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Small Particles, Big Risks: The Impact of Nanotoxicology on the Environmental and Human Health

NEHA AWASTHI ,YASHIKA NANDINI , MANSI AWASTHI

PhD scholar; CDRI, Lucknow
Student, Vikram University , Ujjain, MP
Student, School of Environment and Earth Science, BBAU, Lucknow

ABSTRACT: This article discusses nanoparticles and their detrimental effects on the environment. Nano-toxicity is a current scientific and societal concern that has received attention from the scientific community. This article summarizes the sources of nanoparticles, their effects on various organisms, and available control techniques. Nanotechnology is a new scientific research field that has transformed manufacturing. This revolution focused on the large-scale development of nanomaterials. Nanoparticle behaviour is dominated by small structures, quantum mechanics, high surface volume ratios, and other unique qualities, posing a hazard to the environment and human health as the usage of nanomaterials increases. Understanding the toxicity of manmade nanomaterials or Nano-based goods is crucial for ensuring human health and community safety. Nano-toxicology examines the toxicity of nanomaterials and their products to determine their impact on human health. Nanoparticles have been studied in the atmosphere, including air, water, and soil. The health implications of nanomaterials on several organ systems have been discussed.

INTRODUCTION:

Nanotechnology is a branch of applied science that is concerned with the study, design, creation, and application of materials and devices with control over matter in many dimensions, at the nanoscale, which typically ranges from 1 to 100 nanometres (nm). It has sparked public interest in recent years due to its numerous potential applications in various industries, including oil, medicine, agriculture, electronics, textiles, and space, among others. Since its inception, nanotechnology has been viewed as an area of research capable of surpassing the Moore's Law-defined limit of miniaturised technology. However, there is a limit to nano-miniaturisation. The nanoscale is a fundamentally new size, not simply a step toward shrinking. Nanotechnology refers to the viewing, manipulation, and control of materials on the nanoscale. It's become a buzzword in skills and technology. Nanoscale materials exhibit unique molecular organisational features, distinct physical, chemical, and biological properties that differ from bulk materials. These particles mainly comprise metals, metalloid oxides, and carbon blacks. (barry park).. Table 1 depicts the numerous applications of customized nanoparticles in several disciplines. Nanomaterial refers to the novel application of materials with structural elements in at least one dimension smaller than 1 micrometre (μM). Example such as a RBC size is 7 um, bacteria 1um, virus 10-150 nm, immunoglobulin, nanoparticles, atom 0.2-0.04 nm etc.

These particles are used in various fields, including medicine, electronics, bio- robotics, nano-arrays, cosmetics, environmental remediation, and many more. Although these properties of nanoparticles can be leveraged to create innovative materials, devices, and systems with enhanced performance, functionality, and sustainability and they are explored in targeted drug delivery, improving the efficiency of solar cells, used for water purification, and pollution remediation. Moreover, the surface area-to-volume ratio and physicochemical properties have a substantial impact on biological activity. Their small size, rapid production, high reactivity, and complexity affect their melting point, colour, and electrical conductivity and depending on the conditions, generate nanoparticles that exhibit toxicological effects. They are produced in increasing amounts and discharged to the aquatic and terrestrial environment, and accumulate in organisms, potentially causing toxicity that harms ecosystems and human health.

Toxicology is the study of the harmful effects and interactions of chemicals, substances, or environmental agents on living systems and its responses. Understanding toxicity is pivotal for ensuring the safety of substances used in various industries and is important to protect human health and the environment.

As the use of nanoparticles expands and their distinct properties raise concerns about their potential toxicity. The toxicological effects arise due to the nanoparticles, termed as nanotoxicity, which is the focus of nanotoxicology. Nanotoxicology is a term derived from the combination of the term 'nano,' which refers to particles with dimensions in the nanoscale range (1-100 nm), and 'toxicology,' which is the study of adverse effects of substances on living organisms.

In light of this, we conducted a comprehensive review to elucidate the impact of nanotoxicology on human health, animal well-being, and environmental sustainability, highlighting the potential risks and hazards associated with nanoparticle exposure and their far-reaching consequences.

