

Toxic Phenols in Farmland Soils of Yenagoa Communities: Concentrations and Risk Assessment

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Abstract: Phenolic compounds are potentially toxic contaminants that may accumulate in agricultural soils and pose risks to soil organisms and terrestrial ecosystems. This study investigated the concentrations, distribution, and potential ecological risks of eleven priority phenolic compounds in farmland soils from Kpansia (KP), Ikarama (IK), and Amarata (AM) communities in Yenagoa Local Government Area, Bayelsa State, Nigeria. A total of 135 individual soil samples collected at 0–20 cm depth were composited into 27 samples and analyzed for phenol (Ph), 2-chlorophenol (2-CP), 2-nitrophenol (2-NP), 2,4-dimethylphenol (2,4-DMP), 2,4-dichlorophenol (2,4-DCP), 4-chloro-3-methylphenol (4-C-3-MP), 2,4,6-trichlorophenol (2,4,6-TCP), 2,4-dinitrophenol (2,4-DNP), 4-nitrophenol (4-NP), 2-methyl-4,6-dinitrophenol (2-M-4,6-DNP), and pentachlorophenol (PCP) using gas chromatography–mass spectrometry. All eleven compounds were detected, with individual concentrations ranging from 0.08 to 1.46 mg/kg and total phenolic concentrations ranging from 4.70 to 10.34 mg/kg. Mean total concentrations were 7.19 ± 3.76 mg/kg in IK, 6.22 ± 2.87 mg/kg in KP, and 5.73 ± 2.07 mg/kg in AM. PCP had the highest overall contribution (15.7%), followed by 2,4-DMP (13.6%) and 2-M-4,6-DNP (12.1%). Ecological risk assessment based on risk quotients ($RQ = MEC/PNEC$) showed that all compounds except 4-NP had mean RQ values >1 . PCP recorded the highest mean RQ (334.49), while cumulative $\sum 11RQ$ values were 883.42, 756.36, and 460.78 for KP, IK, and AM, respectively. The findings indicate multiple phenolic contamination and substantial screening-level potential ecological risks, highlighting the need for

continued monitoring, source identification, pollution control, and sustainable management of agricultural soils in Yenagoa LGA.

Keywords: Phenolic compounds; Farmland soils; Ecological risk; Pentachlorophenol; Yenagoa

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1.0 Introduction

Soil is one of the most important natural resources because it supports agricultural production, nutrient cycling, biodiversity, and the functioning of terrestrial ecosystems. (Diaz *et al.*, 2018; van Bruggen *et al.*, 2019; Thiele-Bruhn, 2021; ISRIC, 2026). These functions make soil particularly important in agricultural systems, where its physical, chemical, and biological quality directly influences crop productivity, food quality, and ecosystem sustainability. This is based on the vast services it offers; such as: supporting plant growth and biogeochemical cycling of nutrients, provision of habitats for both micro and macro-organisms, and impacting quality of air and water in contact with it through interactions with these spheres (atmosphere and

hydrosphere) (Kabata-Pendias & Saduiski, 2004; Chokor, 2019) Other services provided by soil include, its function as a transformation and storage compartment that facilitates interactions between biotic and abiotic components, as well as a sink or interacting medium for nutrients and contaminants (including toxic phenols) that affects lives forms (Smith *et al.*, 2015; IECA, 2022; Olayinka *et al.*, 2024). A healthy soil with adequate nutrients and with little or no contaminants will produce healthy crops and support flora and fauna that keep the ecosystem lively and functional (Frac *et al.*, 2018; Maroun & Atkins, 2020). Polluted soil however, represents threat to the functionality of the ecosystem (Chokor, 2019, 2025). Bayelsa, one of the States in the Niger Delta region of Nigeria has a long history of environmental contamination associated with crude oil exploration, pipeline leakages, artisanal refining, and industrial waste discharge. The environmental pressures associated with petroleum-related activities, urbanization, agricultural practices, domestic waste generation, and other anthropogenic activities may introduce a variety of organic contaminants into soils and other environmental compartments. In Yenagoa Local Government Area, where agricultural activities constitute an important component of local livelihoods and food production, contamination of farmland soils is of particular environmental and public-health concern. These incidents have raised concerns on possible contaminations of farmland soils (Nwankwo & Ogagarue, 2011; Chokor *et al.*, 2026a,b,c). Farmland soils sustain the cultivation of crops such as cassava, plantain, vegetables, yam, maize, cocoyam and other crops, which serve as food crops in sustenance of the local economy. Consequently, the occurrence of persistent or toxic organic contaminants in these soils warrants attention because contaminants may remain in the soil

matrix, interact with soil constituents, become available for plant uptake, or contribute to indirect human and ecological exposure. The presence of toxic chemicals in these soils poses potential risks to crop quality, food safety, ecological balance, and human health (Chokor & Ogonegbu, 2023; Chokor & Ediagbonya, 2024). Among the organic contaminants of environmental concern in agricultural soils are phenolic compounds, a diverse group of aromatic compounds characterized by the presence of a hydroxyl group (-OH) directly attached to an aromatic ring. Phenols are characterized by a hydroxyl functional group (-OH) directly attached to a benzene ring. Increased concentrations of phenols in farmland soils can impair nitrogen mineralization, inhibit germination, disturb microbial community composition, and ultimately threaten soil fertility and agricultural productivity (Bakthavatsalam, 2019; Kanjana, *et al.*, 2024). These effects are particularly relevant in agricultural soils because alterations in microbial processes, seed germination, and nutrient cycling may ultimately influence soil fertility and crop productivity.

The occurrence of toxic phenolic compounds in agricultural soils may also create opportunities for exposure through soil–plant and food-chain pathways. Depending on their physicochemical properties and environmental behaviour, some phenolic compounds may be taken up by organisms and contribute to ecological and human exposure. They also exhibit carcinogenic, teretogenic and mutagenic properties (Michalowicz & Dauda, 2007; CPCB, 2016; Zhou *et al.*, 2017; Chokor & Odokwo, 2021; Chokor, 2023; Rapiya *et al.*, 2025).

