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ASSESSMENT OF POLYCHLORINATED BIPHENYLS IN SOIL AND SOME VEGETABLES IN CENTRAL AND SOUTHERN PART OF BORNO STATE, NIGERIA

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***Abstract**: This study was conducted to Assessment of Polychlorinated Biphenyls in Soil and Some Vegetables (tomato, onion, lettuce and pepper) in Central and Southern Part of Borno State, The soil samples were collected at different depth of 0-5cm, 5-10cm and 10-15cm using spiral auger. The soil and vegetable were extracted using standard procedures. The highest PCBs concentration was recorded at a depth of 0-5 cm with a value of 9.23E-01 while 8.12E-03 mg/kg were recorded as lowest concentration at a depth of 10-15cm tomatoes also recorded the lowest concentration of PCBs with a value of 6.00E mg/kg , while lettuce recorded the lowest concentration with value of 2.33E-08 mg/kg. levels of all thirteen PCBs in the soil and vegetable samples in the present study were below the maximum allowable concentrations (MACs). Results from diagnostic ratios shows that the sources of PCBs were from pyrogenic sources. The agricultural locations ender study was classified as low priority sites because the m-ERM-q values in the soil samples from the agricultural locations were below 0.1, indicating an 11% probability of toxicity. The present study also shows that all the studied PCBs in both soil and vegetable samples were below the BaP equivalent levels set by the European Union for processed food (permissible limit of 1 mg/kg).*

***Keyword:** Soil, Vegetable, Polychlorinated Biphenyls.*

Introduction

A polychlorinated Biphenyl (PCBs) are organic chlorine compound with the formula $C_{12}H_{10}$-xClx. polychlorinated biphenyls will be once widely deployed as dielectric and coolant fluids in electrical apparatus, carbonless copy paper and in heat transfer fluids. Because of their longevity, PCBs are still widely in use, even though their manufacture has declined drastically since the 1960s, when a host of problems will be identified. Because of PCBs environmental toxicity and classification as a persistent organic pollutant, PCB production was banned by the United States Congress in 1979 and by the Stockholm Convention on Persistent Organic Pollutants in 2001. The International Research Agency on Cancer (IRAC), rendered PCBs as definite carcinogens in human. According to the United State Environmental Protection Agency (USEPA), PCBs cause cancer in animals and are probable human carcinogens (USEPA, 2018). Many rivers and buildings including schools, parks, and other sites are contaminated with PCBs, and there have been contaminations of food supplies with the toxins. Some PCBs share a structural similarity and toxic mode of action with dioxin. Other toxic effects such as endocrine disruption (notably blocking of thyroid system functioning) and neurotoxicity are known. The maximum allowable contaminant level in drinking water in the United States is set at zero, but because of water treatment technologies, a level of 0.5 parts per billion is the de facto level. The bromine analogues of PCBs are polybrominated biphenyls (PBBs), which have analogous applications and environmental concerns. (Simko, 2022)

PCBs can enter the air by evaporation from both soil and water and can be carried long distances around the globe (Gambaro *et al*, 2015). PCBs can precipitate in rainfall and snow and have been found in snow and sea water in areas such as the Arctic, far away from where they will be released into the environment (Gustafsson *et al*., 2015). PCBs are taken up into the bodies of small organisms and fish in water and increase in concentration as they are taken up by animals higher up the food chain that red on them (Borga *et al*., 2021). PCBs especially accumulate in fish and marine mammals such as seals and whales, reaching levels that may be many thousands of times higher than in water (Shaw *et al*., 2015; Mossner, 2017). Particularly high levels have been found in polar bears PCBs are found widely in human blood serum (Sjodin *et al*., 2014), adipose (fat tissue) (Naert *et al*., 2016) and breast milk (Fangstrom *et al*., 2015; Poon *et al*., 2015; Kalantzi *et al*., 2014).

Methods

Area of Study

The study area was carried out in the southern part of Borno state. The study area is situated in the $35^0$09" to 35^0 59" N and $80^0$10" to 80^0 30" in each of the southern part of the Borno state: Bayo, Biu, Kwaya and Shani local government

Borno State constitutes a political entity within the North-East geopolitical region of Nigeria. It is delineated by Yobe to the west for an approximate distance of 421 kilometers, Gombe to the southwest for 93 kilometers, and Adamawa to the south, while its eastern boundary corresponds with a segment of the national frontier with Cameroon, extending for roughly 426 kilometers (265 miles, partially traversing the Ebedi and Kalia Rivers). The northern boundary is characterized by a portion of the national border with Niger, measuring approximately 223 kilometers, predominantly along the Komadougou-Yobe River, and its northeastern limit encompasses the entirety of the national boundary with Chad, extending for 85 kilometers (53 miles). Notably, it is the singular Nigerian state that shares borders with as many as three sovereign nations. The appellation of the state is derived from the historic emirate of Borno, with the former emirate's capital, Maiduguri, functioning as the administrative capital of Borno State. The establishment of the state occurred in 1976, following the disintegration of the erstwhile North-Eastern State. Initially, it comprised the territory that presently constitutes Yobe State, which attained the status of a separate state in 1991.

Bioaccumulation and bio-concentration of PCBs in the vegetables is capable of reaching toxic levels in the vegetables and soil even at low exposure. The study of the levels of PAHS and PCBs residues in vegetables is very limited in the country. Therefore, the contamination status of vegetables by PCBs residues is unknown in the study area. The calls for an extensive study of the PCBs residues status of vegetables in Konduga and Bama in Central Borno Senatorial District, Kwaya Kusar and Shani in Northern Borno Senatorial District

3.2 Sampling and Sample Preparation

3.2.1 Sampling plants

Fresh vegetable (tomato, onion, paper and lettuce) samples were collected from four different agricultural locations namely Dalori Koduga Local Government, Soye Bama Local Government Central Borno Senatorial District and Jafi Kwaya Kusar Local Government and Bargu Shani Local Government in Northern Borno Senatorial District. Twenty gram each of the four vegetables were collected and divided into leaf and fruit using a method described by Oblinger *et al*. (2019) and was transported to the Department of Chemistry laboratory, Modibbo Adama University, Yola.

3.2.2 Sampling Soil

In each plot, three soil sample increment soil were collected at depths (0-5 cm, 5-10 cm and 10-15 cm), by using a spiral auger of 2.5 cm diameter. Increment soil samples was bulk together to form a composite sample. Samples were collected in clean plastic bags and transported to the Department of Chemistry laboratory, Modibbo Adama University, Yola.

3.3 Sample Preparation

3.3.1 Preparation of Soils and vegetables for XRF analysis.

Method of sample preparation were done in accordance with procedures outlined for determining trace elements using XRF by Ndahi (2016). Dry and clean plant samples was separated cut into small pieces before it is pound in wooden mortar and pestle and sieved with 2mm pore sieve (Ndahi, 2016).

3.5 Extraction of PCBs from Vegetables Sample

Five grams (5g) of finely ground plant sample was weigh and 50m1 of n-hexane was added. Sample were sonicated for 30mm and subsequently shark on for 1 hour. The extract was transfer info a 100 ml volumetric flask and clean with 10mls of concentrated sulphuric acid. Then 20 ml of cleaned extract will be evaporated in a gentle nitrogen stream to near dryness and was filled up to 1 ml with n-hexane for analysis Oblinger *et al*. (2019).

3.5.1 Extraction and Clean-up of Soil Samples for PCBs Analysis

Analysis for PCBs in soil samples were carried out in accordance with USEPA, 2000 analytical meth 0(L Ten grams (log) of the sample was dry using anhydrous sodium sulphate. 30ml of methylene chloride was added and the sample extracted. The sample extract was subsequently filtered through glass wool containing anhydrous sodium sulphate in a glass funnel and allow to concentrate at room temperature to 1 ml volume Oblinger *et al*. (2019).

3. 6 Quality Check

The analysis of samples was conducted for the purposes of quality control and assurance. Analytical-grade chemicals and reagents were used throughout the analytical procedures. Double distilled water (DDW) was employed to formulate the requisite reagents, standards, and to facilitate the processing and dilution of analytical samples. Calibration curves were established for each heavy metal under investigation. Control blanks were also routinely analyzed to uphold analytical integrity. Regular procedural washing with DDW was performed throughout the analysis to prevent any potential contamination of the equipment. The values of the instrumental detection limit (IDL) were found to be less than those of the method detection limit (MDL) and method quantification limit (MQL), indicating the superior sensitivity of the analytical instrument (atomic absorption spectrophotometer) for the quantification of heavy metals.

Result and Discussion

4.11 Concentration of Some Polychlorinated Biphenyls (PCBs) In Soil Samples

Polychlorinated biphenyls (PCBs) are persistent organic pollutants (POPs) known for their long-lasting effects in the environment and potential health risks, including carcinogenicity. The data presented from soil samples taken from different agricultural locations in Borno State, Nigeria (Soye, Bargu, Jafi, and Dalori), at varying depths (0-5 cm, 5-10 cm, and 10-15 cm), reveal the distribution and concentration of PCBs in the soil. The varying PCB concentrations provide insights into the degree of environmental contamination and the potential health implications for the surrounding ecosystems and human populations.

