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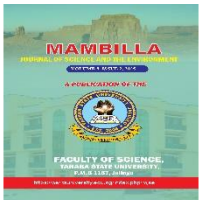

DETERMINATION OF LEVELS OF HERBICIDE RESIDUES AND PHYSICOCHEMICAL CHARACTERIZATION OF SEDIMENTS FROM SELECTED RIVERS IN AGRICULTURAL AREAS OF TARABA STATE, NIGERIA

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ABSTRACT

This study investigated the presence of glyphosate, 2,4-dichlorophenoxyacetic acid (2,4-D), their degradation products and associated physicochemical properties of river sediments from three agriculturally impacted rivers-Kpantinapo, Bakin-Dutse and Lamurde/Nukkai- in Taraba state, Nigeria. Twelve sediment samples were analyzed for pH, total organic carbon (TOC), total organic matter (TOM), cation exchange capacity (CEC) and particle size distribution using standard procedures (Walkley-Black, ammonium acetate and hydrometer methods, respectively). Herbicide residues were extracted via soxhlet extraction with n-hexane and acetone, cleaned, derivatized and quantified using Gas Chromatography-Mass spectrophotometer (GC-MS). 2,4-D was not detected in any of the samples, likely due to its rapid degradation; however, the degradation product 2,4-dichlorophenol was found at a mean concentration of 1.12 mg/kg in six sites. Glyphosate was detected more frequently with a mean concentration of 1.22 mg/kg, indicating more extensive use. Residue concentrations were generally higher in intertidal zones compared to bottom sediments, likely due to surface run-off from surrounding farmlands. Sediment pH ranged from acidic to neutral and moderate levels of TOC and TOM support a medium capacity for contaminant retention and mobility. These findings highlight the persistence of certain herbicide residues and underscore the need for continuous sediment quality monitoring to inform sustainable agricultural and environmental management practices in the region.

1. Introduction

Assessing sediment quality is crucial for understanding the health of aquatic ecosystems and ensuring safe environments for aquatic life. The physicochemical characteristics of river sediments significantly influence the distribution of aquatic organisms and the overall ecological balance. These characteristics play a vital role in the retention, movement, and bioavailability of contaminants such as herbicides in aquatic ecosystems (Arias-Estévez *et al.*, 2008; Kah & Brown, 2006). Herbicides are essential in modern agriculture, enhancing crop yields and reducing labour costs. However, their widespread use raises concern about environmental contamination, especially in aquatic ecosystems where residues can accumulate in sediments (Schulz, 2004).

In Nigeria, the use of herbicides like glyphosate and 2, 4-D has increased alongside large-scale commercial farming (PCPB, 2005). These chemicals enter water bodies through runoff, leaching, equipment washing, and improper disposal (Yang *et al.*, 2005). Sediments serve as reservoirs for herbicide residues, which can be released back into the water and biota through processes like resuspension and bioaccumulation (Xue *et al.*, 2006). This situation poses risks to aquatic organisms and human health, either through direct exposure or by consuming contaminated fish (Johansen *et al.*, 1996). While earlier studies have looked into pesticide residues in water and food crops across Nigeria (Ezekiel *et al.*, 2023; Barau *et al.*, 2023), there is a lack of data regarding herbicide contamination in river sediments, especially in Kpantinapo, Bakin Dutse, and Lamurde Rivers in Taraba State. Given the prevalent use of

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glyphosate and 2, 4-D in local agriculture, it is essential to understand their residue levels and environmental impact. This study aims to evaluate important physicochemical parameters of sediments from selected rivers in Taraba State and determine the concentrations of glyphosate and 2, 4-D residues along with their toxic degradation products in these river sediments. The findings from this research may provide essential data for policymakers, environmental agencies, and farmers regarding sediment quality and herbicide pollution in Taraba State. Gaining insight into residue accumulation in sediments can help to formulate strategies for sustainable herbicide use and effective water quality management (Oruonye *et al.,* 2024). Additionally, understanding the physicochemical properties of sediments is crucial for predicting the fate and transport of contaminants in aquatic ecosystems (Rengasamy & Churchman, 1999).

2. Materials and Methods

2.1 Study Area

The study areas are located in three different Local Governments Areas of Taraba State: Ardo-Kola (8.8333° N, 11.3667° E), Yorro (8.8833° N, 11.5667° E) and Jalingo (8.8935° N, 11.3596° E) Local Government Areas of Taraba State, Nigeria. These locations were selected for their proximity to farming activities and the use of herbicides based on observation. The economic activities in Ardo-Kola, Yorro, and Jalingo Local Governments Areas of Taraba State are predominantly centred on agriculture, which serves as the backbone of the local economy. This agricultural focus significantly influences the choice of these locations for the research work.

