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DETERMINATION OF BIOACCUMULATION OF POLYCYCLIC AROMATIC HYDROCARBON IN SOME VEGETABLES IN CENTRAL AND SOUTHERN PART OF BORNO STATE NIGERIA

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***Abstract**: This study aims to determine the bioaccumulation of polycyclic aromatic hydrocarbon (PAHs). (PAHs) in vegetable (tomato, onion, lettuce and pepper) were determine in Central and Southern part of Borno State. The vegetable was extracted using standard procedures. Instrumental analysis for PAHs was carried out using GC/MS. Among all the vegetable analzed, tomato recorded the highest concentration with a value of 8.00E-04 mg/kg. while lettuce recorded the lowest concentration with value of 2.33E-08 mg/kg. levels of all the sixtee PAHs. vegetable samples in the present study were below the maximum allowable concentrations (MACs). Results from diagnostic ratios shows that the sources of PAHs were from pyrogenic sources. The present study also shows that all the studied PAH in vegetable samples were below the BaP equivalent levels set by the European Union for processed food (permissible limit of 1 mg/kg). data obtained from cancer risk assessment in vegetable samples were below the regulatory standard cancer risk values of 10^{-5}. The highest average daily does value in this vegetable from all the four agricultural locations were recorded in pepper from Soye, Bama agricultural location, while the lowest average daily does value were observed in lettuce from Jafi, Kwaya Kusar agricultural location. The non-carcinogenic PAHs through the consumption of tomato, onion, lettuce and pepper from the four aforementioned agricultural locations produced hazard quotient and hazard index of less than 1, which is the level described by USEPA as having no appreciable risk for the development of non-cancer health effects. Hence, consumption of vegetables grown within the study areas would not result to cancer related illness.*

***Keywords:** Soil, Vegetables, Bioaccumulation, Polycyclic Aromatic Hydrocarbo*

INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) are a group of environmental contaminants that emanate from incomplete combustion of fuel or high temperature pyrolysis of fats and oils. It is well known that PAHs occur in curing smoke and they accumulate on meat products being smoked. They have been environmental threat because of their carcinogenicity and mutagenicity to animals (Anyakora and Coker 2016). In 2001, PAHs ranked 9th on the list of most threatening compounds to human health. Studies in the last few years have showed the presence of more than 600 organic compounds in the environment, the most important of which belong to the following classes of petroleum hydrocarbons, polycyclic aromatic hydrocarbons, ketones, aldehyde and alcohols. Organic pollutants are brought to the atmosphere due to their volatility, they either evaporate from the earth's surface or through emissions from the human activities and are subsequently transported with the masses of air over long distances. Water in clouds become saturated with these substances and precipitation contaminates surface waters and soil, sometimes far away from the emission sources.

A polycyclic aromatic hydrocarbon (PAH) represents a category of organic compounds characterized by the presence of multiple fused aromatic rings. The most elementary is naphthalene, which consists of two aromatic rings, alongside the tri-ring compounds anthracene and phenanthrene. PAHs exhibit properties of being uncharged, non-polar, and planar in structure. Numerous PAHs are colorless. A substantial quantity of these compounds is located in coal and petroleum deposits, in addition to being generated through the incomplete combustion of organic materials such as in the operation of engines and incinerators or during the combustion of biomass in forest fires (Hoover, 2014)

The discourse regarding polycyclic aromatic hydrocarbons encompasses their prospective function as precursor materials for abiotic syntheses of substances considered vital by the primordial forms of life (Allamandola et al., 2017)

METHODS

3.1 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

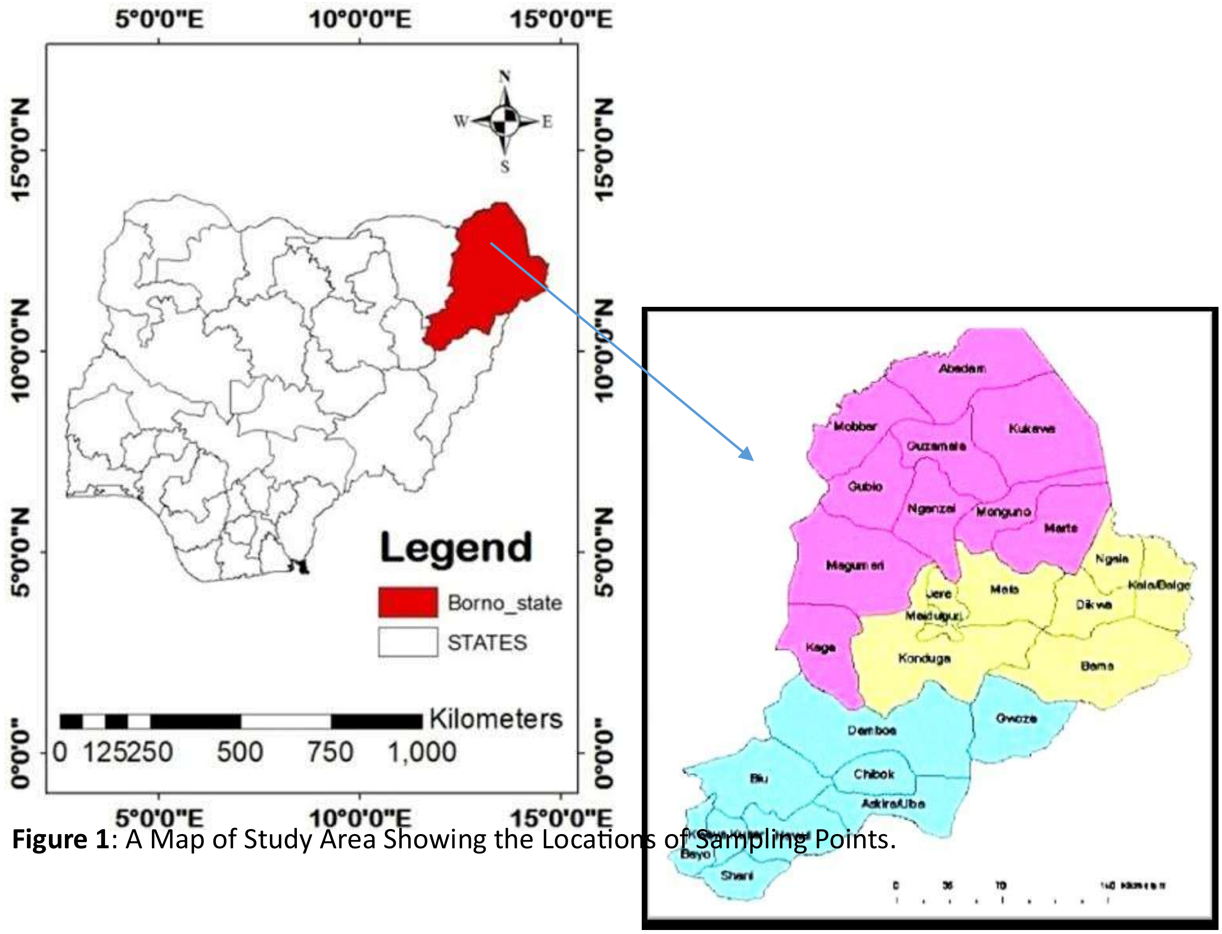


Figure 1: A Map of Study Area Showing the Locations of Sampling Points.

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.

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.

3.3 Sample Preparation

3.3.1 Preparation of 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).

3.3 Extraction of Polycyclic Aromatic Hydrocarbons (PAHs) In Vegetables Samples

1 g of air-dried at room temperature crushed and 2 mm mesh size sieved solid matrix samples were weighed into clean extraction containers. 10 ml of extraction solvent (l: l v/v Dichloromethane/Hexane) was added into the samples and mixed thoroughly using a glass rod, before being allowed to settle. The mixture was carefully filtered into clean solvent rinsed extraction bottles using filter paper fitted into a Buchner funnel; this extract was concentrated to I ml by evaporating on a water bath at 400^{O}C Oblinger *et al*. (2019).

3.4 Sample Clean-up/Separation of Polycyclic Aromatic hydrocarbons (PAHs) In Vegetables Samples

One centimetre (l cm) of moderately packed glass wool was placed at the bottom of a 10 mm is (internal diameter) x 250 mm long chromatographic column. A slurry of two grams (2 g) activated silica in 10 ml dichloromethane was prepared and place into the chromatographic column to the top of the column 0.5 cm of anhydrous sodium sulphate was added. The column was rinsed with additional 10 ml of dichloromethane. The column was pre-eluted with 20ml of dichloromethane, this was allowed to flow through the column for about 2 minutes until the liquid in the column was just above the anhydrous sodium sulphate layer. Immediately, I ml of the extracted sample was transferred into the column, the extraction bottle will be rinsed with 1 ml of dichloromethane and add to the column as well. The stop-cock of the column were opened nd the eluent was collected with a 10 ml graduated cylinder. Just prior to exposure of the anhydrous sodium sulphate layer to air, dichloromethane was added to the column in l- 2ml increments accurately measured volume of 8 - 10 ml of the eluent were collected and labelled Oblinger *et al*. (2019).

Mean Concentration of Some Polycyclic Aromatic Hydrocarbon (PAHs) in Vegetable Samples

Figure 1 shows the concentrations of some polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Soye agricultural location, Bama Local Government of Borno State. The concentration of naphthalene ranged from (2.03E-09 to 2.09E-04) mg/kg; (4.03E-09 to 4.35E- 07) mg/kg 2-methyl naphthalene; (4.45E-07 to 3.1E-06) mg/kg acenaphthylenes; (1.84E-09 to 2.02E-07) mg/kg acenaphthene; anthracene; (4.09E-08 to 2.25E-05) mg/kg fluoranthene; (1.92E-08 to 2.33E-05) mg/kg pyrene; (5.43E-09 to 4.93E-05) mg/kg benz(a)anthracene; (4.00E-07 to 8.00E-05) mg/kg chrysene; (2.09E-06 to 2.09E-04) mg/kg benz(b)fluoranthene; (7.00E-06 to 5.02E-04) mg/kg benz(k)fluoranthene; (1.74E-06 to 4.34E-04) mg/kg benz(a)pyrene; (4.00E-07 to 8.34E-04) mg/kg (8.00E-06 to 5.00E-04) mg/kg benzo(g,h,i)perylene; (2.00E-05 to 3.00E-04) mg/kg Indino (1,2,3-cd)pyrene. Onion recorded the highest total Concentration of PAHs with a value of 2.42E-03 mg/kg while tomato recorded the lowest total Concentration with a value of 6.34E-04. Research from different regions has shown varying PAH levels in vegetables; In southern Nigeria, leafy vegetables had mean ∑16 PAH concentrations ranging from 532 to 2261 µg/kg (Tesi *et al.,* 2021). Bishnoi *et al.,* 2024 carried out analysis in sewage-irrigated vegetables, spinach, carrot, and cucumber. It had mean ∑16 PAH concentrations of 123.36 µg/kg, 105.09 µg/kg, and 63.40 µg/kg, respectively. PAHs are concerning due to their potential carcinogenicity and health risks. Monitoring and minimizing PAH exposure through food consumption are essential (Nsonwu-Anyanwu *et al.,* 2024).

