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Application of Nano-Technology in Water Purification and Treatment, Towards Improving Water Quality for Effective Water Supply in Nigeria

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ABSTRACT*:* *Nanotechnology has myriads of potentials and windows of opportunities cutting across all sectors, but this paper concentrated on the application of nanotechnology in water purification and treatment as a means of improving water quality for effective water supply in Nigeria. The paper reviewed twenty-one manuscripts on the applications of nanotechnology in water treatment, its efficiency and major challenges including original research studies and reviews. It was found that nanotechnology has the potentials to advance and make easy the process of water purification effectively, with the merits of lower costs, energy saving, and relative limited negative environmental and health impacts. Some of the identified nanomaterials useful in water treatment and purification include: carbon nanotubes and alumina fibers for nanofiltration, carbon nanotube membranes for removal of almost all kinds of water contaminants including turbidity, oil, bacteria, viruses and organic contaminants; Zinc oxide nanoparticles for removing arsenic from water; nano titanium oxide used to degrade organic pollutants; zero-valent metal nanoparticles, metal oxides nanoparticles, and nanocomposites among others. The paper recommended that nanotechnology should be adopted in water purification and treatment in order to improve water quality and adequate water supply in Nigeria. Also, the departments of water resources planning and management should partner with available nanotechnology centres to improve the sector using this technology.*

KEYWORDS*:* water purification and treatment, nanotechnology, water quality and supply.

INTRODUCTION

Nanotechnology is the manoeuvring of matter on an infinitesimal, molecular and supra-molecular scale; presently referred to as molecular nanotechnology *(Kafshgari et al,2015*). In fact, the study by Ramsden (2016) found that the term nanotechnology originated from the late Norio Taniguchi of the University of Tokyo in 1974. He used the term to imply the design, characterization, manufacture, and use of nanoscale materials; however, the scope has since been expanded to encompass devices and systems and not just materials.

Hence, nanotechnology can be defined as the design, fabrication and application of material structures, devices and systems through the manipulation of size and shape at the nanometer scale or dimensions (Ramsden, 2016; Onuoha; 2020). The potentials of this technology in providing solutions to various problems of humanity and prospects of new routes for the mitigation of serious developmental issues has turned this technology to an essential area of great interest for both advanced and emerging economies (Bhattacharya *et al*, 2012). Developed and developing nations are seriously harnessing the numerous potentials and windows of opportunities to advance their technologies and grow their economies and Nigeria will not be an exception.

Roco (2011) and Ramani *et al,* (2011) noted that operation of the nanotechnology at nano-scale which is between 1 to 100 nanometers (with 1nanometer being equivalent to 10^{-9} meter), has not limited the technology to be defined only by size. Rather, it extends to certain novel properties which manifests themselves at the nano-size scale, and the capacity to alter and create construct structures at that scale. At nano-scale, some materials gain radically new characteristics and functionalities that can be used for innovative applications in myriad sectors. For example, gold is inert in bulk form but a highly effective catalyst when reduced to nanometer range; carbon atoms infused into nanotube structures makes them to become stronger than steel, conducts electricity better than copper and becomes virtually impervious to heat (Roco, 2011 and Ramani *et al,* 2011). According to Onuoha (2020), several studies forecasted the global market and impact of nanotechnology in key functional components. The US National Science Foundation, (2016) confirmed that in 2015, nanotechnology contributed greatly to their nation's economy 33% in new materials, 30% in electronics, 18% in pharmaceuticals, 10 % in chemicals and over 7% in Aerospace. A forecast of the value of products incorporating nanotechnology was done in 2011 and extended to 2020 as contained in figure 1. Global market of nanotechnology by the year 2015 has been predicted to be in the range of $1 to $2.6 trillion and projected to $3 trillion by 2020. Predictions estimate that the future market will largely be dominated by Nonmaterial followed by nanoelectronics, pharmaceuticals, chemicals and refining, and aerospace. Present market size is largely dominated by nanomaterials followed by nanotools and nanodevices.