TOXICOLOGICAL CONCERN:

Nanotechnology research has reignited interest in the relationship between atom size and toxicity. Renata et al. (2008) found that nanoparticles are more toxic than larger elements due to their larger surface area, increased particle number to mass ratio, improved substance reactivity, and ease of cell infiltration. Nanomaterials have several biological applications, but their potential harm to human health is often overlooked. The process depends on particle absorption and disclosure. Oxidative stress is recognized as critical at the cellular level, and nanoparticles induce stress responses in killer and white blood cells following in vitro exposure. The five parameters that influence the toxicity of nanoparticles are dosage, statement, measurement, duration, and protection. Understanding a substance's toxicity requires knowing how much damage it can inflict on humans and the environment. Toxicology can arise when a body is accidentally exposed to an improper dosage of materials. However, investigations on nanoscale compounds are difficult to explain. At the nanoscale, elements behave differently due to their larger surface area and reactivity, resulting in a distinct region despite comparable mass.

Table 1 : ENGINEERED NANOPARTICLE AND THEIR APPLICATION

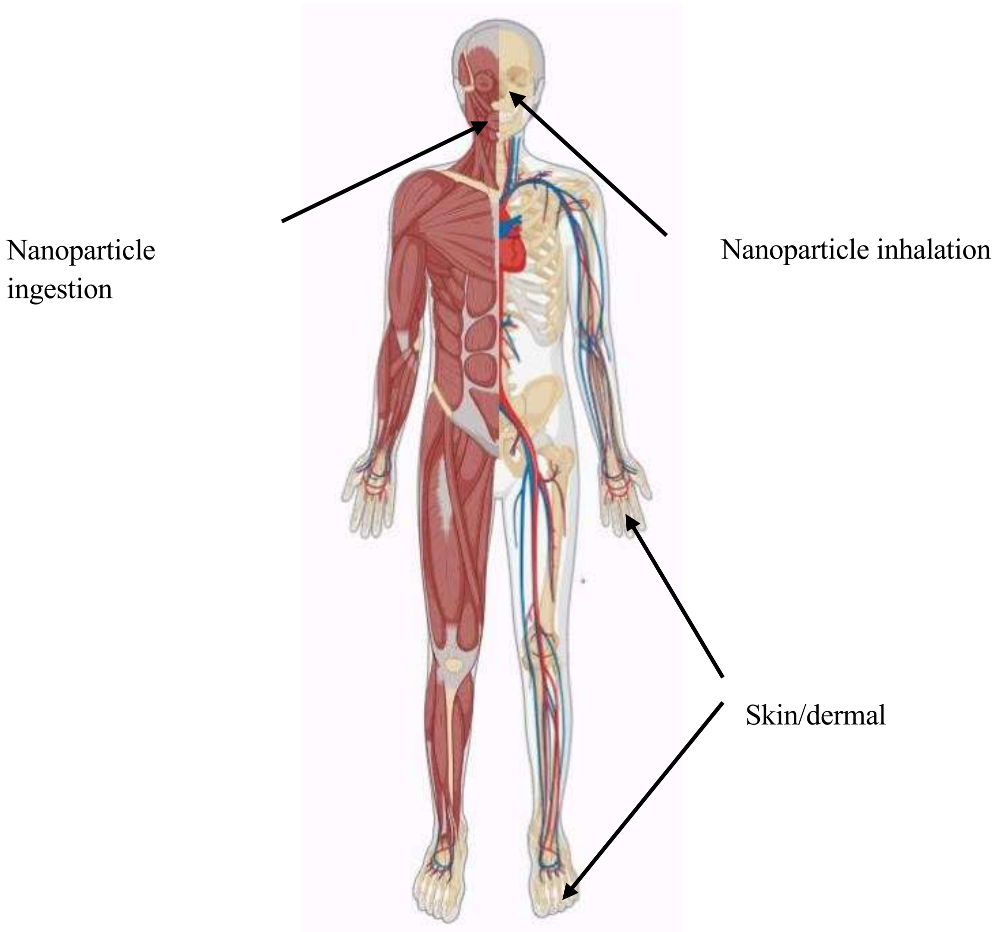
ENP	APPLICATIONS
Fullerenes	Removal of organo-metallic compounds ,cancer treatment, cosmetics , magnetic resonance imaging, X-ray contrasting agent, anti-viral therapy.
Graphene	Ultrafiltration, Nano filtration , optoelectronics ,energy storage devices, photovolataic cell
Zinc oxide	Skin care products, 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