The potential endocrine-disrupting properties of some phenolic compounds have also attracted increasing scientific attention because of their possible effects on hormonal signalling, reproduction, development, and other physiological processes. They easily



mimic estrogens by positioning their hydroxyl residues to bind with those of the estrogen receptors (ER) instead of 17β hydroxyl group of the hormones thereby disrupting the functions of the sexual hormones. Experimental and epidemiological evidence has associated exposure to certain phenolic and phenol-related compounds with reproductive, developmental, endocrine, and other adverse biological effects, although the magnitude and mechanisms of these effects vary among individual compounds and exposure conditions. Overall, the resultant effects are correlated to decline in wildlife and loss of biodiversity (Safe *et al.*, 2004; Delta Seta *et al.*, 2008; Pastasaul & Adewale, 2009; Chen *et al.*, 2013; Chokor & Odokwo, 2021; Chokor, 2023). Phenols are toxic even at low concentrations, and some of them are listed as priority pollutants in many countries and are required to be determined (ECC, 2001; USEPA, 2014). Of particular interest in environmental monitoring are eleven phenolic compounds commonly included among priority pollutants are phenol (Ph), 2-chlorophenol (2-CP), 2-nitrophenol (2-NP), 2,4-dimethylphenol (2,4-DMP), 2,4-dichlorophenol (2,4-DCP), 4-chloro-3-methylphenol (4-C-3-MP), 2,4,6-trichlorophenol (2,4,6-TCP), 2,4-dinitrophenol (2,4-DNP), 4-nitrophenol (4-NP), 2-methyl-4,6-dinitrophenol (2-M-4,6-DNP), and pentachlorophenol (PCP). (USEPA, 2014). Their inclusion in environmental priority pollutant lists reflects concerns regarding their toxicity, environmental occurrence, and potential impacts on ecological and human health (El-Naggar *et al.*, 2022). Phenolic compounds are used in a wide range of domestic, agricultural, and industrial applications, including the manufacture of disinfectants, dyes, pesticides, wood preservatives, phenolic resins, pharmaceuticals, and other chemical products. Consequently, releases from industrial

processes, domestic activities, agricultural applications, petroleum-related activities, and waste disposal can introduce phenolic compounds into environmental media, including soils. Phenols also find use in the production of phenolic resins (used in moulded articles, insulators in electrical equipment such as circuit boards, household laminates, glueing and bonding building materials, etc.); and in the manufacture of medicinal and industrial organic chemicals. Soil contamination and pollution can thus result from any of these wide ranges of applications. The transformation of alkylphenol polyethoxylates, present in detergents as non-ionic surfactants, also yields alkylphenols (Michalowicz and Dauda, 2007; CPCB, 2016; Chokor and Odokwo, 2021). Phenolic biocides like pentachlorophenol (PCP) and some pesticides such as 2-buthyl-4,6-dinitrophenol (dinoseb), 2,4 dichlorophenoxyacetic acid (2,4-D), 4-chloro-2-methylphenoxyacetic acid (MCPA), and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) also transform to generate phenols in soils. The refining, storage, and spillages of oil also generate phenolic compounds to the soil environment. Phenols, though occur naturally in soil environment as a result of the decomposition products of plants, vegetation and animal waste, their elevated levels in the environment usually result from domestic, agricultural and industrial activities (Bouknana *et al.*, 2014; Chokor, 2023; Mhlongo *et al.*, 2024). In petroleum-producing regions such as the Niger Delta, petroleum exploration, refining, storage, transportation, and accidental spillages may provide additional pathways for the introduction of phenolic compounds and other organic contaminants into surrounding soils.

Previous investigations of environmental contamination in the Niger Delta have predominantly focused on petroleum hydrocarbons and related contaminants. Although these studies have established the



vulnerability of soils in the region to anthropogenic contamination, comparatively less attention has been given to the occurrence and distribution of individual priority phenolic compounds in agricultural soils. Furthermore, limited location-specific information is available on whether the concentrations of these compounds constitute potential ecological risks in agricultural environments where contaminated soils may interact directly with crops, soil organisms, and surrounding ecosystems. Consequently, concentration data alone may not adequately characterize the environmental significance of phenolic contamination; risk-based assessment is required to determine the potential magnitude of adverse effects associated with the detected compounds. In particular, there is a need for community-level information from Yenagoa LGA that can establish the occurrence and relative distribution of priority phenols among agricultural soils and provide evidence for identifying locations that may require further investigation or environmental management.

The significance of this study lies in its potential to provide baseline information on priority phenolic contamination in agricultural soils of Yenagoa LGA. The findings may contribute to environmental monitoring, agricultural soil management, food-safety assessment, and community awareness concerning chemical contamination of farmland. The risk assessment may also provide evidence useful to environmental regulators and other stakeholders in identifying areas requiring further investigation, pollution-control measures, and sustainable land-management interventions.

Therefore, this study aims to determine the concentrations and distribution of eleven priority phenolic compounds in farmland soils from three communities in Yenagoa Local Government Area, Bayelsa State, Nigeria, and to assess the potential ecological risks associated with their occurrence.

2.0 Methodology

2.1 Study area and site locations

The study was conducted on farmland soils collected from Yenagoa Local Government Area (LGA), Bayelsa State, Niger Delta, Nigeria. Three communities, namely Ikarama (IK: 05°09'17.45" N, 06°27'08.13" E), Amarata (AM: 04°55'43.91" N, 06°17'11.90" E), and Kpansia (KP: 04°55'47.47" N, 06°18'49.86" E), were selected for the study (Fig. 1).

The selected communities represent rural and peri-urban environments with active agricultural activities and differing potential sources of anthropogenic contamination. The predominant agricultural activities include the cultivation of food crops and other crops that support household consumption and local livelihoods. These communities are known for extensive farming activities but also lie close to oil infrastructure and areas of recurrent pollution events. Ikarama is a rural community that has experienced several incidents of crude-oil spills, whereas Amarata and Kpansia are predominantly peri-urban communities that may experience additional pollution pressures associated with urban waste disposal, automobile-repair activities, and domestic wastewater.