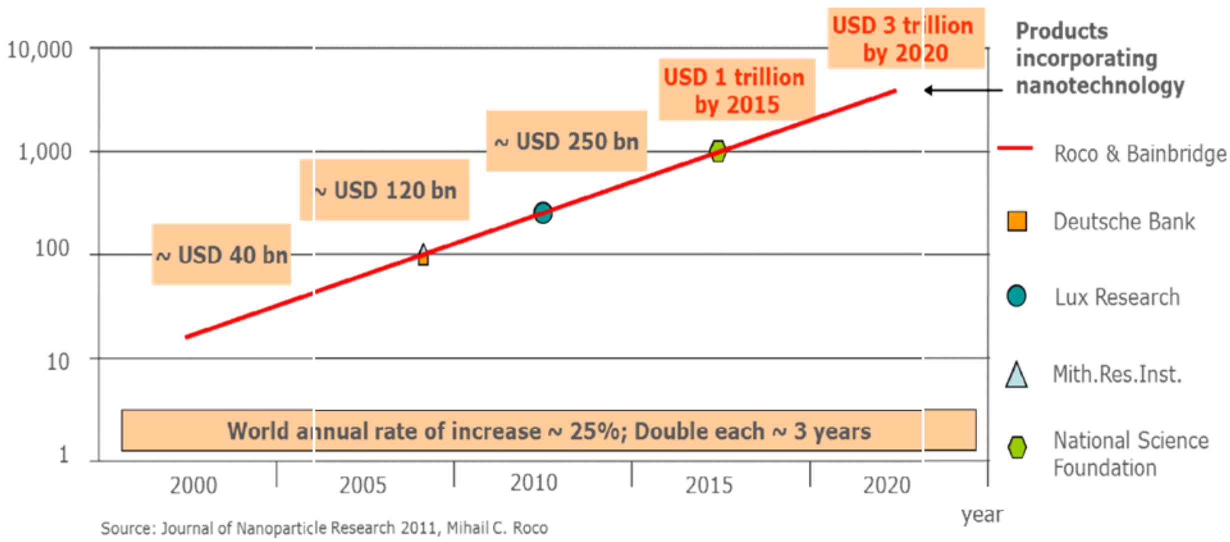

Figure 1: World market incorporating nanotechnology (Billion USD). (Source:Roco, 2011)

These forecasts suffer from difficulties in defining the value-addition of nanotechnology to existing manufacturing processes as well as its role in generating new products. In spite of scepticism of these estimations, products incorporating nanotechnology are entering the marketplace. In 2007, revenues from these products were projected to be $147 billion ($59 billion in the United States, $47 billion in Europe, $31 billion in Asia/Pacific, and $9 billion in other countries). Thus, it is not difficult to see that the country that attains 'first mover advantage' in this technology can derive huge economic benefits.

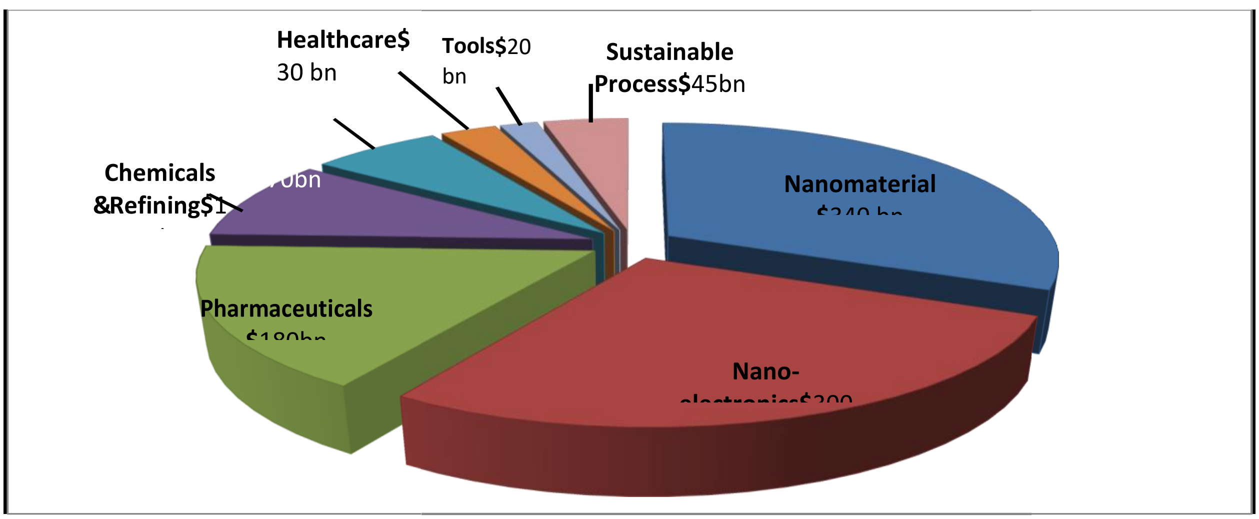

Figure 2: Estimated Market Size in Various Domains of Nanotechnology (In Billion USD) Source: National Science Foundation (Future Estimation).

The vast market for nanomaterials bodes well for nations looking to enter this high-tech field, as it is easier to develop various kinds of nanomaterials than it is to create nano-enabled products like nanodevices. Developing various types of nanomaterials (for example ‘carbon nanotubes’, ‘dendrimers’) is useful as they have diverse applications in myriads of sectors. Another feature that makes nanotechnology attractive is that it can offer improvements not just in technological advanced sectors and societies, but also in sectors where emerging and disadvantaged countries have significant challengesi.e.water purification, energy, agriculture, environment and in a host of other products and services. For example, engineered nanoparticles can provide a number of opportunities in water treatment and re-use by means ofhigh absorption that can help remove arsenic and several other heavy metals, fouling-resistant,anti-microbial properties, filtration membranes, florescence that can detect pathogens and other primary pollutants. There are currently such products on the market, and new water treatment/reuse solutions are in the works. These examples are transforming skepticism into an understanding that, if adequately addressed, nanotechnology might give a 'golden opportunity' for countries to catch up. This has encouraged developing nations to focus their limited resources on growing their nanotechnology capacity and capabilities. Developing nations believe that this technology will enable them to 'advance' the technological development cycles and participate worldwide with value-added products (Onuoha, 2020).

