Communication in Physical Sciences, 2024, 11(1): 160-177

Status of Monitoring, Remediation and Regulation of Chemical Contaminants of Emerging Concern in Nigeria

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Received: 05 December 2023/Accepted: 08 March 2024 /Published: 30 March 2024

Abstract: *Contaminants of emerging concern (CECs) can be divided into chemical contaminants of emerging (CCECs) and microbial contaminants of emerging concern (MCECs). This review was to ascertain the current status of monitoring, remediation and regulation of chemical contaminants of emerging concern (CCECs) in Nigeria. Various publications were accessed through academic databases and search engines including DOAJ, AJOL, SpringerLink, ScienceDirect, Semanticsscholar, Google Scholar, Scopus and Research Gate to obtain literature relevant to the study. A total of 1476 works published between January 2017 and December 2023 were accessed and critically reviewed but only 173 publications were found suitable for use in assessing the subject matter. Seventeen national environmental policies, laws and regulations were also accessed from the websites of the national environmental regulatory agencies and higher education libraries. These were also assessed for information relevant to this study. The vast majority of the publications (163 out of 173) were in the area of CCECs monitoring while a paltry 10 publications (across 7 years) dealt with remediation of polluted matrices. 130 publications were research papers and most of them were studies on CCECs in solid matrices and water/wastewater samples. There is very low research effort on the remediation of CCECs in the Nigerian environment and policymakers seem to have little or no appreciation of CCECs and their potential impacts on the environment. Recommendations were made on future research efforts and how to create awareness and incorporate CCECs' monitoring and remediation into Nigeria's environmental laws.*

Keywords: *Chemical, contaminants, emerging, regulation, research, remediation*

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1.0 Introduction

The words 'pollutants' and 'contaminants' are used interchangeably. However, pollutants are substances that occur at concentrations that are harmful to environmental biota while contaminants are undesirable materials that contaminate another material or the environment but which may not be harmful i.e. "all pollutants are contaminants but not all contaminants are pollutants" (Eddy *et* al., 2023; USEPA, 1994; Chapman, 2007). The terms, "contaminants of emerging concern (CECs)", "emerging contaminants" of concern (ECCs), emerging environmental contaminants (EECs) and emerging pollutants are also used interchangeably to refer to "any synthetic or naturally occurring chemical or microorganism which is not commonly monitored in the

environment but has the potential to cause" adverse ecological or human health effects" (USGS, 2019; Qadir and Scott, 2023). This means that contaminants of emerging concern (CECs) refer to chemical and microbial agents which focus on their effects on the environment are relatively recent compared to other classes of contaminants (Adesokan *et al.* 2022; Dong *et al.* 2023). They include substances which may have existed for long periods in environmental compartments but focus on their occurrence or effects is recent compared to other well-known, regulated and monitored legacy pollutants. Many CECs are not currently monitored or regulated and they are characterized by a relative lack of published health criteria (Lei *et al.* 2015; Dulio *et al.* 2018; Gago-Ferrero *et al*. 2018) and may be of industrial origin or may originate from municipal (domestic), agricultural, hospital or laboratory wastewater. CECs can be divided into chemical contaminants of emerging (CCECs) and microbial contaminants of emerging concern (MCECs). This work focuses on CCECs which is classified into inorganic and organic contaminants but there is no universal agreement on the substances that are CCECs nor is there a general classification of CCECs that is recognized internationally. In this study, CCECs include pesticides; polycyclic aromatic hydrocarbons; flame retardants; pharmaceuticals (drugs and solvents), body care preparations, phthalates, dyes, pigments, preservatives, surface active agents; plasticizers; gasoline additives; per-fluoroalkyl and polyfluoroalkyl substances; micro- and nanoplastics; radionuclides, water disinfection by-products, ultra-violet fillers and nanomaterials (Noguera-Oviedo and Aga, 2016; UNWWDR, 2017; Sophia and Lima, 2018; USGS, 2019; Galindo-Miranda, 2019; Dong *et al*. 2023; Mujingni, 2023).

The rapidly increasing wastewater generation from domestic, commercial, agricultural and industrial activities has resulted in the increasing discharge of CCECs into the environment. The situation is made worse in sub-Saharan countries like Nigeria because environmental pollution guidelines routinely exclude such pollutants and the majority of existing wastewater treatment infrastructure is not advanced enough to handle CCECs removal (Ripanda *et al*. 2022).

