International Journal of Pharmacy and Herbal Technology

e-ISSN: 2583-8962 Vol. 2, Issue 4 (October – December, 2024) pp: (2796-2812)

Health Implication and Application of Nanoparticles

Ankita B. Babar [*], Shrinivas R. Mane, Sanjay K. Bais
Fabtech College of Pharmacy, Sangola, Solapur, Maharashtra, India
[*]Corresponding Author: babarankita998@gmail.com

Received Date: November 28, 2024; Published Date: 21 December,2024

Abstract

Nanoparticles (NPs), defined as materials with sizes ranging from 1 to 100 nm, possess unique physical and chemical properties due to their small size and large surface area. These properties—such as optical characteristics, reactivity, and hardness—are size-dependent, allowing for phenomena like colour variation. NPs can be made from various materials like fullerenes, metals, ceramics, and polymers, each with distinct features. Despite the lack of specific laws for NPs, they share regulatory restrictions with bulk materials. Humans have long been exposed to microscopic particles from natural sources like dust storms and volcanic ash, and the body has evolved protective mechanisms. Due to their exceptional properties, NPs are used in diverse fields, including catalysis, medical imaging, drug delivery, energy, and environmental remediation.

Keywords - Nanotechnology, colloidal Nanoparticles, Quantum dots.

INTRODUCTION

Nanotechnology, often known as nanoscience, has various definitions. In general, it refers to the ability to manipulate, measure, manufacture, and anticipate on a scale of 1-100 nm. Nanomaterials are a class of materials that exhibit unique properties distinct from those of isolated atoms or bulk materials. These exceptional characteristics arise primarily from the materials' small size, typically on the nanometer scale, which is approximately 1 to 100 nanometers. At this scale, the behavior of the material is strongly influenced by surface effects, quantum phenomena, and increased surface-to-volume ratios, resulting in properties such as enhanced strength, conductivity, reactivity, and optical behavior. The structure and size of the nanoparticles carry a critical part in searching these unique attributes, making nanomaterials highly valuable for several uses in disciplines such as environmental research, electronics, medicine, and energy.[1]

Nanotechnology emerged from diverse scientific disciplines. The field is interdisciplinary, including chemistry, physics, biology, engineering, and, more recently, toxicology. Nanotechnologies is often referred to as a plural noun due to its multidisciplinary nature.Nanomaterials, or materials with structures at the nanoscale, have been a part of both natural and human-made environments for centuries. While the scientific study and manipulation of nanoscale materials is a relatively modern development, the use and occurrence of such materials can be traced back to ancient times. For example, silver and gold nanoparticles were employed to create vibrant colors in pottery glazes and stained glass as early as the 4th century AD, with these materials still being valued for their aesthetic and functional properties. Moreover, nanoscale phenomena are not limited to human craftsmanship—such materials are also abundant in nature. They can be found in natural processes such as volcanic eruptions and flames, and in biological systems where they play crucial roles in cellular processes. Notable cases such as, magnetite particles in cells, viruses and ferritin, a protein responsible for storing the body's iron. These naturally occurring nanoscale entities underscore the integral role of nanomaterials in both life and the environment, setting the stage for the advanced technological applications we continue to develop today. Human Particles impact has significantly grown during the past century due to their production through combustion and other industrial processes. This includes emissions from internal combustion engines, power plants, and welding [2]

Nanotechnology, with its vast potential, is industries of revolutionizing numerous, ranging from medicine and electronics to textiles and cosmetics. By manipulating matter at the nanoscale, researchers and engineers have unlocked unique properties in materials that differ dramatically from those observed in their bulk counterparts. This has led to the development of hundreds of consumer products that incorporate nanomaterials, and the market for such innovations is expanding at an exponential rate. Nanotechnology promises to enhance existing products and create entirely new ones, offering significant improvements in efficiency, functionality, and performance.

However, while the opportunities presented by nanoscience are immense, the rapid pace of technological advancement has outstripped comprehensive investigations into the potential risks associated with these materials. As nano-sized substances behave differently from larger particles, concerns are emerging regarding their environmental, health, and safety impacts. Despite the promising future that nanotechnology offers, it is critical to balance innovation with a careful assessment of the risk and hazards involved in performing with and who live alongside these fresh components. This calls for a more rigorous and thorough examination of the implications of nanotechnology to ensure its safe and sustainable integration into everyday life. [3]

Module 1: Nanoparticles classification

It is classified in various basis

Composition

Metallic Nanoparticles

Gold, silver, and platinum nanoparticles, known for their conductive properties.

Nanoparticles of metal oxides

Zinc oxide and titanium dioxide are utilized in electronics and sunscreens.

Polymeric Nanoparticles

Made from polymers, often used in drug delivery systems.

Ceramic Nanoparticles

Such as silica and alumina, utilized in catalysis and biomedical applications.

