Chapter 21
Legal Implications of Nanobiosensors Concerning Environmental Monitoring

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Abstract The international community has been facing significant challenges posed by pollution, depletion, and degradation of the environment mainly due to the introduction of toxic substances or waste by man. However, to ensure the existence, safety, security, and healthy living of humanity, there is a need to guarantee a safe and effective protected environment, free from pollution and substances that could cause the depletion of the ozone layer and hazardous for human being. Though, there have been reported recent cases of the utilization of nanotechnological and scientific methods such as nanobiosensor (NBS) which are developed for detecting toxic substances for environmental, biomedical, and other applications. NBS has been proven to be one of the most useful scientific methods for environmental monitoring and management. NBS has been an effective scientific method for environmental monitoring and is meant to complement the international legal framework that ensures effective monitoring and prevention of the introduction of hazardous substances into the environment. Despite the attractive advantages that NBS tends to provide in the environmental domain, there are still some legal implications and challenges of utilizing NBS, owing to some potential NBS risks in environmental monitoring and management. Consequently, this chapter adopted a doctrinal analysis of NBS for environmental monitoring, its prospect in complimenting some international legal framework in environmental monitoring, the legal implication, and the challenge of using NBS for environmental domain.

Keywords Environment · International community · Legal framework · Nanobiosensor · Pollutants

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21.1 Introduction

Given the growing concern over the deteriorating environmental and atmospheric conditions of the earth and the depletion of the ozone layer ensuing from both natural and human actions, there has been an emergence of the international regulatory regime that tends to rectify some of these environmental or ecological challenges (Adedeji and Eziyi 2010; Riget et al. 2016; Aidonojie et al. 2020; Ukhurebor et al. 2020a, b). This is given the fact that the preservation and conservation of the environment, biological diversity, and promotion of sustainable development are of utmost importance to humanity (Susan 2009; Anderson et al. 2004; Sundström et al. 2014). However, despite the efforts of both the local, national, regional, and international community to curtail the continuous contamination of the environment and depletion of the ozone layer, there is still the release of persistent organic and inorganic pollutants (such as carbon-based compounds) that consist of synthesized substances (such as pesticides and other harmful chemicals) (Falkner 2016; Ladychenko et al. 2019; Nwankwo et al. 2020) and such other related hazardous substances from both domestic and industrial activities which are the by-products from human and natural activity (Yamin and Depledge 2004; Bodansky et al. 2017; Ukhurebor et al. 2021a, b, c, d, e). Scientific studies have revealed that persistent release of dangerous pollutants on the atmospheric environment will cause a depletion of the ozone layer and therefore lead to environmental catastrophe (Bridges and Oldeman 1999; Githeko et al. 2000; Garret et al. 2011; Ukhurebor et al. 2020a, b).

In order to scientifically resolve these environmental abnormalities, there have been some scientific innovations in the field of nanotechnology such as nanobiosensor (NBS) that has been developed, evolved, and accepted as a useful scientific method for environmental monitoring and management (Rapini and Marrazza 2017; Willner and Vikesland 2018; Ukhurebor and Adetunji 2021; Onyancha et al. 2021). NBS are essentially sensors that comprise nanomaterials (Muller and Nowack 2008, Dai et al. 2017; Vogel 2019; Ukhurebor 2020). NBS is used or can be used in detecting substances such as detecting of mycotoxin in foodstuff (Pérez-López and Merkoçi 2011; Ramezani et al. 2017; Liu et al. 2018), detecting of toxic substances for environmental monitoring, monitoring, and detecting of detrimental environmental constituent that may cause environmental pollution or depletion of the ozone layer as well as some biomedical applications (Qin et al. 2016; Alahi and Mukhopadhyay 2017; Ghoto et al. 2019; Ukhurebor 2020; Kerry et al. 2021).

However, the extent of the legal framework that is developed in regulating environmental pollution and waste management may pose some challenges in using or developing NBS for environmental monitoring. This is concerning the fact that some NBS may allegedly contain some substances or chemical that could pose a number of risks or threat to the environment during or at the expiration of their life cycle, and this may be subjected to legal control or maybe truncated from being used for environmental monitoring (Franco et al. 2007). This legal implication is stem from the fact that there is a need to ensure sustainable development of any scientific method in preventing, controlling, and monitoring the introduction of substances or waste that may be hazardous to the environment and humanity (Xu et al. 2014; Selvilini et al. 2018; Zhang et al. 2019); albeit, NBS are been reported and scientifically proven to be environmentally friendly and relevant in several scientific domains (Adetunji et al. 2021a, b; Kerry et al. 2021; Ukhurebor and Adetunji 2021; Onyancha et al. 2021). Given the above, this chapter tends to adopt a doctrinal research method in examining NBS for environmental monitoring. The applications of NBS as one of the most effective scientific methods seem to complement the existing environmental legal framework for environmental monitoring. The legal implications or challenges in this aspect are also discussed.