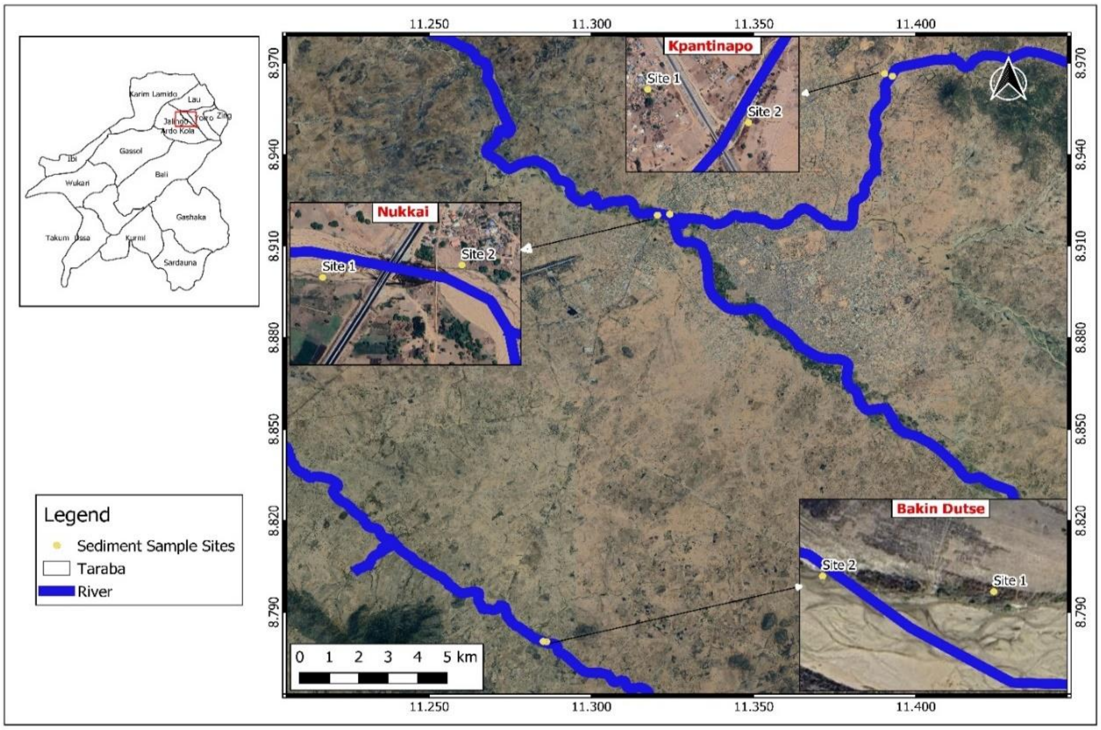

Figure 1. Map of Taraba showing the sampling sites used in the study

2.2 Sample Collection and Preparation

Sediment samples were collected from two points per sampling site, totalling twelve (12) samples. Samples were collected from the bottom bed and intertidal region and transported under refrigerated conditions to prevent degradation. In the laboratory, the samples were dried at 40 °C, homogenized, pulverised through 1 mm sieve mesh and then stored under cold conditions until analysis.

2.3 Analysis of Sediment Samples

Physicochemical parameters of the sediments were analyzed using standard laboratory techniques. pH was measured with a digital pH meter, while Total Organic Carbon (TOC) and Total Organic Matter (TOM) were determined using the Walkley-Black method. Cation Exchange Capacity (CEC) was evaluated using the ammonium acetate method and particle size distribution by hydrometer method to classify sediment texture. For herbicide residue analysis, residues were extracted using the Soxhlet method, cleaned with silica gel column chromatography and derivatized through acid-methanol methylation. Quantification was carried out using GC-MS (Agilent 6980) following AOAC (1990) guidelines.

3. Results and Discussion

The results of concentrations of herbicide residues and physicochemical analysis measured across the different sampling stations are presented in the Tables 1, 2 and 3.

Table 1: Results of analysis of levels of herbicide residues and physicochemical parameters of samples obtained from Nukkai sampling site

Parameter	Nukkai I Bottom bed	Nukkai I Intertidal zone	Nukkai II Bottom Bed	Nukkai II Intertidal zone
2,4-dichlorophenoxyacetic Acid (mg/kg)	0.00 ± 0.0	0.00 ± 0.00	0.00±0.00	0.00 ± 0.00
Dichlorophenol (mg/kg)	0.00± 0.00	-	0.00± 0.00	-
Glyphosate (mg/kg)	1.52± 0.00	-	1.52± 0.00	-
Glycine (mg/kg)	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
AMPA (mg/kg)	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
pH	5.00± 0.00	5.80± 0.00	5.00± 0.00	5.80± 0.00
CEC (Cmolkg^{-1} soil)	10.09±0.00	8.32± 0.00	11.22±0.00	8.79±0.00
TOC %	0.16±0.00	0.39±0.00	0.13±0.00	0.80±0.00
TOM %	0.28±0.00	0.67±0.00	0.22±0.00	1.39±0.00
Particle size (%)				
Clay	1.05±0.00	1.04±0.00	1.01±0.00	1.06±0.00
Silt	0.01±0.00	0.00±0.00	0.01±0.00	0.00±0.00
Sand	98.94±0.00	98.98±0.00	98.98±0.00	98.95±0.00

Table 2: Results of analysis of levels of herbicide residues and physicochemical parameters of samples obtained from Kpantinapo sampling site

Parameter	Kpantinapo I Bottom bed	Kpantinapo I Intertidal region	Kpantinapo II Bottom Bed	Kpantinapo II Intertidal region
2,4-dichlorophenoxyacetic Acid (mg/kg)	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dichlorophenol (mg/kg)	0.00±0.00	2.24±0.00	0.00±0.00	2.31±0.00
Glyphosate (mg/kg)	0.73±0.00	2.57±0.00	0.73±0.00	2.43±0.00
Glycine (mg/kg)	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
AMPA (mg/kg)	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
pH	6.50±0.00	5.80±0.00	5.90±0.00	6.30±0.00
CEC (cmolkg^{-1} soil)	8.46±0.00	11.05±0.00	9.65±0.00	9.47±0.00
TOC %	0.04±0.00	0.00±0.00	0.19±0.00	0.72±0.00
TOM %	0.06±0.00	0.00±0.00	0.33±0.00	1.24±0.00
Particle size (%)				
Clay	1.02±0.00	1.03±0.00	1.05±0.00	1.02±0.00
Silt	0.0014±0.00	0.0015±0.00	0.0806±0.00	0.0036±0.00
Sand	98.98±0.00	98.97±0.00	98.87±0.00	98.98±0.00

