage, with many becoming economically vulnerable due to their dependence on men. This economic instability leaves divorced women at significant risk of poverty, as opportunities for employment or education are scarce. The assumption agrees with Hamid and Sanusi (2016), who stated that the adverse effects of divorce in Northern Nigeria include economic hardship, psychological trauma, poor performance in life activities, immoral behaviour, among others.

Additionally, in all regions, societal pressures make it difficult for women to rebuild their lives post-divorce, as they are often marginalised within their communities. Men, too, face challenges following divorce, particularly in fulfilling financial obligations to former spouses' children, responsibility further strained by the widespread practice of polygamy. In the North East, this burden is exacerbated by the region's economic instability and displacement caused by insurgency, which not only fuels marital tensions but also increases the difficulty of sustaining family life.

On the other hand, in the north central zone, divorce carries a moderate level of stigma, influenced by the mix of Christian and Islamic traditions. The participants noted that economic factors, particularly financial incompatibility, are primary drivers of divorce.

Women in this zone often rely on informal support networks, such as extended families, to mitigate the impacts of divorce. However, the region is witnessing a gradual shift in attitudes, with more individuals embracing divorce as a means of escaping toxic or abusive marriages.

Similarly, the southwest, characterised by higher literacy rates, showed relatively progressive attitudes toward divorce. The participant noted that divorce is increasingly accepted, especially among educated populations. However, economic implications remain significant, with women often struggling to secure financial independence post-divorce. Cultural expectations around child custody also create challenges, with women bearing the brunt of care responsibilities. Psychological impacts, such as stress and depression, were also reported as everyday experiences. Meanwhile, in the southeast, the participants highlighted the cultural importance of marriage as a marker of social status. Divorce is viewed as a failure, particularly for women, who face severe stigma and reduced prospects for remarriage. Economic pressures, such as bride price reimbursements, further complicate the divorce process. For men, the financial burden of supporting estranged families often leads to strained resources. Nonetheless, the participant observed a growing trend of women prioritising their well-being over societal expectations, leading to an increase in divorce cases. The south-south region revealed complex dynamics, influenced by economic activities such as oil exploration and urban migration. The participant noted that economic disparities and infidelity are common causes of divorce. Women often face dual challenges of societal stigma and financial insecurity, while men deal with pressures to fulfil traditional provider roles. Environmental factors, such as westernisation, were also reported to contribute to shifting attitudes toward marriage and divorce. This is in agreement with the opinion of Adaki and Wajim (2024), who asserted that urbanisation and western influences were associated with a rise in divorces, mainly due to shifts towards individualism and self-interest.

Conclusion

This study highlights the regional disparities in marital dissolution across Nigeria, shaped by economic conditions, education, cultural norms, and religious beliefs. Findings reveal that while higher education and financial independence contribute to increased divorce rates in the South-South and South-West, traditional and religious influences suppress reported MDRs in the North, despite qualitative evidence suggesting high divorce prevalence. Economic hardship, particularly in Northern Nigeria, exacerbates the financial vulnerability of divorced women, while urbanisation and shifting gender roles drive changing marital expectations in urban areas.

Overall, marital dissolution in Nigeria is a multifaceted issue that requires targeted legal, economic, and social interventions to mitigate its adverse effects. Without adequate legal protection, economic support, and awareness initiatives, the adverse consequences of divorce—especially for women and children—will persist. Addressing these challenges through policy reforms, financial empowerment, and inclusive social structures is crucial to promoting stable and equitable marital relationships across Nigeria’s diverse regions.

Recommendations

To effectively address marital dissolution in Nigeria, legal reforms should harmonise divorce laws, ensure fair financial and custodial rights, and strengthen mediation services to promote amicable conflict resolution. Economic empowerment initiatives—such as vocational training, microfinance, and housing support—are crucial for supporting divorced individuals, particularly women in vulnerable communities. Additionally, public awareness campaigns should highlight the importance of relationship education, financial literacy, and the socio-economic risks associated with early marriage and polygamy. Mental health services must also provide accessible counselling and community-based support to help individuals navigate the stigma and emotional challenges of divorce.

Furthermore, promoting gender-inclusive policies that support shared financial and caregiving responsibilities, protect workers’ rights, and enforce strict measures against domestic violence and marital abuse is essential. Enhanced data collection on informal and customary divorces, combined with ongoing research into the effects of urbanisation and economic conditions, will facilitate more informed and responsive policymaking. Together, these strategies can alleviate the socio-economic burden of divorce and promote healthier, more equitable marital relationships throughout Nigeria.