CCECs exist in the three environmental compartments of air, soil and water. Volatile CCECs occur individually in the air while some are components of particulate matter. CECs pollution of the soil has become a contemporary health risk for humans and other living things in the ecosystem since it alters the functionalities of the soil and plants grown in soils and may also lead to endocrine disruption, immunotoxic and carcinogenic effects in consumers of plants (Maddela *et al*. 2022). There is also a huge volume of research on CCEC concentrations in drinking, surface and groundwater. However, no previous work on the status of CCECs monitoring, remediation and regulation in Nigeria was found which led to this study. It is hoped that the outcome of this study will help in promoting awareness, research and incorporation CCECs monitoring and remediation in Nigeria's environmental regulations.

2. 0 Chemical Contaminants of Emerging Concern and Global Perspectives

The widespread discharge of legacy chemical pollutants into the environment has become a global issue given the difficulty in putting in place, efficient and effective remediation,

mitigation, and minimization strategies (Libralato *et al*. 2020). To make matters worse, CCECs which have hitherto received little attention are increasingly gaining the attention of researchers and regulators due to their hazardous effects on plants and animals.

The European Union (EU) established the NORMAN Programme in 2005 aimed at enhancing the exchange of information on CCECs, fostering the streamlining of guidelines on CCECs and enhancing the quality CCECs data (Dulio *et al*. 2018). This led to the establishment of regulators, research centres, laboratories and NGOs network which has among other things, engendered cooperation and information exchange on the occurrence, effects, sampling, analyses, monitoring and future regulation of CCECs (NORMAN, 2011, 2018). The EU also established the REACH (Registration, evaluation, authorization and restriction of chemicals) programme in 2006 to aid in the designation of the risk status of chemicals which led to the identification of 205 chemicals as substances of very high concern as of 2020 with 16 of them linked to endocrine disruption. Efforts are also been made to establish maximum permissible limits for identified hazardous CCECs (Barbosa *et al*. 2016).

The Netherlands has developed water quality standards for CCECs like pyrazole while France developed a 5-year monitoring and management programme for CCECs generated from non-point agricultural, domestic and industrial sources (OECD, 2018)

The US government established the Contaminants of emerging concern Interagency Working Group (IWG) in May 2020 to coordinate research in CCECs. This resulted in the National Emerging Contaminants Research Initiative (NECRI) which provides a framework for research (OSTP, 2022). The United States Environmental Protection Agency (USEPA) periodically publishes the names of unregulated contaminants that occur in waterbodies and determines their regulatory status after monitoring their occurrence, exposure levels and health effects over a given period. In March 2023, the USEPA proposed a guideline value of 4.0 ng/L for six PFAS chemicals which usually contaminate water which marked a strategic step in PFAS regulation worldwide (USEPA, 2023).

Miraji *et al*. (2016) concluded that the USA, China, Canada, Germany and Japan are the leading countries with regard to CECs research with Asia countries and South Africa also doing significant research in CCECs. The rest of Africa is largely lagging in terms of CCECs awareness, regulation and research (Bao *et al*. 2015; Selwe *et al*. 2022).

3. 0 Sources and Environmental Impacts of CCECs

CCECs are naturally occurring or synthetic chemical substances that are believed to be toxic to living organisms and ecosystems. Fig. 1 summarizes the types and sources of some CCECs.

The increasing discharge of CCECs do not only impairs the quality of water, air, and or soil but could also infiltrate the food chain thereby undermining human and animal health. A critical pathway for human exposure to CCECs is food and drink. Accumulation of contaminants in fish and fish products is a well-known entry pathway for toxicants into humans and animals. Contamination of drinking water sources also puts humans at risk of CCECs exposure even when water is treated since conventional water treatment is known to be less effective in CCECs removal.