21.2 The Concept of NBS in Environmental Monitoring

The twentieth century has experienced an increase in population and a great industrial developmental stride. Various studies have reviewed that the major hazardous substances polluting the environment (land, water, and air) are majorly caused by human activities in the industrial exploitation and exploration of natural resources (Nwankwo and Ukhurebor 2020; Ukhurebor et al. 2021a, b). This is concerning the fact that the need to increase the level of production has led to undue exploitation and exploration of natural resources, developing chemical to improve food production (McCullum et al. 2003; Mackey and Montgomery 2004; Ukhurebor et al. 2020b, 2021b), genetically modifying plants or animals (Chenet al. 2012; Adetunji et al. 2021a, b). These human activities do not only lead to a high rate of food production, but are also resulting in some reported cases of hazardous and harmful to human health and environmental consequences (Childers et al. 2011; Cordell et al. 2009; Nwankwo and Ukhurebor 2019), and this is in affirmation to the report of Kumar and Guleria (2020) that environmental pollution that directly affects human health account for over 9 million deaths in the world in 2015, which is far higher than other death-causing agents.

However, researchers have been researching on the effective scientific method (especially in the nanotechnology domain) that can be used in detecting hazardous substances that can cause pollution to the environment (Malik et al. 2013; Darsanaki et al. 2013). NBS is one such scientific method, which consists of nano and biosensor machinery (Pandit et al. 2016; Ukhurebor and Adetunji 2021). Nanotechnology has to do with the designing and making of useful devices and systems ranging from 1–100 nm scale (Ma et al. 2018; Andreescu et al. 2005; Ukhurebor and Adetunji 2021). The relevance of utilizing nanotechnology is based on sensing (Touhami 2014; Ukhurebor 2020; Kerry et al. 2021). Given this, the use of nanotechnology in the context of biosensors for environmental monitoring involves the use of nonmaterial in detecting pollutants and hazardous substances within the environment (Fahimi-Kashani and Hormozi-Nezhad 2016; Muenchen et al. 2016).

Biosensors utilize biological components derived from a sensitized component associated with a physicochemical transducer (Gosset et al. 2018). The essence of a biosensor is to generate a digital electronic indicator that is relative to the concentration of an exact analyte or set of analytes. NBS for environmental monitoring can be used in detecting hazardous and pollutant substances that may be harmful to the environment (Malhotra et al. 2017). NBS can be group into nanosensors, which is a biological sensory process used to transmit information concerning nanomaterials to the macroscopic world (Patolsky et al. 2006). Research has shown that the ability to modify the size and composition of nanomaterials can provide tremendous prospects for scheming novel sensing devices or systems and therefore improve the performance of bio-analytical assay or chemical (Devreese 2007; Duhan et al. 2017; Vogel 2019). Furthermore, NBS can be incorporated into miniature devices for speedy screening, monitoring, and detecting a large variety of hazardous substances that can cause pollution of the environment (Bellan et al. 2011).

Up till now, several NMS have been fabricated and reported, ranging from largely utilization gold nanomaterials to novel nanomaterials that are either carbon-built or transition-metal dichalcogenide-built. These nanomaterials could be exploited either by themselves or via the combination (hybridization) with other nanomaterials for the improvement of highly sensitive NMS (Yoon et al. 2020). Some of the utmost contemporary categories and subcategories of NMS and the prominent historical outline of some of the reported evolutions of NMS mechanisms are shown in Figs. 21.1 and 21.2, respectively, as adopted from Kerry et al. (2021).

Given the above, it is apt to state that the concept of NBS is of great relevance in environmental monitoring, given its scientific sustainable means of preserving the climate earth from pollution and hazardous substances.

21.3 NBS for Environmental Monitoring Complimenting Some International Environmental Legal Framework

The growing quantity of possibly harmful contaminants in the environment calls for fast and low-cost investigative procedures to be utilized in all-embracing environmental monitoring plans. Furthermore, over the previous years, a rising quantity of creativities and legislative arrangements for controlling and monitoring environmental contamination have been implemented in parallel with growing scientific, technological, social, and public apprehension in this domain (Rodriguez-Mozaz et al. 2005; Rogers 2006; Silva et al. 2011; Ukhurebor et al. 2021a).