Nanoparticles based on carbon

Includes fullerenes, Graphene and carbon nanotubes are well-known for their strength and conductivity.

Shape

Spherical Nanoparticles

Common in drug delivery.

Rod-like Nanoparticles

Such as nanorods, used in imaging.

Sheet-like Nanoparticles

Like graphene, used in electronics.

Size

Typically classified as ultrafine (1-10 nm), fine (10-100 nm), and coarse (100-1000 nm).[4,5]

Surface Characteristics

Functionalized Nanoparticles

Modified with specific chemical groups for targeted applications.

Coated Nanoparticles

Encapsulated with materials to enhance stability and performance [6.7]

Origin

Natural Nanoparticles

Found in nature, such as those from volcanic ash or bacteria.

Synthetic Nanoparticles

Engineered through chemical processes for specific applications [8]

Nanoparticle sources and their effects on health

Nanoparticles from natural sources

Nature produces nanoparticles through several processes, including

Photochemical reactions (e.g., reactions driven by sunlight in the atmosphere).

Volcanic eruptions (which release ash and gases that can form nanoparticles).

Forest fires (which produce soot and other particulate matter).

Erosion (wind and water erosion of rocks and soil, contributing mineral particles to the atmosphere).

Biological loss (like skin and hair shedding).[9]

Impact of Natural Events on Aerosol Concentrations

Significant natural things like volcanic eruptions, forest fires dust storms release nanoparticulate matter (small particles) that affect air quality on a global scale. These events contribute to aerosols, which are particles suspended in the air.

Comparison of Natural and Human-made Aerosols

Human-generated aerosols account for particulate emission only about 10%.

Remaining 90% comes from natural sources, showing the dominant role that nature plays in aerosol generation.

Global Impact of Aerosols

Aerosols, particularly those that are tiny (micro- to nanoscale), influence the energy balance of the planet. They can reflect solar radiation back into space or absorb it, thereby influencing global temperatures and climate.

Types of Atmospheric Aerosols and Their Sources

Mineral aerosols from soil deflation and wind erosion are the dominant source of atmospheric aerosols.

Other sources include:

Volcanic eruptions (~1% of total emissions).

Sea salt (released from oceans).

Sulfates (often from natural sources like oceans and some volcanic activity).

Biomass burning products (excluding soot).

Industrial emissions.

Nonmethane hydrocarbons (from both natural and anthropogenic sources).

Nitrates and **biological debris** (from plants, soil, etc.)

Module 2: Sources of Nanoparticles and Their Impacts on Health

Dust storms and their impact on health

Dust storms are a major source of environmental nanoparticles, with mineral dust and contaminants being transported over long distances. Around 50% of the aerosol particles in the troposphere come from desert regions. Meteorological studies have identified 10 major regions where dust storms occur frequently, contributing significantly to dust of global levels:

The Salton Sea
The Patagonia
The Altiplano
The Sahel
Desert of Sahara
Desert of Namibia
The Indus Valley
Lake Eyre Basin
Desert of gobi
Taklimakan Desert

These areas are known for their frequent dust events, which are essential to the global dust cycle.[10]

Health impact

Terrestrial dust particles can pose health risks, especially for individuals with asthma or emphysema. Dust containing metals like iron can trigger the Reactive oxygen species production in the lungs, leading to tissue scarring. Additionally, dust contaminated with viruses, bacteria, fungi, or chemicals can harm both human health and the environment. Airborne particles from the lunar module upset Apollo astronauts' lungs and eyes.Longer voyages to the moon or Mars may pose a danger of respiratory infections and mechanical breakdowns in spacesuits and airlocks. In rats, administering modest quantities of lunar material intratracheally caused pneumoconiosis and fibrosis.