Figure 4.37 shows the concentrations of some polychlorinated biphenyls (PCBs) in soil samples of different depths (0-5, 5-10 and 10-15cm) from Soye agricultural location, Bama Local Government of Borno State. The concentration of 2,2',5 trichlorobiphenyl runged from 2.11E-01 to 8.23E-01 mg/kg; 3.00E-02 to 5.59E-01 mg/kg 2,4,4' trichlorobiphenyl; 5.31E-02 to 5.01E-01 mg/kg 2,4'5 trichlorobiphenyl; 7.01E-03 to 8.23E-02 mg/kg 2,2'3,5 tetrachlorobiphenyl; 5.11E-02 to 9.23E-01 mg/kg 2,2,4,5,5' pentachlobiphenyl; 1.92E-02 to 1.028-01 mg/kg 2,3,4,4,5 pentachlorobiphenyl; 1.11E-03 to 1.54F-02 mg/kg 2,2,3,4,5,6 hexachlorobiphenyl; 2.43E-02 to 3.40E-01 mg/kg 2,2,4,4,5,5' hexachlorobiphenyl; 8.23E-02 to 5.32E-01 mg/kg 4.23E-03 to 3.45E-02 mg/kg 2,2,3,4,4'5,5' hexachlorobiphenyl and 8.128-03 to 7.00E-02 mg/kg 2,2'3,3'4,4,5,5' octachlorobiphenyl. The total PAHs concentration at different depth of soil sample was found to be significantly different at 5% probability level (P<0.05). The total PAHs concentrations at different depth of soil samples was found to be significantly different at 5% probability level (P<0.05). The total PCB concentrations decreased with soil depth, with the highest concentration (4.54E+00 mg/kg) recorded at the surface layer (0-5 cm), and the lowest concentration (5.25E-01 mg/kg) at a depth of 10-15 cm. This distribution suggests that the surface soil is more exposed to contamination, likely from atmospheric deposition, industrial emissions, and agricultural practices that introduce PCBs (**Lunder *et al.,* 2023**).

Figure 4.38 shows the mean concentrations of some polychlorinated biphenyls (PCBs) in soil samples of different depths (0-5, 5-10 and 10-15cm) from Bargu agricultural location, Shani Local Government of Borno State. The concentration of 2,2',5 trichlorobiphenyl ranged from 4.00E-03 to 2.00E-01 mg/kg; 5.40E-03 to 4.00E-01 mg/kg 2,4,4' trichlorobiphenyl, 1.23E-02 to 2.12E-01 mg/kg 2,4'5 trichlorobiphenyl; 4.23E-03 to 4.56E-02 mg/kg 2,2',3,5 tetrachlorobiphenyl; (5.40E-02 to 9.23E-01) mg/kg 2,25,5' tetrachlorobiphenyl, (1.00E-02 to 6.40E-01) mg/kg 2,2,4,5,5' pentachlorobiphenyl; (3.22E-02 to 5.23E-01) mg/kg 2,34,4'5

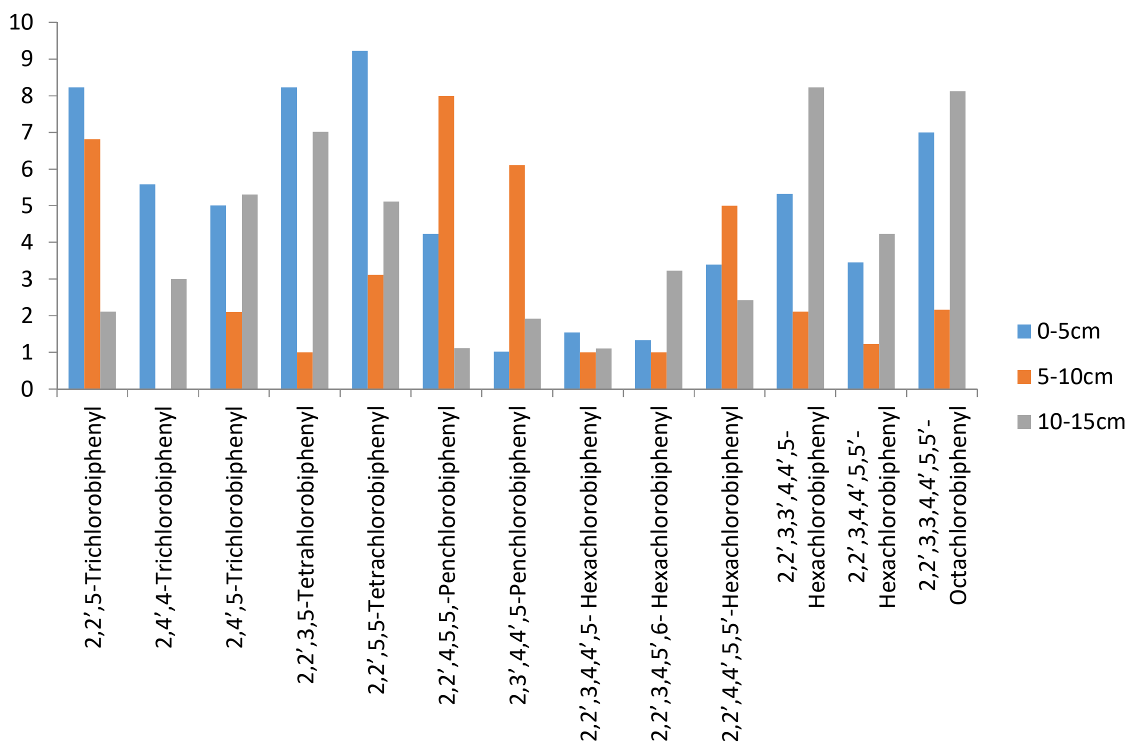

Figure ***4.37: Concentrations of Polychlorinated Biphenyls (PCBs) in soil Sample by Depth Profile from Soye, Bama Local Govt. Agricultural Location***

pentachlorobiphenyl (1.98E-02 to 4.00E-01) mg/kg 2.2'3,4,4' hexachlorobiphenyl: (3.00E-02 to 6.08E-01) mg/kg 2,2'3,4,5'6 hexachlorobiphenyl; (4.23E-02 to 7.23E-01) mg/kg 2,2,4,4,5,5'' hexachlorobiphenyl: (2.20E-02 to 4.12E-01) mg/kg 2,2'3,3,4,4'5 heptachlorobiphenyl, (2.23E-02 to 5.23E-01) mg/kg 2,2'3,4,4'5,5' heptachlorobiphenyl and (3.21E-02 to 4.65E-01) mg/kg 2,2'3,3'4,4,5,5' octachlorobiphenyl. The highest PCB concentration (6.12E+00 mg/kg) was observed at a depth of 0-5 cm, and the lowest (2.91E-01 mg/kg) was recorded at 10-15 cm. The significant difference in concentrations between soil depths ($P < 0.05$) emphasizes that the top soil is the most affected by PCB contamination, likely due to direct exposure to pollution sources (**Kravchenko *et al.*, 2024)**.

Figure 4.39 the concentration of PCBs in soil samples from Jafi agricultural Location. It ranged from (1.01E-02 to 3.23E-01) mg/kg; (1.22E-02 to 4.54E-01) mg/kg 2,4,4 trichlorobiphenyl, (1.00E-02 to 3.12E-01) mg/kg 2,4'5 trichlorobiphenyl; (1.43E-02 to 2.12E-01) mg/kg 2.2.3.5 tetrachlorobiphenyl; (2.23E-02 to 5.66E-01) mg/kg 2,3'4,4'5; (2.44E-02 to 3.54E-01) mg/kg The total PAHs concentration at different depth of soil sample was found to be significantly different at 5% probability level ($P<0.05$)2,2'3,4,4'5,5' heptachlrobiphenyl from (2.54E-02 to 6.45E-01) mg/kg 2,2'3,3'4,4,5,5' octachlorobiphenyl. The total PAHs concentrations at different depth of soil samples was found to be significantly different at 5% probability level ($P<0.05$). Similar to the other locations, the surface soil (0-5 cm) recorded the highest total PCB concentration (5.66E+00 mg/kg), while the lowest concentration (1.42E+00 mg/kg) was recorded at 10-15 cm. These findings again demonstrate that PCB contamination is more concentrated at the soil surface, diminishing with depth (Subramani ***et al.*, 2024)**.