2.2 Sample collection

Surface soil samples were collected from a depth of 0–20 cm from agricultural fields in the three selected communities using a hand auger. A total of 135 individual soil samples were collected from geographically separated farmlands to minimize spatial overlap among sampling locations and combined to produce 27 composite samples, comprising nine composite samples from each community. Samples were placed in wide-mouth amber bottles with Teflon-lined screw caps for onward transportation to the laboratory for analysis (Chokor, 2023).

2.3 Preparation and analysis



The soil samples were air-dried in the dark for approximately three days, homogenized thoroughly, passed through a 1-mm mesh sieve, and stored in amber glass bottles until extraction. For each extraction, 10 g of homogenized soil was extracted with 75 mL of

a 0.1 M NaOH–methanol mixture using an ultrasonic bath for 30 min. The extraction procedure was repeated three times. The mixtures were allowed to settle, after which the extracts were filtered through Whatman No. 41 filter paper.(Khairy, 2013; Kumar *et al.*, 2014).



Fig. 1: Map of the study area

The combined filtrates were transferred into separating funnels and acidified to pH < 2 by gradual addition of 1:1 (v/v) sulfuric acid. The acidified solutions were then extracted three times with 50 mL dichloromethane, with each extraction lasting 2 min. These were then extracted three (3) times with 50 ml of dichloromethane for 2 min each. The dichloromethane extracts were combined, dried over anhydrous sodium sulfate (Na_2SO_4), and concentrated to approximately 2 mL using a rotary evaporator. The solvent was subsequently exchanged to 2-propanol, and the extract was reconcentrated to 2 mL by rotary evaporation and/or gentle nitrogen blow-down. A 1- μL aliquot of each concentrated extract was injected into the GC–MS system for separation and quantification of the target phenolic compounds (Chokor & Odokwo, 2021; Chokor, 2023). The equipment was operated in splitless mode for 2 min at

50mL/min to purge the instrument. The temperature of the injection port was maintained at 220 °C. A capillary column of 30 m X 0.25 mm X 0.25 μm HP-5 was used for the separation of target compounds. The oven temperature was initially held at 40 °C for 1.5 min, increased to 100 °C at a rate of 40 °C/min and held for 0.5 min, then increased to 120 °C at 2 °C/min. The temperature was subsequently ramped to 300 °C at 30 °C/min and held for 5 min, giving a total run time of 25 min. Helium (99.999% purity) was used as a carrier gas with a flow rate of 1mL/min. The temperature of the transfer line, source, and quadrupole was 300, 230 and 150 °C, respectively. Standard electron impact condition (70eV) was used.

2.4 Quality control and assurance

Pesticide-grade solvents were used for the analysis of phenols. Individual and mix standard solutions of eleven priority phenols in propan-2-ol were used to perform method



validation and quality control, with correlation coefficients for calibration curves all higher than 0.9272. A recovery test was performed by spiking blank samples with the mix standards. Method recoveries ranged from 91 to 109%, indicating acceptable analytical performance and satisfactory extraction efficiency for the target phenolic compounds.

2.5 Potential ecological risks

The potential ecological risks of the phenols were evaluated using equation 1.

$$RQ = \frac{MEC}{PNEC} \quad (1)$$

Where RQ is the risk quotient, MEC is the measured environmental concentration in soil, and PNEC is the predicted no-effect concentration. Risk quotients ($RQ < 0.1$) were interpreted as indicating low risk, RQ values of 0.1–1.0 as medium risk, and RQ values > 1.0 as high risk, following the classification reported by Bandowe *et al.* (2014) and Chokor (2023). PNEC soil values were obtained from the European Chemical Agency database portal (ECHA, 2025).

3.0 Results and Discussion

3.1 Concentrations and distribution of priority phenols in farmland soils

The concentrations of the eleven priority phenols detected in farmland soils from Kpansia (KP), Ikarama (IK), and Amarata (AM) are presented in Table 1. The results show that all eleven target phenolic compounds were detected in the investigated soils, although their concentrations varied considerably among compounds and communities. Individual phenol concentrations ranged from 0.08 to 1.46 mg/kg, while the total concentration of the eleven priority phenols ($\Sigma 11\text{Phenols}$) ranged from 4.70 to 10.34 mg/kg. The observed variation indicates that the farmland soils were characterized by heterogeneous phenolic contamination.

As shown in Table 1, Ikarama recorded the highest mean total phenol concentration, with a $\Sigma 11\text{Phenols}$ value of 7.19 ± 3.76 mg/kg and a

range of 5.03–10.34 mg/kg. This was followed by Kpansia, with a mean concentration of 6.22 ± 2.87 mg/kg and a range of 4.70–8.75 mg/kg, whereas Amarata recorded the lowest mean concentration of 5.73 ± 2.07 mg/kg (range: 4.76–7.70 mg/kg). The overall mean concentration across the three communities was approximately 6.38 mg/kg. Thus, based on total phenol concentrations, the communities were ranked $IK > KP > AM$.

The relatively high total concentration observed at Ikarama may be associated with the environmental pressures affecting the community, particularly its documented history of crude-oil spills and petroleum-related activities. Petroleum contamination can introduce complex mixtures of aromatic compounds into soils, including phenolic constituents. The relatively high variability observed at Ikarama, as indicated by the standard deviation of 3.76 mg/kg, further suggests substantial spatial differences in contamination among the sampled farms. However, the concentration data alone do not permit definitive attribution of the phenols to petroleum sources.

Kpansia recorded the second-highest total phenol concentration. Its relatively elevated concentration may reflect the combined influence of agricultural activities and other anthropogenic pressures associated with its peri-urban setting. Domestic waste disposal, automobile-related activities, agricultural chemicals, and other urban inputs can contribute organic contaminants to soils. Amarata had the lowest total concentration, although the detection of all eleven phenols indicates that phenolic contamination was widespread across the three communities.