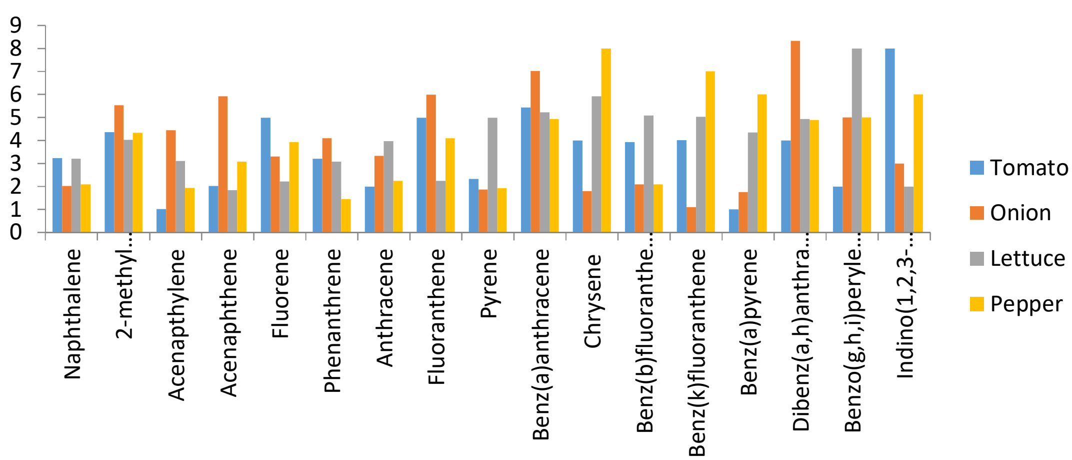


Figure 1: Concentrations of some Polycyclic Aromatic Hydrocarbon(mg/kg) in Vegetable Samples from Soye Bama Local Govt. Agricultural Location

Figure 2 shows the concentrations of some polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Bargu agricultural location, ***Jafi Kwaya Kusar*** Local Government of Borno State. The concentration of naphthalene ranged from (8.00E-05 to 9.00E-09) mg/kg; (6.00E-05 to 3.00E-06) mg/kg 2-methyl naphthalene; (2.00E-06 to 5.00E-05) mg/kg acenaphthylene; (4.00E-08 to 4.00E-06) mg/kg acenaphthene; (96.00E-06 to 6.00E-05) mg/kg fluorene; (3.00E-08 to 8.004.05E-04) mg/kg phenanthrene; (2.00E-06 to 7.00E-05) mg/kg anthracene; (1.00E-06 to 6.00E-05) mg/kg fluoranthene; (2.00E-06 to 3.00E-05) mg/kg pyrene; (2.00E-06 to 6.00E-05) mg/kg benz(a)anthracene; (2.00E-06 to 8.00E-04) mg/kg chrysene; (5.40E-06 to 6.00E-01) mg/kg benz(a)pyrene; (1.00E-04 to 6.00E-04) mg/kg dibenz(a,h)anthracene; (3.00E-06 to 7.00E-05) mg/kg benzo(g,h,i)perylene; (2.00E-05 to 4.00E-04) mg/kg indinol(1,2,3-cd)pyrene. Onion recorded the highest total concentration of PAHs with a value of 6.01 E-01 mg/kg while tomato recorded the lowest total concentration with a value of 1.03E-03 mg/kg. Phenanthrene, fluoranthene, chrysene, pyrene, and benzo(b)fluoranthene were abundant in soil samples, while anthracene, naphthalene, phenanthrene, pyrene, and chrysene dominated in vegetable samples. Soil organic matter plays a crucial role in preventing PAH losses (Tesi *et al.,* 2021).

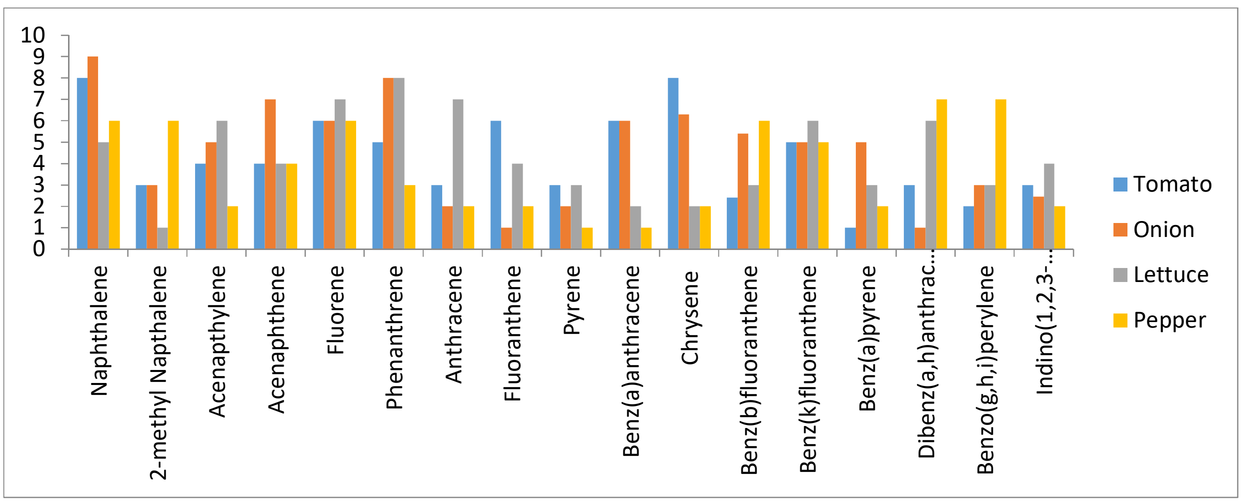


Figure 2: Concentrations of some Polycyclic Aromatic Hydrocarbon(mg/kg) in Vegetable Samples from Jafi Kwaya Kusar Local Govt. Agricultural Location

Figure 3 shows the concentrations of some polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Bargu agricultural location, Shani Local Government of Borno State. The concentration of naphthalene ranged from (1.80E-09 to 2.60E-06) mg/kg; (4.70E-08 to 1.65E-05) mg/kg 2-methyl naphthalene; (5.00E-08 to 5.30E-06) mg/kg acenaphthylenes; (3.00E-09 to 5.00E-05) mg/kg acenaphthene; (1.40E-08 to 5.00E-06) mg/kg fluorene; (5.00E-07 to 4.00E-06) mg/kg phenanthrene; (1.00E-09 to 1.00E-06) mg/kg anthracene; (6.00E-08 to 4.00E-06) mg/kg fluoranthene; (1.00E-08 to 4.00E-05) mg/kg pyrene; (93.00E-07 to 5.00E-05) mg/kg (4.00E-05 to 7.00E-05) mg/kg chrysene; (4.00E-06 to 4.00E-05) mg/kg (5.00E-06 to 2.00E-04) mg/kg benz(k)fluoranthene; (7.00E-08 to 6.00E-05) mg/kg benz(a)pyrene; (4.00E-05 to 3.01E-02) mg/kg dibenz(a,h)anthracene; (3.00E-06 to 1.00E-04) mg/kg; Benz(g.h,i)perylene; (1.00E-05 to 5.00E-04) 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). Tomato recorded the highest total concentration of PAHs Is with a value of 7.8313-04 mg/kg while pepper recorded the lowest total concentration with a value of 2.89E-04 mg/kg. Studies from other regions have investigated PAH levels in vegetables; in subtropical Shunde, China, vegetable samples had total PAH concentrations ranging from 82 to 1,258 µg/kg (Li *et al.,* 2008). Phenanthrene, fluoranthene, chrysene, pyrene, and benzo(b)fluoranthene were abundant in soil samples, while anthracene, naphthalene, phenanthrene, pyrene, and chrysene dominated in vegetable samples (Tesi *et al.,* 2021).

Figure 4 shows the concentrations of some polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Dalori agricultural location, Konduga Local Government of Borno State. The concentration of naphthalene ranged from to (4.00E-05 to 3.05E-06) mg/kg; (4.00E-08 to 3.00E-05) mg/kg 2-methyl naphthalene; (1.00E-07 to 2.00E-05) mg/kg acenaphthylene; (6.00E-09 to 6.00E-06) mg/kg acenaphthene; (3.00E-06 to 3.00E-05) to mg/kg fluorene; (2.00E-08 to 2.00E-05) mg/kg fluoranthene; (1.00E-06 to 3.00E-05) mg/kg pyrene; (3.00E-08 to 4.00E-05) mg/kg benz(a)pyrene; (1.00E-08 to 5.00E-05) mg/kg dibenz(a,h)anthracene; (3.00E-07 to 9.00E-05) mg/kg benzo(g,h,i)perylene; (1.00E-06 to 1.00E-04) mg/kg indinol(1,2,3-cd)pyrene. The total PAHs concentrations at different depth of soil samples was found to be significantly different at 5% probability level (P<0.05). Tomato recorded the highest total concentration of PAHs with a value of 7.03E-04 mg/kg while lettuce recorded the lowest total concentration with a value of 7.81 E-05 mg/kg. Soil organic matter plays a crucial role in preventing PAH losses (Tesi *et al.,* 2021).