Figure 4.40 shows the mean concentrations of some polychlorinated biphenyls (PCBs) in soil samples of different depths (0-5, 5-10 and 10-15cm) from Dalori agricultural location, Konduga Local Government of Borno State. The concentration of 2,2'5 trichlorobiphenyl ranged from (4.67E-03 to 2.23E-01) mg/kg; (4.228-03 to 3.21E-01) mg/kg 2,4,4' trichlorobiphenyl; (1.34E-02 to 1.98E-01) mg/kg 2,4'5 trichlorobiphenyl, (2.23E-03 to 5.23E-01) mg/kg 2,2,3,5 tetrachlorobiphenyl; (5.40E-02 to 5.54E-01) mg/kg for 2,2,5,5' tetrachlorobiphenyl; (1.04E-02 to 5.33E-01) mg/kg 2,2',4,5,5' pentachlorobiphenyl; (1.92E-02 to 4.32E-01) mg/kg 2,34,4'5 pentachlorobiphenyl (1.33E-02 to 4.76E-01) mg/kg 2,2'3,4,4'5 hexachlorobiphenyl: (3.43E-02 to 4.23E-01) mg/kg 2,2'3,4,5'6 hexachlorobiphenyl; (1.98E-02 to 5.23E-01) mg/kg 2.2'4,4'5,5' hexachlorobiphenyl; (2.43E-02 to 2.23E-01) mg/kg 2,2'3,3,4,4'5 heptachlorobiphenyl: (2.63E-02 to 4.33E-01) mg/kg 2,2'3,4,4'5,5' heptachlorobiphenyl from (6.34E-02 to 8.32E-01) mg/kg 2,2'3,3'4,4,5,5' octachlorobiphenyl. The total PAHs

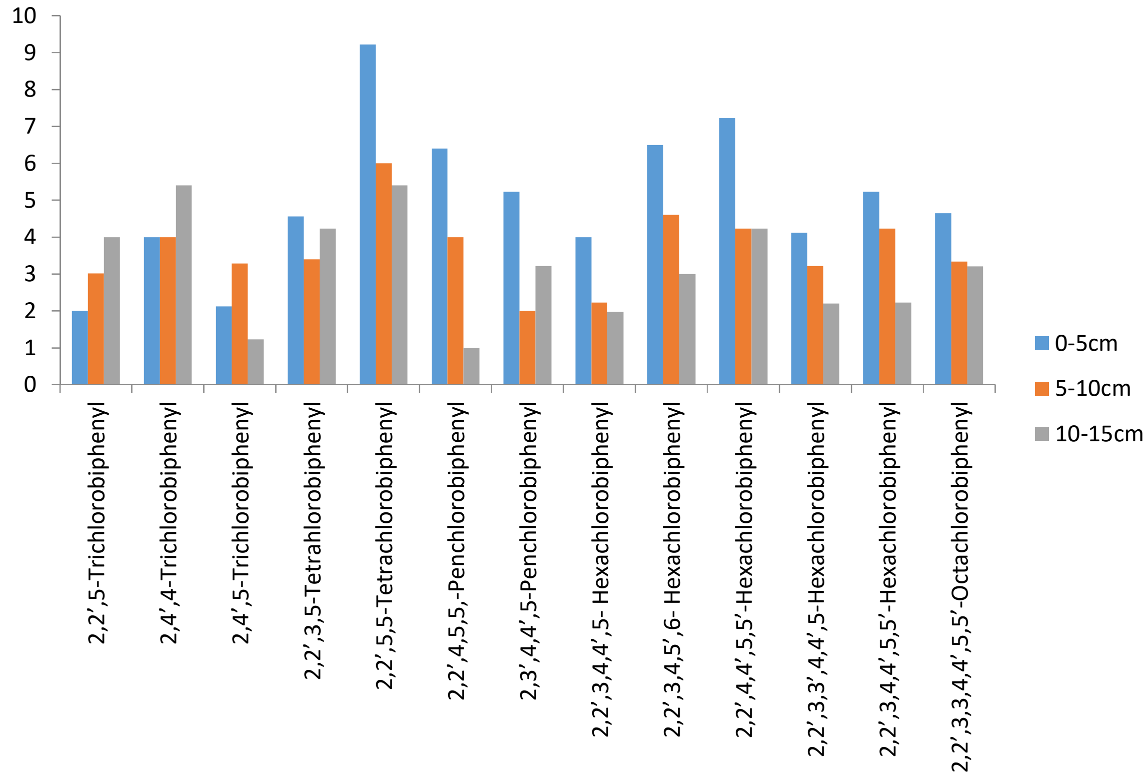

Figure ***4.38: Concentrations of Polychlorinated Biphenyls (PCBs) in soil Sample by Depth Profile from Jafi Kwaya Kusar Local Govt. Agricultural Location***

concentration at different depth of soil sample was found to be significantly different at 5% probability level ($P<0.05$) The lowest total concentration of 2.90E-01 mg/kg was recorded at a depth of 10-15 cm, while 5-0 cm recorded the highest total concentration of 5.59E+00 mg/kg. This distribution suggests that the surface soil is more exposed to contamination, likely from atmospheric deposition, industrial emissions, and agricultural practices that introduce PCBs (Al-Alam ***et al.*****, 2024)**.

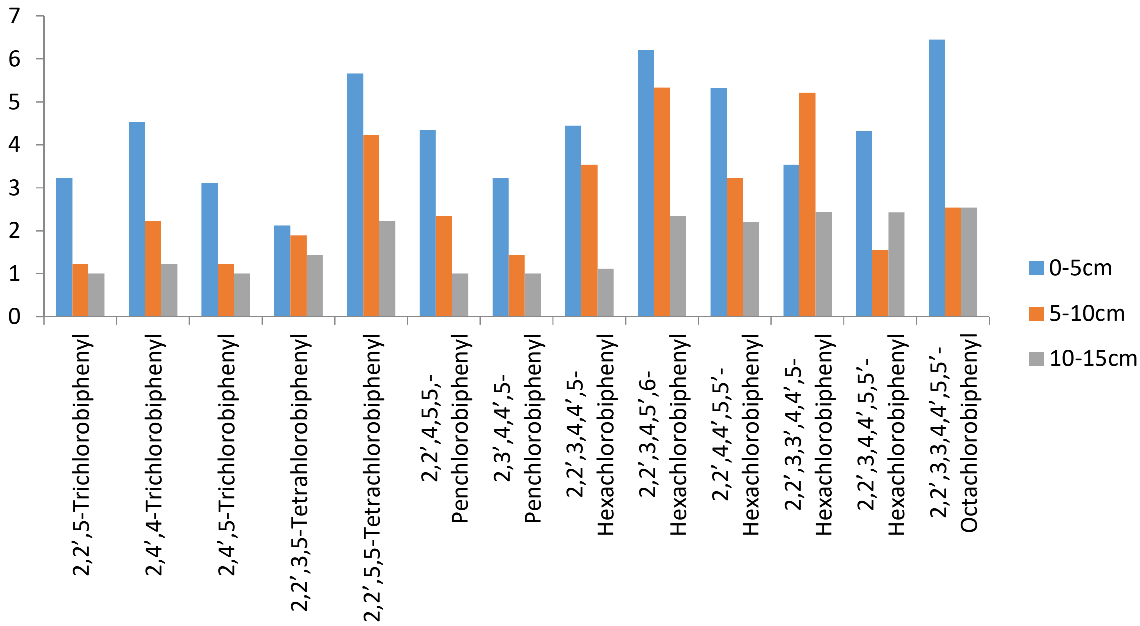

Figure ***4.39: Concentrations of Polychlorinated Biphenyls (PCBs) in soil Sample by Depth Profile from Bargu Shani Local Govt. Agricultural Location***