SOURCES OF NANO PARTICLES:

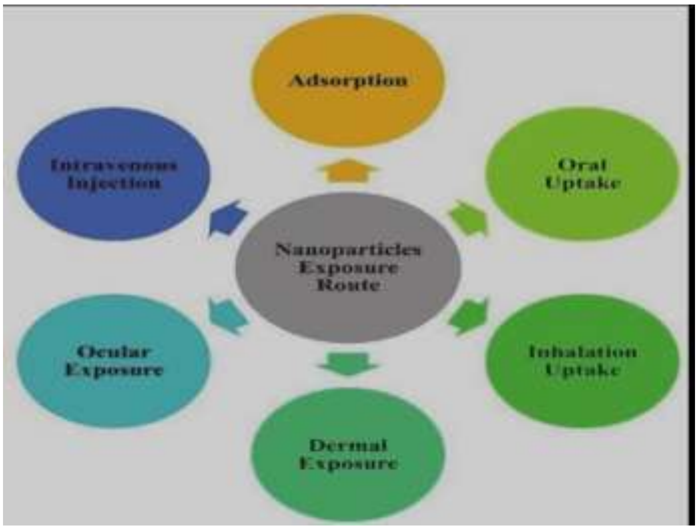
Nanoparticles are synthesized for use in various fields, including health sciences, agriculture, cosmetics, and many more. These are produced in nature or can be synthesized in laboratories, various sources listed in Table….

Natural	Anthropogenic	Occupational	Engineered
Dust storms	Diesel and engine exhaust	Metals and other dusts	Top-down category
Forest fires	Indoor pollution	Coal and coal ash	Bottom-up category
Volcanoes	Cigarette smoke	carcinogens	Sol-gel
Oceans	Building demolition	-	Flame spraying
Organisms	Cosmetics and other consumer products,	-	Sonication

PATHWAYS OF NANOPARTICLE EXPOSURE:



Nanoparticles exposure route in human

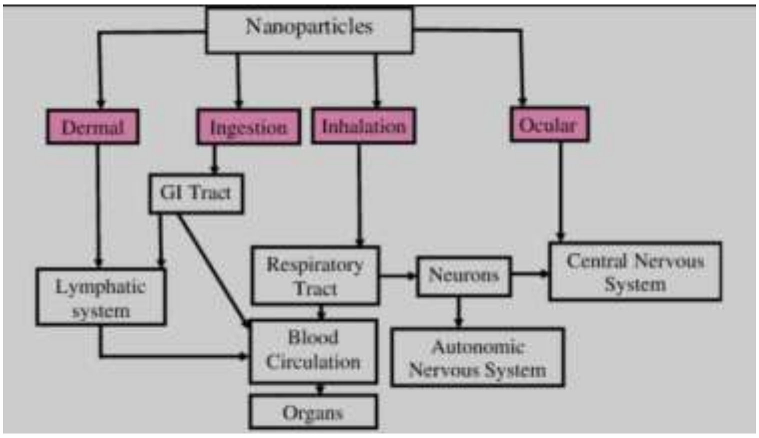


INHALATION- The presence of nanoparticles in the atmosphere poses a significant risk. Because nanoparticles are easily spread by wind, they are more likely to be inhaled by humans. Early studies of nanoparticle inhalation focused on the path and deposition of inhaled particles, as well as their potential toxicity to the inhabited organs. Inhaled particulate matter can be deposited in several parts of the human respiratory system, including the pharynx, nasal, trachea-bronchial, and alveolar areas. The respiratory tract is the primary entrance point for airborne nanoparticles; this exposure route can be used to illustrate certain essential principles in Nano toxicology, such as the importance of dose, dose rate, dose metrics, and bio-kinetics. Particles larger than 5 µm in diameter are filtered out in the airways proximal to the small terminal bronchioles, while those between 0.5 and 5 µm can reach the more distal respiratory part of the lung, though some may be deposited higher up in the nose or large conducting airways. After deposition in the respiratory system, nanoparticles may translocate to the lung interstitium, brain, liver, and spleen, as well as the foetus in pregnant women. It is underlined that there is very little information available on these paths. One human investigation demonstrated the passage of inhaled nanoparticles into the bloodstream, whereas two other identical studies found no such translocation.