There is a vast request for fast, consistent, and cost-effective systems for the controlling, monitoring, detection, and analysis of impurities in the environment (Salouti and Derakhshan 2020). Numerical investigation of environmental samples is typically carried out via the traditional investigative approaches such as spectroscopic and chromatographic procedures in identifying various contaminants or impurities in the environment. These approaches, though precise and sensitive, still need sophisticated and exclusive instrumentation, skilled personnel for their process, and multi-phase as well as complex sample research (Salouti and Derakhshan 2020).

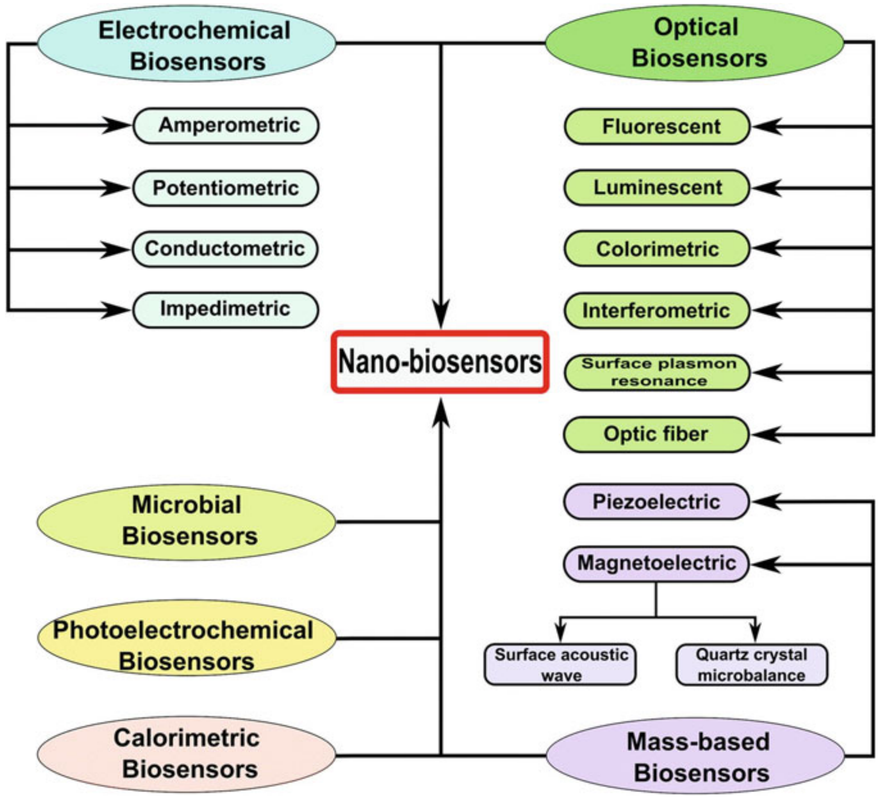

Fig. 21.1 Some of the utmost contemporary categories and subcategories of NMS (Kerry et al. 2021). Permission to reproduce automatically granted by the Royal Society of Chemistry due to authorship

Most of these procedures are also reportedly labor-exhaustive and time-intensive, as well as some difficulties in the monitoring of contaminants on location, in actual duration, and at the high occurrence. To stunned most of these issues connected with the existing environmental investigative and monitoring procedures, several innovative biosensors (an investigative mechanism for the quantifiable monitoring and detection of analyte with an organically active component) are being established, developed, and evolved. Most of these biosensors depend on nanotechnological tendencies (Salouti and Derakhshan 2020; Ukhurebor 2020; Kerry et al. 2021).

Biosensors are typically classified owing to the bioreceptor components involved in the organic recognition procedure (such as the immune-affinity recognition components, enzymes, whole cells of microbes, living organisms (animals or plants), or fragments of DNA), or owing to the physicochemical transducer employed (such as thermal, piezoelectrical, optical, or electrochemical). The foremost kinds of bioreceptor components that are utilized in the environment monitoring and analysis are the whole cells of microbes, enzymes, antibodies, and DNA. Also, from existing