The concentrations observed in the present study can be compared with previous reports. Kumar *et al.* (2014) reported total phenol concentrations ranging from below detection limit to 7.08 mg/kg, with a mean concentration of approximately 1.92 ± 0.35 mg/kg, in soils



from mixed land-use areas. The overall mean concentration of 6.38 mg/kg obtained in the present study is substantially higher than the mean reported by Kumar *et al.* (2014), while the maximum total concentration of 10.34 mg/kg at Ikarama also exceeded their reported

upper value. The difference may reflect variations in land use, contaminant sources, sampling locations, environmental conditions, target compounds, and analytical procedures.

Table 1: Mean and range of concentrations in the communities' farm soils

Types	Mean and range of concentrations (mg/kg)			
	KP	IK	AM	Ave
Ph	0.17±0.09 (0.13 – 0.26)	0.19±0.14 (0.08 – 0.23)	0.35±0.15 (0.26 – 0.44)	0.24±0.09 (0.17 – 0.35)
2-CP	0.22±0.15 (0.16 – 0.37)	0.21±0.10 (0.16 – 0.30)	0.10±0.10 (0.02 – 0.16)	0.18±0.07 (0.10 – 0.22)
2-NP	0.37±0.23 (0.23 – 0.67)	1.33±1.36 (0.38 – 3.07)	0.51±0.54 (0.13 – 1.19)	0.74±0.52 (0.37 – 1.33)
2,4-DMP	0.13±0.11 (0.02 – 0.29)	1.11±0.48 (0.20 – 1.40)	1.38±0.65 (0.32 – 2.38)	0.87±0.66 (0.13 – 1.38)
2,4-DCP	0.79±0.20 (0.74 – 1.01)	0.45±0.20 (0.17 – 0.55)	0.66±0.10 (0.59 – 0.73)	0.64±0.17 (0.45 – 0.79)
4-C-3-MP	0.33±0.17 (0.26 – 0.50)	0.36±0.13 (0.28 – 0.47)	0.86±0.16 (0.75 – 0.97)	0.52±0.30 (0.33 – 0.86)
2,4,6-TCP	0.38±0.17 (0.33 – 0.45)	1.11±0.12 (0.96 – 1.20)	0.36±0.21 (0.20 – 0.61)	0.61±0.43 (0.36 – 1.11)
2,4-DNP	1.32±0.89 (0.96 – 2.22)	0.28±0.49 (0.11 – 0.84)	0.23±0.54 (0.12 – 1.25)	0.61±0.61 (0.23 – 1.32)
4-NP	0.17±1.0 (0.12 – 0.29)	0.31±0.32 (0.09 – 0.72)	0.12±0.02 (0.11 – 0.14)	0.20±0.10 (0.12 – 0.31)
2-M-4,6-DNP	0.88±0.53 (0.09 – 1.09)	0.73±0.85 (0.53 – 2.09)	0.71±0.47 (0.26 – 1.65)	0.77±0.09 (0.71 – 0.88)
PCP	1.46±0.36 (1.30 – 1.99)	1.10±0.25 (0.94 – 1.38)	0.45±0.30 (0.23 – 0.83)	1.00±0.52 (0.45 – 1.46)
Σ ₁₁ Phenols	6.22±2.87 (4.70 – 8.75)	7.19±3.76 (5.03 – 10.34)	5.73±2.07 (4.76 – 7.70)	6.38±0.74 (5.73 – 7.19)

* KP = Kpansia; IK= Ikarama; AM = Amarata; Ave = Average; Ph = phenol; 2-CP = 2-chlorophenol; 2-NP = 2-dinitrophenol; 2,4-DMP = 2,4-Dimethyl phenol; 2,4-DCP = 2, 4-Dichlorophenol; 4-C-3-MP = 4-Chloro-3-methyl phenol; 2,4,6-TCP = 2,4,6-Trichlorophenol; 2,4-DNP = 2,4-Dinitrophenol; 4-NP = 4-Nitrophenol; 2-M-cv 4,6-DNP = 2-Methyl 4,6-dinitrophenol; PCP = Pentachlorophenol

The concentrations of chlorinated phenols also provide useful evidence for comparison. Michalowicz and Dauda (2007) reported approximately 0.18 mg/kg of 2,4,6-trichlorophenol (TCP) in soil from a pesticide plant in Richmond, British Columbia, and

chlorophenol concentrations of 0.5–3.5 mg/kg in soils around four sawmills. In the present study, 2,4,6-TCP concentrations ranged from 0.20 to 1.20 mg/kg, with community means of 0.38 mg/kg in KP, 1.11 mg/kg in IK, and 0.36 mg/kg in AM, giving an overall mean of 0.61



mg/kg. The Ikarama mean was therefore substantially higher than the 0.18 mg/kg reported by Michalowicz and Dauda (2007), whereas the observed values generally fell within the broader chlorophenol range reported around sawmills.

The individual concentrations in Table 1 further show that the compounds responsible for the total phenolic burden differed among the communities. Kpansia recorded its highest mean concentrations for PCP (1.46 mg/kg), 2,4-DNP (1.32 mg/kg), 2-M-4,6-DNP (0.88 mg/kg), and 2,4-DCP (0.79 mg/kg). At Ikarama, the highest mean concentrations were observed for 2-NP (1.33 mg/kg), 2,4-DMP (1.11 mg/kg), 2,4,6-TCP (1.11 mg/kg), and

PCP (1.10 mg/kg). At Amarata, 2,4-DMP recorded the highest mean concentration (1.38 mg/kg), followed by 4-C-3-MP (0.86 mg/kg) and 2-M-4,6-DNP (0.71 mg/kg).

These differences indicate that the three communities had different phenolic contamination profiles. The finding is important because total phenol concentration alone does not adequately describe the environmental significance of a contaminated site. Individual phenolic compounds have different physicochemical properties, environmental behaviour, and toxicity thresholds, which can result in substantially different ecological risks even at comparable concentrations.