Statement of the Problem

The need for beneficial innovations in filtration expertise has led to little consideration of cutting-edge materials, such as nanofiber membranes for water distillation. The residue sludge created by these processes need further processing and disposal.Due to its capacity to develop precise structurally controlled materials for such needs, nanotechnology offers tremendous potential for filtering applications. Electrospun nanofibrous membranes (ENMs) are a cutting-edge membrane technology that offers much higher flux and rejection rates than standard membranes. When compared to traditional membranes, ENMs promises a revolution in water and sewage purification since they provide a lightweight, cost-effective, and low-energy approach.

ENMs have a high porosity, typically around 80%, whereas conventional membranes have a porosity of 5–35%. Because of their unique characteristics, nano-engineered membranes offer a lot of potential in water treatment. Electrospinning membranes are developing as a robust technology for water treatment with promising qualities in this regard. The use of ENM in wastewater treatment and surface modification of nanomembranes to solve fouling concerns and wastewater treatment in Nigeria is highlighted in this paper.Myriads of problems are staring the world in the face due to lack or inadequate supply of clean or fresh water. In the year 2007, Montgomery and Elimelech posited that more than 1.2 billion people lack adequate supply of fresh portable water, 2.6 billion people have little or no hygiene, while millions of people die annually from diseases communicated through hazardous water. With the continually increasing human population and the impending environmental degradation, adequate provision of fresh or portable water becomes essential Montgomery and Elimelech, 2007; Shannon *et al*. 2008). A critical consideration of the present status of world water resources, shows that globally there is scarcity of portable water (Tlili and Tawfeeq, 2019). Although the total surface area coverage of the earth has about 70% covered with water, but in the midst of these waters we are short of portable water (Onuoha and Enete, 2016). Lima *et al* (2000) and Shannon *et al* (2008), has it that although there are series of means adopted by researchers to purify water and make available more portable water, the issue is still lingering as there has been increase in portable water scarcity especially in developing countries, making people to resort to meeting their water needs from any available sources and over time this has resulted in increased intestinal parasitic infections and diarrheal diseases caused by waterborne bacteria and enteric viruses, malnutrition due to poor digestion of food by people sickened by water amongst other negative effects. Evidence from developing and industrialized countries shows that large numbers of contaminants enter municipal water supply systems through human activities, having grave public health and environmental concerns. This is as a result of population increase, urbanization and excessive generation of wastewater (Ramakrishna and Shirazi, 2015; Tlili and Tawfeeq, 2019). With the estimation that world population will be around nine billion by 2050 and approximately 75% will face fresh water shortages by 2075 (Kargari and Shirazi, 2014), the need for more effective, energy saving, low-cost, technologically advanced and healthy means of sterilizing and purifying water to improve the supply of portable water without harming the environment or jeopardizing human health while conducting the treatment becomes expedient, hence the justification of this paper. From the foregoing, it is no gainsaying that the demand for technological innovations for advanced water treatment and desalination is apt.

Tlili and Tawfeeq (2019), found that various technologies have been used in the past such as treatment with chemical disinfectants, distillation, reverse osmosis, sand filtration, and membrane filtration. Of all these, membrane filtration is a relatively novel method, with some merits over other methods like low power consumption, scalability, free from chemicals, and reduced operational temperature. Timoumi*et* al (2008), defined a membrane is a semi-permeable apparatus which allows the passage of certain molecules and compounds and hinder others. Hence to improve the membrane filtration system, we can incorporate some nanofibrous media. Nanofibers have high porosities and good permeabilities and are ideal for water purification (Timoumi*et* al. 2008). Advanced processes like electrospinning should be explored for easy fabrication of nanofibers. Electrospun nanofibers with high filtration efficiency, high permeability, small pore sizes, and low costs are materials of choice for filtration applications as they are very competent in permeability, selectivity, and low fouling.

Aim and Objectives

The aim of this paper is to explore the application of nanotechnology in water purification and treatment as a means of improving water quality for effective water supply in Nigeria through literature review. To achieve this aim, the following objectives were pursued:

1. to review the importance and applications of nanotechnology in water purification and treatment,
2. to review the challenges of nanotechnology in water treatment,
3. to synthesize the reviewed literature and make appropriate recommendations.

METHODOLOGY

The paper conducted a systematic review of related literature on the applications of nanotechnology in water purification and treatment. Twenty-one literature were reviewed and synthesized, both review and empirical studies were considered. Science Direct, PubMed, Google Scholar, Crossref, among other websites were explored. The Critical Appraisal Skills Programme (CASP, 2004) was adopted for the assessment of the methodological quality of the selected literature from the search. The quality of each literature material was assessed with respect to the research design, sample techniques, measurement tools, analyses, findings and applicability of findings. Each of the criteria listed was graded on a three-point scale of 2, 1 and 0. Where 2 stands for yes, 1 stands for partial and 0 stand for no. Thus, each of the literature reviewed scored a maximum of 12, which was finally converted to percentage to determine the percentage quality for a critical and objective comparison of the specific literature among others.

LITERATURE REVIEW

Available literature was reviewed on the importance and applications of nanotechnology in water resources planning and management especially with respect to water purification and treatment.

