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Short review on environment and health effect of nanotoxicology

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Abstract--Nanotechnology is a brand-new area of scientific research that has revolutionized the manufacturing sector. The emphasis of this revolution was on the large-scale development of nano-based materials. Materials confinement in small structures, quantum mechanics, the high surface volumes ratio or other unusual properties, phenomena, and processes dominate nanoparticle behavior use of the nanomaterial containing items on the rise, posing a threat to the environment and human health. For the sake of human health and protection in the community, it's important to understand the toxicity of engineered nanomaterials or nano-based products. Nanotoxicology aims to identify potential toxins' toxicological practices in nanomaterials and these products to assess how these materials endanger human health. In this sense, nanoparticles and their fate in the atmosphere have been examined concerning air, water, and soil. Nanomaterials' health effects, such as their impact on various organ systems, have also been mentioned.

Keywords--Risk assessment, Nonmaterial, Nanotechnology, Nanotoxicology, Health hazards.

1. Introduction

Nanotechnology has piqued public interest in recent years due to its potential effects on industries like oil, Medicine, agriculture, electronics, textiles, and space are only a few examples. Since its inception, nanotechnology has to be regarded as a branch of science that can still exceed Moore's law-defined limit of miniaturization technology, However, in terms of nano, this miniaturization

has a limit. The nanoscale is a qualitatively new size, not just another step toward miniaturization. Nanotechnology is the visualization, Materials manipulation, and control at the nanometer scale. It has become a buzzword in skill and technology. Nanotechnology is a field of applied science that deals with manipulating matter with multiple dimensions ranging from 1 to 100 nanometers[1]. The molecular organizational properties of nanoscale materials vary from those of bulk materials. The design, synthesis, and implementation of materials and devices with at least one dimension in the nano range and whose size and shape have been designed at the nanoscale are referred to as nanotechnology. The many applications of engineered nanomaterials in several fields are presented in table 1. The ingenious utilization of materials with structural elements in at least one dimension smaller than 1 micrometer is called nanomaterial. Nanomaterials'surface area-to-volume ratio and physicochemical properties have a major effect on biological activity. Within the 1–100 nm range, The melting point, color, and electrical conductivity of nanomaterials are all affected by the size and shape of the material. Sensors for environmental monitoring, nano-remediation, nano-drug-delivery systems, bio-robotics, nano-arrays, and nanoscale implants in medicine are only a few of the possible environmental and human health benefits of nanomaterials.

Toxicological effects are present in all nano-based products in some form or another, depending on the parameter to cause nanoparticles. Nanotoxicology studies the negative nanoparticles and their impact on the environment and human health, as well as the effects of nanomaterial exposure. Pollen grains, ultrafine particles in smoke, aerosols, dust particles, and air pollutants, are all examples of air contaminants, Nanomaterials are carried to a higher level by natural exhaust mechanisms than by laboratory experiments and extremely sophisticated goal-oriented practices. The lack of metrological methods to detect nanoparticles poses a major potential problem in terms of identification and remediation, as well as their fate in the human body and the environment[2].

1.1 Toxicological Concerns

The position of the atom size informative toxicity has sparked renewed interest as a result of nanotechnology research. Because Renata et.al in 2008 stated that of their bigger surface area, soaring particle number to the mass ratio, improved substance reactivity, soaring surface reactivity, and the possibility for easier cell infiltration, nanoparticles be more poisonous than the bigger element of the same material[3]. Many biological applications have been suggested for nanomaterials, but very less is known about their danger to human health little is famous about their poisonous, possible, and overall danger to human health. Nanoparticles in general are not harmful to the climate. It depends on the absorption, and revelation of the particles. Oxidative stress is regarded as extremely important at the cellular level. After in vitro exposure, nanoparticles cause stress responses in killer cells and white blood cells. The toxicity of nanoparticles is largely determined by the five parameters: dosage, statement, measurement, time, and protection[4]. Knowing how much a substance can cause damage to humans and the environment is an important part of understanding the toxicity of materials. When a body is exposed to materials in

the wrong dosage accidentally, toxicity may occur; however, the findings of studies on nanoscale materials are hard to understand. One of the difficulties is that elements behave differently at the nanoscale due to enlarged area and large surface reactivity, as a result, what is similar in mass is a very different region.[5]