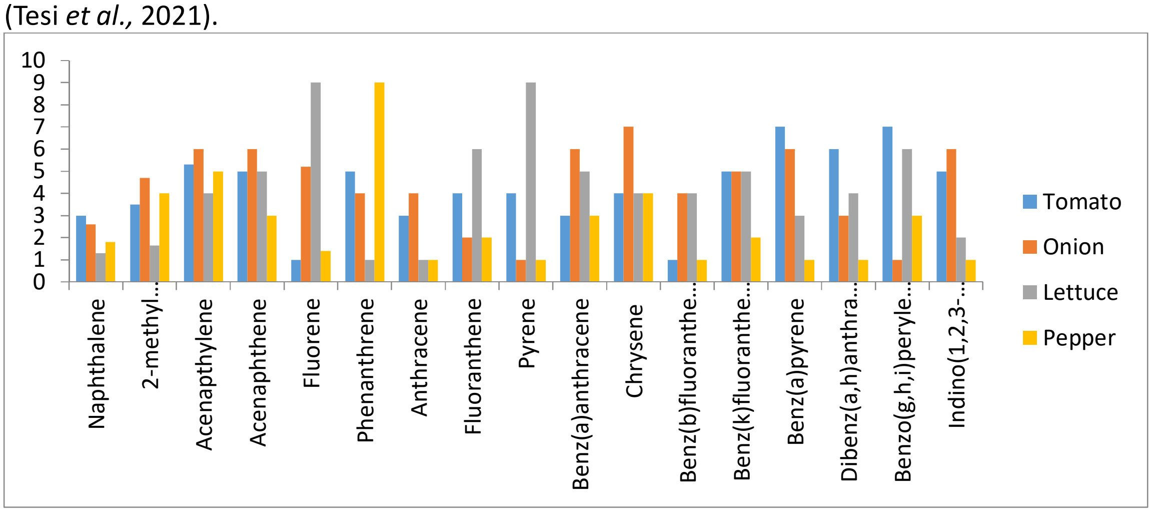


Figure 3: Concentrations of some Polycyclic Aromatic Hydrocarbon(mg/kg) in Vegetable from Bargu Shani Local Govt. Agriculture Location

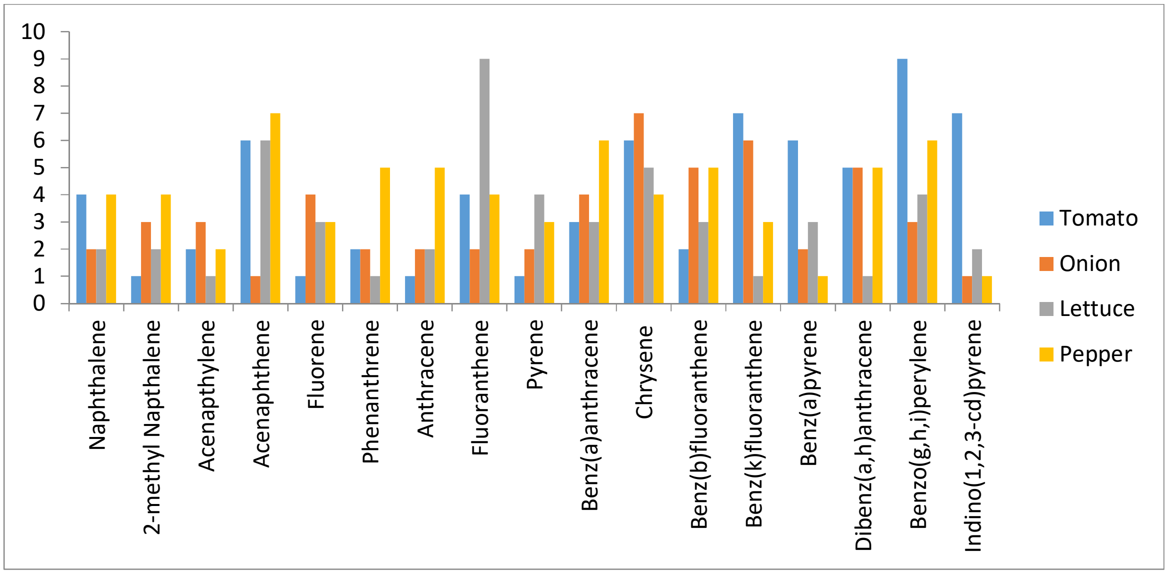


Figure 4: Concentrations of some Polycyclic Aromatic Hydrocarbon(mg/kg) in Vegetable sample from Dalori Agricultural Location

Risk Assessment Based on Benzo(a)pyrene of Some Polycyclic Aromatic Hydrocarbon in Vegetable Samples from Bargu Shani Local Government Area Borno State.

Figure 5 shows the Bap equivalent of some polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Bama Agricultural Location, Bargu Shani Local Government of Borno State. The concentration of naphthalene ranged from (9.00E-12 to 8.00E-08) mg/kg; (3.00E-09 to 3.00E-08) mg/kg 2-methyl napthalene; (6.00E-09 to 4.00E-08) mg/kg acenapthylene; (7.00E-11 to 4.00E-09) mg/kg acenaphthene; (7.00E-09 to 6.00E-08) mg/kg fluorcne; (3.00E-11 to 5.00E-08) mg/kg phenanthrene; (3.00E-08 to 7.00E-07) mg/kg anthracene, (2.00E-10 to 4.00E-08) mg/kg fluoranthene; (3.00E-09 to 1.00E-08) mg/kg pyrene; (2.00E-07 to I.00E-06) mg/kg (2.00E-09 to 8.00E-10) mg/kg chrysene; (5.40E-07 to 6.00E-02) mg/kg (5.00E-06 to 5.00E-05) mg/kg (3.00E-05 to 2.00E-04) mg/kg (7.00E-05 to 1.00E-04) mg/kg (3.00E-08 to 2.00E-07) benzo(g,h,i)perylene; (2.45E-07 to 3.00E-06) mg/kg indinol(1,2,3-cd)pyrene. The lowest total benzo(a)pyrene of 3.00E+09 mg/kg was recorded in onion, while recorded highest total benzo(a)pyrene of 6.12E-04 mg/kg.

Figure 6 shows the BaP equivalent of polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Soye Agricultural Location, Bama Local Government of Borno State. The concentration of naphthalene ranged from (2.03E-12 to 2.09E-07) mg/kg; (4.03E-12 to 4.33E-10) mg/kg 2-methyl napthalenc; (4.45E-10 to 1.21E-09) mg/kg acenapthylenc; (1.84E-12 to 2.02E-10) mg/kg acenaphthcnc; (3.29E-11 to 2.10E-03) mg/kg; fluorene (3.09E-12 to 4.09E-07) mg/kg phenanthrene; (2.25E-08 to 3.34E-07)) mg/kg anthracenc; (4.09E-11 to 2.25E-08) mg/kg fluoranthene; (1.92E-11 to 2.33E-08) mg/kg pyrene; (5.4E-10 to 4.93E- 06) mg/kg benz(a)anthracene; (4.00E-10 to 1.80E-08) mg/kg chrysene; (2.09E-07 to 2.09E-05) mg/kg benz(b)fluoranthcnc; (7.00E-07 to 1.09E-05) mg/kg benz(k)fluoranthene; (1.74E-06 to 4.34E-04) mg/kg benz(a)pyrenc; (4.00E-07 to 4.89E-04) mg/kg dibenz(a,h)anthracene; (8.00E-08 to 5.00E-06)mg/kg benzo(g,h,i)perylene; (8.00E-07 to 3.00E-06) mg/kg indinol(l,2,3-cd)pyrene. The lowest total Benzo(a)pyrene of 5.56E-05 mg/kg was recorded in lettuce, while tomato recorded the highest total Benzo(a)pyrene of 5.39E-04 mg/kg.

Figure 7 shows the Bap equivalent of some polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Jafi Agricultural Location, Kwaya-Kusar Local Government of Borno State. The concentration of naphthalene ranged from (l.80E-12 to 2.60E-09) mg/kg; (4.70E-11 to 1.65E-08) mg/kg 2-methyl napthalene; (6.00E-11 to 5.30E-09) mg/kg acenapthylene, (3.00E-12 to 5.00E-04) mg/kg acenaphthcnc; (9.01E-11 to 6.01-09) mg/kg fluorenc; (9.00E-10 to 1.00E-09) mg/kg phenanthrene; (1.00E-11 to 1.00E-08) mg/kg anthracene; (6.00E-11 to 2.00E-09) mg/kg (1.00E-11 to 4.00E-08) mg/kg pyrene; (3.00E-08 to 5.00E-06) mg/kg fluoranthene; (4.00E-08 to 7.00E-08) mg/kg chrysene; (4.00E-07 to 1.00E-06) mg/kg (5.00E-07 to 2.00E-05) mg/kg; (6.00E-06 to 1.00E-03 mg/kg; (6.00E-07 to 2.00E- 06) mg/kg of 9.68E-05 mg/kg was recorded in lettuce, while tomato the highest of 1.82E-05 mg/kg.