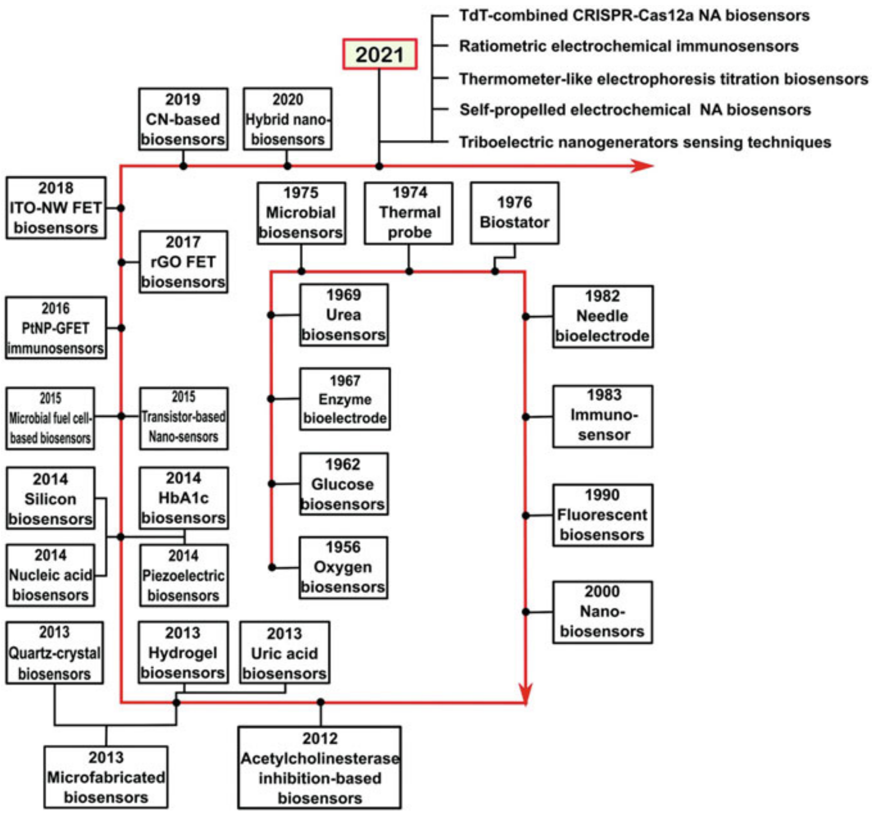

Fig. 21.2 Prominent historical outline of some of the described evolutions of NMS. Where *FET* field effect transistor, *GP* graphene, *PtNP* platinum nanoparticle, *rGPO* reduced graphene oxide, *ITO-NW* indiumtin oxide nanowires, *CN* carbon nanotube, *TdT* terminal deoxynucleotidyl transferase (Kerry et al. 2021). Permission to reproduce automatically granted by the Royal Society of Chemistry due to authorship

works of literature the utmost of the biosensors for environmental, monitoring, analysis and applications are that of the electrochemical transducers (Salouti and Derakhshan 2020).

The foremost benefits offered by biosensors for environmental monitoring and applications over the conventional investigative procedures are the prospect of transferability, miniaturization, work on-site, and the capability of detecting and measuring pollutants in multifaceted matrices with negligible sample research. Though several of the established and developed systems can hardly compete hitherto with conventional investigative procedures in terms of precision and reproducibility, they could be utilized by regulatory establishments and by industries to offer adequate information for routine screening, monitoring, and testing of environmental samples (Rodriguez-Mozaz et al. 2005; Rogers 2006; Salouti and Derakhshan 2020).

NBS has been scientifically proven to be relevant in various scientific research (Gharaatifar and Hasanzadeh 2017; Viswanathan et al. 2009), however, the relevance of NBS for environmental monitoring cannot be overemphasize, given the fact that the essence of introduction of the scientific concept of NBS for environmental monitoring is aimed at ensuring prevention and control of the introduction of hazardous substances or constituents that may contaminate or pollute the environment (Wang et al. 2014; Miao et al. 2016). It must be noted that the introduction of NBS for environmental monitoring is further aimed at scientifically complimenting and strengthening the already existing environmental management procedures as well as the legal framework for environmental monitoring. This is concerning the fact that the development of international, regional, national, states, and local environmental laws was triggered by the need to protect the life of humanity and preserve the ecosystem from hazardous substances that may deteriorate the health of man and cause pollution to the environment (Crutzen et al. 2008; Xiang et al. 2019). Furthermore, it may lead to environmental problems such as pollution, acid rain, deforestation and desertification, the destruction of the ozone layer, and climate change (Auta et al. 2017; Nwankwo et al. 2020). The introduction of hazardous substances to the environment and depletion of the ozone layer is mainly caused by human activities via industrial activities or in the cause of exploiting the earth's natural resources (Barnes et al. 2009; Barboza et al. 2019). In the 1950s and early 1960s, the international community was more inclined with the issue of nuclear damage (a by-product of the atoms for peace proposal) and marine pollution from oil/petroleum resources (Andrady 2015). However, it was Rachel Carson's (1962) famous book *Silent Spring*, the story of silent spring that exposed the hazards of the pesticide Dichlorodiphenyltrichloroethane (DDT) and other harmful substances that causes pollution of the environment and depletion of the ozone layer (Carson 1962). Concerning these environmental abnormalities emanating from the activities of man, she questioned humanity's faith in the development of technological apparatus and industrial activities that are hazardous to the environment. Given this, the stage and quest for an environmental legal framework in environmental monitoring were set rolling within the international community. Several international conferences were held for the negotiation of international environmental treaties and conventions for environmental issues. These give birth to several international environmental legal frameworks that tend to ensure effective environmental monitoring and management within the international community and member states.