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Aquatic ecotoxicology is the study of the effects of chemical contaminants on living organisms, especially on populations and communities within a specific aquatic ecosystem. It concerns the mode of transfer of those contaminants and their interaction with the marine environment (Butler, 1978).

When these foreign materials, also known as contaminants, enter the environment and are absorbed into the water cycle, water gets contaminated. They contaminate water supplies and can risk public health and the environment. Thus, any alteration in water that is detrimental to living things is considered water pollution (Neighborhood Water Quality, 2000).

Heavy metals are naturally occurring components of the Earth's crust. They are not biodegradable and cannot be destroyed. Some of these metals are highly soluble, making it easier for species to take up and absorb them and pass through the food chain. Once heavy metals enter the food chain, they bioaccumulate in living tissues, which can harm the organism. Because these metals are not biodegradable, these elements have accumulated (Lenntech, 2004; Abbas et al., 2016; He et al., 2020). Heavy metals are considered dangerous because they tend to bioaccumulate- when a chemical's concentration in a biological organism rises over time relative to its concentration in the environment. When substances are ingested and stored more quickly than they are degraded or eliminated (metabolised), compounds build up within living organisms. In addition to coming from consumer and industrial waste, heavy metals can also find their way into water supplies through acid rain, which breaks down soil and releases heavy metals into lakes, rivers, streams, and groundwater (Lenntech, 2004). The primary anthropogenic sources of heavy metals are the combustion of fossil fuels and gasoline, waste incinerators, mining, foundries, and smelters. The European Monitoring and Evaluation Program (EMEP) considers mercury, cadmium and lead to be the significant heavy metals of concern because they are the most toxic and have been shown to have profound effects on human health, among other things (Ilia et al., 2004).

Fish is a vital source of protein in the human body. It supplies crucial fatty acids, which lower the risk of heart disease and stroke. It also supplies critical vitamins and minerals and helps lower blood cholesterol levels (Al-Busaidi et al., 2011). Fish and other aquatic creatures are seriously threatened by chemical pollutants such as heavy metals that contaminate the marine environment. This could have long-term consequences for the human food chain (Abah et al., 2016). Fish have been utilised extensively as bioindicators of water and in the identification and evaluation of the biological effects of contaminants in the aquatic environment because they are sensitive indicators of heavy metal pollution (Anders et al., 1988; Ampiah-Bonney et al., 2007).

The accumulation of pollutant concentrations in aquatic species after absorption from the surrounding ambient medium is known as bioaccumulation. It explains how pollutants build up and become more concentrated in organisms than in the environment (Green et al., 2023). Studies concerning heavy metals bioaccumulation and pollution of water bodies have become a major global environmental issue for decades. The capacity of aquatic species to absorb heavy metals from the river, the concentration of heavy metals in the surrounding environment, and the organisms' feeding habits all influence how quickly heavy metals bioaccumulate in aquatic organisms (Ansari et al., 2004). One of the key indicators for keeping an eye on the geochemical cycle of heavy metals in the marine ecosystem is bioaccumulation assessment (Jamil-Emon et al., 2023). This study evaluated the concentrations of some of these metals in water and their bioaccumulation in three commercially abundant fish species from River Gongola to determine their safety for human consumption.

MATERIALS AND METHODS

Study Area

The study area was the Dadinkowa and Kanar axis of the River Gongola at Yamaltu Deba L.G.A. The River lies within latitude 10°21′42.73′′N and longitude 11°23′13.56′′E of the equator. The river is a major tributary of the Benue River, originating in the Jos plateau area. The region experiences two distinct seasons: the rainy season, which is characterised by heavy rainfall and the potential for flooding, and the dry season, which is characterised by dry weather. The region's climate is classified as a tropical continental type in Nigeria. The area typically experiences a short rainy season followed by a long, variable dry season. The dry season is characterised by calm, dusty, dry winds and intense heat (Santuraki et al., 2022). The area's people are into irrigation farming (including irrigation farming), fishing and livestock grazing along the river course.