Table 1. Engineered Nanoparticle (ENP) and their applications[6]

ENP	Applications
Fullerenes	Removal of organo-metallic compounds, cancer treatment, cosmetics, magnetic resonance imaging, X-ray contrasting agent, anti-viral therapy.
Graphene	Ultrafiltration, nanofiltration, optoelectronics, energy storage devices, photovoltaic cell.
Zinc oxide	Skin care products, bottle coatings, gas purification, contaminant sensors photocatalysis
Quantum dots	Medical imaging, targeted therapeutics, solar cells, photovoltaic cells, security links, telecommunications.
Cerium oxide	combustion catalyst in diesel fuels, solar cell oxygen pump coatings, electronic glass /ceramic, ophthalmic lenses.

1.2 Methods To Evaluate Toxicity Of Nanoparticles

Because of their very little size or unknown chemical or physical connections with others, material in the atmosphere and the biological nanomaterials in the environment are difficult to study. vertebrate toxicity tests skin irritation tests mutagenicity tests and is used in determining the danger in the environment. The evaluation of the chemical properties of the resources that enable them to cooperate with and potentially harm biological systems is the first step in a reasonable approach to nanomaterial toxicity. A different series of tests includes within living that represent the retort of a variety of cell types that can be under attack at the nanomaterial entry universal sites after uptake and dissemination. Abused for the detection of nanomaterials in a field, a variety of spectroscopic techniques and microscopic techniques are at present available. The toxicity of the nanoparticles is limited to a size range of 65 nm to 200 nm [7]. Poonam et.al 2011 explained that nanoparticles' increased capacity to generate free radicals that can reason cellular damage has been confirmed in the living organism on cell cultures[8]. When cells are exposed to particulate

matter, immediate oxygen species are generated, which is thought to be a major giver of nanoparticle toxicity. For potential nanoparticle-induced toxic, the mitochondria, and cell membrane are considered acceptable. Nanomaterials are currently being studied for their effect on biochemical reactions in cells up to the survivability of entire multicellular species. Several standard metrics have been developed to allow differentiation between organisms for danger study. The poisonous concentration of a chemical that kills 50% of an uncovered population when compared to regulation, is the most common. To ensure comparability between experiments and laboratories must be monitored or conducted in a standardized way. Oberdörster et al. (2005) used the Daphnia EC50 test to determine the toxicity of nanomaterials in marine environments[9].

2. Ecological And Health Issues Related To Nanomaterial

Despite the extensive uses of nanomaterials, awareness of toxicity or possible health and Ecological threats connected with their uses is severely lacking. The damage of nanomaterials used in nanomedicine and other ecological remedy technique is frequently unseen in practice. A lot of nanomaterials and nano-based foodstuffs are now used in ecological health development, and biomedical applications, resulting in widespread exposure to these nanoparticles or releases to the ecological body from the place of work. The toxicological risks of nanomaterials are caused by several health and ecological problems connected to the use and free of nanomaterial and nano-based products[10].

2.1 Health Risk

Nanomaterials are much more easily absorbed by the human body due to their extremely small size and short surface-to-volume relation, which large the chemical reactivity or biological activity of the element. The toxic effects of the nanoparticle's connections with biological systems can be divided into two types

- 1) increased transmission of identified poisonous chemicals.
- 2) Toxic property of relatively kind material resulting from size-related disturbance of biological structure[11].

Nanoparticles reach the bodies through some pathways, making assessing the risks associated with any substance much more difficult. Particles come into the body from a single path or then spread broadly to the different organisms and tissue, according to various literature. Inhalation is the most common form of nanoparticle exposure. Other methods of entry to the body include ingestion by food or claim to the skin, either deliberately or accidentally[12]. Staff uncovered throughout the processing or uses of the nanomaterial, universal population exposure from release to the atmosphere throughout the production and use in the place of work, or direct general population contact throughout the use of commercially accessible goods containing nanomaterial are all possible living exposure to nanomaterial and mixture of nanomaterial. The skin, gastrointestinal tract, and respiratory tract are the key routes of occupational and environmental nanoparticle exposure [13]. A lot of nanoparticles are the future of medical imaging. On the other hand, are at rest in the research phase, or other major revelation paths, most notably, nano-medical foodstuffs depiction both staff and patients. At this time, no methods

for measuring airborne particulates have been established to measure occupational particulate exposures in the nanoscales dimensions[4]. Nanoparticles enter the human being's body through some routes, including gasp, spoken, and vaccination. The potential dangers of nanoparticles have been summarised in table 2.

