BIO Web of Conferences 86, 01001(2024) https://doi.org/10.1051/bioconf/20248601001
RTBS-2023

A Review of The Impact of Nanoparticles on Environmental Processes

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Abstract. The physicochemical property of the nanoparticles differs considerably from that of bulk material. Due to the enhanced reactivity of the nanoparticles, they react with the components of the environment to a great extent. The impact of the nanoparticles on the environment is of two ways. Some nanoparticles can be used to treat environmental pollutants, on the other hand, nanoparticles may also cause eco-toxicity. The impact of nanoparticles on the environment depends on the path and process of generation of nanoparticles as well as their stability in the environment. It also depends upon the physicochemical properties of the nanoparticles and their ability to accumulate in the environment too. To understand the influence of nanoparticles on the components of the environments we described the types and stability of nanoparticles and their impact on the various components of environments in this review article.

Keywords: nanoparticles, evaluation of nanoparticles, impact of nanoparticles, positive and negative impacts

1 Introduction

Nanoparticles (NPs) have emerged as pivotal components across diverse domains, driven by their remarkable physica chemical, and biological attributes. They find applications in scientific exploration, engineering, healthcare, and environmental safeguarding. For instance, ancient Egypt's renowned blue pigment, cuprorivaite, predominantly consisted of quartz and nanoparticulate glass [1].

The realm of nanotechnology ushers in a new era by affording meticulous control over materials at the nanoscale typically spanning the range of 1 to 100 nanometers (nm). This burgeoning field has become pivotal in research sparking intense curiosity and uncovering novel applications in myriad sectors. The expansion of nanotechnology ha far-reaching repercussions on both the environment and living organisms. Nanoparticles offer advantages but als harbor potential risks. The size of nanoparticles dictates their properties, with smaller particles exhibiting more unique characteristics compared to their larger counterparts [2].

Nanomaterials manifest in the environment through several pathways, including (i) intentionally crafted man-made nanomaterials, which afford precise control over size and attributes, (ii) unintentional nanomaterials generated by industrial processes like combustion in heat engines, and natural phenomena such as fires, and (iii) naturally occurrin nanomaterials, including viruses (Figure 1). Recent years have witnessed an upsurge in nanoparticle productio exemplified in their use as antibacterial agents, where they mitigate bacterial proliferation and enhance the efficacy o antibacterial treatments. In drug delivery systems, nanoparticles offer physiochemical properties that selectively targe cancer cells while minimizing side effects, albeit higher concentrations may induce toxicity. Nanoparticles also serve as protective shields in food preservation, feature in sunscreens to shield against ultraviolet radiation, contribute to diagnostic procedures, and aid in pathogen elimination. Furthermore, their applications extend to the purification of water sources, removal of heavy metals from water, and augmentation of fertilizers for agricultural purposes. The electronics industry also harnesses the potential of nanoparticles [3].

As the production of nanoparticles continues to surge across various sectors, it exert an undeniable influence on both th environment and living organisms, impacting health and well-being. Nanoparticles offer a dual-edged sword, necessitating precautions to mitigate their downsides. This paper delves into the environmental implications of nanoparticles, encompassing their direct interaction with the human body, resulting in health concerns and potentia toxicity. Ongoing research works around the world attempting to reduce the associated toxicity levels [4].