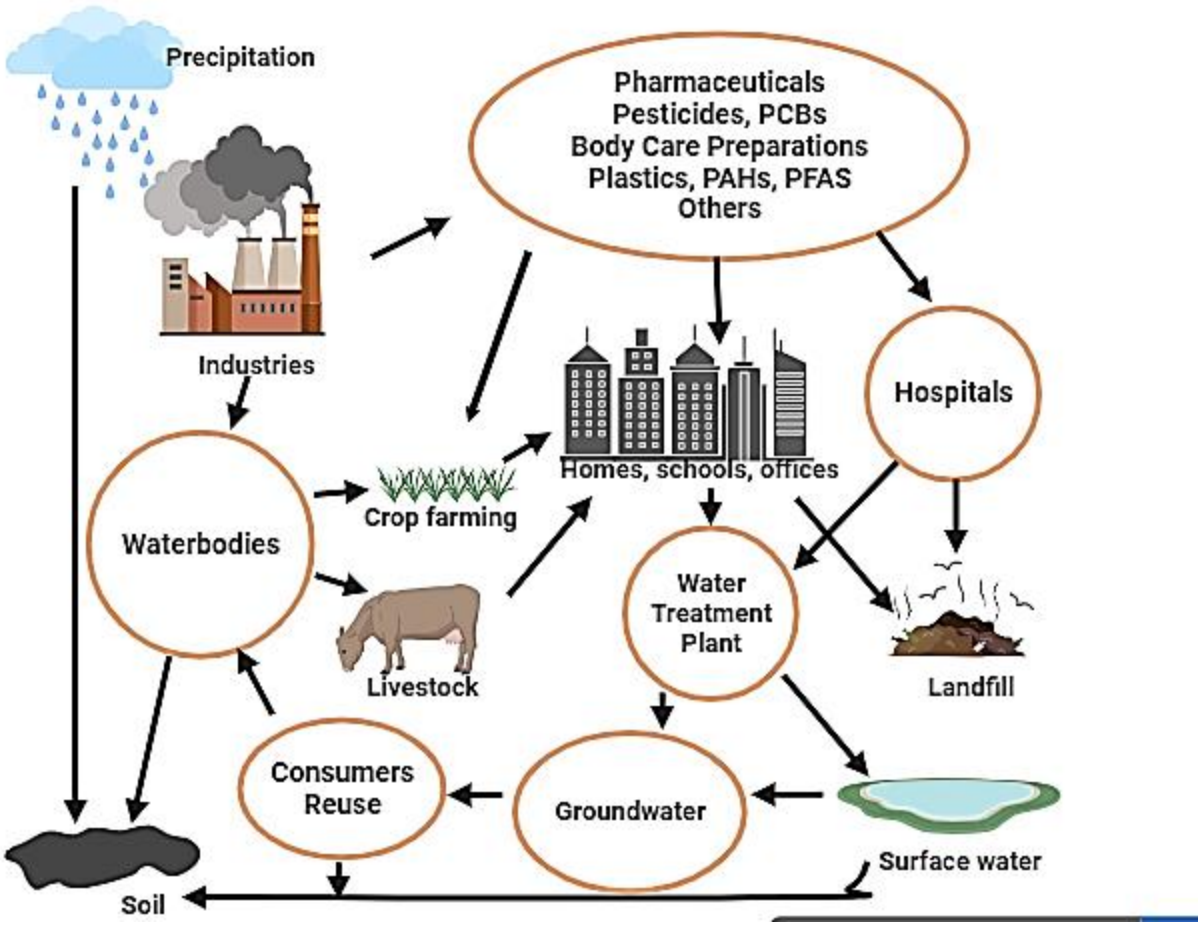

Fig. 1. Sources, circulation and fate of CCECs in the Environment (Adapted from: Hiranmal and Kamanraj, 2021)

4. 0 Estimates of CCECs loads in the Nigerian Environment

There is a dearth of literature on CCEC loads in Nigeria. Issa (2016) gave an estimate of 130,000 metric tons for annual pesticide application with about 85% ending up in the environment as contaminants (Leonila, 2002). UNIDO (2021) estimates that Nigeria generates 2.5 million tonnes of plastic waste annually which mostly ends up in the environment (UNIDO, 2021). Unyimadu *et al*. (2017) studied PCBs concentrations in the River Niger discovered that PCB levels the river were above acceptable limits which made the river water bad for human consumption. A study of PAHs in six major rivers in South West Nigeria by Ololade *et al.* (2023) revealed that the sum of the 16 priority PAHs (ΣPAHs) in each river was higher than the World Health Organization (WHO) maximum limit of 10 μg/L. Boer *et al*. (2023) carried out a two-year study of persistent organic pollutants (pesticides, PCBs etc.) in the atmosphere of 42 countries of Africa (including Nigeria), Asia, Latin America and the Pacific. They concluded that POP concentrations in Africa was dominated by PCBs and DDT with the pesticide chlordane,

having the highest concentration of 7.7 ng/polyurethane foam disk (PUF) in Nigeria.