Table 2. possible Risks of Nanomaterials[14]

Nanomaterials	Possible risks
Carbon nanomaterial, Silica nanoparticle	Pulmonary inflammation, Granulomas, and fibrosis
Carbon, silver and gold nanomaterials	Distribution into other organs including the center nervous system
Quantum dots, carbon and TiO ₂ nanoparticles	Skin penetration
Mno ₂ , TiO ₂ , and carbon nanoparticles	May enter brain through nasal epithelium olfactory neurons

2.1.1 Breathing

The presence of nanoparticles in the atmosphere is a major concern. Since nanoparticles are simply increased by wind, rising their contact to the community, early on a study of nanoparticle gasp has alerted on the direction or statement of gasp particle, as well as their possible poisonous to occupied organs. Depending on particle size, gasp particulate substance can be discrete in the person's respiratory system. The respiratory area is the primary access point of the air nanoparticle. Particles with diameters greater than 5 m are cleanout in the airways proximal to the little fatal bronchioles, even as those with diameters between 0.6 and 6 m can be penetratetheextra distal respiration fraction of the lungs, while a few may be deposited top-up into the nose and broad conduct airways[15]. Nanoparticles may be transported to the lung interesting, liver, or spleen orprobablythefoetusinwith child women after deposition in the respiratory tract. It should be noted that the amount of data available on these pathways is extremely small. One human research showed the movement of inhaled nanoparticles into the bloodstream, other than two extra related studies have failed to prove such a translocation[16].

2.1.2 Skin

Many naturally occurring compounds are blocked by the skin. Certain liquids and dissolved products, on the other hand, can penetrate the skin. The most

important factors are lipid solubility and molecular size, with higher lipid solubility and little molecular mass improving diffusion throughout the skin[17]. Because of concerns about occupational contamination or the amalgamation of nanomaterial such as nano-sized titanium into the drug products, dermal exposure to nanomaterials has gotten a lot of attention since of their ease of diffusion through the endodermal layer, nanomaterial has an upper chance of being captivated through the skin. Some evidence suggests to nanoparticles may enter the epidermal, dermis, and stratum corneum, as well as the stratum and can be a break into the skin by incoming between and via epithelial cells and through the skin as in the case of cosmetics containing nanoparticles[18]. Together in vivostudies and vitrostudy hane been shown the nanoparticles induced dermatoxicity. In aqueous media, however, TiO₂ absorbs a significant quantity of UV radiation, which results in the formation of immediate oxygen species such as hydrogen peroxide, and free hydroxyl singlet oxygen[19].

2.1.3 Injection

The direction of a liquid into the subcutaneous tissue, skin, or body cavities is known as insertion. Injection of nanoparticles medicine delivery or drug based on Nanomedicines. Nanoparticles injected intravenously stayed in the human body longer than those ingested. After one week of exposure, 90% of injected functionally fullerenes are retained[20]. The toxicity of the nanoparticles injected into a body is determined by their chemistry or accuse. Hypersensitivity is a general part cause of injecting nanoparticles. After intravenous injection, nanoparticles were set up to be distributed to the liver, bone marrow, spleen, and lymphatics. Translocation of the nanoparticle after vaccination is dependent upon the injection place: intravenously injected nanoparticles fast disperse across the circulatory systems[21].

2.1.4 Oral

The oral absorption of nanoparticles can also enable them to pass through the blood-brain barrier and into the nervous system. nanoparticle spread to the liver, lungs brain, kidney, spleen, and gastrointestinal tract after oral contact. Some nanoparticles can be passed through the GI tract and are easily removed in the urine, suggesting they can cross the barrier and into the universal movement[22].