Sample Collection

Fresh fish samples of *B. bayad macropterus*, *O. niloticus* and *C. gariepinus* were collected from the river with the help of local fishermen. These fish species were chosen because they are readily available and seen all year round in the river. Both water and Fish samples were collected once monthly between 07:00 and 9:00 hours between December 2021 and May 2023. Water samples were collected for eighteen (18) months, covering two dry and one rainy season at 0.5 m below the water surface (because the water is deep). The water samples were collected from two sampling locations 2 kilometres apart, then filtered in a pre-cleaned litre bottle acidified by adding 5 ml of concentrated nitric acid (HNO_3) and kept for analysis. The fish species were collected from the two sampling locations, where the water samples were taken using gill nets, put in an ice box and transported to the Biochemistry Laboratory of Gombe State University on each sampling day for preparation.

Sample Preparation and Digestion

The fish samples were put on a dissection board and allowed to thaw at room temperature before dissecting. Dissection of the fish samples was done using a clean stainless-steel knife to separate liver, gill, and muscle tissues. Composite samples of each species' liver, gill, and muscle tissues were drawn—each composite sample comprised three (3) fishes of the same species. The liver, gills and muscles of the three different fish species were placed differently on a foil paper and put in an oven at a temperature of 105^0C for 24 hours to obtain a constant weight (AOAC, 2000). After oven drying, the samples were homogenised differently for the three fish species using a porcelain mortar and pestle and put in a sample bottle before digestion.

Samples were digested in the Biochemistry Department laboratory of Gombe State University. Before the digestion process, all glass wares and sample bottles were carefully cleaned with deionised water, oven-dried, and powdered samples (1g of each sediment and fish sample) were precisely weighed using weighing balance (Ohaus Model- AR 2130) and placed into a round bottom flask. Each sample was mixed with concentrated acids W(10 ml nitric acid (HNO_3) and 5 ml perchloric acid ($HClO_4$) prepared in a measuring cylinder), shaken and placed on a hot plate (Kjabahl litter) to digest until a transparent or clear solution was reached. After letting the mixture cool, it was filtered through Whatman No.1 filter paper, and the filtrate was then filled with deionised water to the mark of 100ml. The mixture was then put into a labelled sample bottle for analysis, and a sample blank was made using the same digestion process. Still, it was put into the sample bottles without the fish samples for analysis (AOAC, 2000).

Sample Analysis

Samples were analysed using an atomic absorption spectrophotometer (Bulk Scientific, model 205). The instrument was calibrated by first analysing two standard solutions for each metal, followed by the blank analysis before the sample analysis. The metals analysed were Cu, Cr, Cd, As, Ni, Fe, Mn, and Zn.

Bioaccumulation Factor (BAF) Determination

According to USEPA (2014) guidelines, the BAF is the ratio of the chemical concentration of metals in the organism to that in the surrounding water. The bioaccumulation Factor (BAF) for heavy metals in fish was calculated as described by Oboh and Okpara (2019).

$$\textbf{BAF} = \frac{\text{Heavy metal concentration in fish } (mg/kg)}{\text{Heavy metal concentration in water } (mg/l)}$$

RESULTS AND DISCUSSION

Heavy Metals in Water

The summary of the results for heavy metals in water for the two sampled stations is shown in Table 1. Cd, As and Mn were above the WHO/NSDWQ standard for heavy metals in water. The values for Cd were both 0.006mg/l, which is greater than the 0.003mg/l limit for WHO/NSDWQ. Cd is a very toxic metal that can replace Zn in the body and can be an accumulative toxicant that can harm living organisms (Uba et al., 2019). Majorly, Cd is released into the environment by human activities such as manufacturing, gasoline, waste incineration, etc. (Lenntech, 2004; Ilia et al., 2004). Cd can cause kidney disease and is considered a cancer-causing agent. The high concentration of Cd recorded in this study might result from the dumpsite and municipal sewage in the river; water from other villages and towns upstream, even the Gombe metropolis, finds its way into the river. High Cd levels documented in this study agree with the findings of Talal et al. (2023), Omoigberale et al. (2014) and Emeka and Solomon (2020).