5. 0 Environmental Policies, Laws and Regulations in Nigeria

Environmental law refers to a body of principles, policies, regulations, agreements and common law enacted by sub-national, national, regional or international bodies to regulate the interaction of human beings and the environment with the aim of protecting biota and habitats from substances and effects which may be directly or indirectly hazardous (Cheever and Campbell-Mohn, 2020; Legal Career Path, 2020). The objective of environmental law is "the protection of the environment" from pollution and wasteful depletion "of natural resources in" order to ensure sustainable development (Binali, 2014; Federal Ministry of Environment., 2018).

Environmental policy refers to the policy framework for the environment and it "covers the legislations, standards, regulations and administrations used to control activities" that may damage the environment of a country (Eneh and Agbazue, 2011).

"Environmental Regulations are the general rules and specific actions enforced by regulatory agencies for the control of pollution," environmental and natural resource management of a nation (Stavropoulos *et al*. 2018).

Various environmental laws, policies and regulations aimed at eliminating, reducing and controlling pollution in Nigeria have been enacted (Nnaji and Uzoekwe, 2018). The lead environmental regulator in Nigeria is the Federal Ministry of Environment and it supervises other agencies "under it like the National Environmental Standards Regulations Enforcement Agency (NESREA) and the National Oil Spill Detection and Response Agency (NOSDRA)" (Odionu, 2018). The following laws, regulations and policies of the Nigerian Government were referenced:

(a) The 'Federal Environmental Protection Agency Act' of 1988 (FEPA Act), which was repealed by the NESREA Act" of 2007 (Dalhat, 2017). The FEPA Act outlines the National Environmental Protection Regulations which were designed to guide effluent discharges, pollution reduction and waste management. They include (ATVL, 2020):

(i) Effluent Limitations Regulation (S.1.8) 1991"
(ii) "Pollution Abatement in Industries Generating Waste Regulation (S.1.9) 1991"
(iii) "Management of Solid and Hazardous Wastes Regulation (S.1.15) 1991"

(b) "National Environmental Standards Regulations Enforcement Agency (NESREA) Act 2007" ((Federal Republic of Nigeria, 2007)

(c) "National Environmental Standard and Regulations Enforcement Agency (Establishment Amendment) Act 2018" (Federal Republic of Nigeria, 2018a) and 11 of the 33 Regulations under the NESREA Act including (NESREA, 2023):

(i) The "National Environmental Protection (Sanitation and Wastes Control) Regulations, 2009"
(ii) "National Environmental (Food, Beverages and Tobacco Sector) Regulations 2009"
(iii) "National Environmental Protection (Ozone Layer Protection) Regulations, 2009" which targeted towards ozone layer protection and the conditions for working with ozone depleting substances

(iv) "National Environmental Protection (Mining and processing of coals, ores and industrial minerals) Regulations, 2009"
(v) "National Environmental Protection (Textile, wearing apparel, leather and foot wear industry) Regulations, 2009"
(vi) "National Environmental Protection (Chemical, pharmaceutical, soaps and detergent manufacturing industries) Regulations, 2009"
(vii) "National Environmental (Nonmetallic minerals manufacturing industries sector) Regulations 2011"
(viii) "National Environmental (Domestic and industrial plastic, rubber and foam sector) Regulations 2011"
(ix) "National Environmental (Surface and Groundwater Quality Control) Regulations 2011"
(x) "National Environmental (Hazardous chemical and pesticides) Regulations 2014"
(xi) "National Environmental (Health Care Waste) Regulations 2021"