2.3 Environmental Risk

Over the last decade, ecological health and security investigation has concentrated on the origins, and toxicity of engineered, fat nanomaterials[23]. Since there are fewer studies existing, the primary properties of nanomaterials' ecological fate are not well known. Increased use or development of foodstuff materials results in ecological contact, which includes typical contact routes for determining conservative chemicals, such as manufacture wastes (liquid, solid,), product free through produce life, and misuse cycle release[24]. While there are several unlike forms of nanomaterial, free nanoparticles have been ignited the most interest. Free nanoparticles can enter the atmosphere either

directly or by the degradation of nanomaterials, and they can wait in the environment for a lengthy time [25].

2.3.1 Toxicity Through Ecological Revelation

Environmental relations at the inhabitants, society, and system levels are the subject of environmental nanotoxicology. Exposure to engineered nanomaterials (ENMs), their chemical property, biochemical pathways, or the environmental or physical process that controls ecosystem-level impact or ecosystem service are all powerfully related by eco-nanotoxicology. qualms about the health and ecological, and environmental consequences of exposure to engineered nanomaterials pose concerns about the exposures' possible risks [26].

However, the health issues are focused on respiratory health; epidemiological studies indicate that ultrafine particles have strong effects on respiratory sickness such as coughing and being out of breath, among other things. Nanoparticles such as zinc oxide, and platinum, as well as consumer goods such as makeup, and cream, are the major sources of discharge, which are expected to rise as nanotechnology advances [27].

1. Soil

Soil is defined by the existence of earthly habitats, which are the most important contributors to biodiversity. Because Werlin et al. in 2010 said that due to the extra small size of nanomaterial, its interaction with soil is extremely important [28]. Given the extremely varied existence of soil elements in many dissimilar chemical types, analyzing the behavior of nanomaterials toxicants through their interactions with soil is very difficult. In various soil textures, such as soil organic matter, soil media, and soil pre-existing waste, nanoparticle interactions are different and unpredictable. Depending on the chemical and physical properties of a nanomaterial, the amount of nanomaterial released into the soil is likely to differ [29].

2. Air

Balbus et al. 2007 found that the number of nanoparticles, in the air in urban and rural areas can be remarkably close, with as many as 106-108 nanoparticles/liter of the air depending on the condition [30]. In village areas, nanoparticles are formed by the corrosion of biogenic or anthropogenic unstable compounds, such as secondary organic aerosols. Diesel engines or vehicles and freezing catalytic converters are the main sources of these particles in city areas. In addition to their original dimensional and substance feature, many processes influence the destiny of the air nanomaterial, including the duration of time the particles remain in the air. The coagulation mode the aggregation style, and the coarse mode are the three classes or modes that airborne particles are categorized into based on their size and behavior. Since they quickly clot to form better particles, elements in the coagulation style have a limited lifespan. Gravitational settling affects particles in the coarse mode by Brownian diffusion, nanoparticles can fly great distances in air, and are respirable [31].

3. Water

The connections of nanoparticles with water are critical in assessing the nanomaterial's aquatic nanotoxicity. Another way nanoparticles end up in the

atmosphere is by wastewater runoff or an opening as of a wastewater conduct plants they aren't successfully detained reverse and degraded. Spills from the processing, transportation, and disposal of nanomaterials and their components are other sources of environmental pollution. While several possible routes of exposure remain unknown and need to be verified, the shortest submission of nanoparticles such as nano zero-valent iron for remedy of the contaminated area and underground water is one way of revelation they would almost positively result in ecological experience. While free nanoparticle remedy is one of the most talented ecological nanotechnologies, it may also raise the main concern. Nanoparticles enter the atmosphere most often as a by-product of manufacturing processing, anywhere they are transported as work waste during the air and fluid waste stream[32].

2.3.2 Nano-Ecotoxicological Concerns

Nanomaterials have a distinct effect on marine and terrestrial animals than bigger particles. Also, the use of nanomaterial in the atmosphere creates a novel byproduct, which fronts additional dangers. It is likely to the estimate propensity of nanomaterial to cross cell membranes and bio-accumulate using comparison to physical-chemical properties of the bigger element of a similar substance. However, current research has concentrated on a limited number of nanomaterials and objective species[33].