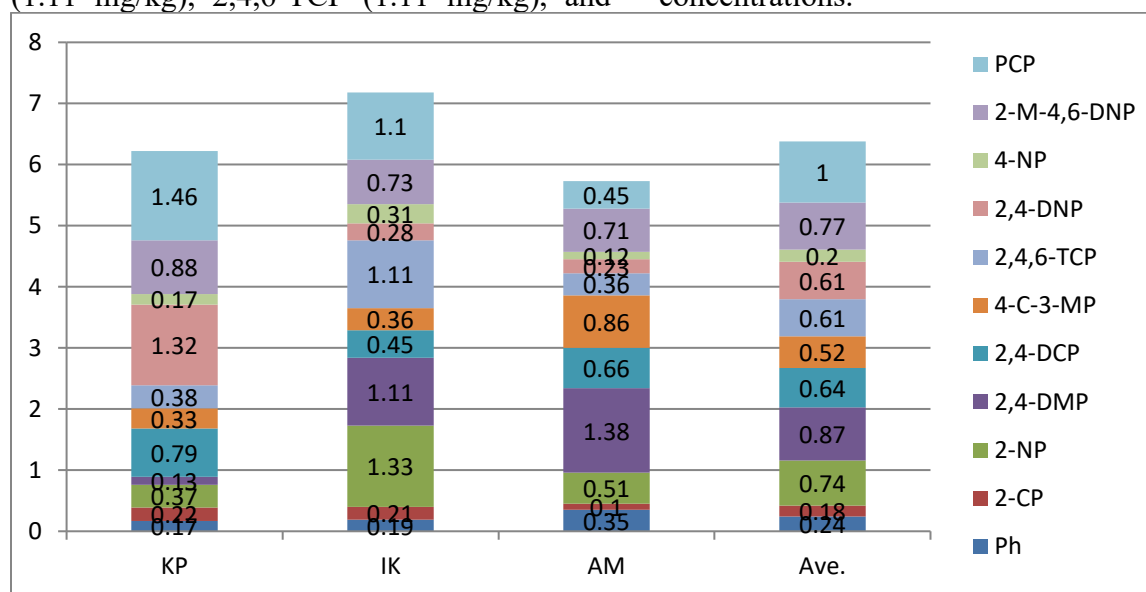


Fig 2: Relative proportion of phenols and total phenols in different communities' farm soils

* KP = Kpansia; IK = Ikarama; AM = Amarata; Ave = Average; Ph = phenol; 2-CP = 2-chlorophenol; 2-NP = 2-dinitrophenol; 2,4-DMP = 2,4-Dimethyl phenol; 2,4-DCP = 2, 4-Dichlorophenol; 4-C-3-MP = 4-Chloro-3-methyl phenol; 2,4,6-TCP = 2,4,6-Trichlorophenol; 2,4-DNP = 2,4-Dinitrophenol; 4-NP = 4-Nitrophenol; 2-M-4,6-DNP = 2-Methyl 4,6-dinitrophenol; PCP = Pentachlorophenol.

3.2 Relative contributions of individual phenols in the communities

The relative proportions of the individual phenols in the farmland soils of the three communities are presented in Fig. 2. The figure illustrates the compounds that contributed most

strongly to the total phenolic burden at each location and provides additional insight into the differences observed in Table 1.

At Kpansia, PCP, 2,4-DNP, 2-M-4,6-DNP, and 2,4-DCP were the dominant compounds, accounting for approximately 23.5%, 21.2%,



14.1%, and 12.7%, respectively, of the total phenols. Collectively, these four compounds contributed approximately 71.5% of the total phenolic concentration at Kpansia. The remaining seven phenols accounted for approximately 28.5%.

3.3 Overall contribution of the eleven priority phenols

The mean percentage contributions of the individual phenols across the three communities are shown in Fig. 3. This figure provides an integrated assessment of the relative importance of each compound in the overall phenolic contamination of the investigated farmland soils.

PCP made the largest contribution, accounting for approximately 15.7% of the total phenolic concentration. It was followed by 2,4-DMP (13.6%), 2-M-4,6-DNP (12.1%), 2-NP (11.6%), and 2,4-DCP (10.0%). 4-C-3-MP and

2,4-DNP each contributed approximately 9.6%, while 2,4,6-TCP contributed 8.2%. Phenol, 4-NP, and 2-CP had comparatively smaller contributions of 3.8%, 3.1%, and 2.8%, respectively.

The five major contributors—PCP, 2,4-DMP, 2-M-4,6-DNP, 2-NP, and 2,4-DCP—accounted for more than half of the overall phenolic burden. The dominance of PCP is particularly noteworthy because of its historical use as a wood preservative and its environmental persistence (Michalowicz & Dauda, 2007). The high contribution of 2,4-DMP may partly reflect its natural occurrence in petroleum and its industrial applications, while the contributions of 2-M-4,6-DNP and 2-NP may be associated with agricultural and industrial applications.