Importance and Application of Nanotechnology Water Treatment and Purification

The importance and applications of Nanotechnology in the area of water resources are numerous and cannot be over-emphasized. They include but are not limited to the following:

Removal of Contaminants

Research reports have it that shortage of good water for the consumption of living things and sustenance of life is a crisis of global interest which is expanding by the day. Exploring some emerging advanced technologies targeted at addressing this challenge becomes expedient. Many studies have through their findings buttressed the fact that Nanotechnology is very promising in the area of water treatment and purification.

Zhang and Wang (2019) used pulse electrodeposition to synthesize nanoscale zero-valent iron (nZVI) particles and loaded them on the surface of biomass activated carbon (BC). The BC-nZVI composite was used to remove methyl orange (MO) from water as an adsorbent. According to the adsorption test, the adsorbent removed 97.94 percent MO from water in one hour. At a higher temperature, it was observed that a larger BC-nZVI dose removal was achieved, and a lower baseline MO concentration under neutral pH was achieved.

Campagnolo et al. (2019) created an Au/ZnO hybrid photocatalyst mounted on a poly (methyl methacrylate) (PMMA) fibrous substrate in a sequential manner. The technique involved thermal conversion of the ZnO precursor already integrated into PMMA electrospunfibers, followed by dipping and heating of the ZnO/PMMA fibers in Au precursor solution. Under UV light, the asformed hierarchical heterogeneous photocatalyst was used to photodegrade organic water contaminants such as methylene blue (MB) and bisphenol A (BPA).

Ying et al. (2019) created a nanocomposite adsorbent system with iron oxide nanoparticles loaded on meso- and microporous tire-derived carbon support. The Se(IV) ions were selectively adsorbed by this nanocomposite adsorbent from simulated wastewater. Inductively coupled plasma-optical emission spectroscopy (ICP-OES) was used to analyze the adsorption kinetics of this nanocomposite adsorbent in a fixed-bed condition and after many column runs, estimating the concentration changes over time. Equilibrium values were derived by fitting the collected data to a pseudo-second-order rate law, which, coupled with the effluent concentration data, might aid in the computation of reaction constants and column coecients using the Adams-Bohart model. The findings, according to the scientists, allow for the use of this nanocomposite adsorbent in fixed-bed column systems and allow for additional investigation using mixed contaminants in actual wastewater.

Shahin (2020), studied water treatment with new nanomaterials at the Institute of Biomaterials, Department of Materials Sciences, University of Erlangen-Nuremberg Germany. He found that a variety of types of nanomaterials produced from carbon, polymer, metals and oxides of metal (photocatalyst and magnetic), can be employed for the removal of contaminants through adsorption and photo-degradation of heavy metals and organic pollutants. This was supported by the findings of Ghadimi*et al.* (2020) who classified materials used for water purification on the basis of benefitting technologies adopting them into: nanophotocatalysts, nano-sized adsorbents, nanomembranes, among others. Yaqoob *et al.* (2020) explored the role of nanomaterials in the treatment of wastewater through critical review; they found that there are classes of nanotechnologies based on the merits of potential application(s) of each and every identified nanomaterial(s) and their various functions in water treatment. They emphasized on nanophotocatalysts, nanomembranes, nano/micromotors and nanosorbents (adsorbents). Homaeigohar&Elbahri (2019) in the findings of their study on synthesized carbon buckypaper adsorbents, supported that contaminant in water can be removed through nanotechnology tools.
Heydari et al. (2019) conducted a comparative analysis of the relative efficiency of four groups of titanium dioxide (TiO_2) as were differentially supported, in the photodegradation of 2,4-dichlorophenoxyacetic acid (2,4-D) in a commercially available herbicide called Killex. They TiO_2 compared include: floating TiO_2 spheres, an anodized TiO_2 plate with nanotube arrays, anodized TiO2 mesh with a 3D nanotube structure, and electro-photocatalysis using the anodized TiO_2 mesh. They found that 3D nanotubes of TiO_2 surrounding the mesh facilitate a increased efficient photodegradation when weighed against the 1D arrays on the anodized plate.

Oil Removal
Oil is a vital source of energy across the world, but there is a danger of spilling when it is explored, transported, or stored (SYED et al., 2011). Spill incidents involving oil have happened due to natural sources or industrial disposal disasters, and as a result, the ecology has been impacted

(TAN et al., 2015). Domestic effluents and industrial effluents can include oil, and their use is rapidly expanding (LU; YUAN, 2018).

Different approaches are used to extract oil from oil-contaminated water, however they are costly and ineffective in some cases (VELAYI; NOROUZBEIGI, 2018). For this aim, new technologies have been investigated, with nanotechnology proving to be the most cost-effective thus far (SYED et al., 2011). Some nanomaterial features, such as high separation efficiency, good recyclability, environmental friendliness, and ease of production, might be useful in successfully separating oil from water (LU; YUAN, 2018).

Researchers have created nanomaterial-based structures to separate oil from water. Syed et. al. (2011) employed hydrophobic nano-silica to remove gasoline and diesel from water in their study. When compared to organic or inorganic adsorbents found in literature, their findings showed that this material was more effective at removing these oils.