(e) "National Oil Spill Detection and Response Agency (Establishment) Act 2006" (Federal Republic of Nigeria, 2006) – This Act created NOSDRA and mandated the agency to monitor, evaluate and respond to oil spillages in Nigeria.
(f) "Harmful Wastes (Special Criminal Provisions etc.) Act of 1988 (Harmful Wastes Act)"
(g) "Harmful Waste (Special Criminal Provisions etc.) Act CAP 165 LFN 1990" – The guidelines and standards on waste disposal provide the protocols for the most effective and efficient options for harmful waste disposal.
(h) Harmful Wastes (Special Criminal Provisions) Act, Cap H1, LFN 2004
(i) Environmental Impact Assessment EIA Act Cap E 12, LFN 2004
(k) The Revised National Policy on Environment 2016
(l) Waste Management and Hazardous Waste Regulations (S.1.15) 1999
(m) "Environmental Guidelines and Standards for Petroleum Industry in Nigeria (EGASPIN) 2018" (ATVL, 2020)
(n) "The Petroleum Industry Act (PIA) 2021" (Federal Republic of Nigeria, 2021)
(o) The Flare Gas (Prevention of Waste and Pollution) Regulations 2018 (Federal Republic of Nigeria, 2018b)
(p) "The Gas Flaring, Venting and Methane Emissions (Prevention of Waste and Pollution) Regulations 2023" (Federal Republic of Nigeria, 2023a)
(q) "The Midstream and Downstream Petroleum Environmental Regulations 2023" (Federal Republic of Nigeria, 2023b)
(r) "Nigerian Standard for Drinking Water Quality (NSDWQ)" by Standards Organization of Nigeria (SON) 2015
(s) "National Guidelines for Environmental Auditing in Nigeria (1999)" (FMMSD, 2020)

6. 0 Status of CCEC Monitoring, Remediation and Regulation in Nigeria

An online search was carried out on various academic platforms (DOAJ, AJOL, SpringerLink, ScienceDirect, Semanticsscholar, Google Scholar and Research Gate) to access research and reviews on CCECs in Nigeria. The search words used included 'emerging contaminants in Nigeria', 'contaminants of emerging concern in Nigeria', remediation of pollution by emerging contaminants in Nigeria', 'organic pollutant pollution in Nigeria', 'endocrine disrupting chemicals in Nigeria', 'pesticide pollution in Nigeria' and 'PAHs in the Nigerian

Environment'. Other search words were; 'personal care products', 'pharmaceutical pollution', 'PCBs', 'PFAS', 'surfactants', 'dyes and pigments', 'preservatives' and 'micro- and nanomaterial (Eddy *et al*., 2024). Each search item in the last sentence had the phrase, 'pollution and remediation in Nigeria'. The search resulted in the discovery of 1476 publications published between January 2017 and December 2023. These were painstakingly perused but only 173 publications (books, reviews and research papers) were found suitable for use in assessing the subject matter. However, the vast majority of the publications (163; 94.22%) were in the area of CCECs monitoring while a paltry 10 publications (5.78%) dealt with remediation of CECs polluted matrices. Table 1 shows the distribution of these publications across the years.

Table 1. Distribution of Publications on CECs in Nigeria January 2017 – December 2023

Year of Publication	Type of Publication	Focus	
		Monitoring	Remediation
2017	Book	–	–
	Reviews	–	–
	Research paper	11	–
2018	Book	1	–
	Reviews	–	–
	Research paper	11	1
2019	Book	–	–
	Reviews	2	–
	Research paper	13	1
2020	Book	1	–
	Reviews	4	1
	Research paper	23	1
2021	Book	1	–
	Reviews	4	–
	Research paper	21	3
2022	Book	1	–
	Reviews	12	–
	Research paper	24	1
2023	Book	–	–
	Reviews	7	–
	Research paper	27	2
	TOTAL	**163**	**10**
	GRAND TOTAL	**173**	

The matrices studied in the 130 research papers in Table 1 include animals; food; water and wastewater; solid matrices (soil/sediment/sludge/particulates); air, mixed matrices (e.g. soil, water and fish; snails and soil; soil and vegetable) and others (personal care products and transformer oil). Fig. 2 shows that the highest number of studies (38) focused on solid matrices (soil/sediment/sludge/particulates) followed by studies on water and wastewater samples. The lowest number numbers of papers were was

recorded for other matrices (3) and 1 research paper by Akinrinade *et al*. (2022) on CECs' concentrations in air samples.

6.1 Status of CEC Monitoring Research in Nigeria

Monitoring of pollutants is the primary duty of governments (through regulatory agencies and government-funded projects) while the remediation of polluted sites is the duty of the polluter under the supervision of regulators in consonance with the polluter pays principle (PPP). Academic researchers and environmental interest groups also help to complement governmental efforts. Wenibowei (2018) stated that despite the existence of various legal frameworks for environmental pollution control in Nigeria, the environment generally continues to experience deterioration and other forms of abuse as a result of the activities of firms legally registered in the country. In addition, existing legal frameworks are not updated to include new pollutants like CCECs.