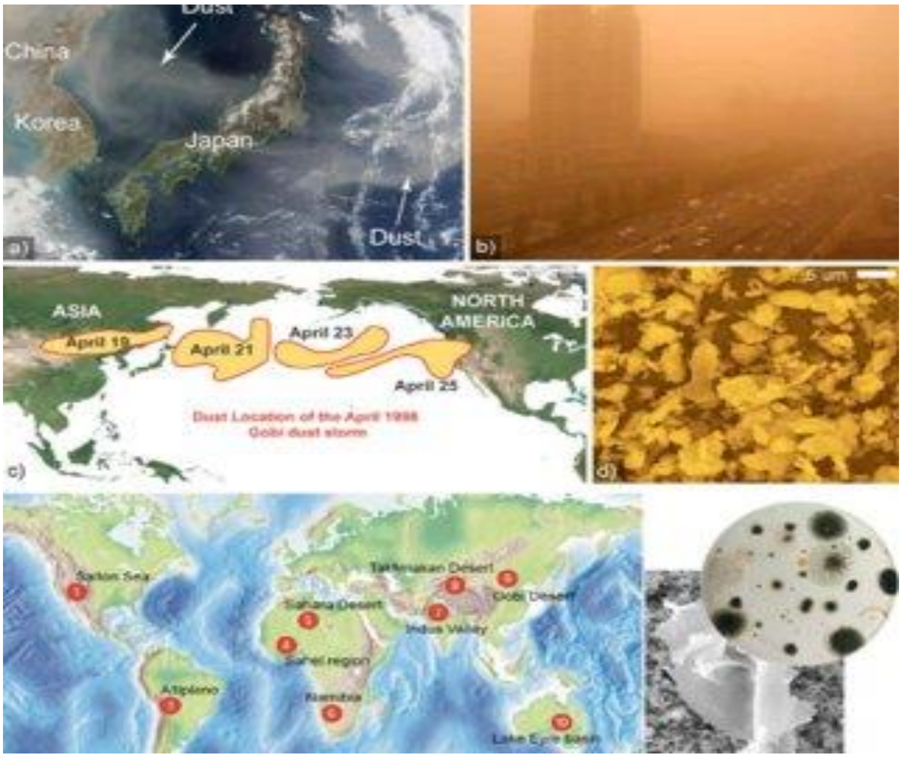

***Figure 1**: Sand storms visualized at macro and microsale*

Forest fires and their impact on health

Lightning strikes or human activity are the main causes of forest and grass fires, which have been a natural occurrence for centuries. Major fires can release ash and smoke across vast areas, significantly increasing particulate matter levels in the air. These fine particles, including nanoparticles, often exceed air quality standards, posing serious health risks. Satellite imagery offers a valuable tool for monitoring global fire activity, providing a comprehensive view of fire spread and its environmental impact.

Since February 2000, NASA's Terra satellite has used MODIS, a moderate-resolution image spectroradiometer, to record daily worldwide fire activity throughout the Earth's surface Fires occur globally, including savannas in North America, Europe, and Asia, as well as Africa, Australia, and Brazil. Since February 2000, NASA's Terra satellite has used MODIS, a moderate-resolution image spectroradiometer, to track daily worldwide fire activity across the Earth's surface. Fires occur globally, including savannas in North America, Europe, and Asia, as well as Africa, Australia, and Brazil.

Health effects

Medical visits during forest fires rise by about 50%, according to epidemiological research. Patients with underlying cardiopulmonary problems experienced increasing symptoms that occur with sessions of smoking. Air purifier use was linked to reduced negative effects on the lower respiratory system health. Health consequences.

Fire-related deaths about 75% result from respiring issues due to inhale smoke rather than burn. In the emergency department, oxygen is commonly used to treat smoke inhalation. Symptoms may not appear until 24–36 hours after exposure, so patients should be monitored for respiratory complications for several days, even if they seem stable initially. [11]

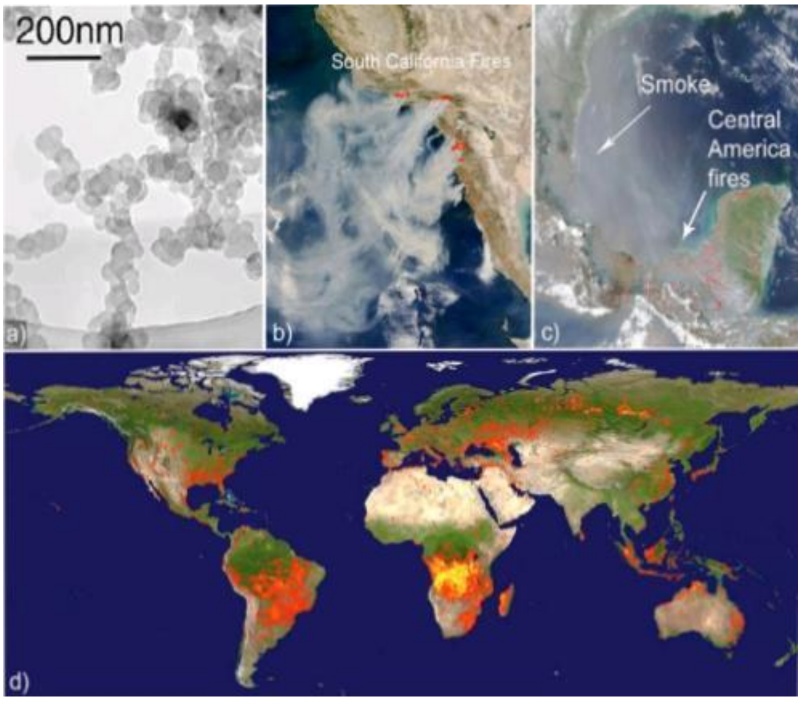

Figure 2: *Image of TEM of smoke aggregates*

Volcanoes' impact on health

Volcanic eruptions release massive amounts of gases and ash, with particles that size ranging from nanometer to micrometer, often reaching altitudes above 18,000 meters up to thirty million tons of ash can be released in an individual outburst. These particles, especially those in the higher stratosphere and troposphere, can path globally and have long-term environmental impacts. They block and scatter solar radiation, leading to cooling effects on the Earth's climate. In addition to ash, heavy metal particles released by volcanoes can be toxic to humans, posing significant health risks. While particulate matter levels are highest near the eruption site, the effects can be felt worldwide**.**