Tan et al. (2015) investigated the ability of several titanium dioxide (TiO2) nanoparticle architectures (nanowire, nanotube, and nanosheet) to act as filters. They created nanostructured membranes with superhydrophilic and superoleophobic properties in water. The results showed that the TiO2 nanosheest was the most effective at separating oil from oil-contaminated water.
Lu and Yuan (2018) created a sponge that can extract oil from water. They used silver nanoparticles coated on a porous sponge's surface. The sponge was found to have superhydrophobicity and self-cleaning characteristics, as well as the ability to be reused several times. However, the sponge's absorption capacity was sensitive on the density, viscosity, and surface tension of the materials tested, resulting in varied volumes of absorption capacity.

Metal Removal

Heavy metals, as well as certain anions, have a high toxicity, which can have serious consequences for humans and ecosystems (HATAMIE et al., 2016). Hatamie et. al (2016) investigated the effectiveness of magnetic nano-ferrofluid, which works as a coagulant in water, as a prospective heavy metal absorber. The results showed that when the pH was raised from 4 to 8, the metal removal efficiency improved to about 100%. The heavy metals studied were Fe2+, Pb2+, Zn2+, and Cu2+. The metal removal efficiency of the other metals studied (Ni2+, Mn2+, Co2+, Cd2+) increased as well, but it was still less than 90%.

Ion exchange, chemical precipitation, membrane filtration, coagulation, biological or electrochemical remediation, and adsorption are some of the methods used to remove heavy metals from water (VILARDI et al., 2018). Adsorption, among these processes, has shown to be more adaptable in terms of design and operation, and can provide high-quality treated water (HUA et al., 2012).

Metal oxides of nanoscale, such as iron oxides, manganese oxides, aluminum oxides, and titanium oxides, are essential adsorbents. The adsorption performance of these materials is influenced by their size and shape (HUA et al., 2012). Iron oxide nanoparticles can be used in water treatment in two ways: (i) as a form of nanoadsorbent, and (ii) as photocatalysts, converting pollutants to less hazardous compounds.(XU *et al.*, 2012).

Carbon-based materials, such as carbon nanotubes (CNTs), are utilized as adsorbents because of their high surface area to volume ratio and pore size dispersion. In comparison to granular or powder activated carbon, CNT has a significant sorption capacity. Graphene is another carbon-based substance that is regarded an effective adsorbent because of its huge specific area and electron-rich environment. Because of its strong functional groups, graphene oxide has shown to have a high adsorbent capacity.(SANTHOSH *et al.*, 2016).

Desalination

Desalination is being explored as a major source of drinking water, as saltwater represents a vast supply of water. This is because population expansion and urbanization will ultimately demand new accessible fresh water supply (SURWADE et al., 2015). Desalination is the process of extracting mineral components from a variety of water sources, including sea water, brackish water, and treated water. Precipitation, oxidation, reduction, ion exchange, membrane filtration, and adsorption are some of the traditional ways for removing salt from water (ZAHED *et al.*, 2018).

Although conventional water treatment is ineffective in removing salt from water (TEOW & MOHAMMAD, 2017), alternative approaches, such as reverse osmosis membranes, require high pressures and produce large amounts of liquid waste. As a result, nanomaterials with low pressure requirements, low energy consumption, and high salt rejection are being investigated as a possible option for long-term membrane desalination.(GOH *et al.*, 2016).

Graphene, an allotrope of carbon, is one nanomaterial that has attracted a lot of attention due to its unique qualities such as strength, chemical composition, and thickness. The potential of nanoporous graphene as a selective membrane for water desalination has been established (SURWADE et al., 2015). Graphene oxide (GO), a kind of graphene, has functional groups that provide it hydrophilicity and a high negative charge density, both of which are important for desalination (ZAHED et al., 2018).

Abo-Almaged and Gaber (2017) investigated the potential of nano-hydroxyapatite membranes to reject salt from water in another study. The results demonstrated that when the NaCl concentration increased, the salt rejection by the membrane increased as well, reaching a rejection of 73% to a 5000 ppm concentration of salt.

Antimicrobial Activity

Infectious diseases are the most common common and widespread health risks associated with drinking water, this is according to the World Health Organization's Guidelines for Drinking-Water Quality (World Health Organization, 2017). Khaydarov et. al (2013) synthesized nanocarbon-titanium nanophotocatalysts with functional groups on the surface of carbon nanoparticles. They tested antimicrobial action on Escherichia coli in water for 6 hours after being exposed to sunlight at 11 a.m. The results showed that water disinfection takes a long time (about 1 hour) depending on the bacterium concentration, but it was successful in destroying the germs. Pina and associates (2014) produced a poly(ethylene) glycol (PEG)-coated magnetic nanoparticles functionalized with (RW)3 (an antimicrobial peptide) to work as an antibacterial against E. coli and Bacillus subtilis as another example of antimicrobial activity utilizing nanotechnology. These magnetic nanoparticles are frequently utilized in the removal of metals, the detection of bacteria, parasites, viruses, and antibiotics, as well as the separation of pollutants. These magnetic nanoparticles can, however, be functionalized with chemicals that interact with or destroy microorganisms. The findings revealed that the nanoparticle was capable of disinfecting the water, dramatically reducing both bacterial populations (*E. coli* and *B. subtilis*).