1. Marine ecosystem effects

A small number of nanoscale materials have been studied, as well as a small number of marine organisms. Here have been reports of complete life-cycle studies to date. Nanoparticles, also known as colloids, are made up of natural materials such as fulvic or humic acid, as well as non-living species such as manganese oxides and hydrous iron, which form as a result of the squalor of various natural complex, and peptides in aquatic environments. The tendency of engineered nanomaterials to agglomerate and aggregate is a significant feature[34]. As particles agglomerate, they are kept jointly by quite weak forces such as Vander-Waals forces, and surface tension. The nanoparticle may as well forms a series of the closely linked particle to cannot be simply re-dispersed by automatic means. They form a haphazard aggregate in the wild and go into the food chain of marine organisms. They persevere longer in the seawater, or this inclination leads to the display of novel effects, as well as the behavior of aggregate complete would substantially dissimilar from the individual nanoparticle[35].

2. Land ecosystem effects

Just a little study has been carried out to determine the possible poisonous of nanomaterial to environmental worldly test species such as wildlife, plant invertebrate. Nanomaterial property that controls uptake in marine organisms often restricts nanoparticle uptake by plant roots by dropping inert transport at lower molecular weight and scale, as well as moving through plant's leaves and stomata. The capacity to extrapolate toxicity data from traditional materials to nanomaterials would necessitate a detailed understanding of absorption, delivery, and emission rates, as well as toxic action mode[36].

3. Biodegradability Bioavailability And Bioaccumulation Of Nanomaterial

In adding to the influence of different nanoparticles on the earth's biodiversity domain, the final phenomena of biodegradation, bioaccumulation, and bio persistence should be taken into account when considering the toxic effects of nanoparticles. A possibility for biodegradation of nano-sized particles, as well as possible mechanisms, is only now being studied. Many nanomaterials in use today are made up of inorganic chemicals that are naturally non-biodegradable, such as ceramics and metal oxides, and are unlikely to biodegrade[37].

Nanomaterial will accumulate in living things over time. Living cells are bacteria capable of absorbing nanoparticles, laying the groundwork for bioaccumulation of the food chain. The nanoparticle can simply reach the food chain and reason serious health and environmental problems. The chemical and physical structure of the particle would have a big impact on its biodegradation potential[38]. The extent to which nanomaterials contaminate the human food chain will be determined in part by ecological excellence and whether and not resources pollute agricultural property, as well as the uses of specific nanoparticles farming. Environmental fate mechanisms may be too sluggish to effectively remove persistent nanomaterials until they're in use up by a person.

4. Governing Body

For the assessment of ecological, and safety risks internationally harmonized standards and methods are required. The organization for economic devolvment and cooperation has formed various committees which help in forming different text procedures and guidelines for nanoparticles. The OECD founded the effective Party on contrived Nanomaterialsin 2006 to foster international cooperation on manufactured nanomaterials safety and health environmental issues. this is the primary round-table for international cooperation in the field, particularly in the creation of test methods required for good regulatory completion[39]. The Royal military institute of Engineering expressed concerns about the evaluation and restriction of chemical applications for the chemical safety evaluation of nanomaterials due to a lack of information about their physical-chemical properties and belongings on the human being health and the atmosphere. The new Cosmetic Products Regulation was approved by the European Parliament and Council in2013 which deals with various properties of nanoparticles[40].

5. Result and Conclusion

Nanotechnology is a "double-edged sword," in that "the same properties that render nanoparticles useful for new applications may also increase their harmfulness." approximately without immunity, every study of nanoparticle toxicology issues caution against all types of nanoparticle exposure before further definitive research can conducted. Extra study into the physical-chemical property of the nanomaterials, as well as their possible effects on a person and the atmosphere, will be essential for the in-charge growth of nanotechnology. Nanomedicine needs extra caution because it is a field where there is a higher risk of exposure. There is an increasing international discussion about the moral, lawful, and social aspects of nanotechnology, especially the possible risk to human being health and the atmosphere posed

by engineered nanomaterials. Nanotechnology is still primarily a problem-solving tool, including for issues related to sustainable development. While nanotechnology holds great promise, its misuse or malicious implementation could endanger humanity's survival. Nanotechnology's relevance to the economy and our future well-being is undeniable, but its possible negative consequences must be investigated in the same way. Nanotoxicology a regulation will make a major donation to the expansion of long-term or health nanotechnology.