Table 3: Results of Analysis of levels of herbicide residues and physicochemical parameters of samples obtained from Bakin-Dutse sampling site

Parameter	Bakin-Duste I Bottom bed	Bakin-Duste I Intertidal region	Bakin-Duste II Bottom bed	Bakin-Duste II Intertidal region
2,4-dichlorophenoxyacetic Acid (mg/kg)	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dichlorophenol (mg/kg)	2.51±0.00	1.84±0.00	2.58±0.00	1.92±0.00
Glyphosate (mg/kg)	0.00±0.00	2.37±0.00	0.28±0.00	2.53±0.00
Glycine (mg/kg)	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
AMPA (mg/kg)	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
pH	5.60±0.00	5.00±0.00	6.60±0.00	4.60±0.00
CEC (cmolkg^{-1} soil)	10.58±0.00	10.02±0.00	8.22±0.00	8.04±0.00
TOC %	0.59±0.00	0.80±0.00	0.05±0.00	0.80±0.00
TOM %	1.02±0.00	1.37±0.00	0.08±0.00	1.39±0.00
Particle size (%)				
Clay	1.05±0.00	1.05±0.00	1.03±0.00	1.05±0.00
Silt	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Sand	98.96±0.00	98.96±0.00	98.97±0.00	98.96±0.00

Key**:** AMPA= aminomethylphosphonic acid; CEC= catione exchange capacity; TOC= total organic carbon; TOM= total organic matter.

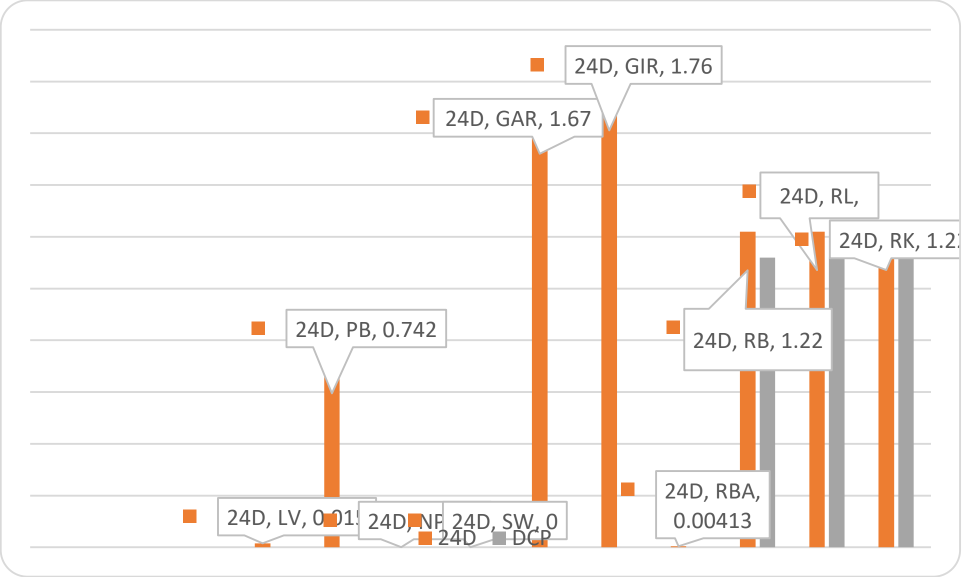

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Figure 1. Values of parameters obtained in the present study and those obtained in similar studies

Key:

PS - Plateau State (Fadama soils)	RBA- River Benue Adamawa
GIR- Giade River, Nigeria	RB- River Bakin-dutse
RL- River Lamurde	RK- River Kpanti-Napo
MR- Mannitoba Rivers, Canada	SSR- South Saskatchewan River, Canada
LV- Lagoon of Venice, Italy	GAR- Gadau River, Nigeria
PB- Parana Basin, Argentina	
NPR- North Pampasic Region, Argentina	
SW- Standing water, Canada	