Table 1: Summary of Heavy Metals Concentration in Water of River Gongola (Dec. 2021- May 2023)

Heavy Metals	**Station 1**	**Station 2**	**P-Value**	**WHO**	**NSDWQ**
	Mean±SD	**Mean±SD**			
Cu	0.035	0.039	P>0.05	2	1
Cr	0.045	0.021	P>0.05	0.05	0.05
Cd	0.006	0.006	P>0.05	0.003	0.003
As	0.018	0.024	P>0.05	0.01	0.01
Ni	0.056	0.091	P>0.05	0.7	0.2
Fe	0.017	0.027	P>0.05	0.3	0.3
Mn	0.289	0.259	P>0.05	0.4	0.2
Zn	0.878	0.333	P<0.05	5	3

The values were 0.018 and 0.024mg/l for stations 1 and 2, respectively. Even at low concentrations, it is not an essential element, so it may be detrimental to the body. The high As values recorded in the study might be due to anthropogenic activities, especially of agricultural origin. The stations studied are close to agricultural lands that engage in rainy and dry season farming, and runoffs from these farmlands might end up in the water channel. These runoffs might contain heavy metals because farmers use pesticides and herbicides. Some of these heavy metals might be from fertilisers applied on the farmlands to boost productivity. Other causes can be municipal waste discharges from towns and cities nearby. Mn had 0.289 and 0.259 mg/l for stations 1 and 2, respectively. The trend for heavy metals concentration in station 1 was Zn >Mn>Ni>Cr>Cu>As>Fe>Cd, and for station 2 was Zn> Mn>Ni>Cu>Fe>As>Cr>Cd. Cr, Mn and Zn were higher in station 1 while Cu, As, Ni and Fe were higher in station 2. Both stations had the same value for Cd.

Heavy Metals in Fish

The variation of the concentrations of the different heavy metals studied in the liver of the three fish species is shown in Figure 1. Zn had the highest value in the liver of all the three fish species. However, the liver of *Clarias gariepinus* recorded the highest value of 0.508mg/kg, followed by *Bagrus bayad macropterus* with 0.478mg/kg. *Oreochromis niloticus* had the lowest value of Zn (0.195mg/kg). Zn, Cu, Cr, As, Ni, Fe and Mn were reported to be higher in the liver of *C. gariepinus* than the other two fish species. *O. niloticus* recorded the lowest concentration for most heavy metals studied (Figure 1).

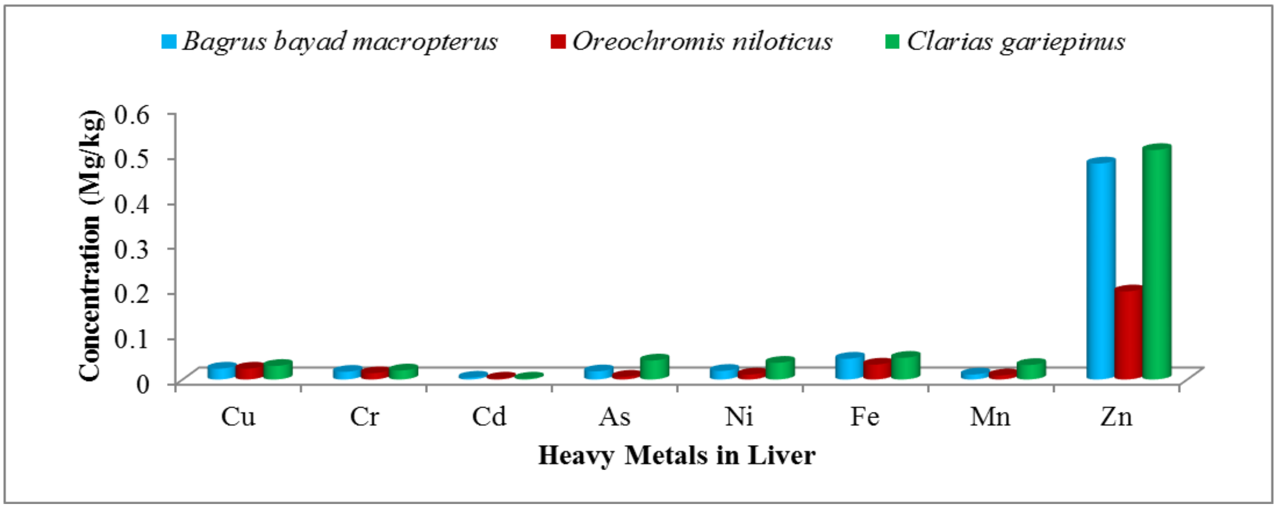

Figure 1: **Variation of Heavy metals in the liver of the three fish species**

In the muscle, Cd, Fe and Zn were the metals that recorded higher values in the muscle of *B. bayad macropterus.* Cu, Cr, As, Ni and Mn recorded higher values in the muscle of *C. gariepinus*. O. niloticus recorded the lowest muscle values for all the heavy metals studied. Zn was the highest in the muscles of the three fish species (figure 2) with the following values: 0.184, 0.170 and 0.177mg/kg, respectively, for *B. bayad macropterus, O.niloticus* and *C. gariepinus*. However, all the values of the heavy metals in the muscles were below the recommended limits for heavy metals in fish.