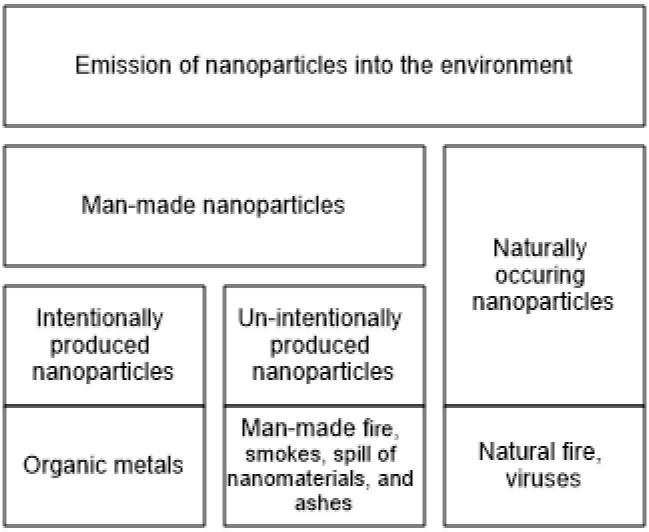

Figure 1: Sources of nanoparticles in the environment

TOP DOWN & BOTTOM-UP METHOD

There are two types of methods to synthesize nanoparticles: The top-down process involves taking raw materials in bulk and reducing their dimensions using various techniques, such as grinding and lithography (Figure 2). The bottom-up method is a chemical and biological approach in which atoms or chemical compounds, along with a reducing agen (such as leaf extract), are used for cost-effective nanoparticle synthesis, allowing for the rapid formation of nanoparticles. [5].

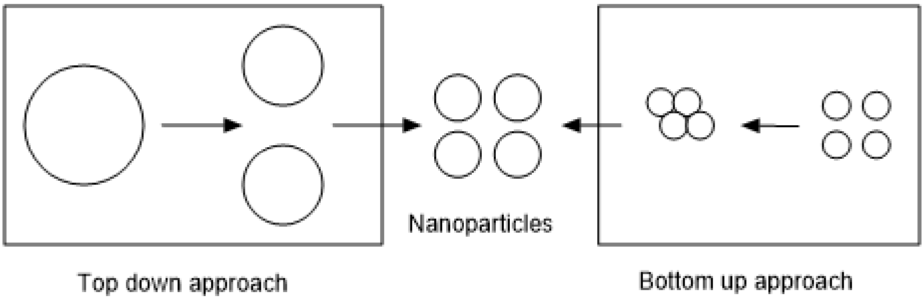

Figure 2: Top-down and bottom-up approach to the synthesis of nanoparticles

2 Green technology

Green nanotechnology is a technology used to synthesize nanoparticles (NPs) in an environmentally sustainable an eco-friendly manner. Green synthesis employs traditional methods. Instead of using chemicals, this process utilizes natural species such as DNA, bacteria, fungi enzymes, and plant extracts, which helps maintain low toxicity. It is an eco-friendly process that is easily handled and cost-effective. However, in the green synthesis process, size matters most [6]. Vegetable extracts or plant extracts act as reducing agents that are naturally produced from plants, fruits, flowers and leaves, among other compositions. For example, tulsi leaves are used as a tonic for illnesses and coughs, amo other purposes [7-8].

3 Nanoparticle emission to the environment

Nanoparticles have unique properties. These NPs may be released into the environment at different stages and different ways. To control nanomaterial emissions to the environment, evaluating the life cycle of NP from its production to its disposal procedures is crucial. In all of these processes, the emission of nanoparticles is observe (Figure 3). This life cycle may have an impact on the environment [9].

3 1 Product manufacture and employment

Whilemanufacturing, nanoparticles may easily be emitted if the procedure is not strictly followed. This emission can occur unintentionally, leading to indirect emissions. Unintentional emissions can result from combustion, spills of nanoparticles, and various sources such as fireworks. Intentional emissions of nanoparticles, known as manma procedures, involve selected parameters used in the process, which can lead to emissions into the environment. T emission and properties vary according to the product type. The employment of nanoparticles takes place at differe stages for solid, liquid, and spray products, with nanoparticles being released immediately [10].

3 2 Disposal

Nanomaterials are typically disposed of in landfills, a practice that carries the risk of degradation and potential release of NPs into the environment. In the case of incineration, there is a concern that ash particles might escape into th environment. Therefore, incineration plants employ specialized filters to effectively control and minimize the emission of ash [11].

3 3Recycling process

The recycling process depends on the product, and as a result, emissions and resistance occur. This process shoul carried out while following certain safety norms [12].