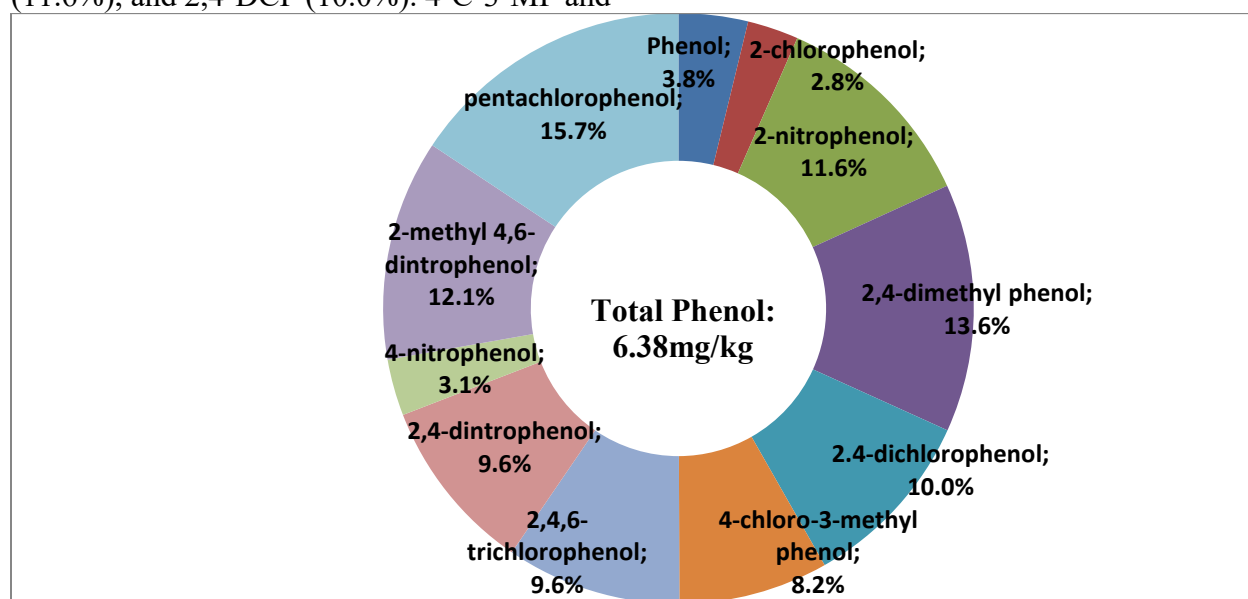


Fig. 3: mean percent contribution of each phenol in the communities farms soils

The relatively low contributions of phenol, 4-NP, and 2-CP may result from differences in their sources, environmental fate, degradation, mobility, sorption, or other physicochemical processes. Although the original interpretation suggested that these compounds may have been transformed into more substituted forms, such

a transformation cannot be established from the concentration data alone. Laboratory degradation studies or detailed environmental fate investigations would be required to demonstrate such transformation pathways. The relatively high overall contribution of PCP is also consistent with its low PNEC reported



in Table 2. Therefore, the importance of PCP in this study is evident from both its concentration and its risk quotient. This observation demonstrates the importance of integrating contaminant concentration with compound-specific toxicity when evaluating environmental contamination. Phenolic compounds have numerous domestic and industrial applications, including uses in pesticides, disinfectants, dyes, preservatives, plastics, medicines, paints, detergents, and other chemical products (Michalowicz & Dauda, 2007; Li *et al.*, 2020; Bibi & Al-Ghouti, 2026). Their occurrence in soils may therefore result from several overlapping sources,

particularly in environments influenced by agricultural, urban, industrial, and petroleum-related activities.

3.4 Risk quotients of the priority phenols

The predicted no-effect concentrations (PNECs) and risk quotients (RQs) of the eleven priority phenols in the three communities are presented in Table 2. The RQ values provide a toxicity-weighted interpretation of the measured concentrations because the risk associated with a compound depends not only on its concentration but also on its predicted no-effect concentration.

The results in Table 2 show that all the

Table 2: The Risk Quotients (RQs) values of Eleven Priority Phenols in different Communities

Types	PNEC (mg/kg)	RQs values			
		KP	IK	AM	Ave.
Ph	0.136	1.28	1.42	2.55	1.75
2-CP	0.042	5.24	5.11	2.36	4.24
2-NP	0.088	4.15	15.11	5.85	8.37
2,4-DMP	0.031	4.11	35.66	44.40	28.06
2,4-DCP	0.018	43.96	25.03	36.86	35.28
4-C-3-MP	0.055	5.99	6.61	15.66	9.42
2,4,6-TCP	0.0085	44.42	130.05	41.94	72.13
2,4-DNP	0.012	110.13	23.37	19.56	51.02
4-NP	0.23	0.76	1.36	0.52	0.88
2-M-4,6-DNP	0.005	175.33	145.74	142.58	154.55
PCP	0.003	488.04	366.90	148.52	334.49
$\sum_{11}RQ$		883.42	756.36	460.78	700.19

* KP = Kpansia; IK = Ikarama; AM = Amarata.

investigated phenols except 4-NP had mean RQ values greater than 1.0. Under the risk classification adopted in this study, RQ values greater than 1 indicate high potential ecological risk (Bandowe *et al.*, 2014; Chokor, 2023). The mean RQ for 4-NP was 0.88; placing it below the high-risk threshold. The results therefore indicate that most of the detected phenolic compounds were of potential ecological concern under the adopted screening framework.

The particularly high RQ of PCP can be explained by the combination of its measured concentration and very low PNEC of 0.003 mg/kg. Similarly, the high RQ of 2-M-4,6-DNP is related to its PNEC of only 0.005 mg/kg.

The results demonstrate that compounds with relatively low PNEC values can contribute disproportionately to ecological risk. This is particularly evident for PCP and 2-M-4,6-DNP. Conversely, phenol recorded a much



lower mean RQ of 1.75, despite being detected across the communities, because its PNEC was considerably higher (0.136 mg/kg). 4-NP had the lowest mean RQ (0.88) and also had the highest PNEC among the compounds listed in Table 2 (0.23 mg/kg).

The community-specific RQs show that Kpansia had the highest cumulative $\sum 11$ RQ of 883.42, followed by Ikarama (756.36) and Amarata (460.78). Consequently, the risk-based ranking was $KP > IK > AM$. This ranking differs from the concentration-based ranking obtained from Table 1, which was $IK > KP > AM$.

The difference between these two rankings is important because it demonstrates that the ecological significance of contamination cannot be inferred from total phenol concentrations alone. Kpansia had a lower total phenol concentration than Ikarama but a higher cumulative risk quotient. This is largely attributable to the greater contribution of compounds with very low PNECs, particularly PCP, 2-M-4,6-DNP, and 2,4-DNP.