Homaeigohar&Elbahri (2019) experimented the application of Amphiphilic, Graphitic (Carbon) Buckypaper Adsorbents in dynamically adsorbing and separating organic biomolecules. They found that the adsorbent is optimally efficient about (88%) in adsorption of the enzyme with notable permeablility to water, hence ensures selective permeability needed in low energy water treatment.When it comes to removing or even inactivating dangerous bacteria and viruses from water, carbon nanotubes have shown to have promising outcomes. Parham and partners (2013) developed carbon nanotubes that grew in the open pores of a porous ceramic matrix based on these claims. They used Saccharomyces cerevisiae as a model to assess the filter's capacity to remove microorganisms from water. Following the filtering, various procedures were carried out to assess the filter's effectiveness. The filter has yeast connected to the carbon nanotube network, according to the findings. They also looked at the impact of filter length and aqueous flow, both of which were found to have a significant impact on yeast filtering effectiveness.. The filter length of 50 and 70 mm with an aqueous flow of 20 mL/h demonstrated an efficiency of 98% yeast filtration.

Weighing the Potentials of Nanotechnology Against Other Water Purification and Treatment Methods

Potential Risks of Adopting Nanotechnology

Although nanotechnology has shown to be highly beneficial in improving environmental quality in a variety of sectors, certain concerns about how nanomaterials and/or nanoparticles may harm the environment and aquatic biota must be addressed. However, given the rapid advancement of nanotechnology, there is little data on the impacts on human health. Another difficulty is that nanoparticles have yet to be discovered in the environment, which can lead to a variety of environmental issues.(KABIR *et al.*, 2018).

Intentional and inadvertent releases of nanoparticles from air emissions and solid or liquid waste streams from manufacturing services are among the various sources of nanomaterials in the environment (KLAINE et al., 2008). Concentration, presence of organic or inorganic materials, and pH are all factors that impact the effect of nanomaterials in the environment. In addition, the length of time a particle spends in an environment affects its toxicity; the longer the duration, the more hazardous the particle becomes (PUROHIT et al., 2017). For example, if photosynthetic bacteria, which are at the base of many trophic chains, are exposed to nanomaterials, the entire trophic chain might suffer catastrophic consequences (MOTTIER *et al.*, 2017).

Naasz et. al (2018) conducted a literature review of publications on the evaluation of ecotoxicology effects on organisms (cell lines, bacteria, algae, crustaceans, fish, mollusks, nematodes, and plants) exposed to nanomaterials and chemicals mixtures. According to their findings, there were 151 publications on this subject, TiO2 was the nanomaterial with the most publications in connection to exposure, and crustaceans were the most commonly examined organism. 127 research (66 percent) of the 151 investigations found that combination exposure enhanced toxicity when compared to single-substance exposure. The remaining research (26) found that when organisms were exposed to a combination of substances, their toxicity decreased. Knowledge of the primary sources, channels, transformations, and sinks of nanomaterials plays an essential role in determining the impacts that nanomaterials can have on organisms, giving information on the places, such as water, sediment, and biota, that will be affected by this exposure (LEAD et al., 2018). To summarize, while nanotechnology can deliver significant benefits in water treatment, it can also cause harm to creatures exposed to nanomaterials and/or nanoparticles. As a result, many more studies are needed to draw further conclusions regarding their possible environmental dangers.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The goal of this paper is to describe several nanomaterials that can be used in water treatment. Some contaminants, such as heavy metals, oil, and microorganisms, are difficult to remove using traditional water treatment methods. Nanomaterials are being investigated as a viable solution to eliminate these impurities. Furthermore, as urbanization and industrialization progress, resulting in water pollution, it will become necessary to utilize a different source of drinking water in the future. Seawater is one possibility, and nanomaterial-assisted desalination is an innovative way to remove salt from water. However, because nanotechnology is still relatively new, its effects cannot be fully understood, necessitating a large number of studies focusing on its possible threats to the environment and biota.Finally, various nanomaterials have demonstrated their efficacy in eliminating toxins from water, making them a prospective possibility for water treatment..

Recommendations

The paper recommended that nanotechnology should be adopted, embraced and pursued with every enthusiasm in water purification and treatment in order to improve water quality and adequate water supply in Nigeria. It is also recommended that the water resources departments at the various tiers of government should partner with available nanotechnology centres to improve the sector using this technology, the adoption of Nanotechnology in the research and development projects of the nation should be made as a policy so as to help us build our economy like other developed nations like United States and China. Funds should be made available to procure the necessary equipment for research and development in this area.