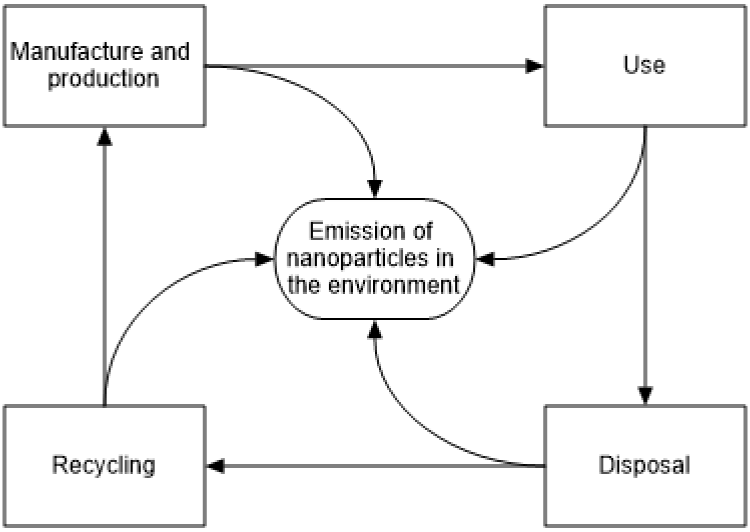

Figure 3: Emission of nanoparticles from manufacturing, use, disposal and recycling process

4 Models used to evaluate nanoparticle emission

The Environmental exposure model is designed to evaluate contaminants in the environment, especially nanomaterial In recent years, these models have extensively assessed emission concentrations in the environment. There are vari types of exposure models

4 1Material flow analysis (MFA)

Material Flow Analysis (MFA) is one of the methods used to measure nanomaterials in the environment. The MFA model acts as a technical system that predicts the material flow from the first stage to the last stage of the lifecycl process. The released nanomaterial primarily enters the water, air, soil, and other compartments. MFA predict emissions in various compartments such as landfills, recycling, and water treatment plants, and their subsequent impa on the environment [13]. While MFA mainly focuses on the final destination of nanomaterials, it does not provide information about the specific concentration of nanoparticles in the environment [11]. The MFA model describes the size and shape, which is the characterization of nanoparticles. Regarding nanoparticles released into the environme Mitarno et al. studied the release of nano-Ag textiles through garment washing, and data is available for released nanoparticles. However, incorporating this data into the MFA model is challenging [12].

4 2 Environmental fate model (EFM)

EFM models predict the behavior within the environmental compartments, including air, water, and soil. EFM estimates that the MFA model is an extended version. The EFM model includes various fate models, and one of these is th equilibrium model. This concept pertains to a two-phased system consisting of organic chemicals and engineered nanoparticles (ENP) at liquid-liquid and solid-liquid phases. A partition exists between dissolved molecules and particle deposition. The equilibrium partition involves two processes: molecular diffusion and intermolecular interaction. Intermolecular interaction has two phases, phase A and phase B, which exhibit spontaneous transfer between the tw phases at equilibrium. An example of this method is water partition, and it is more suitable for small particles compare to colloidal particles, as small particles can easily dissolve in the solvent, according to the solvents chosen fo nanoparticles.

Nanoparticles are kinetically stable but thermodynamically unstable. They behave differently compared to organic molecules but can potentially be stabilized by reducing surface energy through cluster formation (aggregation). The EFM includes clusters that cannot be accounted for by the equilibrium model. Steady-state models calculate the input and output of water flow, ensuring balance. An example of this method is sedimentation. In rivers, a spatially resolve fate model is used to account for changes in stream flows. The fate model relies solely on colloid behavior. Fate model provide data on the size of ENP and also address various environmental properties and conditions. However, it' important to note that EFM provides limited information, and scientists are actively working to reduce these limitations. Researchers are developing different models to decrease emissions in the environment. These models can serve a solid foundation for decision-making aimed at reducing emissions in the near future [14].

5 Impact of nanoparticles on outdoor

Nowadays, various man-made processes lead to the emission of nanoparticles into the environment, causing contamination in elements such as soil, air, and water. Emissions in the environment result from various sources including the burning of unwanted nanomaterial waste, which is released in the form of ashes. Construction sites, a well as gas, petroleum, and water pipelines, also contribute to environmental emissions. Cement industries release sm particles into the environment during their processes, and even different fields like agriculture, roadside traffic, and the polymer industry experience toxic emissions of nanoparticles. Workers are particularly susceptible to this nanoparticle exposure, which may increase the risk of health problems such as skin issues, damage to the respiratory system, a harm to certain cells in the body. Many researchers are exploring various methods to determine the concentration c nanoparticles and assess worker exposure [15].