DERMAL- The skin blocks several naturally occurring chemicals. However, some liquids and dissolved compounds can permeate the skin. The most critical parameters are lipid solubility and molecular size, with higher lipid solubility and low molecular mass enhancing diffusion across the skin. Because of concerns about occupational contamination or the incorporation of nanomaterials such as Nano-sized titanium into drug products, dermal exposure to nanomaterials has received a lot of attention. Because of their ease of diffusion through the endodermal layer, nanomaterials have a higher chance of being absorbed through the skin. According to some data, nanoparticles can enter the epidermis, dermis, and stratum corneum, as well as the stratum, and can break into the skin by arriving between and across epithelial cells and through the skin, as shown in nanoparticle-containing cosmetics.

INJECTION-Insertion is the process of directing a liquid into subcutaneous tissue, skin, or bodily cavities. Medicine or medication administration via nanoparticle injection. Nanoparticles administered intravenously remained in the body longer than those consumed. After one week of exposure, 90% of the functioning fullerenes introduced were maintained. The toxicity of nanoparticles administered into the body is dictated by their chemical composition or chemistry. Hypersensitivity is a common result of nanoparticle injection. Nanoparticles were administered via intravenous injection and disseminated to the liver, bone marrow, spleen, and lymphatic system.

ORAL- Nanoparticles can enter the neurological system by passing through the blood-brain barrier after oral absorption. Nanoparticles can move to the liver, lungs, brain, kidney, spleen, and gastrointestinal tract by oral contact. Nanoparticles can penetrate the GI tract and are easily eliminated in urine, indicating their potential for universal mobility.



Nanoparticles effects in human body

Table 2 summarizes the potential risks associated with nanoparticles.

Table 2 : POSSIBLE RISK OF NANOMATERIALS

NANOMATERIALS	POSSIBLE RISK
Carbon Nanomaterials, Silica Nanoparticles	Pulmonary Inflammation, Granulomas, and Fibrosis
Carbon, Silver, and Gold Nanomaterials	Distribution into other including the central nervous system
Quantum dots, Carbon, and TiO2 nanoparticles	Skin Penetration
Mno2, Tio2, and Carbon nanoparticles	May enter the brain through the nasal epithelium, olfactory neurons

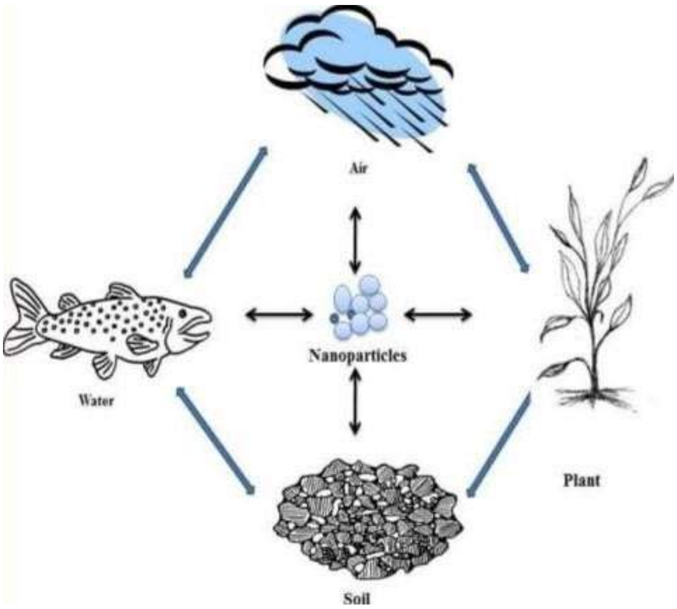
HEALTH RISK-Nanomaterials are rapidly absorbed by the body due to their small size and short surface-to-volume ratio, resulting in increased chemical reactivity and biological activity. Nanoparticles' harmful impacts on biological systems fall into two categories.

1) Increased spread of identified dangerous substances.

2) Toxic behaviour of comparably similar materials caused by size-related disruption of biological structure .