Nanomaterials have great promise as building blocks for the next era of water purification and pollution control solutions. There are still a few milestones to be met in order for nano-based water treatment technologies to become a reality:

(1) Next generation of nanoadsorbents: Nanomaterials can be used to create nanoadsorbents with various surface functions that collect polar and non-polar contaminants from water efficiently. Adsorption and photodecomposition are combined utilizing nanophotocatalysts. As a result, the adsorbed organic pollutant decomposes into innocuous byproducts, freeing up the previously occupied surface for another adsorption/photodecomposition cycle. In terms of photocatalysis-based water treatment, it's critical to prevent hole-electron recombination in the photocatalyst and to substitute UVlight with solar visible light as the process's major stimulus. This latter goal ensures energy efficiency and a wider range of applications for photocatalysis in water treatment. The aggregation propensity and difficult recovery of nanoparticulate adsorbents is a key bottleneck. They might be placed on nanofiber substrates to solve these issues. As a result, not only is the aggregation level reduced and nanoparticle recovery made easier, but their high availability to the external aqueous medium is also conserved.

(2) Next generation of nanomembranes: Nanomaterials can also be employed as nanostructured membrane building blocks. Electrospun nanofibers and graphene nanosheets, in particular, have been extensively studied for this purpose during the last decade. Electrospun nanofiber mats have a lot of promise for size exclusion and water pollution absorption. They offer an energy-efficient and cost-effective, water treatment procedure because of their changeable pore size, exceptional porosity, and open porous structure. As a result, they have advocated for the development of cutting-edge ultrafiltration (UF) and nanofiltration (NF) membranes as a permeable, solid foundation for the selective layer. Despite its advantages, nanofibrous membranes have yet to be commercialized..This problem might be caused by a lack of adequate and reliable membrane testing. Nanofibrous membranes must be evaluated for a long period of time, under a variety of chemical, thermal, and mechanical environments, and with actual wastewater models. Surprisingly, nanofibrous membranes are often examined in the presence of only one type of pollutant at the lab scale, with the presence of additional dye, ionic, or organic contaminants, as seen in actual wastewater is usually omitted. The next generation of water membranes also includes graphene membranes, which are made up of mono-/few-layer graphene nanosheets. They have the potential to provide exceptional water permeability while maintaining ionic selectivity equivalent to traditional NF and, ideally, reverse osmosis (RO) membranes.However, their water-treatment potential has mostly been demonstrated theoretically rather than practically, and actual use of such membranes would require time.

(3) Energy efficiency and scalability: There are various challenges in the way of extensive commercial usage of nanomaterials for water purification right now. These issues include scale-up and integration of nanomaterials into water purification technologies, as well as safety,

affordability, and energy efficiency. TiO2 nanoparticles and carbon nanotubes (CNTs), for example, are two of the most studied nanomaterials for dye adsorption. However, their toxicity and expensive production technique, which involves high temperatures and pressure, are deterrents to industrialization. Apart from that, TiO2 nanoparticles need be UV-irradiated to photodecompose the dye molecules, which increases the process expenses. As a result, the use of nanomaterials for water treatment is feasible in the future provided they can be generated in large quantities at affordable costs, corresponding to the various classes of wastewaters.

(4) Sustainable and ecofriendly nanomaterials: When exposed to strong water streams with complex stress patterns, the nanomaterials used in the construction of micro-, ultra-, and nanofiltration membranes may be released into the water. As a result, nanoparticles must be securely anchored on/in the membrane structure using physicochemical treatments as it is of utmost importance. Furthermore, nontoxic materials that are less harmful to the environment should be explored. The emerging generation of nature-derived nanomaterials, such as cellulose nanoparticles, may prove promising in this respect. Furthermore, it is critical to design green synthesis and processing procedures that use as few harmful chemicals as possible. According to preliminary research, certain nanoparticles are harmless for humans, plants, and animals. However, there is no assurance that they will be safe in the long run.As a result, the development of cutting-edge water treatment systems based on nanomaterials should be approached cautiously. From a technological standpoint, it's also critical to correctly design these systems so that they do not leak nanomaterials into the environment(Shahin, 2020)

REFERENCES

Bhattacharya, S. &Bhati, M. (2011). 'China’s Emergence as a Global Nanotech Player: Lessons for Countries in Transition'. *China Report*, 47 (4).

Bhattacharya, S., Bhati, M. &Kshitij, A. P. (2011). 'Investigating the Role of Policies, Strategies, and Governance in China’s Emergence as a Global Nanotech Player'.*IEEE Conference Proceeding of the 2011 Atlanta Conference on Science and Innovation Policy* (http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6064462)

Bhattacharya, S., Jayanthi, A. & Shilpa, P. (2012). 'Nanotechnology Development in India: Investigating Ten Years of India’s Efforts in Capacity Building.'*CSIR-NISTADS Strategy Paper on Nanotechnology,* No.I - July 2012, NISTADS, India.

Fymat, A. L. (2016). 'Recent Developments in Nanomedicine Research.' *Journal of Nanomed Res* 4(4): 00096. DOI: 10.15406/jnmr.2016.04.00096 https://medcraveonline.com/JNMR/recent-developments-in-nanomedicine-research.html

Kafshgari, M. H., Voelcker, N. H., & Harding, F. J. (2015). 'Applications of zero-valent silicon nanostructures in biomedicine'. Nanomedicine (Lond).10 (16): 2553–71. doi:10.2217/nnm.15.91

Kurtoglu, M. E., Longenbach, T., Reddington, P. &Gogotsi, Y. (2011).'Effect of Calcination Temperature and Environment on Photocatalytic and Mechanical Properties of Ultrathin

Sol–Gel Titanium Dioxide Films. 'Journal of the American Ceramic Society.94 (4): 1101–1108. doi:10.1111/j.1551-2916.2010.04218.