5 1 Negative impact

Once nanoparticles are emitted into the compartments of the environment, they can harm organisms depending on the circumstances (Figure 4). The absorption and distribution of nanoparticles by living beings through the respiratory system can lead to damage to the gastrointestinal system or skin [16]. When nanoparticles enter cell membranes, th can cause damage and toxicity to different cell compartments, depending on the type of nanoparticle. Reactive oxyge species (ROS) present in oxidant organelles such as mitochondria can further exacerbate nanoparticle reactivity. R can damage the proteins, lipids, nucleic acids, and DNA etc present in the cell ultimately leading to cell death [17].

Carbon nanotubes can directly enter the body and cause toxicity, while carbon nanoparticles, like fullerenes, can als induce toxicity. Carbon nanotubes primarily affect mitochondria [18]. In amphibians, carbon nanotubes have been shown to induce genotoxicity, resulting in DNA damage and oxidative stress after short-term exposure [19].

Consumer products containing silver nanoparticles (AgNP) can pollute aquatic environments. The dissolution of AgNP can cause toxicity in aquatic organisms such as fish and algae. The toxicity of AgNP is highly dependent on particle properties, including concentration, pH, size, and shape, which influence the nanoparticle's reactivity. Frenk et al. foun that CuO and Fe3O4 nanoparticles, with different concentrations in two different sand soils, exhibited varying levels of toxicity, with CuO showing more toxicity between them [20].

Burrowing is a crucial method for water filtration and the stabilization of erosion effects. Nanoparticles can affect the soil's burrowing organisms such as earthworms which constitute a significant portion of soil biomass [21].

Nanoparticles have significant effects on animal's lives. The impact of NP on soil, water, and air is essential for the foo chain. Plants can absorb nanoparticles through leaves, roots, damaged areas, flowers, and from water sources.

Xia et al. found that the impact of TiO_2 nanoparticles showed a tendency for reduced toxicity with an increase in particle size, as Ti nanoparticles could cause DNA damage [22].

Zinc nanoparticles can induce cellular toxicity in plants, leading to growth retardation, reduced photosynthesis, and altered gene expression in all affected plants. Higher nanoparticle concentrations are primarily responsible for the reduction in photosynthesis. AgNP can also inhibit plant growth. The properties of nanoparticles change depending o the nature of the metal they contain.

Nanoparticles can disrupt various biological structures, including the kidney, heart, liver, amino acids, and fatty acids. As nanoparticle production increases, emissions into the environment also increase. A lack of trained engineers an workers can have an adverse impact on the environment. During the life cycle, emissions of nanoparticles occur whe conducting batches or experiments and when decomposing nanoparticles [23].

Studies have shown that silver nanoparticles-(AgNPs), titanium dioxide nanoparticles (TiO2-NPs), and zinc oxide nanoparticles (ZnO-NPs) are toxic elements for aquatic animals. Moore, Hund-Rinke, and Simon have discussed how nanoparticles affect biota by generating reactive oxygen species (ROS).

Nanoparticles' behavior changes depending on their size, shape, and other factors, leading to changes in their chemic and physical properties. Nano fertilizers are responsible for soil toxicity, climate changes, soil deficiency, and other issues. Thakur et al. conducted an investigation and provided an AgNP dose of 20 µg/kg for male Wistar rats. The results showed that the accumulation of nanoparticles in the lysosomes of sterile cells may cause cell death [24 Superparamagnetic Fe3O4 NPs have been found to disrupt kidney, liver, and heart activities in mice, leading t symptoms like vomiting and nausea. Fishes that consume carbon nanotubes in higher concentrations than thos consumed by humans may experience tissue damage [25]. In zebrafish, nanoparticle concentration is linked to live inflammation and fatty acid accumulation [26]. As the nation's and population's growth leads to an increase in industries and crop production, this may result in the contamination of water with organic pollutants such as Co, Cu, Pb, Zn, As, Cd, and Hg. Water contamination can lead to the spread of harmful diseases like typhoid, cholera, and diarrhea [27 Many studies and experiments have been conducted in recent years.