Nanoparticles can enter the body through several channels, making it difficult to determine their hazards. According to literature, particles might enter the body through a single passage or spread to multiple organs and tissues. The most common type of nanoparticle exposure is through inhalation. Other means of entrance into the body include food ingestion and intentional or unintentional skin contact. Staff exposed during the processing or use of the nanomaterial, general population exposure from release into the atmosphere during production and use in the workplace, or direct general population contact during the use of commercially available goods containing nanomaterial are all examples of possible living exposure to nanomaterial and nanomaterial mixtures. The epidermis, gastrointestinal system, and respiratory tract are the primary sources of occupational and environmental nanoparticle exposure. Many nanoparticles represent the future of medical imaging. On the other hand, are in the research phase, or other key discovery avenues, most notably, Nano-medical foodstuffs portray both personnel and Patients. Currently, there are no validated methodologies for monitoring airborne particles at the nanoscale for occupational exposures. Nanoparticles can enter the body by several means, such as breathing, speaking, or immunization.

ENVIROMENTAL RISKS- Over the last decade, eco-health and security researchers have focused on the origins and toxicity of manufactured fat nanoparticles. Because there are fewer research, the major ecological features of nanomaterials are unknown. Increased usage or development of food materials causes ecological contact, which comprises typical contact routes for assessing conservative chemicals, such as manufacturing wastes (liquid, solid), product free via production life, and misuse cycle release. While there are various different types of nanomaterials, free nanoparticles have sparked the most curiosity. Nanoparticles can enter the atmosphere through breakdown of nanomaterials and remain there for extended periods of time.



Nanoparticle Exposure in the Environment

SOIL- Soil is defined by the presence of terrestrial ecosystems, which are the primary contributors to biodiversity. Because, according to Werlin et al. (2010), the interaction of nanomaterials with soil is highly essential due to their small size. Given the wide range of soil constituents in many different chemical kinds, evaluating the behaviour of nanomaterial toxicants through their interactions with soil is particularly complex. Nanoparticle interactions vary and are unpredictable across varied soil textures, including soil organic matter, soil medium, and soil pre-existing trash. The amount of nanomaterial discharged into the soil will vary depending on its chemical and physical qualities.

AIR- The amount of nanoparticles in the air can be remarkably similar in urban and rural locations, with values ranging from 106 to 108 np/L (nanoparticles per liter) depending on the conditions. In rural settings, nanoparticles are typically formed through the oxidation of volatile substances of biological or anthropogenic origin, such as secondary organic aerosol. Diesel engines and cars with malfunctioning or cold catalytic converters are the main emitters of these particles in cities. Several processes influence the fate of airborne nanomaterials, including their initial dimensional and chemical properties, the amount of time the particles remain airborne, the nature of their interaction with other airborne particles or molecules, and the distance they may travel before being removed. Airborne particles are divided into three modes: coagulation (diameters <80 nm), accumulation (diameters >80 nm and <2 μm), and coarse (diameters >2 μm). Coagulation mode particles have a brief lifespan as they rapidly coagulate to produce larger particles. Particles in the coarse mode settle due to gravity. Nanoparticles can travel long distances in the air through Brownian diffusion, deposit in the alveolar areas of the lung, and spread throughout the body.

WATER- The interaction of nanoparticles with water is critical in defining aquatic Nano-toxicity . Nanoparticles can also enter the atmosphere by wastewater runoff or an opening in a wastewater treatment facility where they are not properly stored, reversed, or destroyed. Other sources of environmental pollution include spills from nanomaterial and component processing, transportation, and disposal. While various possible routes of exposure are unknown and must be validated, the shortest submission of nanoparticles such as Nano zero-valent iron for remediation of contaminated areas and underground water is one method of revelation that would almost certainly result in ecological experience.

While free nanoparticle therapy is one of the most promising environmental nanotechnologies, it may raise serious difficulties.

NANO-ECOTOXOLOGICAL CONCERN- Nanomaterials have different effects on marine and terrestrial species than larger particles. The usage of nanomaterials in the atmosphere creates a new by-product, which poses additional risks. Nanomaterials' ability to pass cell membranes and bio- accumulate can be estimated by comparing their physical-chemical properties to those of larger, similar substances. The current study focuses on specific nanomaterials and objective species.