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References

- [1] R. D. Handy and B. J. Shaw, "Toxic effects of nanoparticles and nanomaterials: Implications for public health, risk assessment and the public perception of nanotechnology," *Heal. Risk Soc.*, vol. 9, no. 2, pp. 125–144, 2007, doi: 10.1080/13698570701306807.
- [2] K. Donaldson, V. Stone, C. L. Tran, W. Kreyling, and P. J. A. Borm, "Nanotoxicology," *Occup. Environ. Med.*, vol. 61, no. 9, pp. 727–728, 2004, doi: 10.1136/oem.2004.013243.
- [3] R. Behra and H. Krug, "Nanoecotoxicology: nanoparticles at large," *Nat. Nanotechnol.*, vol. 3, no. 5, pp. 253–254, 2008, doi: 10.1038/NNANO.2008.113.
- [4] D. R. Hristozov, S. Gottardo, A. Critto, and A. Marcomini, "Risk assessment of engineered nanomaterials: A review of available data and approaches from a regulatory perspective," *Nanotoxicology*, vol. 6, no. 8, pp. 880–898, 2012, doi: 10.3109/17435390.2011.626534.
- [5] M. Auffan, J. Rose, J. Y. Bottero, G. V. Lowry, J. P. Jolivet, and M. R. Wiesner, "Towards a definition of inorganic nanoparticles from an environmental, health and safety perspective," *Nat. Nanotechnol. 2009 410*, vol. 4, no. 10, pp. 634–641, Sep. 2009, doi: 10.1038/nnano.2009.242.
- [6] S. H. Khan, M. H. Fulekar, and B. Pathak, "Nanotoxicology - Health and Environmental Impacts: A Review," *J. Environ. Nanotechnol.*, vol. 4, no. 3, pp. 55–73, 2015, doi: 10.13074/jent.2015.09.153165.
- [7] K. W. Powers, M. Palazuelos, B. M. Moudgil, and S. M. Roberts, "Characterization of the size, shape, and state of dispersion of nanoparticles for toxicological studies," *Nanotoxicology*, vol. 1, no. 1, pp. 42–51, 2007, doi: 10.1080/17435390701314902.
- [8] S. Takhar, Poonam and Mahant, "In vitro methods for nanotoxicity assessment: advantages and applications," *Arch. Appl. Sci. Res.*, vol. 3, no. 2, pp. 389–403, 2011.
- [9] G. Oberdörster, E. Oberdörster, and J. Oberdörster, "Nanotoxicology: an emerging discipline evolving from studies of ultrafine particles," *Environ. Health Perspect.*, vol. 113, no. 7, pp. 823–839, Jul. 2005, doi: 10.1289/EHP.7339.