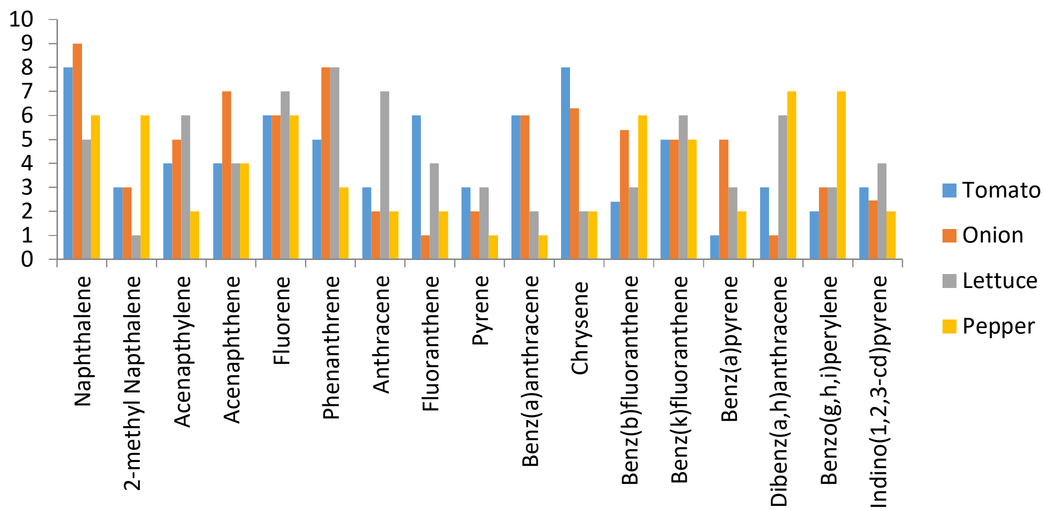


***Figure 5: Benzo (a) pyrene Equivalent of Some Polycyclic Aromatic Hydrocarbonin Vegetable Sample from* Bama, Shani Local Government of Borno State, Agricultural Location.**

Figure 8 shows the Bap equivalent polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Dalori agricultural location, Konduga Local Government of Borno state. concentration of naphthalcnc ranged from (1.56E-04 to 2.00E-08) mg/kg; (4.00E-ll to 3.00E-08) mg/kg 2-methyl napthalene; (2.00E-10 to 2.00E-08) mg/kg acenapthylene; (6.00E-12 to 6.00E-09)mg/kg acenaphthcnc; (4.00E-09 to 1.00E-08) mg/kg fluorene; (5.00E-11 to 2.00E-03) mg/kg phenanthrene; (1.00E-09 to 2.00E-08) mg/kg anthraccne; (4.00E-12 to 4.00E-08) mg/kg fluoranthene; (4.00E-09 to 3.00E-08) mg/kg pyrene; (6.00F.-09 to (3.00E-06) mg/kg benz(a)anthracenc; (5.00E-10 to 6.00E-08) mg/kg chrysene; (5.00E-08 to 2.00E-05) mg/kg benz(b)fluoranthene; (3.00E-07 to 1.00E-06) mg/kg benz(k)fluoranthene; (6.00E-05 to 2.00E-04) mg/kg benz(a)pyrene; (1.00E-08 to 5.00E-05) mg/kg dibenz(a,h)anthracene; (4.00E-09 to 6.00E- 07)mg/kg benzo(g,h,i)perylcne; (1.00E-06 to 2.00E-03) mg/kg indinol(l,2,3-cd)pyrcne. The lowest total Benzo(a)pyrene of 9.67E-05 mg/kg was recorded in lettuce, while tomato recorded the highest total Benzo(a)pyrene of 2.62E-04 mg/kg.

The consumption of vegetables contaminated with BaP and other PAHs can lead to severe health consequences. Chronic exposure to PAHs is associated with an increased risk of cancer, particularly lung and skin cancers (Tesi *et al.,* 2021. The International Agency for Research on Cancer (IARC) classifies BaP as a Group 1 carcinogen, meaning there is sufficient evidence of its carcinogenicity in humans (IARC, 2012). In addition, exposure to BaP has been linked to developmental and reproductive toxicity, causing harm to the nervous and immune systems (Perera *et al.,* 2004).

The high levels of BAP equivalents in these vegetables exceed safety thresholds set by health authorities. The European Food Safety Authority (EFSA) sets a maximum allowable limit for BaP in foodstuffs at 1 µg/kg, particularly for processed foods like cereals, oils, and fats (EFSA, 2008).

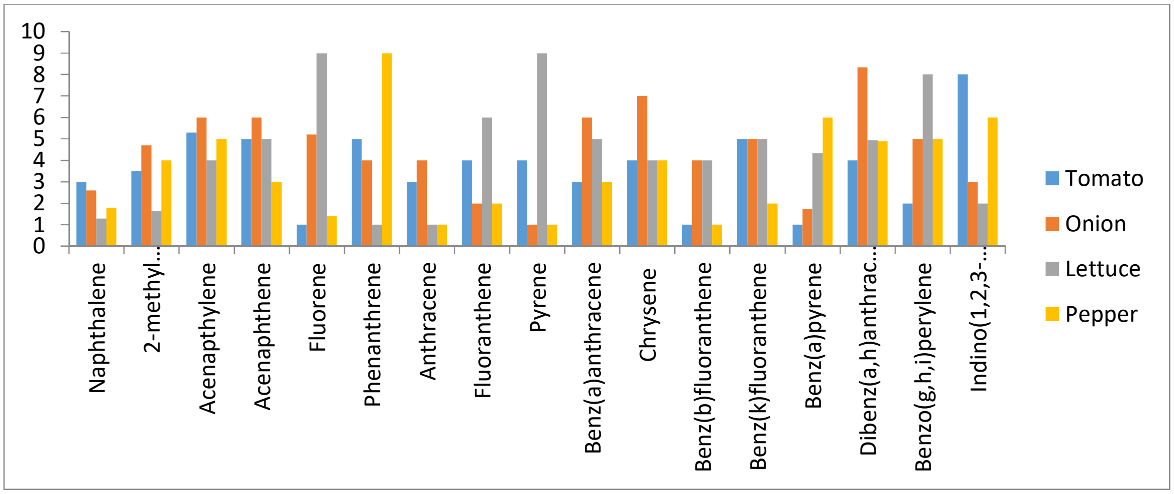


***Figure 6: Benzo (a) pyrene Equivalent of Some Polycyclic Aromatic Hydrocarbon in Vegetable from* Jafi Agricultural Location, Kwaya-Kusar Local Government of Borno State.**

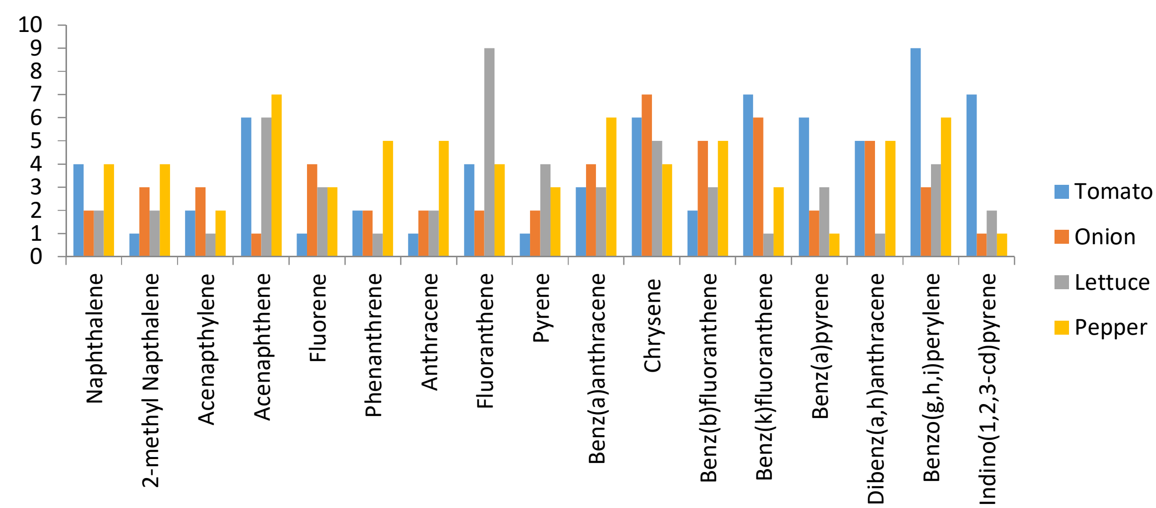


Figure 7: Benzo (a) pyrene Equivalent of some Polycyclic Aromatic hydrocarbon in Vegetable Samples from Dalori Agricultural Location

Estimation of Average Daily Dose of Some Polycyclic Aromatic Hydrocarbon in Vegctablc Samples from Bargu Shani Local Government Area Borno State.

The results from the analysis of vegetable samples in different locations of Borno State indicate the presence of polycyclic aromatic hydrocarbons (PAHs) in varying concentrations. PAHs are organic pollutants known for their persistence in the environment and potential to bioaccumulate in agricultural products, including vegetables. The significant variation in the average daily dose (ADD) of PAHs among different vegetables, particularly in locations like Bargu, Soye, Jafi, and Dalori, demonstrates the influence of both environmental factors and vegetable type on PAH concentrations. The results are presented from Figure 4.25 to Figure 4.28

Figure 9 shows the average daily dose (ADD) of some polycyclic aromatic hydrocarbon (PAHS) in vegetable samples from Bargu agricultural location, Shani Local Government of Borno State. The concentration of naphthalene ranged from (5.87E-16 to 9.00E-12) mg/kg; (8.81E-18 to 5.87E-14) mg/kg 2-methyl napthalenc; (3.91E-16 to 4.89E-14) mg/kg acenapthylene; (6.85E-17 to 3.91E-15) mg/kg acenaphthene; (6.85E-15 to 5.87E-14) mg/kg fluorene; (2.94E-17 to 4.89E-14) mg/kg phenanthrene; (2.94E-14 to 6.85E-13) mg/kg anthracene, (9.79E-16 to 3.91E-14) mg/kg fluoranthene; (9.76E-15 to 2.94E-14) mg/kg pyrene; (9.79E-13 to 5.87E-12) mg/kg benz(a)anthracene: (1.96F-15 to 7.83E-13) mg/kg chrysene; (5.29E-13 to 5.87E-08) mg/kg benz(b)fluoranthene; (4.89E-12 to 4.89E-11) mg/kg benz(k)fluoranthene, (9.76E-12 to 1.96E-10) mg/kg benz(a)pyrene; (9.79E-11 to 2.94E-10) mg/kg dibenz(a,h)anthracene; (2.94E-14 to 1.966-13) benzo(g,h,i)perylene; (1.96E-13 to 2.45E-07) mg/kg indinol(1,2,3-cd)pyrene. The lowest total average daily dose of 3.651E-10 mg/kg was recorded in onion, while tomato recorded the highest total average daily dose of 7.10E-04 mg/kg.