*Mashaghi, S., Jadidi, T., Koenderink, G., &Mashaghi, A. (2013).'Lipid Nanotechnology'. Int. Journal of Molecular Sci. 2013(14): 4242–4282. doi:10.*3390/ijms14024242. *PMC* 3588097

Nicolas, B. (2012). 'Convergence and multidisciplinarity in nanotechnology: Laboratories as technolog-ical hubs'. *Technovation, Elsevier,* 2012, 32 (3-4), pp.234-244. 10.1016/j.technovation.2011.09.001.hal-01514795 https://hal.archives-ouvertes.fr/hal-01514795/document

Pendergast, M. M. & Hoek, E. M. V. (2011) 'A review of water treatment membrane nanotechnologies' *Journal of Energy and Environmental Sciences. 6(1)2011. https://pubs.rsc.org/en/content/articlelanding/2011/ee/c0ee00541j#!divAbstract*

Ramani, S. V., Chowdhury, N., Coronini, R. & Reid, S. (2011). 'On India's Plunge into Nanotechnology: What are Good Ways to Catch-up?' *UNU-MERIT Working Paper* #2011-020. Retrievable from http://www.merit.unu.edu/publications/wppdf/2011/wp2011-020.pdf.

Ramsden, J. (2016). What is nanotechnology? *Nanotechnology Perceptions* 1 (2005) 3–17. DOI: 10.1016/B978-0-323-39311-9.00007-8

Roco, M. (2011).'Innovative and Responsible Governance of Nanotechnology for Societal Development.' *Journal of Nanoparticle Research.* Available at: www.wtec.org/nano2/Nanotechnology_Research.../chapter13.pdf

Onuoha, D. C. (2020): "Attaining sustainable development in solid mineral industry in Nigeria: the role of nanotechnology" in Anyaogu, F. A., Eme, C. A. and Ogbodo J. A. (Eds.) *University-Led Knowledge and Innovation for Sustainable Development.*Boldscholar Research Limited, Abuja. Nigeria for CSD, NAU, Awka. Pages 319-330. ISBN: 978-978-988-790-3

Shahin, H. (2020). 'Water Treatment with New Nanomaterials' *Nanochemistry and Nanoengineering,* Institute of Biomaterials, Department of Materials Science and Engineering, University of Erlangen-Nuremberg, 91058 Erlangen, Germany. 1(2020), 1-4. Water **2020**, 12, 1507; doi:10.3390/w12051507 www.mdpi.com/journal/water.

Tlili, I. and Tawfeeq, A. A. (2019). 'Nanotechnology for water purification: electrospun nanofibrous membrane in water and wastewater treatment' Journal of Water Reuse and Desalination (2019) 9 (3): 232–248. https://doi.org/10.2166/wrd.2019.057

Onuoha**, D. C.** and Enete, I. C. (2016): "World Water Bodies" in Ezenwaji, E. E.; Enete, I. C. and Anyaeze, E. U. (Eds.) *General Geography for Schools and Colleges.* Scoa Heritage Nigeria Limited, Awka, Anambra State, Nigeria. Pages 87-101.

Ghadimi, M.; Zangenehtabar, S.; Homaeigohar, S. (2020). 'An Overview of the Water Remediation Potential of Nanomaterials and Their Ecotoxicological Impacts.' *Water 2020*, 12, 1150.

Yaqoob, A.A.; Parveen, T.; Umar, K.; Mohamad Ibrahim, M.N. (2020). 'Role of nanomaterials in the treatment of wastewater: A review'. *Water **2020***, 12, 495.

Homaeigohar, S. &Elbahri, M. (2019). 'An Amphiphilic, Graphitic Buckypaper Capturing Enzyme Biomolecules from Water.' *Water* ***2019***, 11, 2.

Heydari, G.; Hollman, J.; Achari, G.; Langford, C.H. (2019). 'Comparative study of four TiO2-based photocatalysts to degrade 2, 4-D in a semi-passive system.' *Water* ***2019***, 11, 621.

Zhang, B.; Wang, D. (2019). 'Preparation of Biomass Activated Carbon Supported Nanoscale Zero-Valent Iron (Nzvi) and Its Application in Decolorization of Methyl Orange from Aqueous Solution.' *Water* ***2019***, 11, 1671.

Campagnolo, L.; Lauciello, S.; Athanassiou, A.; Fragouli, D. (2019). 'Au/ZnO hybrid nanostructures on electrospun polymeric mats for improved photocatalytic degradation of organic pollutants.' *Water* ***2019****,* 11, 1787.

Ying, A.; Evans, S.F.; Tsouris, C.; Paranthaman, M.P. (2019). 'Magnetic Sorbent for the Removal of Selenium (IV) from Simulated Industrial Wastewaters: Determination of Column Kinetic Parameters.' *Water* ***2020***, 12, 1234.