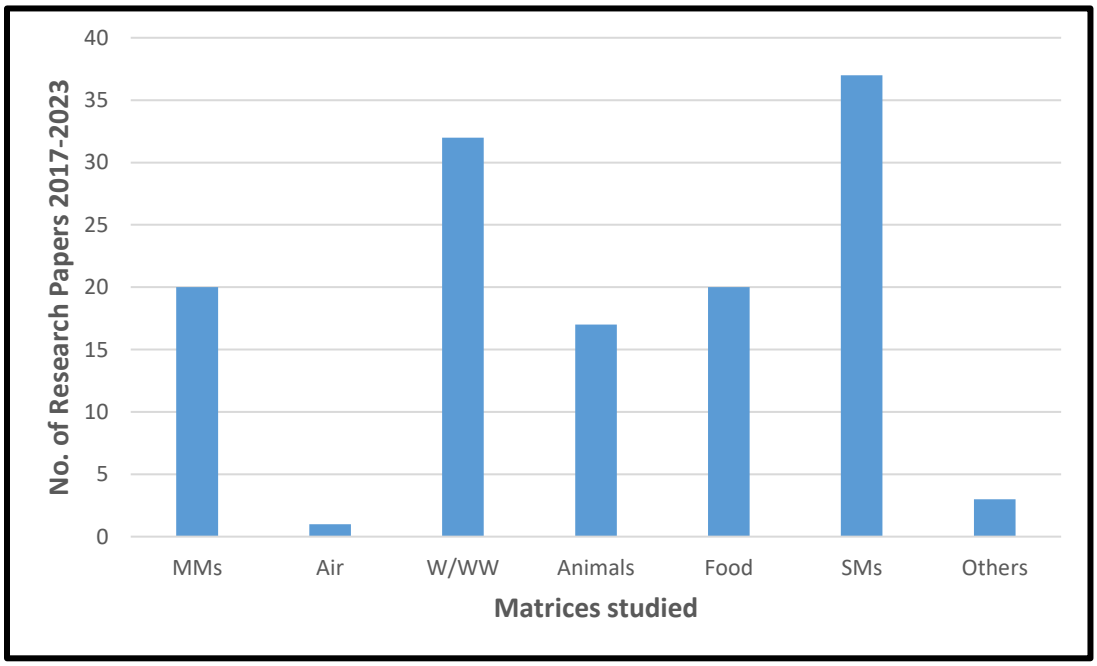

Fig. 2: Number of research papers and matrices studied (2017 - 2023)
(MMs = mixed matrices, W/WW = water & wastewater, SMs = solid matrices)

No publication on the monitoring of CCECs by the regulatory agencies in Nigeria was found within the period under consideration. The vast majority of publications on CCECs were by researchers in both local and foreign institutions of Higher Education. Some of them are shown in Table 2.

However, there is a relative dearth of literature on the environmental contamination by CCECs like pharmaceuticals and body care preparations (PBCPs) in Nigeria as a result of factors such as lack of awareness and non-availability of sensitive analytical equipment (Ebele *et al*. 2020; Jari *et al*. 2022).

6.2 Status of CCECs Remediation Research in Nigeria

The number of publications on remediation of CCECs was 10 with 9 being research papers while 1 publication was a review paper (Table 1). The results show that publications on remediation pales into insignificance compared to works on monitoring and with only 10 papers found across 7 years, it can easily be concluded that there is very low research effort on the remediation of CECs in the Nigerian environment. This may also be the situation in Africa because Okoye *et al*. (2022) reported that they found more than 35 publications on the concentrations and mobility of pesticides, pharmaceuticals and personal care products in African waterbodies but there was little or no information on the control of PPCPs discharge or the remediation of the affected waterbodies.

6.3 Status of CCEC Regulation in Nigeria

A thorough scrutiny of the laws, policies and legislations on the Nigerian environment outlined in Section 5 above shows little mention of CCECs. The Effluent Limitation Regulation of 1991 "makes it mandatory for industries to install anti-pollution and pollution abatement equipment on site. The regulation was specific for each category of waste generating facility concerning limitations of solid and liquid discharges or gaseous emissions into the environment" (FEPA 1991a). "The Pollution Abatement Regulation of 1991 imposes restrictions on the release of toxic substances and stipulates requirements for pollution monitoring units, machinery for combating pollution and contingency plan by industries; submission of lists and details of chemicals used by industries to Federal Ministry of Environment, strategies for waste reduction; permissible limits of discharge into public drains; protection of workers and safety requirements; penalties for contravention" (FEPA 1991b).