Figure 10 shows the ADD of some polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Soye agricultural location, Bama Local Government of Borno State. The concentration of naphthalene ranged from (2.03E-18 to 2.05E-13) mg/kg; (3.94E-18 to 4.24E-16) mg/kg 2-methyl napthalene; (9.98E-16 to 1.89E-15) mg/kg acenapthylene; (1.80E-18 to 1.98E-16) mg/kg acenaphthene; (3.22E-17 to 2.17E-14) mg/kg fluorene; (3.02E-18 to 3.89E-13) mg/kg phenanthrene; (2.20E-14 to 3.27E-13) mg/kg anthracene: (3.85E-17 to 2.20E-14) mg/kg fluoranthene; (1.88E-17 to 2.28E-14) mg/kg pyrene; (5.31E-16 to 4.82E-12) mg/kg benz(a)anthracene; (3.91E-16 to 1.76E-14) mg/kg chrysene; (2.05E-13 to 2.05E-11) mg/kg benz(b)fluoranthene; (6.85E-13 to 1.07E-11) mg/kg benz(k)fluoranthene; (9.76E-12 to 4.24E-

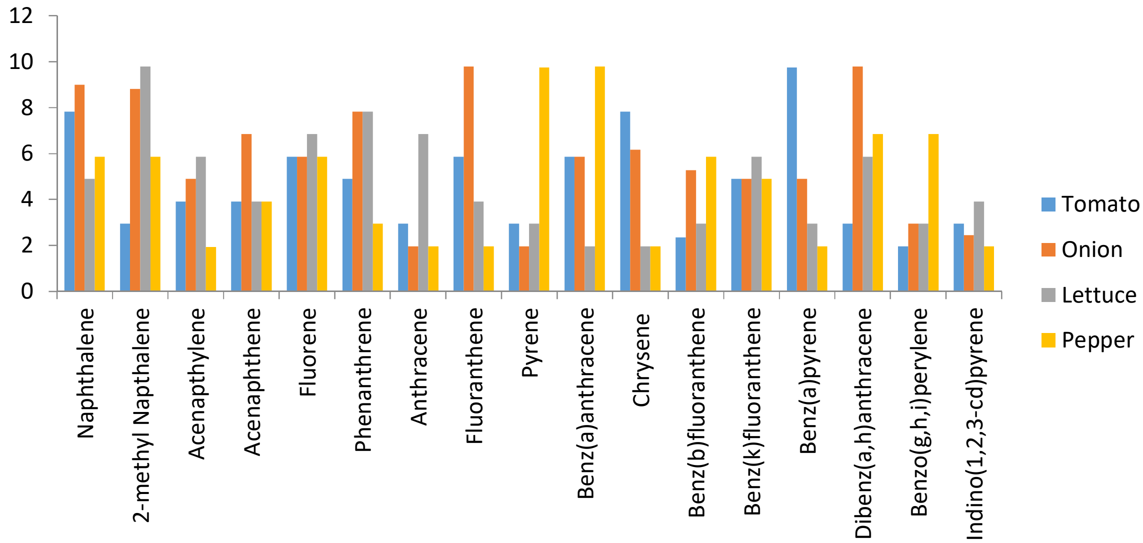


Figure 8: Estimation of Average Daily Dose of stone Polycyclic Aromatic Hydrocarbon in Vegetable Samples from Jafi, Kwaya Kusar Local Govt. Agricultural Location

10) mg/kg benz(a)pyrene; (3.91E-13 to 4.79E-10) mg/kg dibenz(a,h)anthracene; (1.96E-13 to 4.89E-12) benzo(g,h,i)perylene; (7.83E-13 to 2.94E-12) mg/kg indinol(1,2,3-cd) pyrene. The lowest total average daily dose of 5.44E-11 mg/kg was recorded in lettuce, while tomato recorded the highest total average daily dose of 5.27E-10 mg/kg.

Figure 11 shows the average daily dose of some polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Jafi agricultural location, Kwaya-Kusar Local Government of Borno State. The concentration of naphthalene ranged from (1.76E-18 to 2.54E-15) mg/kg; (4.60E-17 to 1.61E-14) mg/kg 2-methyl napthalene; (4.89E-17 to 6.00E-11) mg/kg acenapthylene, (2.94E-18 to 4,89E-15) mg/kg ucenaphthene; (8.81E-17 to 5.09E-15) mg/kg fluorene; (9.79E-16 to 3.91E-12)mg/kg phenanthrene; (9.79E-18 to 3.918-15) mg/kg anthracene; (5.87E-17 to 1.96E-15) mg/kg fluoranthene; (9.79E-18 to 3.91E-14) mg/kg pyrene; (2.94E-14 to 4.89E-12) mg/kg benz(a)anthracene; (3.91E-14 to 6.85E-14) mg/kg chrysene; (9.76E-13 to 3.91E-12) mg/kg benz(b)fluoranthene; (4.89E-13 to 1.96E-11) mg/kg benz(k)fluoranthene, (6.85E-14 to 5.87E-11) mg/kg benz(a)pyrene; (9.79E-12 to 2.94E-11) mg/kg dibenz(a,h)anthracene; (2.94E-14 to 5.878-13) benzo(g,h,i)perylene; (9.76E-14 to 1.96E-12) mg/kg indinol (1,2,3-ed)pyrene. The lowest total average daily dose of 9.57E-11 mg/kg was recorded in onion, while pepper recorded the highest total average daily dose of 4.04E-05 mg/kg.

Figure 12 shows the ADD of some polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Dalori agricultural location, Konduga Local Government of Borno State. The concentration of naphthalene ranged from (3.91E-15 to 3.91E-14) mg/kg; (9.79E-16 to 3.91E-11) mg/kg 2-methyl napthalene; (9.79E-17 to 1.96E-14) mg/kg acenapthylene; (9.79E-18 to 5.87E-15) mg/kg acenaphthene; (9.76E-15 to 2.94E-14) mg/kg fluorene; (9.76E-15 to 2.94E-14) mg/kg phenanthrene; (4.89E-17 to 1.96E-14) mg/kg anthracene; (9.79E-16 to 1.96E-14) mg/kg fluoranthene; (3.91E-18 to 3.91E-14) mg/kg pyrene, (9.79E-16 to 2.94E-14) mg/kg benz(a)anthracene; (4.89E-16 to 5.87E-14) mg/kg chrysene; (4.89E-14 to 1.96E-11) mg/kg benz(b)fluoranthene; (2.94E-13 to 5.87E-12) mg/kg benz(k)fluoranthene; (9.76E-11 to 1.96E-10) mg/kg benz(a)pyrene; (9.79E-14 to 4.89E-11) mg/kg dibenz(a,h)anthracene; (3.91E-15 to

5.87E- 12) benzo(g,h,i)perylene; (9.79E-14 to 9.79E-12) mg/kg indinol(1,2,3-cd)pyrene. The lowest total average daily dose of 9.47E-11 mg/kg was recorded in onion, while tomato recorded the highest total average daily dose of 2.48E-10 mg/kg.

The concentrations of some PAHs in vegetable samples from these locations, particularly benz(a)pyrene, chrysene, and benz(b)fluoranthene, are concerning due to their well-

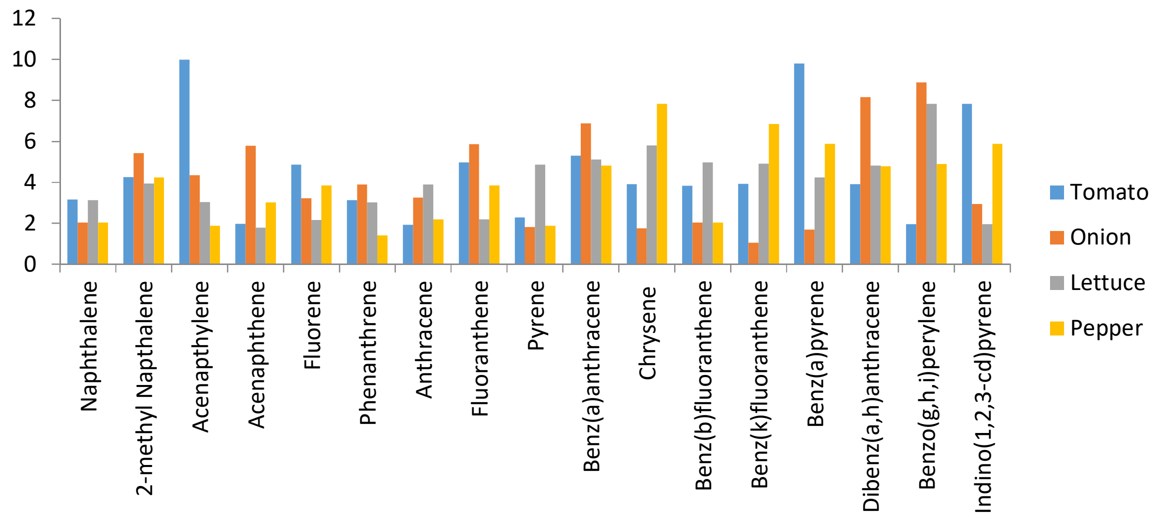


Figure 9: Estimation of Average Daily Dose of Some Polycyclic Aromatic Hydrocarbon in Vegetable Samples from Soye, Bama Local Govt. Agricultural Location

documented carcinogenic and mutagenic properties. PAHs such as benzo(a)pyrene have been identified as potential human carcinogens by the International Agency for Research on Cancer (IARC) (IARC, 2012). Exposure to these compounds, even in low doses, can accumulate over time and lead to significant health risks, including cancer and developmental effects (USEPA, 2016). The highest total ADD in vegetables such as tomato suggests that these crops may pose a greater risk when compared to others like onions and lettuce, which had lower PAH concentrations.