The essence of the *Stockholm Convention* on persistence of organic pollutants was aimed at the prevention, controlling, and monitoring of the use of persistent organic pollutants (Lallas 2001; Thanh et al. 2009) and other related substances which are the by-products from human and natural activities, which is also one of the major aims of NBS for environmental monitoring. *Article 3 of the Stockholm Convention on persistence of organic pollutants* emphasize the need for member states to take measures to reduce or eliminate and monitor the releases from intentional production and use of substances or chemicals that may be hazardous and harmful to the environment (Godduhn and Duffy 2003; Henry et al. 2016). Furthermore, *Article 7 of the Stockholm Convention on persistence organic pollutants* required each party or member state to develop and implement plans for the implementation of its obligations under this *Stockholm Convention* within their nation. Also, member states to the *Stockholm Convention* are required to establish the means to integrate national implementation plans for persistent organic pollutants in their sustainable development strategies where appropriate (Lamon et al. 2009; Torres et al. 2013).

Also, the *Rio Declaration on Environment and Development* was adopted to mitigate, control and monitor the systematic examination of patterns of production, specifically the production of toxic substance or components, such as radioactive chemicals and lead in gasoline, or poisonous waste that may be harmful and hazardous to the environment (Aidonojie et al. 2020). *Principle 3 of the Rio Declaration* emphasize the need to effectively monitor the activities of man as it relates to the environment, it also stated that man must engage in sustainable development for the preservation and conservation of the ecosystem which is one of the major reasons for introducing scientific and technological means (such as NBS mechanisms) for environmental monitoring. Furthermore, there are other relevant international environmental legal frameworks such as the *United Nation Framework Convention on Climate Change* (UNFCCC), the *Kyoto Protocol and United Nations Convention to Combat Desertification*, the *Basel Convention*, *and the Bamako Convention* that also emphasize the need for environmental monitoring and prevention of the ecosystem from pollution and depletion caused by hazardous constituent or substance. In this regard, given the above, NBS for environmental monitoring further seems to scientifically complement and enhance environmental legal framework which tends to ensure the effective control and monitoring of the environment from pollution, deterioration, and depletion by means of the introduction of hazardous substances into the environment. This is concerning the fact that the introduction of NBS for environmental monitoring is a perfect scientific sustainable development plan and strategies contemplated by *Article 7 of the Stockholm Convention on persistence of organic pollutants and the Rio Declaration*; that emphasize the need to effectively control and monitor the environment from pollution, degradation, and depletion.

21.4 Legal Implications and Challenges Concerning NBS for Environmental Monitoring

In the cause of utilizing nanomaterials or other substances in developing NBS, waste (such waste could be hazardous and non-hazardous) could easily or possibly be generated in the process or at the expiration of the life cycle of such NBS products (Hrapovic 2004; Kuswandi and Mascini 2005; Kuswandi 2018). Also, utilizing NBS for environmental monitoring may also release certain organic compound (carbon-based) that consist of or are made of synthesized substances such as pesticides and polychlorinated biphenyls (PCBs) that may be an agent of pollution to the environment (Nagatani et al. 2007; Liu et al. 2010). Given this, it is relevant when for using or utilizing NBS for environmental monitoring, to determine the effective process of handling, treating, and disposing of such wastes or organic pollutant contain in the nanomaterials or substances that encompasses NBS for environmental monitoring (Tchounwou et al. 2012; Liu et al. 2013). This is given the fact that failure to ensure appropriate utilization and applications of NBS for environmental monitoring does not only constitute more danger to the ecosystem but to humanity as well (Luo et al. 2006; Guo et al. 2011); possibly or maybe strictly faced with the legal implications of prohibiting the use of NBS. However, some of the relevant environmental legal frameworks that posed a challenge or affect the use of NBS for environmental monitoring will now be briefly discussed.