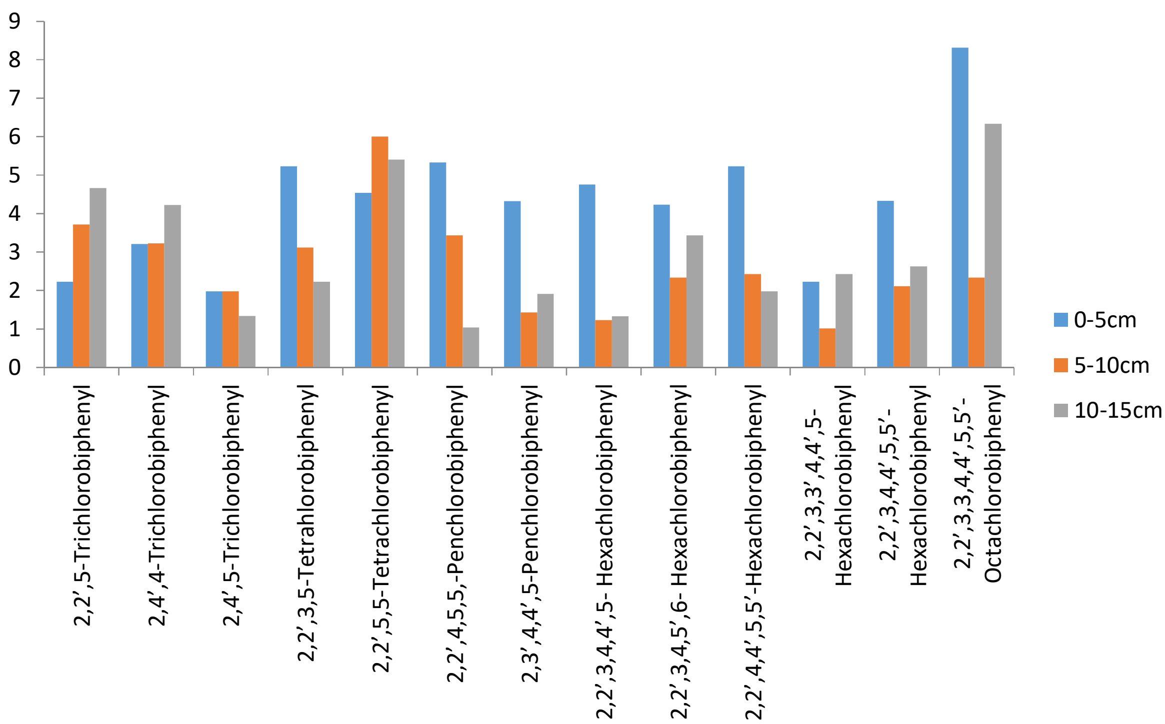

Figure ***4.40: Concentrations of Polychlorinated Biphenyls (PCBs) in soil Sample by Depth Profile from Dalori Konduga Local Govt. Agricultural Locat*ion***

4.12 Mean Concentration of Some Polychlorinated Biphenyl (PCBs) in Vegetable Samples

The results on the concentrations of polychlorinated biphenyls (PCBs) in vegetable samples collected from various agricultural locations in Borno State reveal important insights into environmental contamination.

Figure 4.41 shows the concentrations of some polychlorinated biphenyls (PCBs) in vegetable samples from Soye agricultural location, Bama Local Government of Borno State. The concentration of 2,2',5 trichlorobiphenyl ranged from (1.45E-04 to 2.98E-01) mg/kg; (1.22E-04 to 3.12E-01) mg/kg 2,2',5,5' tetrachlorobiphenyl; (1.23E-02 to 5.23E-02) mg/kg 2,3'4,4'5 pentachlorobiphenyl (1.71E-04 to 2.13E-01) mg/kg 2,2'3,4,4'5' hexachlorobiphenyl: (1.92E-03 to 2.35E-01) mg/kg 2,2'3,4,5'6 hexachlorobiphenyl; (1.09E-03 to 5.83E-01) mg/kg 2,2'4,4'5,5' hexachlorobiphenyl; (1.87E-05 to 2.33E-01) mg/kg 2,2'3,3,4,4'5 heptachlorobiphenyl: (2.43E-02 to 4.02E-01) mg/kg 2,2'3,4,4'5,5' heptachlorobiphenyl and (3.22E-05 to 4.12E-03) mg/kg 2,2'3,3'4,4,5,5' octachlorobiphenyl.

The total PAHs concentrations at different depth of soil samples was found to be significantly different at 5% probability level ($P<0.05$) pepper recorded the highest total concentration of PCBs with a value of 1.40E+00 mg/kg while onion recorded the lowest total concentration with a value of 7.328-01 mg/kg. These values suggest that certain vegetables, like pepper, accumulated higher PCB levels than others, with pepper recording the highest total concentration, while onions recorded the lowest total concentration. This could be due to differences in the root structure and physiology of these plants, which affect the absorption of PCBs from the soil (Zeng *et al.,* 2014).

Figure 4.42 shows the concentrations of some polychlorinated biphenyls (PCBs) in vegetable samples from Bargu agricultural location, Shani Local Government of Borno State. The concentration of 2,2',5 trichlorobiphenyl ranged from (3.226-06 to 2.11E-03) mg/kg; (2. 10E-06 to 2.33E-01) mg/kg 2,4,4' trichlorobiphenyl; (3.76E-08 to 1.23E-01) mg/kg 2,4'5 trichlorobiphenyl; (1.23E- 05 to 2.43E-03) mg/kg 2,2,3,5 tetrachlorobiphenyl; (2.45E-04 to 2.87E-03) mg/kg 2,2,5,5 tetrachlorobiphenyl; (3.22E-05 to 1.09E-03)mg/kg 2,2,4,5,5' pentachlorobiphenyl; (1.02E-06 to 1.98E-03)mg/kg 2,3,4,4'5 pentachlorobiphenyl; (1.33E-06 to 2.98E-03)mg/kg 2,2',34,4'5' hexachlorobiphenyl; (1.11E-05 to 3.44E-03) 2,2'3,4,4' hexachorinatedbiphenyl; (3.02E-04 to 3.11E-03)mg/kg 2,24,4'5,5' hexachlorobiphenyl; (4.23E-04 to 4.23E-03)mg/kg 2,2'3,3'4,4'5 hepchlorobiphenyl; (1.23E-04 to 2.12E-03) 2,2'3,4,4,5,5'

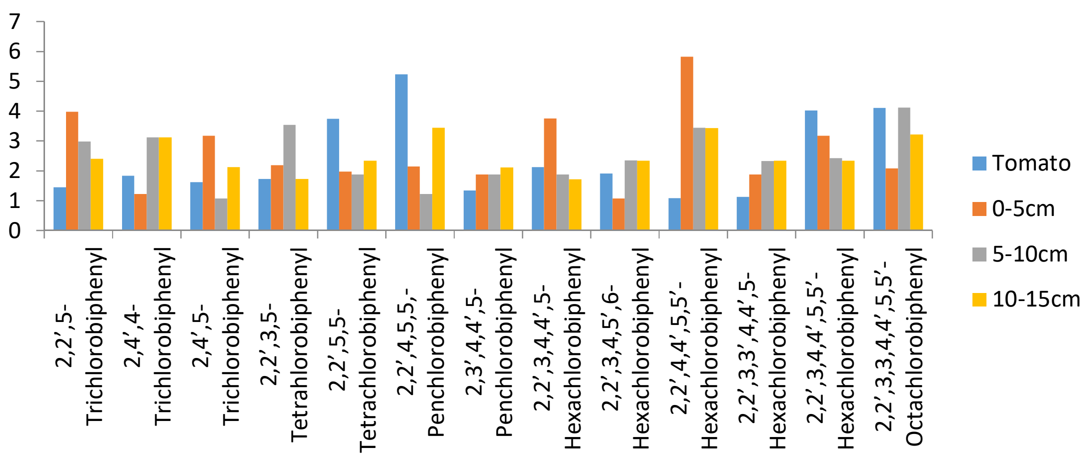

Figure ***4.41: Concentrations of Polychlorinated Biphenyls (PCBs) in Vegetables from Soye Bama Local Govt. Agricultural Location***

heptachlorobiphenyl; (2.88E-06 to 4.23E-02) mg/kg 2,2'3,34,4,5,5' octachorinatedbiphenyl. The total PAHs concentrations at different depth of soil samples was found to be significantly different at 5% probability level ($P<0.05$). Pepper again recorded the highest concentration of PCBs (7.66E-02 mg/kg), while lettuce had the lowest levels (1.13E-02 mg/kg). This pattern suggests that PCB contamination in the region may be influenced by factors such as soil properties, climate, and agricultural practices (Eze *et al.,* 2024).

Figure 4.43 shows the mean concentrations of some polychlorinated biphenyls (PCBs) in vegetable samples of different locations from Bargu agricultural location, Shani Local Government of Borno State. The concentration of 2,2',5 trichorobiphenyl ranged from (3.21E-03 to 3.21E-02) mg/kg; (1.09E-03 to 3.23E-01) 2,4'5 trichlorobiphenyl; (2.01E-03 to 8.23E-01)mg/kg 2,2',5,5' tetrachlorobiphenyl; (1.02E-03 to 1.22E-02)mg/kg 2,2,4,5,5' pentachlorobiphenyl; (1.23E-03 to 1.11E-02)mg/kg 2,3'4.4'5 Pentachlorobiphenyl (2.34E-04 to 1.45E-02)mg/kg 2,2'3,4,4' hexachlorobiphenyl; (1.20E-03 to 421E-02)mg/kg 2,2'4,4'5,5' hexachlorobiphenyl; 2.01E-04 to 5.23E-02)mg/kg 2,2'3,3,4,4'5 heptachlorobiphenyl, (1.02E-01 to 7.22E-02)mg/kg 2,23,4,435 heptachlorobiphenyl (1.09E-03 to 3.218-02) mg/kg 2,2'3,34,4,5,5 octachlorobiphenyl.