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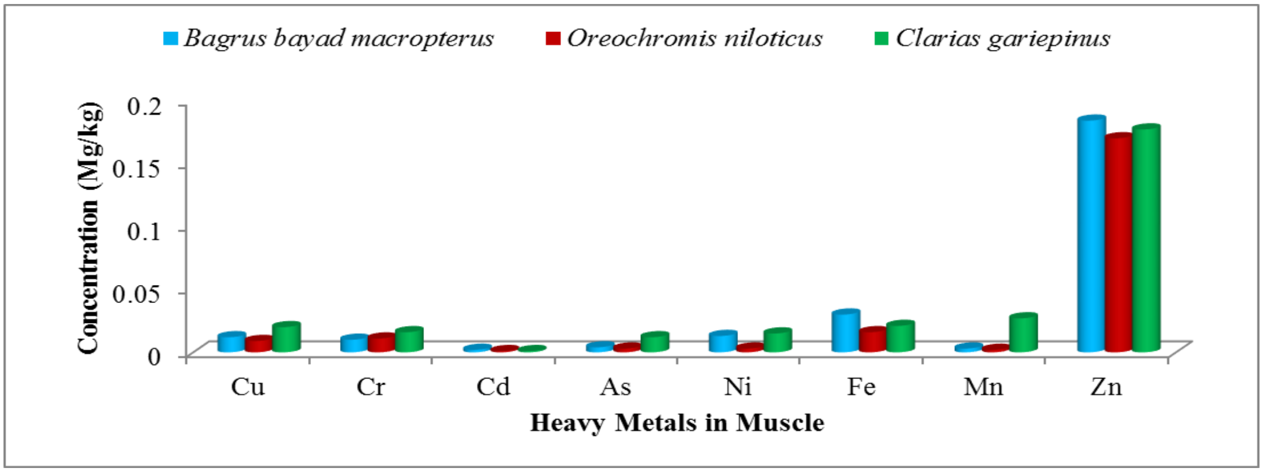

Figure 2: Variation of Heavy metals in the Muscles of the three fish species

Like the muscle and liver, Zn also recorded the highest concentration in the gills of the three fish species. However, *C. gariepinus* had the highest value (0.317mg/kg), followed by B. bayad macropterus (0.238mg/kg), then O. niloticus (0.202mg/kg), as seen in Figure 3 below. Cu, Cr, Ni and Zn were higher in *C. gariepinus* gills. Cd and Fe were higher in *B. bayad macropterus* gills and as was higher in the gills of *O. niloticus.* In all the heavy metals studied, Cd recorded the lowest values. However, the concentrations of these metals in the muscles were below the standard limit of WHO for heavy metals in fish.