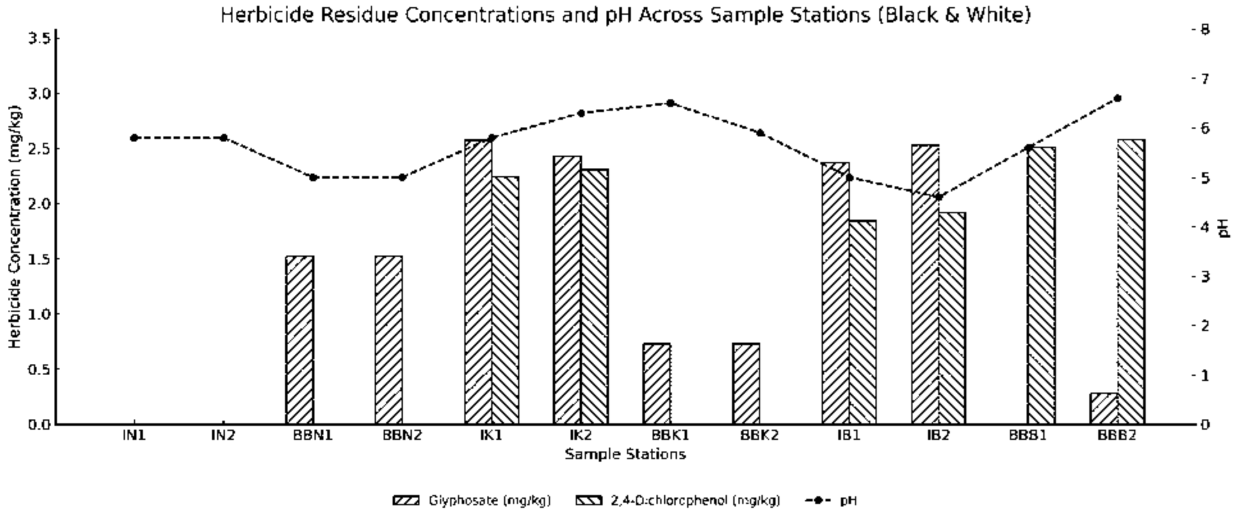

Figure 2. Herbicides Residue Concentrations and pH across the different Sampling Sites
Key: IN- Intertidal Nukkai ; IB- Intertidal Bakin-Dutse ; IK- Intertidal Kpanti-Napo
BBB - Bottom bed Bakin-Dutse ; BBK- Bottom bed Kpanti-Napo ; BBN- Bottom bed Nukkai

The results as shown in Tables 1-3, depict an interesting pattern in the distribution and persistence of these chemicals in the environment. 2, 4-Dichlorophenoxyacetic acid (2, 4-D), a widely used herbicide has a mean concentration of 0 mg/kg, indicating its absence in sediment samples. The absence of 2, 4-D in the sediment samples from the twelve sites is consistent with studies that documented its rapid degradation in the environment. Under moist conditions at moderate temperatures, the half-life of 2, 4-D in soil is typically around 7 days or less. This implies that the herbicide breaks down quickly and may not be detected if sampling occurs after this period (Inchem.org, 2000). In dry or acidic soils, however, degradation can slow considerably, with half-lives extending up to 250 days under extreme dry conditions (Inchem.org, 2000). Microbial degradation is known to be the primary mechanism driving 2, 4-D breakdown, and its efficiency depends on microbial populations adapted to the herbicide and tends to increase after repeated exposure (Inchem.org, 2000; PMC, 2024). It is also established in other researches that 2, 4-D is often short-lived in sediments due to microbial degradation and environmental factors (Gaultier *et al.,* 2009; Nesbitt & Watson, 1980). The occurrence of 2,4-Dichlorophenol, a degradation product found at several sites in this study, further supports that 2,4-D was applied but metabolized before sampling (Pub Med, 2018; PMC, 2024). Prajaprati *et al.* (2023) and Gamhewage (2020) in similar works reported low concentrations in sediments. Glyphosate, another commonly used herbicide was detected in the majority of the samples with the exception of sites IN1, IN2, and BBB1. This widespread presence suggests more extensive use of glyphosate compared to 2, 4-D in the studied areas. The mean glyphosate concentration in the sediment samples analyzed in this study was 1.223 mg/kg. This level is high but slightly low comparable to glyphosate concentrations reported by Kolo *et al.* (2024) for two Nigerian rivers: Gadau (1.67 mg/kg) and Giade (1.76 mg/kg). In contrast, glyphosate concentrations in other regions of the world were notably lower: 0.250 mg/kg in standing water in Canada (Robichaud *et al.,* 2021), 0.015 mg/kg in the Lagoon of Venice, Italy (Feltracco *et al.,* 2022) and 0.742 mg/kg in the Paraná Basin, Argentina (Ronco *et al.,* 2016). These differences likely reflect variations in local agricultural practices, environmental conditions, and regulatory enforcements. The relatively high glyphosate levels in Nigeria environments may be attributed to its widespread usage by untrained applicators and weaker regulatory controls compared to other countries. Earlier researchers corroborate our findings that glyphosate and its degradation products in water, sediment, and fish tissues at levels exceeding acceptable safety limits, posing potential ecological and human health risks (Alarape *et al.,* 2023). Similarly, Nwinyimagu *et al.* (2023) reported ecological risks linked to glyphosate residues in sediments and aquatic organisms in Ebonyi State. Collectively, these findings highlight concerns over herbicide use practices and their consequences in Nigerian environments.

Notably, glycine and aminomethylphosphonic acid (AMPA), known degradation product of glyphosate, were not detected in any of the samples. Its absence is somewhat surprising, as AMPA is typically considered a persistent degradation product of glyphosate in soil. Its absence could potentially be due to rapid degradation or leaching of these compounds, or other environmental factors influencing their persistence (Ohara *et al.,* 2021). The mean concentration of dichlorophenol in the sediment samples was 1.116 mg/kg, a notably high value. This is significant because previous studies, including those carried out in Nigeria (Kolo *et al.,* 2024) and Canada (Prajaprati *et al.,* 2023), reported dichlorophenol concentrations as not detected. The elevated levels found in this study suggest the presence of localized environmental factors or contamination sources that have led to increased accumulation of dichlorophenol in the sediments.

The pH values of the collected samples were in the range of 4.6 - 6.6, indicating acidic soil conditions. The pH values exhibited some variability across the sampling locations as shown in Tables 1-3. The predominantly acidic nature of the samples (pH range 4.6 - 6.6) could explain the moderately elevated herbicide residue levels found in the study area. Generally, herbicide degradation tends to occur in sediments with higher pH levels. This phenomenon could potentially lead to reduced residue levels in less acidic environments (Ye *et al.*, 2018). In acidic conditions, herbicide residues may exhibit increased stability and persistence in sediments. Conversely, in more basic environments, herbicide residues might degrade faster or become more mobile (Mamy *et al.,* 2015). Also, pH affects adsorption to sediment particles. At lower pH levels, herbicides may bind more strongly to sediment particles, resulting in moderately higher detectable residue levels (Schilder, 2008). However, adsorption could result in higher residue levels detection in more acidic soils (Kah and Brown, 2006). Likewise, pH can indirectly affect herbicide behaviour by altering sediment properties such as particle size and organic matter content. These changes can influence herbicide adsorption and mobility (Simmons *et al.,* 2006). Comparing the pH data with the herbicide residue levels presented in Table 1-3, a potential correlation between the acidic soil conditions and the detected herbicide residues is observed as shown in Figure 2. The persistence patterns observed for glyphosate and dichlorophenol (DCP) in acidic soils (pH 4.6-6.6) agrees with established literature on pH-dependent herbicide behaviour. The findings of Börjesson *et al.* (2000) who reported slowed microbial degradation in acidic soils (pH < 6.0) supports our results. The weaker adsorption of glyphosate at low pH (Dollinger *et al.,* 2015) further suggests that microbial factors, rather than sorption, primarily control residue levels in these acidic soils.