Figure 4.44 shows the concentrations of some polychlorinated biphenyls (PCBs) in vegetable samples from Dolari, Konduga local of Borno State. The concentration of 2,2'5 trichlorobiphenyl ranged from (3.230E-02 to 3.22E-01) mg/kg; (1.10E-01 to 2.98E-01) mg/kg 2,4,4 trichlorobiphenyl; (3.22E-02 to 3.92E-01) mg/kg 2,4'5 trichlorobiphenyl; (1.208-04 to 1.328-01) mg/kg 2,2'3,5 tretrachlorobiphenyl; (1.44E-04 to 9.23E-01) mg/kg 2,2'5,5'tetrachlorobiphenyls; (1.32E-02 to 8.20E-01) mg/kg 2,2,4,5,5' pentachlorobiphenyl; (1.20E-01 to 4.23E-01) mg/kg 2,3'4,4'5 pentachlorobiphenyl; (1.02E-02 to 3.43E-01) mg/kg 2,2'3,4,4 hexachlorobiphenyl, (1.02E-01 to 4.32E-01) mg/kg 2,2'3,4,4'5,5' heptachlorobiphenyl; (2.33E-08 to 4.23E-03) mg/kg 2,2'3,4,4'5,5' heptachlorobiphenyl; (1.29E-02 to 3.12E-01) mg/kg 2,2 3,3 4,4,5,5' octachlorobiphenyl. 2.91E-01 mg/kg. The total PAHs concentrations at different depth of soil samples was found to be significantly different at 5% probability level ($P<0.05$). In Bargu, tomato samples had the highest concentration of 1.39E+00 mg/kg, whereas in Dolari (Konduga LGA), tomatoes also showed elevated PCB concentrations of up to 8.37E+01 mg/kg. These findings align with previous research that highlights how plants with high lipid content, such as tomatoes, are more prone to accumulating lipophilic compounds like PCBs (Zeng *et al.,* 2014).

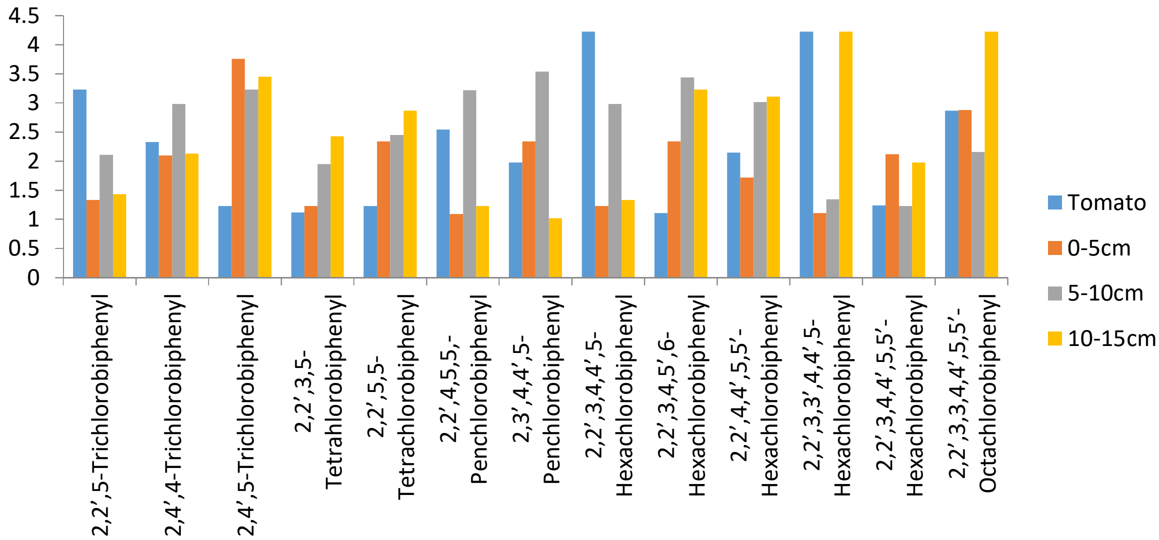

Figure ***4.42: Concentrations of Polychlorinated Biphenyls (PCBs) in Vegetables from Jafi Kwaya Kusar Local Govt. Agricultural Location***

The observed PCB concentrations in vegetables from Borno State present significant public health concerns, particularly because PCBs are persistent organic pollutants (POPs) known for their carcinogenic and endocrine-disrupting properties. Prolonged consumption of vegetables contaminated with PCBs can lead to bioaccumulation in human tissues, resulting in adverse health effects such as immune system suppression, reproductive disorders, and neurological issues (Sakshi and Haritash, 2019)

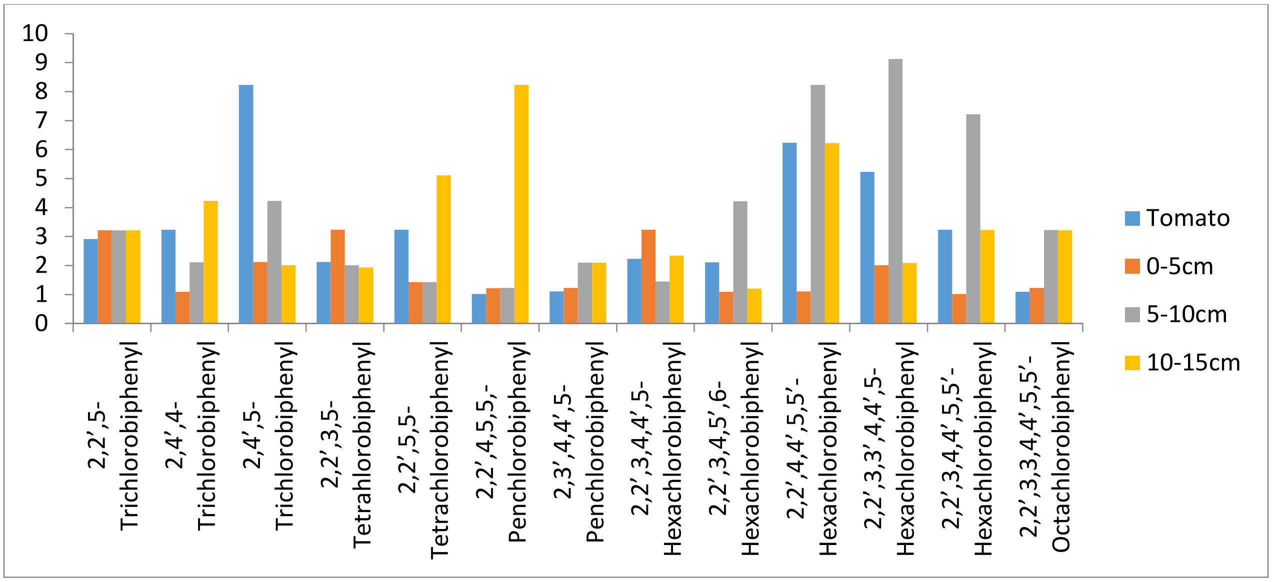

Figure ***4.43: Concentrations of Polychlorinated Biphenyls (PCBs) in Vegetables from Bargu Shani Local Govt. Agricultural Location***

4.13 Carcinogenic Risk Assessments and of Some Polychlorinated Biphenyls (PCBs) In Soil Samples

Figure 4.45 demonstrates the carcinogenic risk of PCBs at various depths (0-5 cm, 5-10 cm, and 10-15 cm) at Soye agricultural location. The primary PCB congeners considered include 2,3,4,4',5 pentachlorobiphenyl and 2,2',3,3',4,4',5,5' octachlorobiphenyl. The carcinogenic risk values for 2,3,4,4',5 pentachlorobiphenyl range from **4.23E-08 to 3.45E-07 mg/kg**, while for 2,2',3,3',4,4',5,5' octachlorobiphenyl, the risk values span from **4.06E-06 to 3.50E-05 mg/kg**. The highest total carcinogenic risk recorded at a depth of 0-5 cm was **5.64E-05 mg/kg**, whereas the lowest value at 10-15 cm was **5.54E-06 mg/kg**. These findings highlight that the carcinogenic risk decreases with soil depth (Ravanipour *et al.,* 2022). At the Bargu agricultural site, the carcinogenic risk of PCBs at varying depths is reported in

Figure 4.46. The PCBs measured include 2,3,4,4',5 pentachlorobiphenyl and 2,2',3,3',4,4',5 heptachlorobiphenyl. The cancer risk for 2,3,4,4',5 pentachlorobiphenyl ranged from **3.00E-07 to 1.92E-05 mg/kg**, and for 2,2',3,3',4,4',5 heptachlorobiphenyl, the values were **9.66E-07 to 1.57E-05 mg/kg**. The total carcinogenic risk at 0-5 cm depth reached **6.74E-05 mg/kg,** while the lowest value of **3.31E-06 mg/kg** was observed at 10-15 cm. The decrease in carcinogenic risk with soil depth suggests a higher concentration of PCBs at the surface, potentially due to deposition or limited downward mobility (Eze *et al.,* 2024).