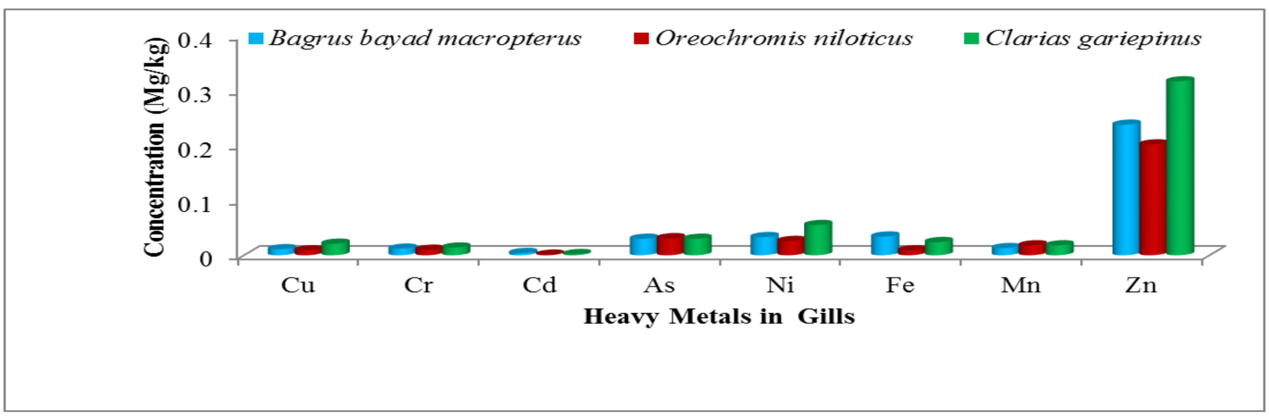

Figure 3: **Variation of Heavy metals in the Gills of the three fish species**

The mean values of the heavy metals studied in the different tissues of the three fish species were all below the WHO's recommended standard. This agrees with the findings of Ezekiel *et al.* (2019) and Rajesh-Kumar and Li (2018). The result of this study reported elevated values of the metals in the liver followed by the gills and then the muscles (Liver > gills > muscles) for all three fish species. Higher values in the liver agree with the reports of Green et al. (2023), who attributed the reason being that the liver is an active organ for physiological processes in metabolism and storage of essential metals. The gill is next in terms of high concentration. Due to their large surface area, the gills are pathways for metal ion exchange from water. This could be one of the reasons for high metal uptake (Dhaneesh et al., 2012). The muscles reported the lowest concentration of the metals in all three fish species. This could be because the muscle is not an active organ. Zn recorded the highest in all tissues (liver, muscles and gills) regarding individual metal concentration levels.

However, all the values were below the recommended standard. Zn is an essential metal with high bioavailability in soil and water (Akbulut & Akbulut, 2010). According to Al-weather (2008), most Zn uptake was through the skin, not the gills. He attributed the high levels of zinc in the tissues due to the uptake of the metals through the skin. Higher concentrations of Zn in this study agree with the reports of Ayodele et al. (2019). Analysis of variance showed that the cumulative heavy metal concentrations were higher in C.gariepinus, followed by B. bayad macropterus than in *O. niloticus* (figure 4).

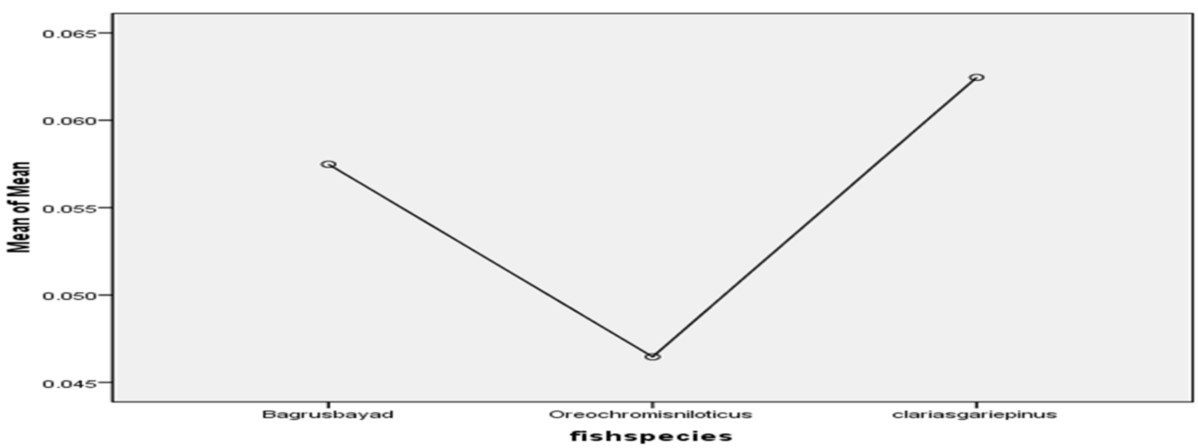

Figure 4: ANOVA Graph showing variation in heavy metals concentrations between fish species