The observed cation exchange capacity (CEC) range of 8-11 cmol/kg in our study soils classifies them as having low to moderate cation retention capacity (CEC Management Board, 2019) and follows an established soil classification system. This CEC range typically indicates reduced ability to retain cationic herbicides (Mendes *et al.*, 2014; Kanissery *et al.,* 2018). Wagenet *et al.* (1987) demonstrated that soils with CEC < 15 cmol/kg generally show reduced herbicide adsorption; our results suggest that other soil properties may compensate for limited cation exchange capacity. Kanissery *et al.* (2018) have shown that specific mineral surfaces in coarse-textured soils can provide active binding sites independent of CEC, which may explain the retention observed in our study. This is particularly relevant given that sediment mineral composition including iron and aluminium oxides is known to interact strongly with herbicides like glyphosate and dichlorophenol through surface complexation (Li *et al.*, 2019).

The acidic pH conditions (4.6 - 6.6) in our study area likely played a pivotal role in modifying typical CEC-herbicide relationships. Manuchehri *et al.* (2018) demonstrated that pH values below 6.0 can increase herbicide adsorption to soil particles by up to 40 %, regardless of CEC, through protonation of functional groups and changes in surface charge. Therefore, the growing recognition that pH can override CEC as the dominant factor controlling herbicide retention in acidic environments supports our findings (UC ANR, 2017).

Microbial degradation dynamics provide another crucial piece of this puzzle. Kah and Brown (2006) emphasize CEC's role in herbicide availability for degradation, our results align more closely with Huang *et al.* (2019), who found that acidic conditions can inhibit microbial activity to such an extent that degradation rates become negligible, even when herbicides are not strongly adsorbed. This may explain the persistence that was observed in our work despite moderate CEC values that would typically suggest greater herbicide mobility and availability for breakdown. Soils with low to moderate CEC, typically between 5 and 15 cmol/kg, are more prone to nutrient deficiencies and the leaching of important cations like potassium (K^+) and magnesium (Mg^{2+}) (CEC Management Board, 2019). This can lead to reduced fertility and create challenges for plant growth in terrestrial ecosystems.

The TOC values ranged from 0 - 0.80 %, while TOM values ranged from 0 to 1.39 %. The relationship between total organic carbon (TOC), total organic matter (TOM), and herbicide retention observed in this study presents both confirmations and extensions of current scientific understanding. The measured TOC (0 - 0.80 %) and TOM (0 - 1.39 %) values classify these soils as organically depleted according to standard guidelines (ELGA Lab Water, 2021), which would typically suggest reduced herbicide retention capacity. The measured TOC (0 - 0.80 %) and TOM (0 - 1.39 %) values in our study soils are significantly lower than the ranges typically examined in herbicide retention studies (Mendes *et al.,* 2014 and Guo *et al.,* 2000). Moderately high herbicide residues were observed in our work that challenges conventional organic matter-adsorption relationships. Mendes *et al.* (2014) established that herbicide adsorption coefficients (Kd) increase linearly with TOC content, our results demonstrate retention exceeding these predictions. This discrepancy is explained by Kah and Brown's (2006) finding that mineral surfaces become the dominant adsorption sites when TOC falls below 1 %, a threshold soils used in our study consistently met and agrees with the work of Mendes *et al.* (2014), where lower organic content generally leads to increased herbicide mobility due to fewer adsorption sites. Low organic matter content is expected to limit microbial degradation potential (Guo *et al.,* 2000) and reduce particle aggregation (Boivin *et al.,* 2005) thus potentially increasing herbicide presence in the water column. However, the detection of moderately high herbicide residues despite low TOC/TOM values reveals a more complex interaction of soil properties governing herbicide fate. This apparent contradiction can be explained through several mechanisms supported by contemporary research. The acidic pH conditions (4.60 - 6.60) in these soils likely enhanced herbicide binding to mineral surfaces, as demonstrated by Manuchehri *et al.* (2018), showing that low pH can increase adsorption to soil particles independent of organic matter content. Similarly, the hydrophobic nature of certain herbicides like dichlorophenol enables strong binding to available organic matter and mineral surfaces even at low concentrations (Li *et al.,* 2019). Also, the presence of reactive mineral components (clays, iron/aluminum oxides) may have provided alternative adsorption sites, compensating for the limited organic matter (Kanissery *et al.,* 2018). Other environmental conditions such as moisture content may have facilitated herbicide-soil particle interactions (UC ANR, 2017), while potentially limited microbial activities in these challenging conditions could have reduced degradation rates (Huang *et al.,* 2018).