- [10] M. C. Powell, "New risk or old risk, high risk or no risk? How scientists' standpoints shape their nanotechnology risk frames," *Heal. Risk Soc.*, vol. 9, no. 2, pp. 173–190, 2007, doi: 10.1080/13698570701306872.
- [11] G. Oberdörster *et al.*, "Translocation of inhaled ultrafine particles to the brain," *Inhal. Toxicol.*, vol. 16, no. 6–7, pp. 437–445, 2004, doi: 10.1080/08958370490439597.
- [12] A. T. John, S. Wadhwa, and A. Mathur, "Nanotoxicology: Exposure, Mechanism, and Effects on Human Health," *New Front. Environ. Toxicol.*, pp. 35–77, 2022, doi: 10.1007/978-3-030-72173-2_5.
- [13] A. K. Madl and K. E. Pinkerton, "Health effects of inhaled engineered and incidental nanoparticles Health effects of inhaled nanoparticles," *Crit. Rev. Toxicol.*, vol. 39, no. 8, pp. 629–658, 2009, doi: 10.1080/10408440903133788.
- [14] P. C. Ray, H. Yu, and P. P. Fu, *Toxicity and environmental risks of nanomaterials: Challenges and future needs*, vol. 27, no. 1, 2009.
- [15] J. P. Ryman-Rasmussen *et al.*, "Inhaled carbon nanotubes reach the subpleural tissue in mice," *Nat. Nanotechnol.*, vol. 4, no. 11, pp. 747–751, 2009, doi: 10.1038/NNANO.2009.305.
- [16] S. Bakand, A. Hayes, and F. Dechsakulthorn, "Nanoparticles: A review of particle toxicology following inhalation exposure," *Inhal. Toxicol.*, vol. 24, no. 2, pp. 125–135, 2012, doi: 10.3109/08958378.2010.642021.
- [17] T. W. Prow *et al.*, "Quantum dot penetration into viable human skin," *Nanotoxicology*, vol. 6, no. 2, pp. 173–185, 2012, doi: 10.3109/17435390.2011.569092.
- [18] R. De Groot, P. Brekelmans, J. Herremans, and J. Meulenbelt, "The changes in hazard classification and product notification procedures of the new European CLP and Cosmetics Regulations," *Clin. Toxicol.*, vol. 48, no. 1, pp. 28–33, 2010, doi: 10.3109/15563650903376097.
- [19] J. P. Dehollain *et al.*, "Supplementary Information: Bell's inequality violation with spins in silicon," *Nat. Nanotechnol.*, no. 2, pp. 1–6, 2015, doi: 10.1038/NNANO.
- [20] A. A. Shvedova, V. E. Kagan, and B. Fadeel, "Close encounters of the small kind: Adverse effects of man-made materials interfacing with the nanocosmos of biological systems," *Annu. Rev. Pharmacol. Toxicol.*, vol. 50, pp. 63–88, 2010, doi: 10.1146/annurev.pharmtox.010909.105819.
- [21] W. H. De Jong and P. J. A. Borm, "Drug delivery and nanoparticles: Applications and hazards," *Int. J. Nanomedicine*, vol. 3, no. 2, p. 133, 2008, doi: 10.2147/IJN.S596.
- [22] J. Grigg, A. Tellabati, G. D. D. Jones, and P. Howes, "DNA damage of macrophages induced by metal nanoparticulates using an air-liquid interface exposure model," *Nanotoxicology*, vol. 7, no. 5, pp. 961–962, 2013, doi: 10.3109/17435390.2012.682354.
- [23] Z. A. Lewicka, A. F. Benedetto, D. N. Benoit, W. W. Yu, J. D. Fortner, and V. L. Colvin, "The structure, composition, and dimensions of TiO₂ and ZnO nanomaterials in commercial sunscreens," *J. Nanoparticle Res.*, vol. 13, no. 9, pp. 3607–3617, 2011, doi: 10.1007/s11051-011-0438-4.
- [24] R. K. Basniwal, A. Ranjan, and A. Chauhan, "Environmental Nanotoxicology: Features, Application, and Characterization," *New Front. Environ. Toxicol.*, pp. 79–90, 2022, doi: 10.1007/978-3-030-72173-2_6.