1- MARINE ECOSYSTEM EFFECTS- Limited research has been undertaken on nanoscale materials and marine organisms. There have been reports of extensive life-cycle study to date. Nanoparticles, also known as colloids, are composed of natural ingredients such as fulvic or humic acid, as well as non- living substances such as manganese oxides and hydrous iron. They are formed by the aggregation of various natural compounds and peptides prevalent in aquatic settings. Engineered nanoparticles have a high tendency to agglomerate and aggregate. When particles aggregate, they are kept together by weak forces such as Vander-Waals and surface tension. Nanoparticles can create a chain of closely linked particles, making them difficult to re-disperse automatically. In the wild, they aggregate randomly and become part of the marine food chain. The persistence of nanoparticles in seawater can lead to unique consequences and behaviour that differs significantly from individual nanoparticles.

2- LAND ECOSYSTEM EFFECTS- There has been limited research on the potential toxicity of nanomaterials to many environmental species, including mammals, plants, and invertebrates. Nanomaterial properties hinder nanoparticle uptake by plant roots by reducing inert transport at lower molecular weights and scales, as well as moving through leaves and stomata, similar to how they affect marine creatures. Extrapolating toxicity data from regular materials to nanoparticles requires a thorough understanding of absorption, transport, and emission rates, as well as the manner of hazardous action

BIODEGRADABILITY, BIOAVAILABILITY AND BIOACCUMULATION OF NANOMATERIAL :

In addition to the impact of various nanoparticles on the earth's biodiversity, the final phenomenon of biodegradation, bioaccumulation, and biopersistance should be taken into account when considering hazardous impacts. The potential for and methods of biodegradation of nanoparticles are only now being researched. Many of the nanomaterials in use today are made of inorganic substances that are intrinsically non-biodegradable, such as ceramics, metals, and metal oxides, and are not expected to biodegrade. Researchers at Rice University's Center for Biological and Environmental Nanotechnology discovered that nanomaterials can accumulate in living things over time, with increasing concentrations in microbes, worms that feed microbes, and animals higher up the food chain. Bacteria and living cells can absorb nanoparticles, which could lead to bioaccumulation in the food chain. Nanoparticles can quickly penetrate the food chain and inflict serious harm to people and the environment. The chemical and physical characteristics of the particle will have a significant impact on its biodegradability potential. The presence of nanomaterials in the human food chain will be determined in part by environmental quality and the contamination of agricultural land, as well as the usage of specific nanoparticles in farming. Environmental fate processes may be too slow to effectively remove persistent nanoparticles before they are absorbed by an organism. In a study, the researchers examined how well existing methods of water purification would remove nanoparticles, specifically metal oxides, from commercial drinking water and concluded that removal of nanomaterials by coagulation, flocculation, and sedimentation processes was comparatively difficult. If they are difficult to remove from water using current industrial purification techniques, it stands to reason that their introduction to natural water sources could pose Earlier investigations some years ago by Rice University's CBEN (Center for Biological and Environmental Nanotechnology) showed that nanoparticles accumulated in the bodies of lab animals, while other studies showed that fullerenes migrate freely through soil and can be taken by earthworms.

This is a potential link up the food chain to people, highlighting one of the potential risks of nanotechnology. Other nanoparticles have been demonstrated to have harmful consequences, such as cadmium selenide (CdS) nanoparticles, commonly known as quantum dots, which can cause cadmium poisoning in people. Another study found that gold nanoparticles may pass from a mother's placenta to the baby. The toxicity of nanomaterials at various levels of the food chain must be studied and assessed in order to create a more accurate picture of the effects of Nano particulates on the environment and human health.

RESULT AND CONCLUSION- Nanotechnology can be a "double-edged sword," yet "the same properties that render nanoparticles useful for new applications may also increase their harmfulness." Without immunity, every study on nanoparticle toxicity warns against all forms of nanoparticle exposure before additional definite research can be undertaken. More research into the physical-chemical properties of nanomaterials, as well as their potential effects on humans and the environment, will be required to accelerate the growth of nanotechnology. Nanomedicine necessitates greater caution since it carries a higher risk of exposure. There is a growing international debate regarding the moral, legal, and social implications of nanotechnology, particularly the potential damage to human health and the environment posed by manmade nanomaterials. Nanotechnology remains a problem-solving tool, particularly in sustainable development. Although nanotechnology has immense potential, its misuse or malicious deployment could threaten humanity's survival. While nanotechnology has unquestionable benefits for the economy and future well- being, it is important to also consider its potential negative repercussions. Regulation of Nano-toxicology will significantly contribute to the growth of health-related nanotechnology.

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