Tables 1-3 depict the relationship between soil particle size distribution and herbicide retention across the twelve sampling sites. The particle size analysis across all sampling sites indicates a remarkably homogeneous sandy composition, with sand content consistently exceeding 98.8 %, clay fractions barely reaching 1.06 %, and silt nearly absent (0 - 0.08 %). Such extreme textural characteristics would traditionally predict rapid herbicide leaching. 2.57 mg/kg of glyphosate and 2.58 mg/kg of dichlorophenol were detected and this poses a challenge to conventional soil-texture models. These findings contrast sharply with established thresholds from Kah and Brown (2006), who identified 15-20 % clay as necessary for substantial herbicide adsorption (Kd > 20 L/kg) but agrees with more recent work by Kanissery *et al.* (2018) who reported that iron oxide coatings on sand grains can provide adsorption capacity equivalent to 5 - 8 % clay content. The apparent contradiction between the ultra-sandy texture soils deployed in our study and herbicide retention becomes explicable when considering the modifying effects of acidic pH (4.60 - 6.60) and the work of Manuchehri *et al.* (2018) supports this finding. This pH effect appears particularly pronounced in Bakin-Dutse sediments, where despite nearly identical particle size distributions to other sites (98.96 - 98.97 % sand, 1.05 % clay), dichlorophenol concentrations reached 2.58 mg/kg at pH 4.60 - a phenomenon consistent with UC ANR (2017) reports on pH-enhanced hydrophobic compound retention in sandy matrices. The virtual absence of silt (0 - 0.08 %) removes what Mendes *et al.* (2014) identified as an important transitional retention phase in soils with 20 - 40 % silt content, forcing greater reliance on sand mineralogy for adsorption. Amazingly, in the Kpantinapo site even the complete absence of measurable TOC (0 %) does not preclude significant glyphosate retention (2.57 mg/kg) when minimal clay (1.03 %) is present under acidic conditions (pH = 5.80) and agrees with of work of Li *et al.* (2019) where mineral-dominated adsorption in ultra-low TOC sands is reported. Even with a higher sand content, if the sand particles are coated with iron oxides or other substances, they can still adsorb and retain herbicides (Gimsing *et al.,* 2004). Although silt and clay are present in smaller amounts, they might form aggregates or complexes with sand particles, increasing the surface area for herbicide adsorption (Six *et al.,* 2004). The presence of certain metal oxides like iron oxides, aluminum oxides, or calcium carbonate in the sand can enhance herbicide adsorption (Gimsing *et al.,* 2007). Most herbicides are weak acids or bases, and their adsorption increases at lower pH values. This is because the herbicide molecules become more protonated, making them more compatible with the sediment surface as already mentioned (Kah and Brown, 2006). Application history also plays a major role. Recent or repeated applications of glyphosate and dichlorophenol can lead to higher residue levels, regardless of particle size distribution (Borggaard and Gimsing, 2008). The high sand content (> 98 %) in all samples would typically suggest low herbicide retention. However, the observed moderately high herbicide residue levels indicate that other factors are influencing herbicide behavior in these soils as explained above.

The persistence of glyphosate and dichlorophenol in these sandy soils could be attributed to their specific chemical properties. Glyphosate, for instance, has been shown to form strong complexes with metal ions present in soil minerals, which can enhance its retention even in sandy soils (Gimsing *et al.,* 2007). The small fractions of clay (1-1.06 %) and silt (0 - 0.08 %) present in the samples may play a disproportionate role in herbicide retention. Clay particles, despite their low percentage, have a much higher surface area per unit mass compared to sand and can significantly contribute to herbicide adsorption (Spark & Swift, 2002). Furthermore, the potential presence of metal oxides coating the sand particles could provide additional adsorption sites for herbicides. Iron and aluminum oxides, in particular, have been shown to strongly adsorb glyphosate (Gimsing *et al.,* 2004). These results collectively suggest that in tropical sandy sediments, the surface chemistry of sand grains - particularly their iron/aluminum oxide coatings and pH-dependent charge characteristics - outweigh classical texture-based predictions of herbicide behaviour. There are no established Maximum Residue Limits (MRLs) or sediment quality guidelines for glyphosate, 2, 4-D, and their degradation products like AMPA and dichlorophenol. von Mérey *et al.* (2016) reported that typical environmental levels of glyphosate and AMPA pose minimal risk to soil organisms, with high no-observed-effect concentrations (NOECs) indicating low ecological impact. This suggests that while herbicide residues are present in sediments, they may not exceed harmful thresholds based on current research, highlighting the need for continued monitoring and management strategies.

4. Conclusion

This study highlights the presence of glyphosate and its degradation product in Taraba State river sediments, with higher concentrations in intertidal zones. Dichlorophenol, a key degradation product of the widely used herbicide 2, 4-D, has often been overlooked in research, as the focus predominantly centers on the parent herbicide itself. This study's deliberate inclusion and analysis of dichlorophenol provide a more comprehensive understanding of herbicide residue dynamics and their environmental impact. By addressing both 2, 4-D and its degradation product, this study enhances knowledge on the persistence and fate of herbicide residues in ecosystems, which is critical for assessing long-term environmental risks.

The findings underscore the need for regular monitoring to assess long-term environmental impacts and inform sustainable herbicide application practices. Higher contamination in intertidal zones suggests potential ecological risks. Monitoring and sustainable herbicide application is necessary to prevent further accumulation. This analysis highlights the urgent need for continuous herbicide residue monitoring to protect aquatic ecosystems and public health. The results emphasize the need for multi-factorial assessment approaches that consider mineral composition, pH, and moisture conditions alongside organic matter content when predicting herbicide persistence. Overall, these findings emphasize the importance of monitoring herbicide residues in agricultural zones, as their persistence varies significantly across locations due to environmental, regulatory, and agricultural differences.

References

AOAC. (1990). Official methods of analysis (15th ed.). Association of Official Analytical Chemists.