"The Management of Solid and Hazardous Wastes Regulation 1991 defines the requirements for groundwater protection, surface impoundment, land treatment, waste piles, and landfills. It describes the hazardous substances tracking program with a comprehensive list of acutely hazardous chemical products and dangerous waste constituents. It also states the requirements and procedure for inspection, enforcement and penalty" (ATVL, 2020). The 1991 regulations included CCECs like pesticides, PCBs and detergents but were silent on most others.

In the "National Environmental (Surface and Groundwater Quality Control) Regulations 2011" (Federal Ministry of Environment, 2018), no CCEC was mentioned in the ambient quality criteria for surface water while anionic detergents and PAHs were the only CCECs given guideline values for groundwater. Furthermore, only 5 PAHs out of the 16 priority PAHs (Mojiri *et al*. 2019) as spelt out by the USEPA were considered. The National Environmental Protection (Chemical, pharmaceutical, soaps and detergent manufacturing industries) Regulations, 2009 set effluent guidelines for only the following CCECs; detergents (as linear alkylbenzene sulfonate), total pesticides and organo-phosphorus pesticides. It classified some CCECs like PAHs, polychlorinated biphenyls (PCBs) and polychlorinated terphenyls as restricted chemicals without any guideline values for them. Detergents (as linear alkylbenzene sulfonate) were the only CCECs for which effluent limitation standards were set in "the National Environmental (Textile,

Wearing Apparel, Leather and Footwear Industry) Regulations 2009" (NESREA, 2023). The National Environmental (Hazardous Chemical and Pesticides) Regulations 2014 outlines a list of banned and restricted chemicals and pesticides. It provides guidelines for storage and transportation of hazardous chemicals and pesticides but only a few CCECs like pesticides (e.g. parathion, lindane, Aldrin, heptachlor and chlordane) and perchlorooctane sulphonate (PFOS) are mentioned. The National Environmental (Health Care Waste) Regulations 2021 simply categorizes health care wastes into pharmaceutical, infectious and bio-wastes among others. There is no mention of CCECs or guideline values for effluents. Neither the quality standards for domestic water nor the permissible limits for wastewater discharge set by NESREA (2023) "in the National Environmental Protection (Sanitation and Wastes Control) Regulations, 2009" mentioned any CCEC. However, the regulations set standards for the disposal of industrial effluents containing radioactive materials. "The National Environmental (Food, Beverages and Tobacco Sector) Regulations 2009" mentioned only pesticides while neglecting CCECs like dyes, flavourings, preservatives, hormones and nicotine usually associated with the food and tobacco industry.

The NSDWQ stipulates standards for CCECs like detergents, pesticides, PAHs, water disinfection by-products (trihalomethanes & 2,4,6-trichlorophenol) and radionuclides but the highly persistent and toxic CCECs classified as Perfluoroalkyl substances (PFAS) were left out. The standards urgently need to be updated.

The aim of the NESREA Amendment Act of 2018 was mainly the review of appointment for council members, penalties and the permission for the Agency to search any premises without warrant. Issues concerning CCECs or any other pollutant were completely absent in the amendment.

The Revised National Policy on the Environment (2016) outlines guidelines and strategies to achieve a good quality environment for the good of the Nigerian citizens. It also provides for the improvement of ecosystems and the institution of processes that will preserve biodiversity and ensure the development of living natural resources and ecosystems sustainably. Under emerging environmental issues, the document mentioned climate change, genetically modified organisms (GMO) and Biosafety but was completely silent on CCECs.

The 2018 version of the EGASPIN published by the defunct DPR ("now split the Nigerian Upstream Petroleum Regulatory Commission, NUPRC and Nigerian Midstream and Downstream Petroleum Regulatory Authority, NMDPRA" Okumagba, 2022) was aimed at promoting good governance and environmental sustainability in the Nigerian Petroleum Industry (Olawuyi and Tubodenyefa, 2018). However, standards are set for only 10 out of the 16 priority PAHs and otherC CCECs associated with oil and gas activities like surfactants and chlorinated aromatics were not mentioned.

A well-known source of CCECs in Nigeria is gas flaring and about "7.4 billion cubic feet of gas" was flared in 2018 (PwC, 2019; Chete and Chete, 2021). Several toxic chemicals (including greenhouse gases and CCECs) like carbon, nitrogen and sulphur oxides; PAHs, soot and photochemical oxidants (Gobo, 2009; Elehinafe *et al*. 2022) are emitted during gas flaring depending on the extent of combustion (complete or incomplete).