21.4.1 The European Union Directives of 2008/98/EC with Regard to Waste

It is apt to opine that the European Union (EU) Directives of 2008/98/EC with regard to waste is a policy framework on waste prevention and control. The EU Directives classified waste into hazardous and non-hazardous substances or waste (Ukhurebor and Aidonojie 2021). Although, no specific reference to waste generated from NBS for environmental monitoring was mention in the EU Directive of 2008/98/EC. However, when a waste generated from NBS becomes harmful to the environment that is, doing more harm to the ecosystem and humanity, it can be legally classified as hazardous.

Given the above, where the EU Directive of 2008/98/EC on waste can be applied in categorizing harmful waste generated from nanomaterials or substances in developing NBS for environmental monitoring, it may be categorized as hazardous. This is concerning the fact that substances such as zinc oxide and some of the substances mentioned above are regarded or classified as dangerous and very toxic to the environment, most especially to the aquatic environment. In this regard, when a NBS comprises substances such as zinc oxide or other substances which are considered harmful to the environment (aquatic to be specific), the EU Waste Directives of 2008/98/EC may limit, control or truncates the use of such NBS for environmental monitoring, most especially with regard to an aquatic environment.

21.4.2 The Stockholm Convention on Persistence Organic Pollutants

The United Nations has via several treaties and conventions prohibit the use of synthesized substances that may be a potential environmental pollutant (Heidelore 2007). In recognition of the fact that certain substances or chemicals possess harmful and toxic properties that may resist bioaccumulation, degradation and they can easily contaminate or pollute the air, water, and other environ (Weiguang et al. 2013). *The*

Stockholm Convention on Persistence Organic Pollutants 2004 via *Article 3 and 5* encourage member states to eliminate or control the use of substances or chemicals contain in Annex A, B, and C to the convention. These chemicals include Heptachlor, Aldrin, Hexachlorobenzene, Chlordane, Dieldrin, Endrin, PCB, Mirex, Toxaphene, Dichlorodiphenyltrichloroethane (also called DDT), Hexachlorobenzene (HCB), dibenzofurans, Polychlorinated biphenyls, and Polychlorinated dibenzo-p-dioxins. These chemicals can only be used to the extent permitted by the *Stockholm Convention on Persistence Organic Pollutants in Article 6 and Annex A, B, and C*, which NBS was not expressly mentioned or among the listed purpose for which these chemicals can be used. Furthermore, *Article 3(3)–(5) of the Stockholm Convention on Persistence Organic Pollutants* also required member states to ensure that the development of new industrial chemical or substance must be adequate screen in accordance with Annex D to the Convention to determine the toxicity level to the environment and human health. Given the above, the *Stockholm Convention* on Persistence Organic Pollutants encourages the use of minimal waste technology and substances or chemical those are less harmful and hazardous to the environment (Karlagans et al. 2001).

The implication of the above provision of the *Stockholm Convention on Persistence Organic Pollutants* with regard to NBS for environmental monitoring is that if any of these chemicals contain or use as a nanomaterial in developing NBS or are directly use in NBS, the usage of such NBS for environmental monitoring may be disallowed if consider harmful to the environment and to human health, *given Article 3, 5, 6, and Annex A, B, C, and D of the Stockholm Convention on Persistence Organic Pollutants.*

21.4.3 The Basel Convention

The *Basel Convention on the Control of Tran Boundary Movement of Hazardous Waste and their Disposal* is an international treaty that has a similar provision like the European Union Directive of 2008/98/EC on waste (Ukhurebor and Aidonojie 2021). The major aim of the Basel Convention is to ensure an effective control or prevention of waste that may be adversely hazardous to the environment and human health (Kummer 1992). *Article 2(1) of the Basel Convention* provides that waste can be classified as an object or chemical or substances which are hazardous in nature (that is the hazardous nature is determined based on their origin and composition) and are meant to be disposed of (Sejal 2001; Kempel 1999). *Article 1 of the Basel Convention* specifically stated that substances that fall under the category of *Annex I to the Basel Convention* are classified or regarded as hazardous waste, except they do not have the characteristic or nature of substance contained in *Annex III to the Basel Convention.* Some of these substances include; Waste water/oils, water mixtures/hydrocarbons, emulsions, selenium compounds, compounds that contain Inorganic fluorine, mercury compounds, a substance that contains phenol compounds, and chlorophenols, substances containing thallium, Metal carbonyls substance. Also, wastes that contain substances such as polychlorinated terphenyls, PCBs, cyanides, Zinc, Arsenic, Selenium, Cadmium, and several others as contained in *Annex 1 to the Basel Convention* are considered hazardous. Provided they exhibit one of the hazardous characteristics contained in *Annex III to the Basel Convention*, in other words, it must both be listed and contain some characteristic such as being explosive, flammable, toxic, or corrosive.