Figure 4.47 shows the carcinogenic risk assessment of some polychlorinated biphenyls (PCBs) in soil samples of different depths (0-5, 5-10 and 10-15cm) from Jafi agricultural location, Kwaya-Kusar Local Government of Borno State. The risk values for 2,3,4,4',5 pentachlorobiphenyl ranged from **4.00E-06 to 1.30E-05 mg/kg**, and for 2,2',4,5,5' pentachlorobiphenyl, they spanned **3.00E-07 to 9.69E-06 mg/kg**. The total carcinogenic risk at 0-5 cm depth was **6.46E-05 mg/kg**, while the lowest value of **6.06E-06 mg/kg** was observed at 10-15 cm. These values indicate that shallow soil layers are more contaminated with carcinogenic PCB congeners (Ravanipour *et al.,* 2022).

Figure 4.48 shows the carcinogenic risk assessment of some polychlorinated biphenyls (PCBs) in soil samples of different depths (0-5, 5-10 and 10-15cm) from Dalori Agricultural location, Konduga Local Government of Borno State. Pentachlorobiphenyl ranged from (3.12E-07 to 1.59E-05) mg/kg; (5.766-07 to 1.30E-05) mg/kg 2,2,4,5,5'pentachlobiphenyl; (2.43E-07 to 2.23E-06) mg/kg 2,2,3,34,4' Heptachlorobiphenyl (2.63E-07 to 4.33E-06) mg/kg 2,2'3,3,4,4,5 heptachlorobiphenyl (3.175-06 to 4168-05) mg/kg 2,2'3,3'4,4,5,5' octachlorobiphenyl. The highest total carcinogenic risk value of 7.71E-05 mg/kg was recorded

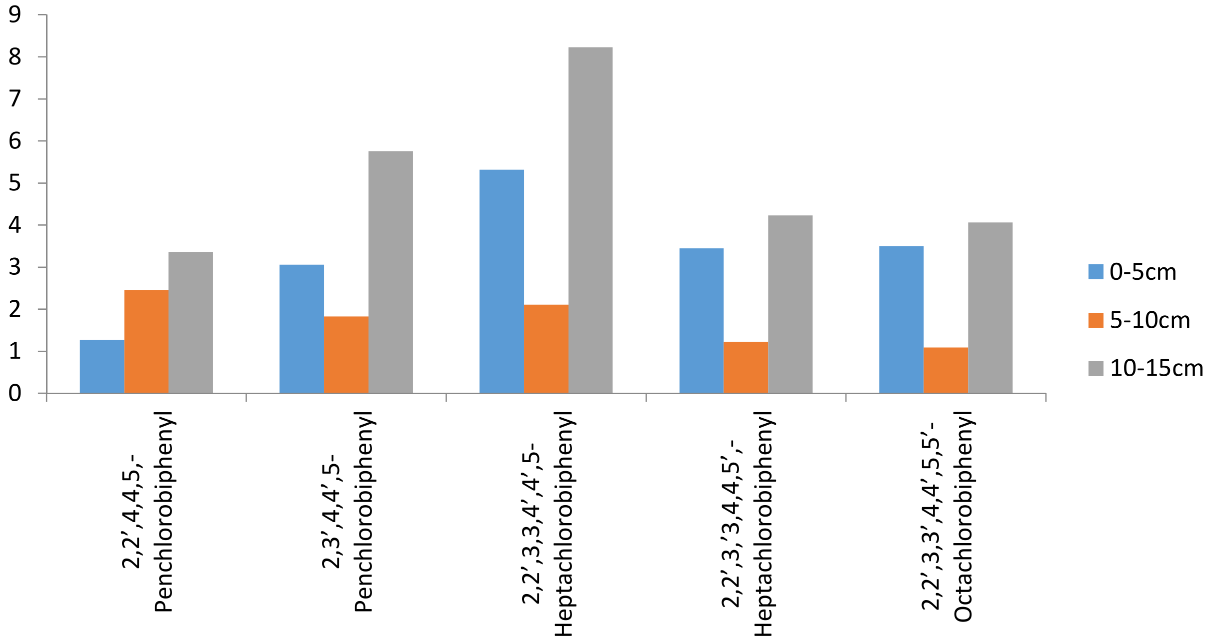

Figure 4.45: Carcinogenic Rick Assessment of some Polychlorinated Biphenyls (PCBs) in soil Sample from Soye Bama* Local Govt. *Agricultural Location

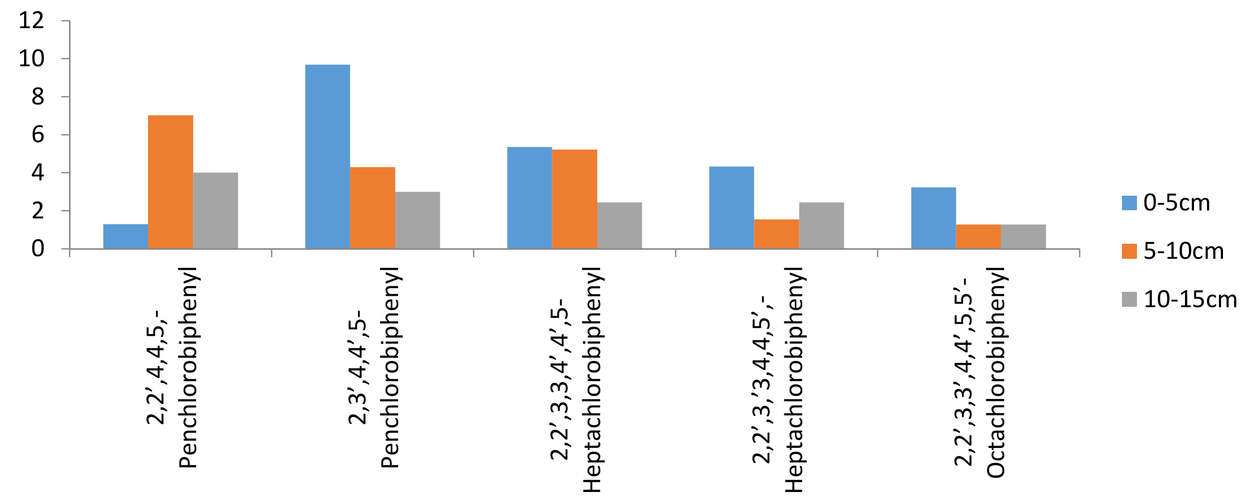

Figure 4.46: Concentrations of Polychlorinated Biphenyls (PCBs) in soil Sample by Depth Profile from Bargu Shani Local Govt. Agricultural Location

at a depth of 0-5 cm, while 10-15 cm recorded the lowest total carcinogenic risk value of 4.88E-06 mg/kg.

The carcinogenic risk values, although variable between locations, indicate that soils in these agricultural areas present a significant risk, particularly in the top 5 cm of soil. The assessment also reveals that certain PCB congeners, such as 2,2',3,3',4,4',5,5' octachlorobiphenyl, contribute disproportionately to the total carcinogenic risk, due to their higher persistence and bioaccumulation potential (Zeng *et al.,* 2014).

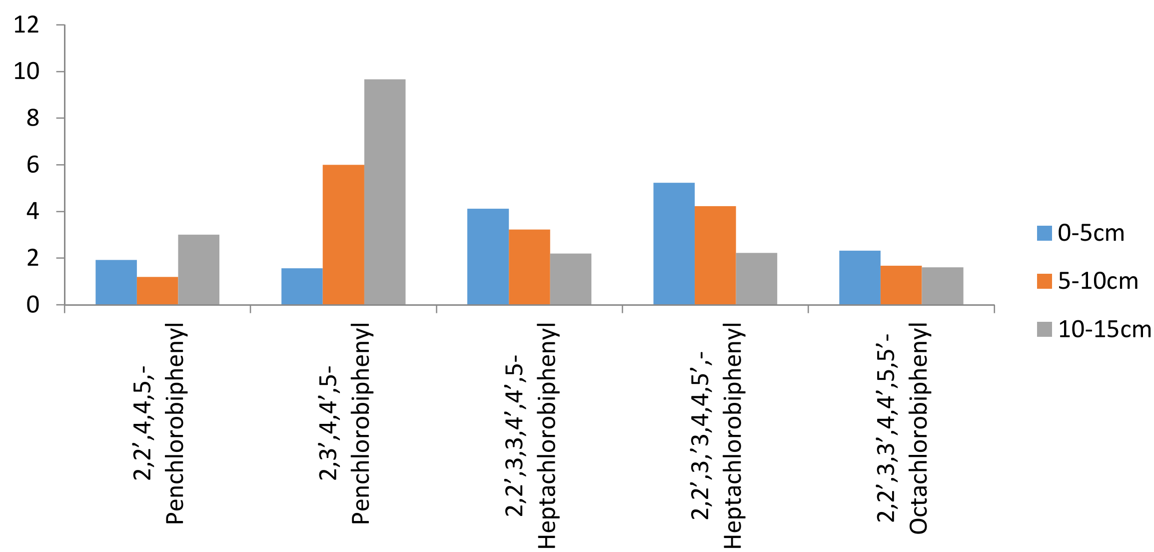

Figure 4.47: Concentrations of Polychlorinated Biphenyls (PCBs) in soil Sample by Depth Profile from Jafi Kwaya Kusar *Local Govt.* Agricultural Location