The Petroleum Industry Act which was signed into law in 2021 and was touted as a game changer for the Nigerian Petroleum Industry. The Act aims to eliminate gas flaring and stipulates penalties for gas flaring in accordance with "the Flare Gas (Prevention of Waste and Pollution) Regulations" (Federal Republic of Nigeria, 2018b).

The Flare Gas (Prevention of Waste and Pollution) Regulations, 2018 stipulates the payment of fines for given quantities of gas flared depending on oil production volumes, protocols for gas flaring permits and reporting of gas flare data but fails to set standards for emitted pollutants.

The Gas Flaring, Venting and Methane Emissions (Prevention of Waste and Pollution) Regulations 2023 ((Federal Republic of Nigeria, 2018a) sets no standards in terms of amounts of pollutants including CCECs to be emitted into the environment but merely outlines the protocols for gas flaring permit, reporting of gas flaring data and associated issues.

The Midstream and Downstream Petroleum Environmental Regulations, 2023 issued by the NMDPRA is also silent on the limits for pollutants including CCECs but spells out protocols for environmental management systems and plans, studies and assessments, waste management, and associated issues. Even the section on climate change does not set limits for greenhouse gas emissions.

The foregoing shows that policymakers in Nigeria seem to have little or no appreciation of the potential negative impacts of CCECs on the environment. Ogunkan (2022) concluded that since the Nigerian environmental regulation system is bedevilled by low public participation, unenforceable legislation and weak institutions, it is completely inadequate to tackle the country's environmental challenges.

7.0 Suggestions for awareness creation and incorporation CCECs into Nigeria's Environmental Laws

(i) Stakeholder engagements – Governments at all levels, regulatory agencies, industry, academia and environmental interest groups need to work together to counter the effects of pollution. Stakeholder workshops on awareness creation and health risks associated with CCECs should be organized in this regard.

(ii) Capacity building on CCECs monitoring, remediation and regulation among regulators – This is crucial since one can only monitor what one has a good knowledge of

(iii) A nationwide study of CCECs concentrations in water resources, soil and air in Nigeria

(iv) The development of a national framework for CCECs identification, research, monitoring, remediation and regulation

(v) Establishment of a national database and management program for CCECs

(vi) Identification of factors enhancing and militating against CCECs legislation in Nigeria

(vii) Revision of existing environmental laws to fully incorporate CCECs – the legislature at all levels should be encouraged to buy into pollution abatement in Nigeria and enact relevant legislation on CCECs

(viii) Inclusion of subjects/courses on environmental issues including human health risks of CCECs in the curriculum

of secondary and tertiary institutions – such subjects/courses should be made mandatory for students in light of the negative impacts of these contaminants

(ix) Adequate funding of research on CECs by governments at all levels and industries – A critical part of this is the equipment of higher education laboratories with advanced equipment for the analysis of CCECs

(x) Creation of a National Early Warning System with emphasis on CCECs and other pollutants

(xi) Increased research efforts on the remediation of CCECs' polluted media

8.0 Conclusion

Environmental regulatory agencies in Nigeria are largely uninvolved in CCECs monitoring and awareness creation on their potential negative impacts. This study revealed that no publication on the monitoring of CCECs by the regulatory agencies in Nigeria was found within the period January 2017 to August 2023. All the scientific publications on CCECs were by researchers in local and foreign Higher Education Institutions. In addition, very little research effort is focused on the remediation of CCECs in the Nigerian environment and the assessment of existing environmental laws and regulations revealed that policymakers in Nigeria seem to have little or no appreciation of CCECs and their environmental impacts. The recommendations made will promote awareness, research and incorporation CCECs monitoring and remediation in Nigeria's environmental regulations.

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Compliance with Ethical Standards Declarations

The authors declare that they have no conflict of interest.

Data availability

All data used in this study will be readily available to the public.

Consent for publication

Not Applicable

Availability of data and materials

The publisher has the right to make the data public.

Competing interests

The authors declared no conflict of interest.

Funding

The authors are grateful to the Tertiary Education Fund (TETFUND) for sponsorship this study under the Nigeria National Research Fund grant (Ref. No. TETF/DR&D/CE/NRF/STI/ 66/Vol. I) programme.

Authors' Contributions

JCN: Conceptualization, writing, graphical plots and corrections. MOE: Methodology, writing, proofreading