Furthermore, *Article 2* and 4 of the *Basel Convention* required state parties to ensure that steps are taken for an overall reduction, prevention, and control of any hazardous waste or substance generated within members' states. *Article 12 of the Basel Convention* further directs state parties to adopt a protocol that establishes liability rules and procedures appropriate for damage resulting from the movement of hazardous waste across borders. Given this, waste can pollute the environment via air and water, they capable of moving from one boundary to another. In this regard, where a NBS for environmental monitoring contain any of the above substances or there is a likelihood that waste that may be generated from a NBS during or after its life cycle may constitute a hazardous waste, the process of scientifically utilizing such a NBS for environmental monitoring may be truncated.

21.4.4 Bamako Convention

The *Bamako Convention* is also known as the *Bamako Convention on the Importation and Control of Trans-Boundary Movement of Hazardous* waste within Africa (Ukhurebor and Aidonojie 2021). This convention is similar to the *Basel Convention* (Shearer 1993; Ovink 1995), given the following reasons:

(i) Both conventions share the same objective of protecting human health and the environment from the potentially harmful impacts of the trans-boundary movement and disposal of hazardous waste.
(ii) Both conventions recognize the sovereign right of states to ban the import and export of hazardous waste.
(iii) Both conventions call for cooperation in the development of appropriate technical guidelines and codes of practice.

Given the above, it means the use of NBS for environmental monitoring may also be truncated by the *Bamako Convention* if in the circumstances such NBS could pose a threat of being a hazardous waste. However, the origin of the *Bamako Convention* is traceable to the alleged failure of the *Basel Convention* as regards two pertinent issues (Murphy 1994; Kitt 1994) which are:

(i) The realization that the *Basel Convention* had failed to prohibit the trade of hazardous wastes to less developed countries like those in Africa
(ii) The realization that many developed nations were still exporting waste to Africa
(iii) The *Basel Convention* states that illegal hazardous waste traffic is criminal but it contains no enforcement provisions.

In order to address the above concerns, the *Bamako Convention* placed a complete prohibition on the import or any activities that may lead to generating hazardous wastes (Eguh 1997; Dzidzornu 2004; Gutierrez 2014). Given this complete ban of waste, *Section 1, of Articles 1 of the Bamako Convention*, defined waste as harmful materials or substances which are meant to be disposed of or are intended to be properly disposed of in accordance with members' state provisions of national law (Ijaiya et al. 2018; Fatsah 1993). Furthermore, *Sections. 2, of Article 1 of the Bamako Convention*, defined hazardous wastes, as wastes that have been so-referred to as hazardous by virtue of the provision of state legislation, harmful substances that is banned, canceled, and declared as harmful by government regulation action, wastes which are subjected to the international regulation mechanism as a result of being radioactive (Kaminsky 1992; Eze 2007). In this regard, where a developed NBS for environmental monitoring life cycle has expired or may possibly pose a threat to be hazardous, such developed NBS may falls within the definition of substances that are hazardous as provided for in the *Bamako Convention.*

Also, *Article 4 of the Bamako Convention* further identified substances that are regarded as hazardous wastes as provided for in *Annex I, II of the Bamako Convention* and nations or members' state legislation. Some of material or substances referred to as hazardous as contained in Annex I to the *Bamako Convention* are as follows; any substances containing radionuclide as a result of human activities; substances that generated into waste as a result of the fact it was formulated and produce from biocides; wastes that emanate in the treatment of heat and operation that involve cyanides; substances that degenerate into wastes as a result of the use of organic solvent; substances that contain polychlorinated biphenyls, terphyenyls, and polybrominated biphenyls; wastes emanating from the development of an invention and research that are new and their effect to the environment are unknown, of which any waste emanating from a NBS may fall into this category. Furthermore, substances may also be regarded as hazardous if it contains any of the following constituents; arsenic composite, mercury element, leads element, beryllium composite, cadmium composite, tellurium, thallium compound, and hexavalent chromium substances (Ukhurebor et al. 2021c). Furthermore, *Annex II to the Bamako Convention* also stated that a substance may be regarded as hazardous if it possesses the following characteristic; being flammable, explosive, organic peroxides, toxic, ecotoxic, corrosive, and poisonous to man and the environment.