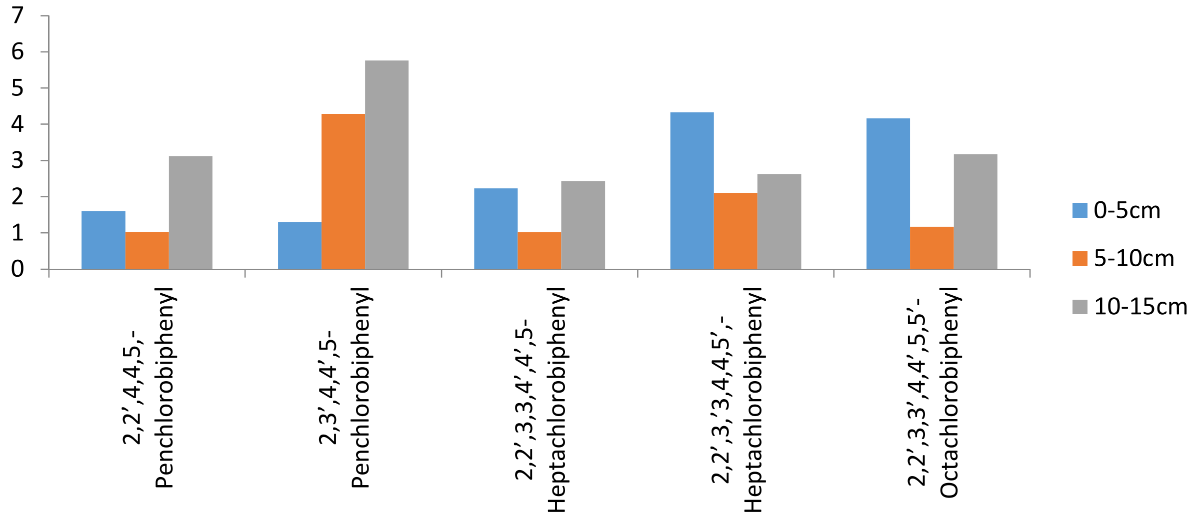

Figure 4.48: Concentrations of Polychlorinated Biphenyls (PCBs) in soil Sample by Depth Profile from Dalori Konduga* Local Govt. *Agricultural Location

4.14: Carcinogenic Risk Assessment of Polychlorinated Biphenyls (PCBs) in Vegetable Samples

The carcinogenic risk assessment of various polychlorinated biphenyls (PCBs) in vegetable samples from different agricultural locations in Borno State, Nigeria, provides a crucial insight into the potential health risks posed by these environmental pollutants. The results from the four different locations Soye, Bargu, Jafi, and Dalori highlight significant variations in the levels of PCBs, leading to differences in the associated cancer risks.

Figure 4.49 shows carcinogenic risk assessment of various polychlorinated biphenyls (PCBs) in vegetable samples **Soye Agricultural Location (Bama Local Government.**The carcinogenic risk values for PCBs such as 2,3',4,4',5-pentachlorobiphenyl, 2,2',4,5,5'-pentachlorobiphenyl, 2,2',3,3',4,4',5-heptachlorobiphenyl, and 2,2',3,3',4,4',5,5'-octachlorobiphenyl showed a range of risk values from as low as 1.87E-10 mg/kg to as high as 4.02E-06 mg/kg. The highest total

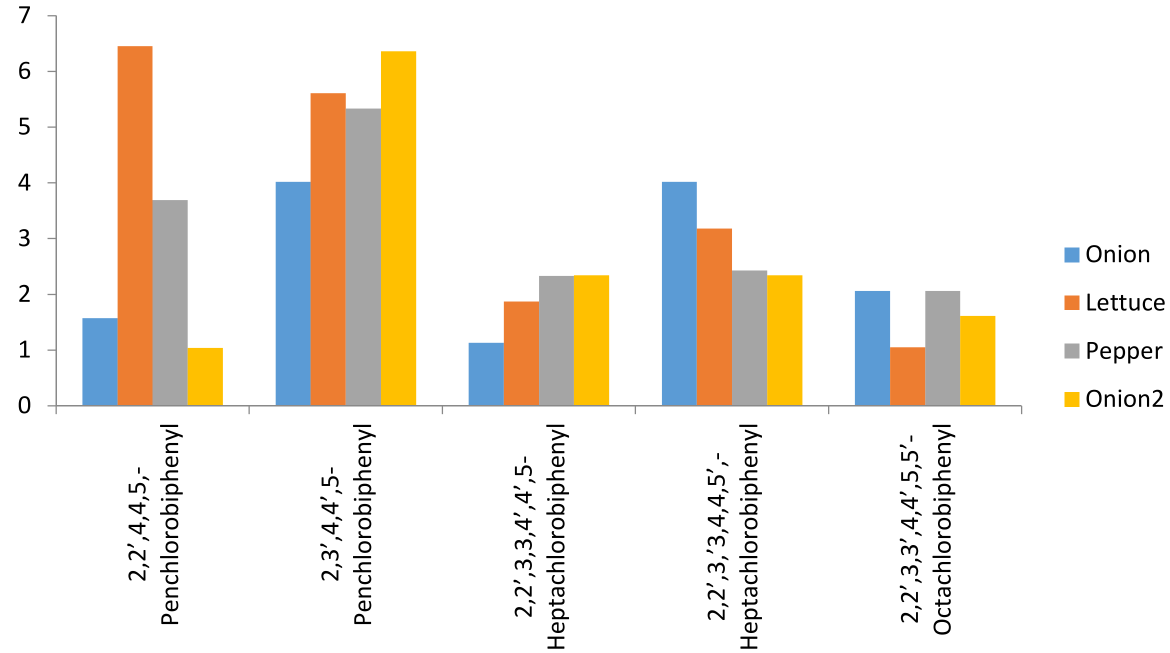

Figure ***4.49: Carcinogenic Rick Assessment of Polychlorinated Biphenyls (PCBs) Vegetables Sample from Soye Bama Local Govt. Agricultural Location***

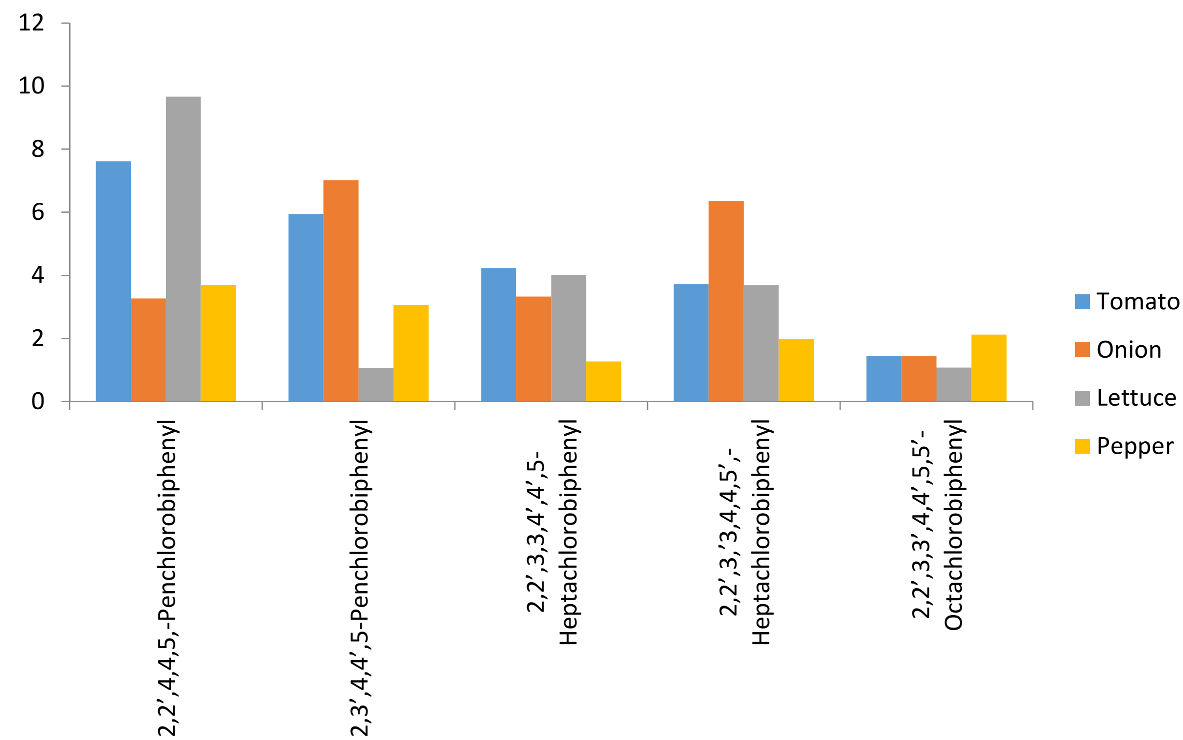

Figure ***4.50: Carcinogenic Rick Assessment of Polychlorinated Biphenyls (PCBs) Vegetables Sample from Bargu Shani Local Govt. Agricultural Location***

carcinogenic risk was recorded in tomatoes (6.31E-06 mg/kg), indicating that this vegetable had the highest potential risk for cancer development due to PCB exposure (Mahfooz et al., 2022). Onions, on the other hand, had the lowest total carcinogenic risk (1.54E-06 mg/kg)**.**