- [25] H. M. Kipen and D. L. Laskin, "Smaller is not always better: Nanotechnology yields nanotoxicology," *Am. J. Physiol. - Lung Cell. Mol. Physiol.*, vol. 289, no. 5 33-5, pp. 696–697, 2005, doi: 10.1152/ajplung.00277.2005.
- [26] P. A. Holden *et al.*, "Ecological nanotoxicology: Integrating nanomaterial hazard considerations across the subcellular, population, community, and ecosystems levels," *Acc. Chem. Res.*, vol. 46, no. 3, pp. 813–822, 2013, doi: 10.1021/ar300069t.
- [27] H. Johnston *et al.*, "Engineered nanomaterial risk. Lessons learnt from completed nanotoxicology studies: Potential solutions to current and future challenges," *Crit. Rev. Toxicol.*, vol. 43, no. 1, pp. 1–20, 2013, doi: 10.3109/10408444.2012.738187.
- [28] R. Werlin *et al.*, "Biomagnification of cadmium selenide quantum dots in a simple experimental microbial food chain," *Nat. Nanotechnol.* 2011 61, vol. 6, no. 1, pp. 65–71, Dec. 2010, doi: 10.1038/nnano.2010.251.
- [29] J. M. Unrine, W. A. Shoults-Wilson, O. Zhurbich, P. M. Bertsch, and O. V. Tsyusko, "Trophic transfer of Au nanoparticles from soil along a simulated terrestrial food chain," *Environ. Sci. Technol.*, vol. 46, no. 17, pp. 9753–9760, 2012, doi: 10.1021/es3025325.
- [30] J. M. Balbus *et al.*, "Meeting report: Hazard assessment for nanoparticles-report from an interdisciplinary workshop," *Environ. Health Perspect.*, vol. 115, no. 11, pp. 1654–1659, 2007, doi: 10.1289/ehp.10327.
- [31] A. Nel, "Air pollution-related illness: Effects of particles," *Science (80-.)*, vol. 308, no. 5723, pp. 804–806, 2005, doi: 10.1126/science.1108752.
- [32] F. R. Cassee *et al.*, "Exposure, health and ecological effects review of engineered nanoscale cerium and cerium oxide associated with its use as a fuel additive," *Crit. Rev. Toxicol.*, vol. 41, no. 3, pp. 213–229, 2011, doi: 10.3109/10408444.2010.529105.
- [33] J. Hawthorne *et al.*, "Particle-Size Dependent Accumulation and Trophic Transfer of Cerium Oxide through a Terrestrial Food Chain," *Environ. Sci. Technol.*, vol. 48, no. 22, pp. 13102–13109, Nov. 2014, doi: 10.1021/ES503792F.
- [34] A. Schierz, B. Espinasse, M. R. Wiesner, J. H. Bisesi, T. Sabo-Attwood, and P. Lee Ferguson, "Fate of single walled carbon nanotubes in wetland ecosystems," *Environ. Sci. Nano*, vol. 1, no. 6, pp. 574–583, 2014, doi: 10.1039/c4en00063c.
- [35] M. J. C. Van Der Ploeg, R. D. Handy, L. H. Heckmann, A. Van Der Hout, and N. W. Van Den Brink, "C60 exposure induced tissue damage and gene expression alterations in the earthworm *Lumbricus rubellus*," *Nanotoxicology*, vol. 7, no. 4, pp. 432–440, 2013, doi: 10.3109/17435390.2012.668569.
- [36] J. D. Judy, J. M. Unrine, and P. M. Bertsch, "Evidence for biomagnification of gold nanoparticles within a terrestrial food chain," *Environ. Sci. Technol.*, vol. 45, no. 2, pp. 776–781, 2011, doi: 10.1021/es103031a.
- [37] P. J. Liroy, Y. Nazarenko, T. W. Han, M. J. Liroy, and G. Mainelis, "Nanotechnology and Exposure Science What Is Needed To Fill the Research and Data Gaps for Consumer Products," *Int. J. Occup. Environ. Health*, vol. 16, no. 4, pp. 378–387, 2010, doi: 10.1179/107735210799160057.
- [38] R. Chen *et al.*, "Differential uptake of carbon nanoparticles by plant and mammalian cells," *Small*, vol. 6, no. 5, pp. 612–617, 2010, doi: 10.1002/sml.200901911.

- [39] V. Stone *et al.*, “ITS-NANO - Prioritising nanosafety research to develop a stakeholder driven intelligent testing strategy,” *Part. Fibre Toxicol.*, vol. 11, no. 1, 2014, doi: 10.1186/1743-8977-11-9.
- [40] S. Foss Hansen, A. Maynard, A. Baun, and J. A. Tickner, “Late lessons from early warnings for nanotechnology,” *Nat. Nanotechnol.*, vol. 3, no. 8, pp. 444–447, 2008, doi: 10.1038/NNANO.2008.198.
- [41] Suryasa, I. W., Rodríguez-Gámez, M., & Koldoris, T. (2022). Post-pandemic health and its sustainability: Educational situation. *International Journal of Health Sciences*, 6(1), i-v. <https://doi.org/10.53730/ijhs.v6n1.5949>