Alarape, S. A., Adeoye, D. D., Amusa, A. O. & Adeyemo, O. K. (2024). Haematological parameters and biochemical indices of African catfish (Clarias gariepinus) exposed to glyphosate-based herbicide (Force up) for 96 hours. *Frontiers in Toxicology*, *6*, 1448861

Arias-Estévez, M., López-Periago, E., Martínez-Carballo, E., Simal-Gándara, J., Mejuto, J. C. & García-Río, L. (2008). The mobility and degradation of pesticides in soils and the pollution of groundwater resources. *Agriculture, Ecosystems and Environment*, 123(4), 247-260.

Barau, B.W., Yusufu, W.N., Abubakar, A. & Fadilah, A.S. (2023). Pesticide Residue Contamination of Some Cereals and their Consequential Health Implication in the Food Chain of Taraba Northern Geo-political Region, Taraba State. *Asian Journal of Environment & Ecology*, 22(1), 1-18. DOI: 10.9734/ajee/2023/v22i1470.

Boivin, A., Cherrier, R. & Schiavon, M. (2005). A comparison of five pesticides adsorption and desorption processes in thirteen contrasting field soils. *Chemosphere*, 61(5), 668-676.

Börjesson, E. & Torstensson, L. (2000). New methods for determination of glyphosate and (aminomethyl) phosphonic acid in water and soil. *Journal of Chromatography A*, 886(1-2), 207-216.

CEC Management Board. (2019). CEC guidelines - Issue 33. Retrieved October 15, 2024, https://cectests.org/assets/CEC_Guidelines_Issue_33.pdf

Dollinger, J., Dagès, C. & Voltz, M. (2015). Glyphosate sorption to soils and sediments predicted by pedo transfer functions. *Environmental Chemistry Letters*, 13(3), 293-307.

ELGA Lab Water. (2021). Total organic carbon (TOC) analysis and measurement. https://www.elgalabwater.com/blog/total-organic-carbon-toc

Ezekiel, B. B., Adelalu, T. G., Christopher, J. N. & Alhassan, T. (2023). Assessment of agro-allied chemical pollution on surface water quality of River Lamurde and Mayo-gwoi, Jalingo, Taraba state, Nigeria. *Advances in Environmental and Engineering Research*, 4(1), 1-21.

Feltracco, M., Barbaro, E., Morabito, E., Zangrando, R., Piazza, R., Barbante, C. & Gambaro, A. (2022). Assessing glyphosate in water, marine particulate matter, and sediments in the Lagoon of Venice. *Environmental Science and Pollution Research*, *29*(11), 16383-16391.

Gamhewage, M. (2020). Pesticides in the water-column and bottom sediments of four Manitobarivers.

Gaultier, J., Farenhorst, A., Kim, S. M., Saiyed, I., Messing, P., Cessna, A. J. & Glozier, N. E.(2009). Sorption-desorption of 2, 4-dichlorophenoxyacetic acid by wetland sediments. *Wetlands*, 29(3), 837-844.

Gimsing, A. L., Borggaard, O. K. & Bang, M. (2004). Influence of soil composition on adsorption of glyphosate and phosphate by contrasting Danish surface soils. *European Journal of Soil Science*, 55(1), 183-191.

Gimsing, A. L., Szilas, C. & Borggaard, O. K. (2007). Sorption of glyphosate and phosphate by variable-charge tropical soils from Tanzania. *Geoderma*, 138(1-2), 127-132.

Borggaard, O. K. & Gimsing, A. L (2008). Fate of glyphosate in soil and the possibility of leaching to ground and surface waters: a review. *Pest Management Science: formerly Pesticide Science*, 64(4), 441-456.

Guo, L., Jury, W. A., Wagenet, R. J. & Flury, M. (2000). Dependence of pesticide degradation on sorption: nonequilibrium model and application to soil reactors. *Journal of Contaminant Hydrology*, 43(1), 45-62.

Huang, Y., Xiao, L., Li, F., Xiao, M., Lin, D., Long, X. & Wu, Z. (2019). Microbial degradation of pesticide residues and an emphasis on the degradation of cypermethrin and 3-phenoxy benzoic acid: A review. *Molecules*, 23(9), 2313.

Inchem.org.(2000).(2,4-D):Environmental Aspects. https://www.inchem.org/documents/ehc/ehc/ehc84.htm

Johansen, H. R., Alexander J., Ronland, O. J., Planting, S. M., Lovik, P. I., Gaarder, G., Gdyma, N., Bjerve, S. & Becher, G. (1996). PCDDs, PCDFs and PCBs in human blood in relation to consumption of crabs from a contaminated Fjord area in Norway. *Environmental Health Perspective*, 7:756-764.

Kah, M. & Brown, C. D. (2006). Adsorption of ionisable pesticides in soils. *Reviews of Environmental Contamination and Toxicology*, 188, 149-217.

Kanissery, R., Gairhe, B., Kadyampakeni, D. & Morgan, K. (2018). Herbicide-nutrient interactions in soil: A short review. *Environments*, *82*(3-4), 255-292.

Kolo, B., Mohammed, U. A., Shehu, A. A. & Jibrin, H. H. (2024). Determination of PesticideResidues in Sediment, Water and Fish from Some Selected Agricultural Sites in Bauchi State, Nigeria. *Bima Journal of Science and Technology* (2536-6041), 8(2A), 180-186.

Li, Y. & Zhang, N. (2019). Adsorption of phenol and 2, 4-dichlorophenol from wastewater:kinetic and equilibrium studies. *Desalination and Water Treatment*, 170, 225-238.