Figure 4.50 shows carcinogenic risk assessment of various polychlorinated biphenyls (PCBs) in vegetable samples in Bargu Agricultural Location (Shani Local Government). Similar PCBs were assessed, with risk values ranging from 3.06E-11 mg/kg to 2.12E-06 mg/kg. The ranges for different PCBs were generally lower compared to those from Soye. Pepper had the highest total carcinogenic risk (2.15E-06 mg/kg), while lettuce showed the lowest risk (5.66E-08 mg/kg), indicating significant variability even within a single location.

Figure 4.51 shows carcinogenic risk assessment of various polychlorinated biphenyls (PCBs) in vegetable samples Jafi Agricultural Location (Kwaya-Kusar Local Government). The carcinogenic risk values ranged from 2.01E-09 mg/kg to 1.605E-06 mg/kg. The risk for each PCB was generally lower than those found in the Soye and Dalori locations but higher than those in Bargu. Tomatoes again had the highest carcinogenic risk (4.51E-05 mg/kg), while onions had the lowest risk (5.68E-07 mg/kg). This consistent finding across locations suggests that tomatoes might be more prone to PCB accumulation, leading to higher health risks (Mahfooz et al., 2022).

Figure 4.52 shows carcinogenic risk assessment of various polychlorinated biphenyls (PCBs) in vegetable samples in Dalori Agricultural Location (Konduga Local Government). The risk values here were quite variable, with a range from 2.33E-13 mg/kg to 2.46E-05 mg/kg. This location displayed the highest variability in PCB concentration and associated risks (Mohankumar et al., 2024). Tomato showed the highest total carcinogenic risk (4.51E-05 mg/kg), similar to Jafi. Pepper recorded the lowest risk (1.72E-05 mg/kg), indicating a substantial variation between the types of vegetables even within the same location. Across all locations, tomatoes consistently had the highest total carcinogenic risk values, suggesting that they may accumulate PCBs more readily than other vegetables like onions, lettuce, and peppers. This makes tomatoes a potential vector for higher cancer risk due to PCB exposure in these regions (Mahfooz et al., 2022). The different agricultural locations showed varying levels of PCB contamination and associated cancer risks. This could be due to differences in environmental contamination, soil composition, agricultural practices, and proximity to pollution sources (Eze et al., 2024). The carcinogenic risk values, particularly those in tomatoes, suggest a public health concern for populations consuming these vegetables. The highest recorded risk value (4.51E-05 mg/kg) exceeds commonly acceptable risk levels, emphasizing the need for regulatory intervention and monitoring to reduce exposure (Mohankumar et al., 2024).

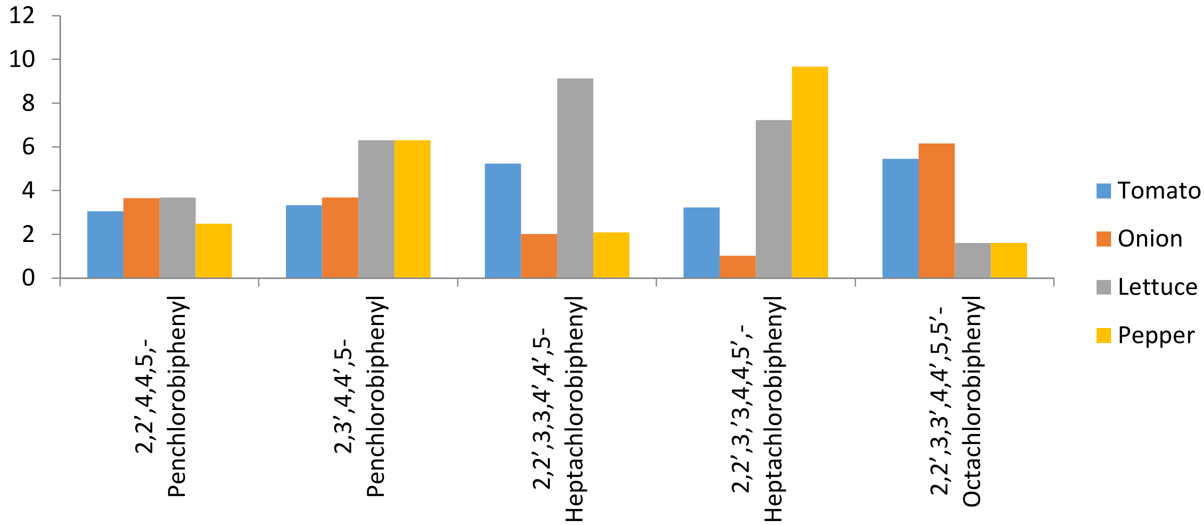

Figure ***4.51: Carcinogenic Rick Assessment of Polychlorinated Biphenyls (PCBs) Vegetables Sample from*** **Jafi agricultural location, Kwaya-Kusar Local Government of Borno State**

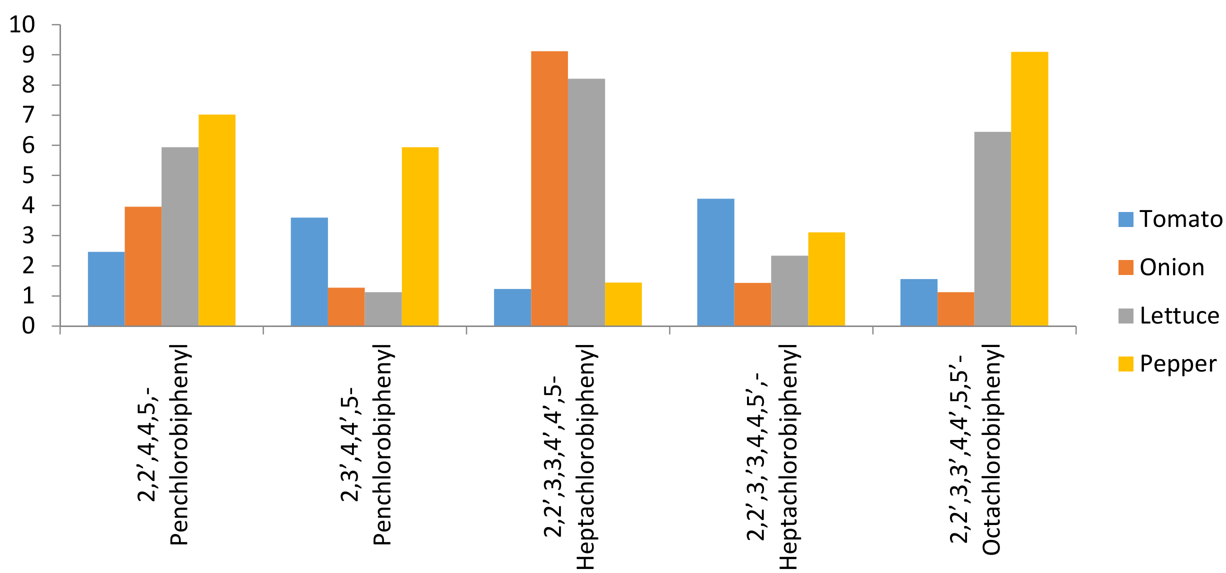

Figure ***4.52: Carcinogenic Rick Assessment of Polychlorinated Biphenyls (PCBs)Vegetables Sample from Dalori Konduga Local Government Agricultural Location***

Conclusion

The study concludes that the vegetables and soils in the central and southern senatorial zones of Borno State was contaminated with PCBs raising serious environmental and health concerns. The contamination of agricultural products reflects the environmental risks posed by industrial activities, improper waste disposal, vehicular emissions, and the use of polluted water for irrigation. PCBs were found in concentrations that suggest significant pollution, likely from human activities like burning fossil fuels and waste incineration. The bioaccumulation of these pollutants in food crops suggests an ongoing transfer of contaminants from soil to crops to humans. If left unaddressed, this contamination could have severe public health and environmental consequences, including toxic buildup in the food chain, increased disease burden, and reduced agricultural productivity.

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