The differences in PAH levels across various locations may be attributed to agricultural practices, the proximity to industrial activities, and pollution sources such as vehicular emissions and incomplete combustion of organic matter (Abdel-Shafy and Mansour, 2016). Shani and Konduga Local Government Areas are prone to environmental pollution, which could result in higher PAH contamination in vegetables. When compared to international safety standards, the concentrations of PAHs found in these vegetables, particularly the carcinogenic ones, exceed permissible limits in some cases. The European Food Safety Authority (EFSA) sets a maximum level for benzo(a)pyrene in foods at 2 µg/kg (EFSA, 2008), and the levels observed in some samples far exceed this, indicating a potential health hazard for consumers in the region

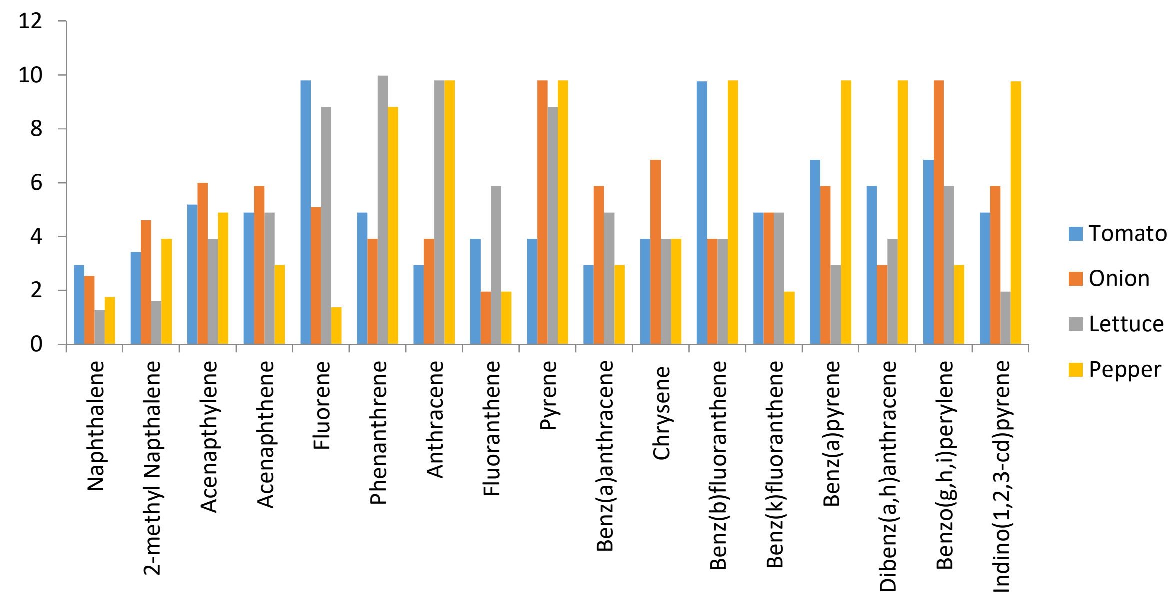


Figure 10: Estimation of Average Daily Dose of Some Polycyclic Aromatic Hydrocarbon in Vegetable Samples from Bargu Shani Local Govt. Agricultural Location

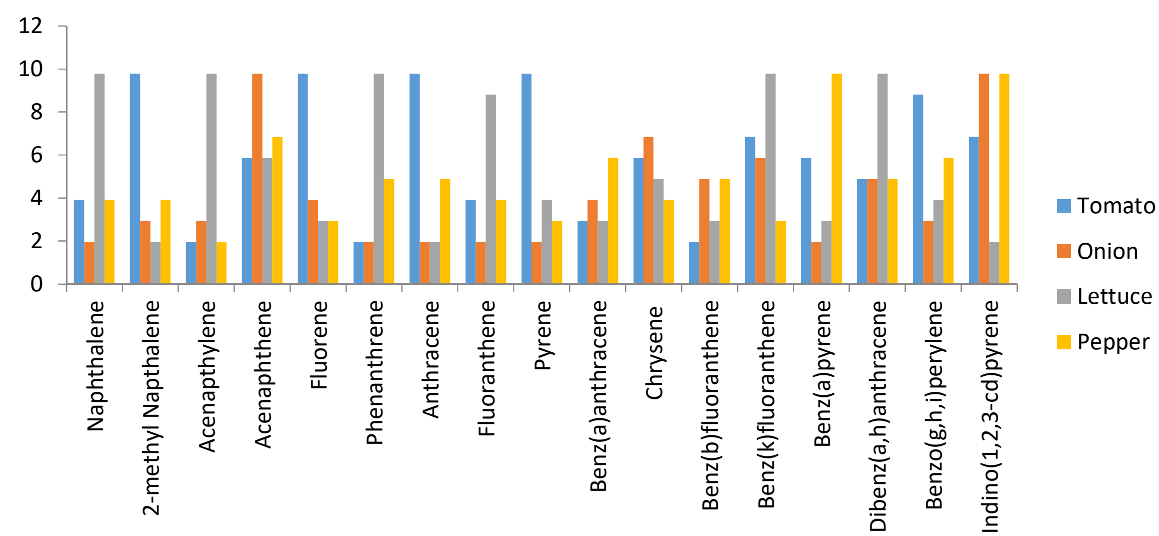


Figure 11: Estimation of Average Daily Dose of Some Polycyclic Aromatic Hydrocarbonin Vagetable Samples from Dalori Konduga Local Govt. Agricultural Location

Carcinogenic Risk Assessment of Some Polycyclic Aromatic Hydrocarbon in Vegetable Samples from Bargu, Shani Local Government Area Borno State

Figure 4.29 shows the risk assessment of some polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Bargu agricultural location, Shani Local Government of Borno State. The risk assessment of benz(a)anthracene; ranged from (7.15B-13 to 1.438-12)mg/kg: (1.43E 17 to 5.72E-15) mg/kg chrysene; (3.85E-13 to 4.298-08) mg/kg benz(b)fluoranthene: (3.578-12 to 157E-11) mg/kg benz(k)fluoranthene; (7.13E-11 to 1.43E-09) mg/kg benz(a)pyrene; (7.15E-11 to 2.15E-09) mg/kg dibenz(a,h)anthracene; (1.43E-14 to 1.79E-08) indinol(1,2,3-

ed)pyrene. The lowest total risk assessment of 4.57E-09 mg/kg was recorded in onion, while lettuce recorded the highest total risk assessment of 1.83E-08 mg/kg.

Figure 13 shows the risk assessment of some polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Soye agricultural location, Bama Local Government of Borno State. The risk assessment of benz(a)anthracene; ranged from (3.88E-16 to 4.57E-12) mg/kg; (2.85E-17 to 1.29F-14) mg/kg chrysene; (1.50E-13 to 1.50E-11) mg/kg benz(b)fluoranthene; (5.00E-13 to 2.87E-11) mg/kg benz(k)fluoranthene; (7.15E-12 to 3.10E-09) mg/kg bernz(a)pyrene; (2.85E-12 to 3.50E-09) mg/kg dibenz(a,h)anthracene; (5.72E-14 to 2.158-13) indinol(1,2,3-cd)pyrene. The lowest total adult daily dose of 4.16E-11 mg/kg was recorded in lettuce, while tomato recorded the highest total risk assessment of 3.49E-09 mg/kg. The elevated levels of carcinogenic PAHs in common vegetables such as lettuce and tomatoes raise concerns about long-term exposure to these toxic substances through dietary intake. Chronic exposure to even low levels of PAHs has been associated with increased cancer risks, as reported in studies focusing on occupational exposure and dietary consumption (Rengarajan *et al.,* 2015). The carcinogenic effects of PAHs have been reported to be more prominent in certain parts of the body which include the gastro-intestine, liver, lung, bladder and skin (Benson *et al.,* 2017; ATSDR, 2013).

The risk assessment highlights significant carcinogenic potential from consuming PAH-contaminated vegetables, particularly from locations like Bargu and Soye. The variability in PAH concentration across different vegetable types underscores the importance of monitoring and mitigating PAH contamination in agricultural settings (Rengarajan *et al.,* 2015

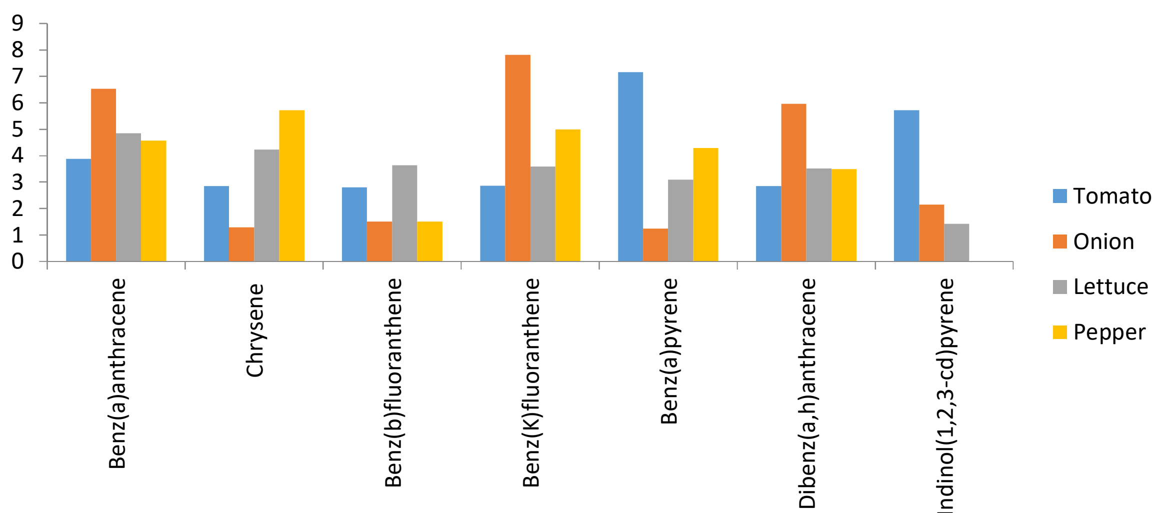


Figure 12: Carcinogenic Rick Assessment of some Polycyclic Aromatic Hydrocarbon in Vegetable Samples from Soye, Bama Local Govt. Agricultural Locatio

Carcinogenic Risk Assessment of Some Polycyclic Aromatic Hydrocarbon in Vegetable Samples from Jafi, Kwaya-Kusar Local Government Area Borno State

The carcinogenic risk assessment of polycyclic aromatic hydrocarbons (PAHs) in vegetable samples from the Jafi and Dolari agricultural locations of Kwaya-Kusar and Dolari Local Government Areas (LGAs) in Borno State reveals varying levels of PAH contamination, with different vegetables showing a range of exposure risks. The findings from these regions further illustrate the potential health risks associated with consuming PAH-contaminated crops.