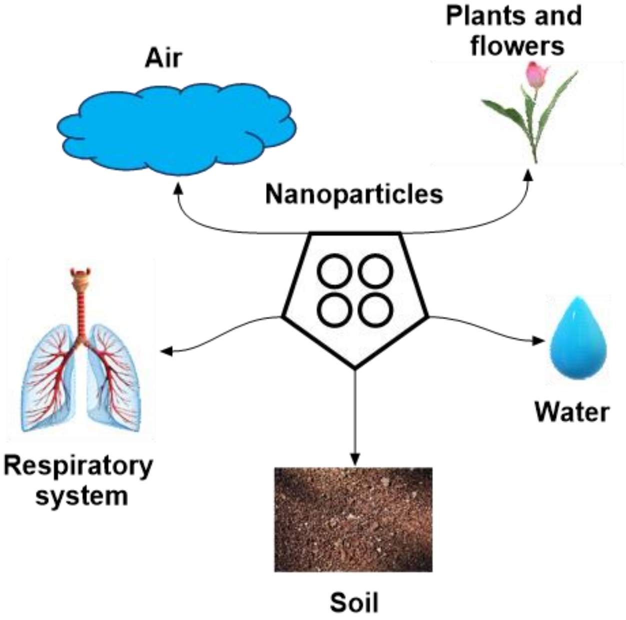

Figure 4: Effects of nanoparticle contamination encompasses all major components of the environment

5 2 Positive impact

NPS are utilized in a wide range of fields, including nanostructured ingredients, food packaging, nano-coating (making surfaces scratch-resistant), nanofiltration, and nano-delivery systems for agriculture to enhance crop nutrition and are used in many agro-industries [28-33]. NPs play a vital role in food sciences and food microbiology, aiding in the detection of foodborne illnesses and extending the shelf life of food. NPS also receives significant attention for seed germination and root elongation. They are employed in cosmetic products, such as skin creams that utilize protein derived from stem cells to combat skin aging.

NPs find application in wastewater treatment, a technique employed worldwide. They reduce heavy metals, fertilizers and pesticides to provide clean water for drinking and irrigation [34]. This process is both cost-effective and environmentally friendly. NPs inhibit certain pathogenic microorganisms and can also remove dyes, such as methylen blue. NPS act as catalysts to enhance various reactions.

In agriculture, it is impossible to sustain crop growth without using fertilizers, pesticides, and herbicides for crop protection. Insect pests and plant diseases cause significant economic and food losses, making it essential to devel sustainable nano fertilizers, nano pesticides, and nano herbicides [35]. Nano fertilizers assist in maintaining soil fertility, while nano pesticides and herbicides protect plants from early degradation, control pests for longer periods, and enhance solubility. Pesticides can be applied directly to seeds and grains, inhibiting plant pathogens [36].

Silver nanoparticles [AgNPs] have piqued the interest of scientists due to their properties and wide-ranging applications. They are extensively used in wastewater treatment, influencing microorganisms to promote plant growth and nutrient cycling in the soil, increasing crop yields, controlling pathogens, and in the textile industry.

Magnetite nanoparticles [MNPs] exhibit paramagnetic behaviour and are used for wastewater purification, treatment and phototherapeutic treatment for removing heavy metals from the ground [37, 38]. MNPs do not exhibit any cytotoxic effects and provide a greener and more cost-effective approach. Various adsorbents, including activated carbon, rice husk, carbon nanotubes, and silica, are used to treat wastewater [39,40].

Nanotechnology is pervasive across various fields, including medicine, fabrics, cosmetics, food packaging, paints, ca coatings, and tanning lotions. Sensors are powerful tools for monitoring environmental contaminants such as pesticides and microorganisms [41,42,43]. NPS serve as catalysts to enhance reactions and are utilized in solar, electrical, biological, and geothermal applications [44,45].

5 Conclusion

Nanoparticles play an efficient role in our day-to-day life. They are highly demanded in every field because of their physical, chemical, and biological properties. Nanoparticles undergo a life cycle, and during this process, it is difficult to identify the actual emissions in the environment. Many techniques are used to identify emissions in the environment Nanoparticles undergo transformation and characterization, depending on their size, shape, pH, and concentratio Based on this, impacts on the environment take place. Nanoparticles have both negative and positive impacts. They ca harm the environment by undergoing some reactions, but they also have a positive side. They help us in wate treatment, promote plant growth, and enable a green synthesis process with natural extracts instead of chemicals, whi is an eco-friendly process with low toxicity. Nanoparticles are used in renewable energy and drug therapy as well, playing a role in different areas with both positive and negative impacts. It is necessary to maintain a balanced environment for the well-being of living beings by following eco-friendly norms.

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