Given, the above provision of Annex I and II to the *Bamako Convention*, there is no doubt that if a NBS for environmental monitoring contains any of the substances as provided for in Annex I to the *Bamako Convention* or possess any of the characters as provided for in Annex II to the *Bamako Convention*, such NBS may be prohibited for being used for environmental monitoring. This is concerning the fact that; the *Bamako Convention* blacklist such substances use in the formulation and development of the NBS. Furthermore, the inventor and user of NBS may be discouraged from utilizing NBS for environmental monitoring, given the fact that *Article 4(3) (C) of the Bamako Convention* required that the generation of hazardous wastes within the area under its jurisdiction be reduced to a minimum and in ensuring the reduction of hazardous wastes parties must take into account social, technological, and economic aspects.

Article 9(4) of the Bamako Convention, provide that a trans-boundary movement of hazardous wastes is deemed to be illegal traffic and that proceedings according to the provisions of the convention are taken against the contravener(s) (Wordsworth 1993; Donald 1992; Kaya 2012). *Article 4(3) (b) of the Bamako Convention*, further, imposes strict and unlimited liability, as well as joint and several liability on anyone, involve in generating hazardous waste.

Given the above, it suffices to say that the *Bamako Convention* covers a wider spectrum of what constitutes wastes or substances that may be categorized as harmful to the environment and man. It covers and regulates the trans-boundary movement of both hazardous and radioactive waste. Furthermore, it also categorizes wastes emanating from the development of an invention and research that are new and their effect on the environment is unknown. In this regard, NBS being a current scientific invention for environmental monitoring could fall into this category where possess substances that may harmful to the environment or in the circumstances after the life cycle of NBS it becomes a threat to the environment, such NBS may be truncated from being used for environmental monitoring, given the *Bamako Convention.*

21.5 Conclusion and Recommendations

The study has been able to evaluate the concept of NBS for environmental monitoring, and how the concept of NBS tends to compliment some of the environmental legal frameworks concerning environmental monitoring in mitigating and reducing the effect of atmospheric pollution and hazardous substances in the environment. Furthermore, some of the international environmental legal frameworks such as the European Union Directives of 2008/98/EC with regard to waste, the *Stockholm Convention on Persistence Organic Pollutants*, *Bamako*, and *Basel Conventions* that tend to regulate how man relate to its environment was also considered. These environmental legal frameworks were evaluated with regard to the relevant provisions that may limit or truncate the use of NBS for environmental monitoring. This is concerning the fact that some substances that may be used in developing NBS for environmental monitoring may possibly fall within the category of substances that are considered harmful and hazardous within the *Stockholm Convention*, *Basel*, and *Bamako Convention.*

However, in order to effectively utilized NBS for environmental monitoring, is hereby recommended that it will be relevant to always conduct an environmental impact assessment on the possible risk of using such NBS for environmental monitoring, where such NBS contain substances that are possibly classified as hazardous under the legal framework. For a better, accessible, and sustainable environment, further investigation on the use of NBS and other smart systems for environmental monitoring needs to be urgently carried out. To achieve this mission, biosensors are emerging and evolving as a crucial investigative mechanism for effective investigations for environment quality analysis and evaluation. Progressions in sensing constituents' growth together with enhanced integration made NBS very smart, which meets environment quality analysis and evaluation requirements. In addition, the interfacing of biosensing models with other systems as well as the internet of things (IoT) and AI made biosensing-based investigations accessible in the environmental domain.

Incorporating NBS for environmental monitoring into international environmental treaties or conventions will also be of great relevance in ensuring effective monitoring and usage of NBS for environmental monitoring. This recommendation is concerning the fact that NBS being a recent scientific method was not within the contemplation of the drafter of most environmental legal framework. Also, in incorporating the concept of NBS into environmental treaties and convention, there is a need to also establish monitoring-based agencies that will ensure effective compliance with the provisions of the treaty or convention that provide for and regulate the use of NBS for environmental monitoring, receive periodic reports, and advisory opinions from states parties concerning the use of NBS for environmental monitoring within their jurisdiction.

Furthermore, it is also required that members state of the international community incorporate NBS for environmental monitoring into their local and national environmental laws so as to ensure effective compliance of the use of NBS for environmental monitoring.

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