Figure 14 shows the risk assessment of some polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Jafi agricultural location, Kwaya-Kusar Local Government of Borno State. The risk assessment of benz(a)anthracene; ranged from (2.15E-14 to 3.57E-12) mg/kg; (2.85E-14 to 5.00E-14) mg/kg chrysene; (7.13E-13 to 2.85E-12) mg/kg benz(b)fluoranthene: (3.57E-13 to 1.43E-11) mg/kg benz(k)fluoranthene; (5.00E-13 to 4.29E-10) mg/kg benz(a)pyrene; (7.15E-11 to 2.15E-10) mg/kg dibenz(a,h)anthracene; (7.13E-15 to 1.43E-13) mg/kg indinol(1,2,3-cd) pyrene. The vegetable-specific carcinogenic risk assessment indicates that **pepper** had the lowest risk assessment (4.82E-11 mg/kg), while **tomato** recorded the highest total risk assessment (1.58E-10 mg/kg). This aligns with the findings from other regions where tomatoes and leafy vegetables such as lettuce tend to accumulate higher levels of PAHs (Li *et al.,* 2021).
Figure 15 shows the risk assessment of some polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Dolari Local Government of Borno State. The risk assessment of benz(a)anthracene; ranged from (4.29E-15 to 2.15E-12) mg/kg; (3.57F-18 to 4.29E-16) mg/kg chrysene; (3.57E-14 to 1.43E-11) mg/kg benz(b)fluoranthene; (2.15E-13 to 4.29E-12) mg/kg benz(k)fluoranthene; (7.15E-10 to 1.43E-09) mg/kg benz(a)pyrene; (7.15E-13 to 3.578-10) mg/kg dibenz(ah)anthracene; (7.15E-15 to 7.15E-14) indinol(1,2,3-ed) pyrene. The total risk assessment shows that **pepper** had the lowest total risk (7.19E-10 mg/kg), while **tomato** had the highest (1.82E-09 mg/kg), similar to the findings in Jafi. These results suggest that certain vegetables, like tomatoes, may be more prone to PAH accumulation. Across both Jafi and Dolari, tomatoes consistently show the highest PAH contamination, which may be linked to the plant's ability to absorb pollutants from the soil. This is significant because tomatoes are a staple food in many diets, potentially leading to chronic exposure to these carcinogenic compounds. On the other hand, peppers, which show the lowest total risk assessments in both locations, may have a lower uptake of PAHs, possibly due to their morphological characteristics or growing conditions (Rengarajan *et al.,* 2015). are known to induce carcinogenic effects, primarily through the formation of DNA adducts, which result in genetic mutations if not repaired. Chronic exposure to PAHs through food consumption has been associated with an increased risk of cancers in organs such as the lungs, liver, and skin (ATSDR, 2013; Rengarajan *et al.,* 2015). **Benz(a)pyrene**, in particular, is a potent carcinogen that is often used as a reference compound in risk assessments for PAH mixtures. The high levels of benz(a)pyrene in both Jafi and Dolari samples indicate a significant cancer risk, especially for populations with prolonged exposure (EPA, 2020).

The presence of elevated PAH levels in the vegetables from these locations could be attributed to multiple factors, including the proximity of agricultural fields to pollution sources such as vehicular emissions, industrial activities, or the use of contaminated irrigation water (Wang *et al.,* 2016).Soil contamination may also result from the deposition of atmospheric PAHs, which then accumulate in plants through their roots and leaves (Khan *et al.,* 2008). Vegetables such as tomatoes, with their relatively high surface area and permeability, are more likely to absorb PAHs from both soil and air, making them high-risk crops in contaminated regions (Li *et al.,* 2021).

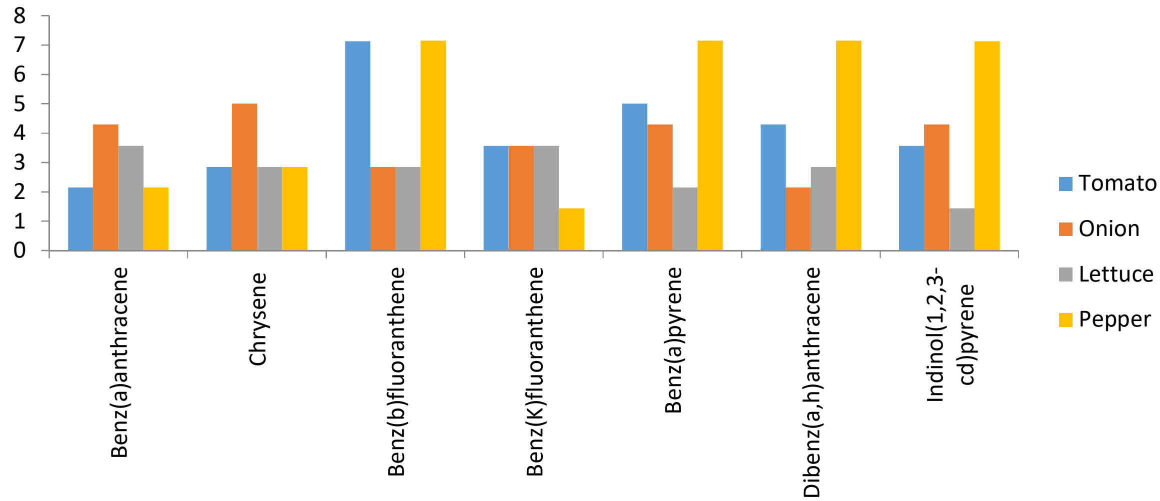


Figure 13: Carcinogenic Rick Assessment of some Polycyclic Aromatic Hydrocarbon in Vegetable Samples from Bargu, Shani Local Government Agricultural Location

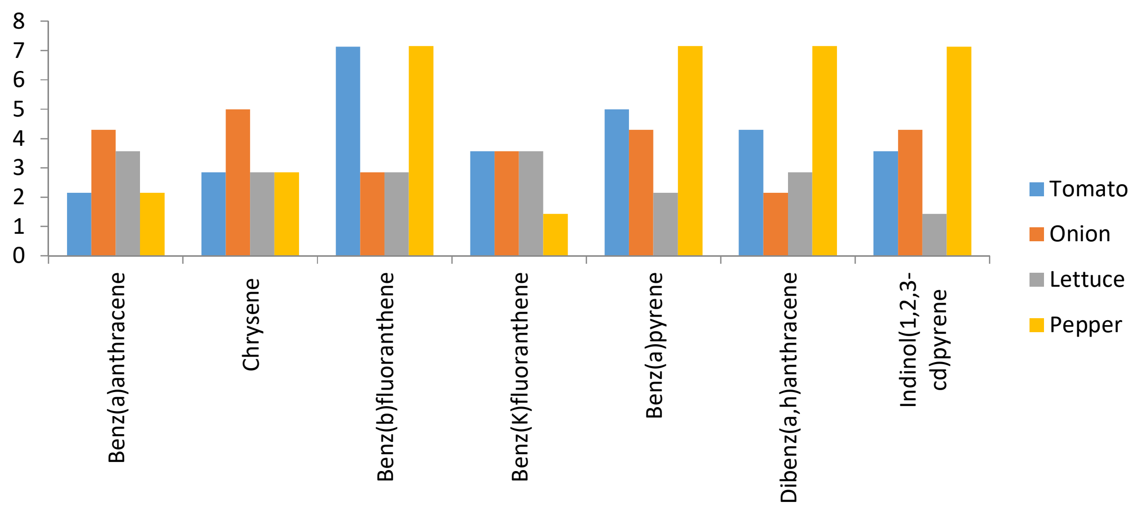


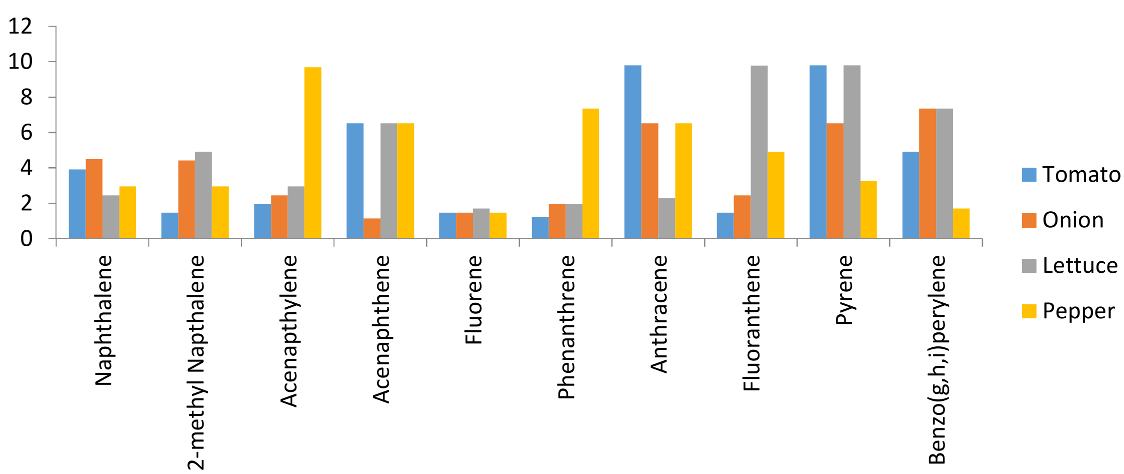
Figure 14: Carcinogenic Rick Assessment of some Polycyclic Aromatic Hydrocarbon in Vegetable Samples from Dalori Local Government Agricultural Location

Risk Assessment Based on Non-Carcinogenic Hazard Quotient and Hazard Index of Some Polycyclic Aromatic Hydrocarbon in Vegetable Samples from Bargu, Shani Local Government Area Borno State

Figure 16 shows the hazard quotient and hazard index (HQ and HI) of some polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Bargu agricultural location, Shani Local Government of Borno State. The concentration of naphthalene ranged from (2.94E-14 to 4.50E-10) mg/kg; (4.41E-16 to 2.94E-12) mg/kg 2-methyl napthalene: (9.70E-14 to 2.45E-12) mg/kg acenapthylene; (6.52E-16 to 1.14E-12) mg/kg acenaphthene; (1.71E-13 to 1.47E-12) mg/kg fluorene; (7.35E-16 to 1.22E-12) mg/kg phenanthrene; (9.80E-14 to 2.28E-12) mg/kg anthracene; (4.90E-15 to 1.47E-12) mg/kg fluoranthene; (9.80E-14 to 3.25E-13) mg/kg pyrene; (7.35E-14 to 1.72E-11) benzo(g,h,i)perylene; The lowest total hazard quotient and hazard index of 2.07E-11 mg/kg was recorded in onion, while tomato recorded the highest total hazard quotient and hazard index of 4.58E-10 mg/kg. This indicates that **tomatoes** pose a higher non-carcinogenic health risk when compared to other vegetables in Bargu, reflecting the ability of tomatoes to accumulate PAHs more readily due to their morphology and surface area (Li *et al.,* 2021).