Mamy, L. & Barriuso, E. (2015). Glyphosate adsorption in soils compared to herbicides replaced with the introduction of glyphosate resistant crops.

Manuchehri, M. & Arnall, B. (2018). How does soil pH impact herbicides? Oklahoma Cooperative Extension Service. Retrieved on October 15, 2024. https://extension.okstate.edu/fact-sheets/how-does-soil-ph-impact-herbicides.html

Mendes, K. F., Reis, M. R., Dias, A. C. R., Formiga, J. A., Christoffoleti, P. J. & Tornisielo, V.L. (2014). A proposal to standardize herbicide sorption coefficients in Brazilian tropical soils compared to temperate soils. *Journal of Food, Agriculture and Environment*, 12(3-4), 424-433.

Mitryasova, O., Koszelnik, P., Gruca-Rokosz, R., Smirnov V., Smirnova, S., Bezsonov Y. & Ziembowicz, S. (2020). Features of heavy metals accumulation in bottom sediments of the Southern. Bug hydro ecosystem.

Nesbitt, H. J. & Watson, J. R. (1980). Degradation of the herbicide 2, 4-D in river water Description of study area and survey of rate determining factors. *Water Research*, 14(12), 1683-1688.

Nwinyimagu, A. J., Eyo, J. E., & Nwonumara, G. N. (2023). Distribution and ecological risk assessment of herbicide residues in water, sediment and fish from Anyim River, Ebonyi State, Nigeria. *Environmental Toxicology and Pharmacology*, 100, 104131.

Ohara, T., Yoshimoto, T., Natori, Y. & Ishii, A. (2021). A simple method for the determination of glyphosate, glufosinate and their metabolites in biological specimen by liquid chromatography/tandem mass spectrometry: an application for forensic toxicology. NCBI, PMC8437997. https://doi.org/10.1186/s40360-021-00517-1

Oruonye, E. D., Dinshiya, U., Anger, R. T. & Ahmed, Y. M. (2024). Assessment of Rural Livelihood Strategies in Taraba State, Nigeria. Jalingo. *Journal of Social and Management Sciences*, 5(4), 216-231.

PCPB. (2005). Annual report. Pest Control Products Board of Kenya.

PMC. (2024). Microorganism-Driven 2,4-D Biodegradation: Current Status and Perspectives. https://pmc.ncbi.nlm.nih.gov/articles/PMC11357097/

Prajapati, S., Sabokruhie, P., Brinkmann, M. & Lindenschmidt, K. E. (2023). Modelling Transport and Fate of Copper and Nickel across the South Saskatchewan River Using WASP-TOXI. *Water*, 15(2), 265.
PubMed. (2018). Potential impact of the herbicide 2, 4-dichlorophenoxyacetic acid on environment. https://pubmed.ncbi.nlm.nih.gov/29203058/

Rengasamy, P. & Churchman, G. J. (1999). Cation exchange capacity methodology. In Soil Quality Fact Sheets. Soil Quality Australia.

Robichaud, C. D. & Rooney, R. C. (2021). Low concentrations of glyphosate in water and sediment after direct over-water application to control an invasive aquatic plant. *Water Research*, 188, 116573.

Ronco, A. E., Marino, D. J. G., Abelando, M., Almada, P. & Apartin, C. D. (2016). Water quality of the main tributaries of the Paraná Basin: glyphosate and AMPA in surface water and bottom sediments *Environmental monitoring and assessment*, 188(8), 458.

Schilder, A. (2008). Effect of water pH on the stability of pesticides. Michigan State UniversityExtension. Retrieved October 15, 2024, https://www.canr.msu.edu/outreach/

Schulz, R. (2004). Field studies on exposure, effects, and risk mitigation of aquatic non-pointsource insecticide pollution: A review. *Journal of Environmental Quality*, 33(2), 419-448.

Simmons, B. (2006). Soil properties and herbicide behaviour. In Proceedings: Indiana CCA Conference, Indianapolis, IN. Six, J., Bossuyt, H., Degryze, S., and Denef, K. (2004). A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. *Soil and tillage research*, 79(1), 7-31.

Spark, K. M. & Swift, R. S. (2002). Effect of soil composition and dissolved organic matter on pesticide sorption. Science of the Total Environment, 298(1-3), 147-161.

University of California Agriculture and Natural Resources. (2017). Soil moisture and herbicides. https://ucanr.edu/repository/fileaccess.cfm?article=161669&p=JVCQWS

von Mérey, G., Manson, P. S., Mehrsheikh, A., Sutton, P. & Levine, S. L. (2016). Glyphosate and aminomethylphosphonic acid chronic risk assessment for soil biota. *Environmental Toxicology and Chemistry*, 35(11), 2742-2752.

Wagenet, R. J. & Hutson, J. L. (1987). Leaching estimation and chemistry model: A process-based model of water and solute movement, transformations, plant uptake and chemical reactions in the unsaturated zone. Continuum Water Resources Institute, Cornell University.

Xue, N., Zhang, D. & Xu, X. (2006). Organochlorinated pesticide multiresidues in surface sediments from Beijing Guanting reservoir. *Water Research*, 40(2), 183-194.

Yang, R., Wang, Y., Ren, C., Deng, J., Wei, C. & Fan, D. (2005). Comparative leaching behaviour of six pesticides in different agricultural soils. *Journal of Food, Agriculture & Environment*, 3(1), 279-287.

Ye, X., Hu, Y., Liu, W., Zhu, B., Yu, J., Deng, W., & Guo, Y. (2018). pH-dependent degradation of five pharmaceuticals in aerobic sediment-water systems. Ecotoxicology and Environmental Safety, 165, 111-118.