The mean cumulative $\sum 11$ RQ of **700.19** across the three communities is substantially greater than the high-risk threshold of 1.0. Within the RQ framework adopted in this study, this indicates a substantial potential ecological concern. However, the RQ should be interpreted as a **screening-level indicator of potential risk** rather than direct evidence of actual ecological damage. Likewise, the cumulative RQ does not by itself demonstrate synergistic interactions among the eleven phenols.

The results are consistent with the principle that environmental risk is influenced by both contaminant concentration and toxicity. Consequently, environmental monitoring programs should not rely exclusively on total phenol concentrations but should identify the individual compounds present and consider their respective PNECs.

3.5 Comparison of concentration and risk patterns among communities

A comparison of Tables 1 and 2 demonstrates a notable difference between the distribution of contaminant concentrations and the distribution of calculated ecological risk. Based on $\sum 11$ Phenols, the communities followed the order $IK > KP > AM$, whereas the corresponding order based on $\sum 11$ RQ was $KP > IK > AM$.

Ikarama therefore had the highest total concentration of phenols but did not have the highest cumulative risk quotient. In contrast, Kpansia had the highest cumulative RQ despite having a lower total phenol concentration than Ikarama. This difference can be attributed to the different toxicity thresholds of the compounds contributing to the contamination profiles.

For example, Kpansia recorded the highest mean PCP concentration (1.46 mg/kg) and the highest 2,4-DNP concentration (1.32 mg/kg). PCP had an exceptionally low PNEC of 0.003 mg/kg, resulting in a mean RQ of 488.04 in Kpansia. Similarly, 2-M-4,6-DNP had a mean RQ of 175.33 in Kpansia. These high compound-specific RQs caused Kpansia to have the highest cumulative risk despite its lower total phenol concentration compared with Ikarama. This finding reinforces the importance of combining chemical monitoring with toxicity-based assessment. A location with a lower total contaminant concentration may have a greater potential ecological risk if its contaminant mixture is dominated by compounds with lower PNECs. Bandowe *et al.* (2014) and Chokor (2023) similarly demonstrate the usefulness of RQ-based approaches for interpreting environmental contaminant data.

3.6 Correlations among individual phenolic compounds

The Pearson correlation coefficients among the eleven phenolic compounds are presented in



Table 3. Correlation analysis was used to evaluate whether the concentrations of individual phenols varied together across the sampled farmland soils. Significant positive correlations may indicate similar spatial behaviour or possible common sources, whereas negative relationships may reflect differences in source inputs, environmental transport, degradation, partitioning, or other processes. However, correlation analysis alone cannot establish a common source or demonstrate chemical transformation.

As shown in Table 3, several significant positive correlations were observed. Phenol was strongly and positively correlated with 4-C-3-MP ($r = 0.761$, $p < 0.01$), while 2-NP showed strong positive correlations with 2,4,6-TCP ($r = 0.756$, $p < 0.01$), 4-NP ($r = 0.933$, $p < 0.01$), and DNOC/2-M-4,6-DNP ($r = 0.732$, $p < 0.01$). The strongest positive association in the correlation matrix occurred between 2-NP and 4-NP ($r = 0.933$, $p < 0.01$). Their similar spatial variation suggests that they may have been influenced by related environmental inputs or processes.

A strong positive relationship was also observed between 2,4-DNP and PCP ($r = 0.795$, $p < 0.01$). This association is noteworthy because both compounds contributed substantially to the phenolic contamination profile in Kpansia. However, the observed correlation should not be interpreted as definitive evidence of a common source without additional source-specific information. Other statistically significant positive correlations included 2-CP with 4-NP ($r = 0.600$, $p < 0.05$) and PCP ($r = 0.639$, $p < 0.05$), 2,4-DCP with 2,4-DNP ($r = 0.550$, $p < 0.05$), 2,4,6-TCP with 4-NP ($r = 0.659$, $p < 0.05$), and 4-NP with DNOC ($r = 0.649$, $p < 0.05$). These relationships indicate that several phenols exhibited similar patterns of occurrence across the sampled soils.

In contrast, significant negative correlations

were observed between phenol and 2-CP ($r = -0.848$, $p < 0.01$), phenol and PCP ($r = -0.814$, $p < 0.01$), 2-NP and 2,4-DCP ($r = -0.795$, $p < 0.01$), and 2,4-DCP and 4-NP ($r = -0.644$, $p < 0.05$). Significant negative relationships were also observed between 2,4-DMP and 2,4,6-TCP ($r = -0.664$, $p < 0.05$) and between 2,4-DCP and 2,4-DNP ($r = -0.644$, $p < 0.05$).

These negative relationships indicate that the concentrations of the respective compounds tended to vary in opposite directions across the sampled soils. Such patterns could reflect differences in source contributions, environmental partitioning, degradation, transport, or other processes. The original suggestion that negative correlations demonstrate conversion of one phenol into another should, however, be treated cautiously because correlation alone cannot establish chemical transformation.

Several pairs showed weak or non-significant relationships. For example, 2,4-DMP had a weak positive relationship with 2-NP ($r = 0.156$) and a moderate but non-significant negative relationship with 2,4-DCP ($r = -0.348$). DNOC and PCP also showed a weak negative relationship ($r = -0.206$). These results suggest that the occurrence of one phenol does not necessarily predict the occurrence of another in the investigated soils. Overall, the correlation structure presented in Table 3 indicates that the eleven phenols did not exhibit a uniform pattern of distribution. Instead, some compounds displayed similar spatial behaviour, whereas others varied independently or inversely. This finding supports the concentration profiles presented in Tables 1 and 2 and further suggests that phenolic contamination in the study area is likely influenced by multiple environmental processes and potential sources.

3.7 Environmental implications

The results collectively demonstrate that all eleven investigated priority phenols were



present in the farmland soils of the three Yenagoa communities, with considerable variation in concentration, relative contribution, and calculated ecological risk. Ikarama recorded the highest total phenol concentration, whereas Kpansia recorded the

highest cumulative risk quotient. The difference between these rankings emphasizes the importance of considering both contaminant loading and compound-specific toxicity in environmental assessments.