Figure 17 shows the HQ and HI of some polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Soye agricultural location, Bama Local Government of Borno State. The concentration of naphthalene ranged from (1.026-16 so 103E-11) mg/kg: (3.94E-16 to 2.12B-14) mg/kg 2-methyl napthalene, (9.458-14 to 1.528-13) mg/kg acenupthylene; (3.00E-17 to 3.308-15) mg/kg acenaphthene, (8.058-16 to 1.228-12) mg/kg lumene: (7,83E-15 to 9.73E-12) mg/kg phenanthrene; (7.336-14 to 1.09E-12) mg/kg anthracene: (9.63E-16 1.22E-13) mg/kg fluoranthene; (6.27E-17 to 7.608-13) mg/kg pyrene; (4.908-12 to 1226-10) benzo(g,h,i) perylene; The lowest total hazard quotient and hazard index of 7.15E-12 mg/kg was recorded in onion, while tomato recorded the highest total hazard quotient and hazard index of 133E-10 mg/kg. The relatively low values in **onions** and **other vegetables** imply that the risk from these foods is significantly lower. These findings align with other studies, such as those by **Shen et al. (2017)**, which report that leafy and root vegetables tend to absorb less PAHs than fruits like tomatoes.

Figure 18 shows the hazard quotient and hazard index of some polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Jafi agricultural location, Kwaya-Kusar Local Government of Borno State. The concentration of naphthalene ranged from (8.80E-17 to 1.27E-13) mg/kg; (2.30E-15 to 1.72E-13) mg/kg 2-methyl napthalene; (2.45E-15 to 3.00E-09) mg/kg



Rick Assessment Based on Non Carcinogenic Hazard Quotient and Hazard Index of Some Polycyclic Aromatic Hydrocarbon Samples from Jafi Kwaya Kusar Local Govt. Agricultural Location

acenapthylene; (4.90E-17 to 8.15E-14) mg/kg acenaphthene; (3.43E-17 to 1.27E-13) mg/kg fluorene, (1.22E-14 to 9.78E-14) mg/kg phenanthrene; (9.80E-16 to 3.26E-13) mg/kg anthracene; (4.90E-15 to 4.90E-13) mg/kg fluoranthene; (3.26E-16 to 1.30E-12) mg/kg pyrene, (7.35E-13 to 1.47E-11) benzo(g,h,i)perylene. The lowest HQ and HI were found in **onion** (9.93E-13 mg/kg), while **tomato** again recorded the highest HQ and HI values (3.03E-19 mg/kg). The low HQ and HI values across all vegetables suggest that the risk from these vegetables is negligible, with **onions** being the safest choice from a non-carcinogenic perspective. **Tomato**, while consistently showing higher HQ and HI values across different locations, still does not exceed dangerous levels. This finding is consistent with research that suggests **PAHs** can bind to soil particles and organic matter, leading to varying degrees of uptake by different crops (Wang *et al.,* 2017).

Figure 19 shows the HQ and HI of some polycyclic aromatic hydrocarbon (PAHs) in vegetable samples from Jafi agricultural location, Kwaya-Kusar Local Government of Borno State. The concentration of naphthalene ranged from (9.80E-14 to 1.96E-12) mg/kg: (9.808- 14 to 1.96E-09) mg/kg 2-methyl napthalene; (9.80E-15 to 1.47E-13) mg/kg acenapthylene, (9.78E- 17 to 1.14E-14) mg/kg acenaphthene; (9.78E-14 to 2.44E-13) mg/kg fluorene; (4.90E-16 to 4.90E-13) mg/kg phenanthrene; (3.26E-15 to 1.63E-13) mg/kg anthracene; (9.78E-17 to 9.78E-13) mg/kg fluoranthene; 6.53E-14 to 1.30E-13 mg/kg pyrene; 9.788-14 to 1.478-11 benzo(ghi)perylene. The lowest HQ and HI were recorded in **onion** (7.35E-14 mg/kg), while **tomato** recorded the highest HQ and HI (1.978E-09 mg/kg). The fact that tomatoes consistently show the highest HQ and HI values across multiple agricultural locations reinforces the conclusion that **tomatoes** present a higher risk of PAH exposure. Although the HQ and HI values do not surpass dangerous thresholds, continued exposure could pose cumulative risks. The consistency of **onions** showing the lowest HQ and HI values suggests that onions are generally a safer vegetable in terms of PAH contamination (Shen *et al.,* 2017).

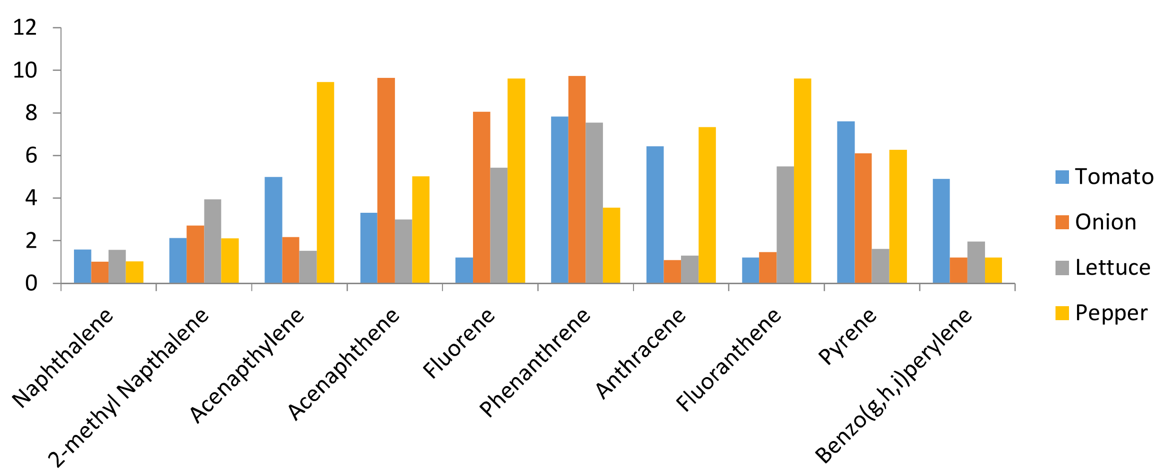


Figure ***16: Rick Assessment Based on Non-Carcinogenic Hazard Quotient and Hazard Index of Some Polycyclic Aromatic Hydrocarbon Samples from Soye Bama Local Govt. Agricultural Location***

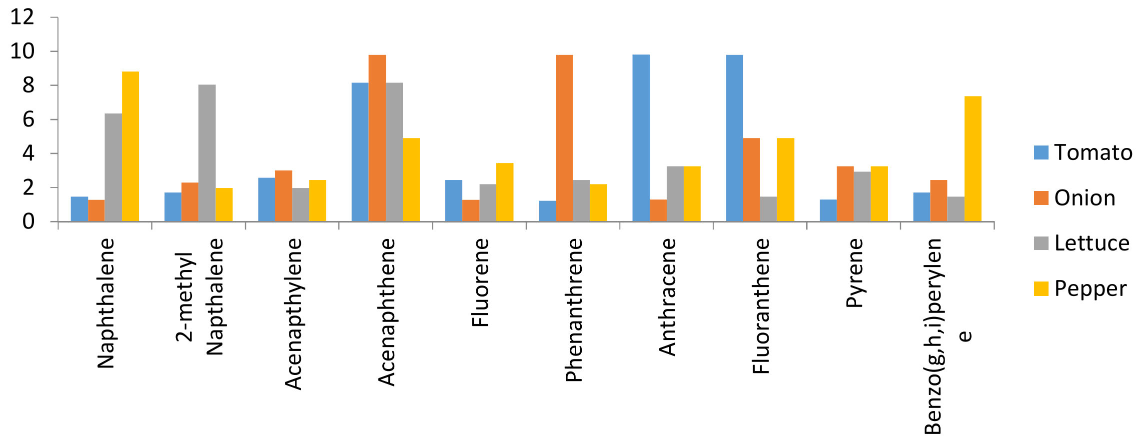


Figure ***17: Rick Assessment Based on Non-Carcinogenic Hazard Quotient and Hazard Index of Some Polycyclic Aromatic Hydrocarbon Samples From Bargu Shani Local Govt. Agricultural Location***

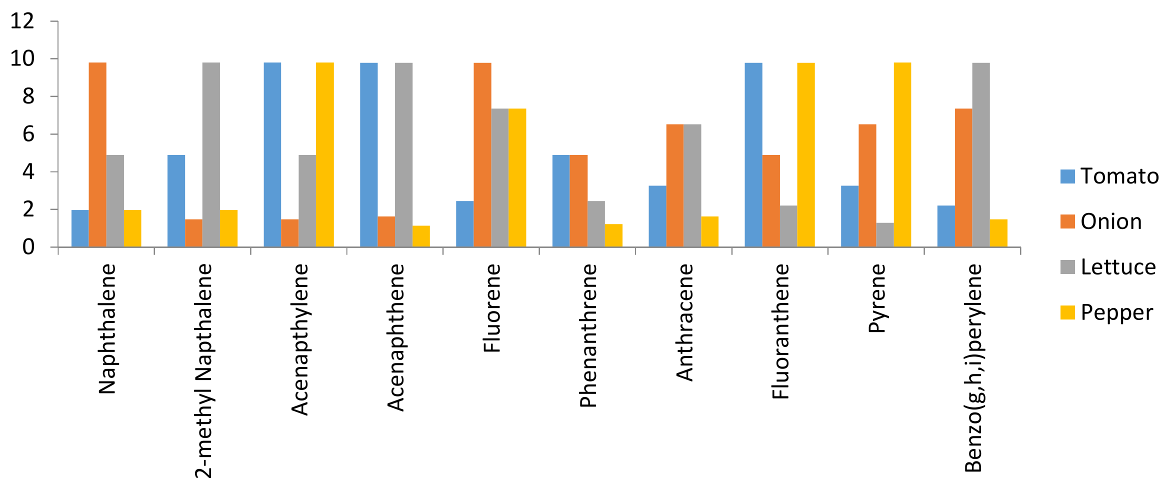


Figure ***18: Risk Assessment Based on Non-Carcinogenic Hazard Quotient and Hazard Index of Some Polycyclic Aromatic Hydrocarbon Samples From Dalori Konduga Local Govt. Agricultural Locatio***

CONCLUTION

The study concludes that the vegetables in the central and southern senatorial zones of Borno State are contaminated with PAHs, 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. PAHs 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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