The following factors may have contributed to *C. gariepinus'* higher metal concentration than the other fish species: 1. Feeding behaviour: *C. gariepinus* are omnivores, meaning they will consume a wide range of foods, such as dead animals, birds, reptiles, microscopic zooplankton, fish that are half their length or 10% of their body weight, and other fish (Moussa *et al.,* 2022; Mwebaza-Ndawula, 1984). When a fish engages in this type of feeding behaviour, it may be exposed to a wider variety of heavy metals than when it feeds on detritus and other aquatic foods like *B. bayad macropterus,* which is also omnivorous and *O. niloticus,* which is primarily herbivorous (Zita *et al.,* 2021; Usman *et al*., 2021). Even though both *C. gariepinus* and *B. bayad macropterus* are benthic and omnivorous fish species, *C. gariepinus* has a more varied diet than *B. bayad macropterus,* encompassing a greater variety of food items. 2. Habitat: compared to *O. niloticus*, a pelagic fish, *C. gariepinus,* a bottom-dwelling fish that spends most of its time feeding, may be more exposed to heavy metals in the sediment in this habitat (Moussa *et al.,* 2022; Zita *et al*., 2021). 3. Metabolism: *C. gariepinus* may metabolise metals differently than other species, impacting how it bioaccumulates metals (Heba *et al.,* 2022; Ezeonyejiaku *et al*., 2014). 4. Size and Exposure duration: compared to other fish species, *C. gariepinus* most have been exposed to heavy metals for a longer duration. They are also larger fish than *O. niloticus* and *B. bayad macropterus,* which may cause a higher accumulation because of their large bodies (Moussa *et al*., 2022; Kosgei *et al*., 2019).

Bioaccumulation Factors (BAF) for Heavy Metals in Fish

The BAF values of heavy metals for the three fish species studied are presented in Table 2. The BAF values were attained by dividing the concentration of heavy metals in fish by the concentration of heavy metals in water. According to Davies and Ekperusi (2021), an effective absorption of pollutants is indicated by a BAF value > 1. For *B. bayad macropterus*, all the heavy metals studied had BAF values < 1 except for Fe (1.36±0.01). All the BAF values for *O.niloticus* for all heavy metals studied were <1. Fe had BAF values >1, Zn had BAF = 1 for C. gariepinus, while the other heavy metals were <1. The BAF values were 1.16±0.01, 1.15±0.01 and 1.00±0.017 for As, Fe and Zn, respectively.

Table 2: Bioaccumulation factors of Metals in *B. bayad macropterous, O. niloticus* and *C. gariepinus*

Heavy Metals	*B. bayad macropterus*	*O. niloticus*	*C. gariepinus*
Cu	0.40±0.01	0.36±0.01	0.61±0.01
Cr	0.62±0.00	0.56±0.00	0.79±0.00
Cd	0.56±0.00	0.22±0.00	0.28±0.00
As	0.72±0.01	0.56±0.01	1.16±0.01
Ni	0.24±0.01	0.15±0.01	0.39±0.02
Fe	1.36±0.01	0.72±0.01	1.15±0.01
Mn	0.03±0.01	0.04±0.01	0.10±0.01
Zn	0.90±0.16	0.57±0.02	1.00±0.17

Most of the BAF values for this study were < 1 except for Fe in *B. bayad macropterus* and *C. gariepinus* and As and Zn in *C. gariepinus,* which were ≥ 1, indicating possible bioaccumulation by these metals. The BAF values show that *C. gariepinus* had BAF values ≥ 1 in As, Fe and Zn, showing that it has the highest potential for bioaccumulation among the three fish species. This could be due to the high concentration of heavy metals in the tissues of the fish compared to other species. A benthic fish with a diverse diet can concentrate higher values than *O. niloticus*. The *B. bayad macropterus* was the next, having a BAF > 1 for Fe. For *O. niloticus*, all the heavy metals had BAF < 1, showing no probability of bioaccumulation. This could be due to lower levels of heavy metals in its tissues compared to the other two species, which are also pelagic. Another reason could be that the fish had a short exposure period/residence time in the river.

CONCLUSION AND RECOMMENDATIONS

The study's findings showed that River Gongola's water at this location is contaminated due to higher Cd, As and Mn values. Heavy metal accumulation varied depending on the fish tissue and species. *C. gariepinus* had the highest cumulative heavy metals concentration, followed by B. bayad macropterus and *O. niloticus*. The liver had the highest concentration, followed by the gills and the muscles. Most BAF values showed no probability of bioaccumulation except for Fe in *B. bayad macropterus*, *C. gariepinus,* and As in *C.gariepinus*. From the study, it can be concluded that the water of River Gongola at this location is contaminated with Cd, As, and Mn. Therefore, environmental laws should be reinforced and strictly adhered to to protect the aquatic ecosystem and humans that depend on them. Watershed management should be focused on agricultural activities by encouraging organic farming practices to minimise the use of inorganic substances that currently serve as contaminants in the river

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Conflict of Interest
The authors declare that there is no conflict of interest regarding the publication of this paper.

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