Table 3: Coefficients of relations between the concentrations of the various forms of phenols

	2-CP	2-NP	2,4-DMP	2,4-DCP	4-C-3-MP	2,4,6-TCP	2,4-DNP	4-NP	DNOC	PCP
Ph	-	-	0.291	0.048	0.761**	-0.490	-0.484	-0.545*	-0.020	-
2-CP	0.848**	0.350								0.814**
2-NP	1.000	0.308	-0.300	0.099	-0.394	0.233	0.485	0.600*	0.153	0.639*
2,4-DMP		1.000	0.156	-	-0.094	0.756**	-0.017	0.933**	0.732**	-0.009
2,4-DCP			1.000	-0.348	0.263	0.210	-	0.037	-0.131	-0.444
4-C-3-MP				1.000	0.101	-0.809	0.550*	-0.644*	-0.448	0.402
2,4,6-TCP					1.000	-0.456	-0.234	-0.189	0.413	-0.714
2,4-DNP						1.000	-0.218	0.659*	0.304	0.099
4-NP							1.000	0.096	0.180	0.795**
DNOC								1.000	0.649*	0.152
PCP									1.000	-0.206
										1.000

****significant at the 1% level; *significant at the 5% level; Ph = phenol; 2-CP = 2-chlorophenol; 2-NP = 2-dinitrophenol; 2,4-DMP = 2,4-Dimethyl phenol; 2,4-DCP = 2, 4-Dichlorophenol; 4-C-3-MP = 4-Chloro-3-methyl phenol; 2,4,6-TCP = 2,4,6-Trichlorophenol; 2,4-DNP = 2,4-Dinitrophenol; 4-NP = 4-Nitrophenol; DNOC = dinitro σ -cresol; PCP = Pentachlorophenol.**

PCP, 2,4-DMP, 2-M-4,6-DNP, 2-NP, and 2,4-DCP were the major contributors to the overall phenolic concentration, while PCP and 2-M-4,6-DNP were particularly important from the perspective of ecological risk because of their very low PNEC values. These findings are consistent with previous reports that phenolic compounds can originate from a broad range of domestic, agricultural, industrial, petroleum-related, and waste-management activities (Michalowicz & Dauda, 2007; Li *et al.*, 2020; Bibi & Al-Ghouti, 2026).

The occurrence of these compounds in agricultural soils is of environmental importance because soil can act as a reservoir

for contaminants and may facilitate interactions among contaminants, plants, soil organisms, and other environmental compartments. Previous studies have similarly highlighted the environmental significance of phenolic compounds and their potential toxicity (Chokor & Odokwo, 2021; Chokor, 2023).

Nevertheless, the present findings should be interpreted within the limitations of the study. The measured concentrations and RQs provide evidence of potential ecological concern, but they do not demonstrate actual ecological injury, food-chain transfer, bioaccumulation, or synergistic toxicity. Likewise, the observed



correlations provide useful information about co-occurrence patterns but do not conclusively establish common sources or transformation pathways.

The findings nevertheless provide important baseline information on phenolic contamination of farmland soils in Yenagoa LGA. Regular monitoring of agricultural soils, improved management of agricultural chemicals and wastes, investigation of petroleum-related contamination sources, and appropriate pollution-control measures would be useful for reducing further environmental loading. Particular attention should be directed towards compounds such as PCP and 2-M-4,6-DNP that produced disproportionately high RQs relative to their measured concentrations. Overall, the study demonstrates that phenolic contamination in the investigated farmland soils is spatially heterogeneous, chemically diverse, and associated with substantial screening-level ecological risk under the adopted RQ framework. The results further demonstrate that concentration-based assessment alone may underestimate the environmental importance of individual toxic compounds. Integrating concentration measurements, compound-specific toxicity information, and correlation analysis therefore provides a more informative basis for evaluating phenolic contamination and supporting future environmental monitoring and sustainable soil-management strategies in Yenagoa LGA.

4.0 Conclusion

This study investigated the occurrence, distribution, and potential ecological risks of eleven priority phenolic compounds in farmland soils from Kpansia, Ikarama, and Amarata communities in Yenagoa Local Government Area, Bayelsa State, Nigeria. All eleven phenols were detected, with individual concentrations ranging from 0.08 to 1.46 mg/kg, while total $\Sigma 11$ Phenols concentrations

ranged from 4.70 to 10.34 mg/kg. Ikarama recorded the highest mean total phenol concentration (7.19 ± 3.76 mg/kg), followed by Kpansia (6.22 ± 2.87 mg/kg) and Amarata (5.73 ± 2.07 mg/kg), giving a concentration-based order of IK > KP > AM.

The phenolic profiles varied among the communities. PCP, 2,4-DMP, 2-M-4,6-DNP, 2-NP, and 2,4-DCP were the major contributors to the overall contamination, with PCP accounting for the highest proportion (15.7%). Ecological risk assessment revealed that all phenols except 4-NP had mean risk quotients (RQs) greater than one. PCP recorded the highest mean RQ (334.49), followed by 2-M-4,6-DNP (154.55) and 2,4,6-TCP (72.13). The mean cumulative $\Sigma 11$ RQ was 700.19, with community values of 883.42, 756.36, and 460.78 for Kpansia, Ikarama, and Amarata, respectively. Thus, the risk-based order (KP > IK > AM) differed from the concentration-based order.

The findings indicate substantial screening-level potential ecological risks and highlight the need for continued monitoring, source investigation, pollution control, and sustainable farmland management in Yenagoa LGA.

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Consent for publication

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Augustine Avwerosuo Chokor conceptualized the research idea and methodology. Liberty Matthew Seiba did the field work, sample analysis, and data acquisition. Both parties interpreted the results. Liberty Matthew Seiba developed the manuscript and wrote the first draft. Augustine Avwerosuo Chokor reviewed, edited and produced the final