Health effects

Long-term exposure to volcanic particle pollution can have significant health consequences, especially for barefoot agricultural communities in regions with soils of volcanic, like parts of the Mediterranean, Central America, Africa. These populations are often exposed to fine volcanic ash and aerosols through daily activities like farming, walking barefoot, and living in close proximity to volcanic environments.

Chronic exposure to volcanic particles can lead to respiratory problems such as chronic bronchitis, lung diseases, and even a heightened risk of lung cancer. Additionally, fine ash particles can irritate the eyes and skin, causing conditions like conjunctivitis and dermatitis. Over time, prolonged exposure may also contribute to cardiovascular problems, weaken immune systems, and exacerbate pre-existing health conditions. The risk of these health issues is compounded in areas where air quality is consistently poor, and where access to healthcare may be limited. Many individuals in this demographic suffer from lympho-endothelial disorders. The illnesses include podoconiosis and Kaposi's ***sarcoma.***[12]

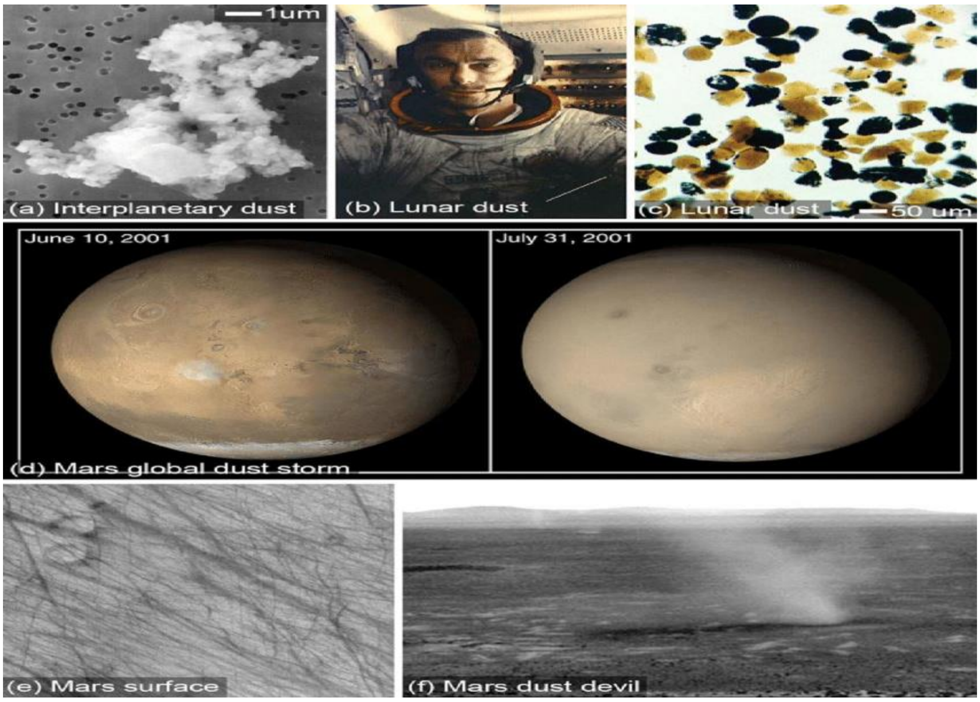

Figure 3: *Extraterrestrial dust*

Water and ocean evaporation, and health impacts

Seas and oceans release sea salt aerosols into the atmosphere, produced by the evaporated water and water droplets propelled by waves. These aerosols range in size from 100 nm to several microns. Additionally, water bodies like Lake Michigan, which is located in a limestone basin, also produce nanoparticles. During colder months, calcium carbonate dissolves in the water, but as temperatures rise in summer, its solubility decreases, causing it to precipitate. This process creates clouds of tiny particles, which, when seen from above, can resemble bright swirls.

Health Impact

There have been no reported harmful health consequences related with sea salt aerosols. Salt aerosols may improve mucociliary clearance in individuals with respiratory disorders, perhaps benefiting their health. Salt mines, with their peculiar microclimate, are commonly used in Eastern Europe to treat asthma. However, pollutants and microorganisms that could have detrimental effects on health could be carried by sea salt aerosols.[13]

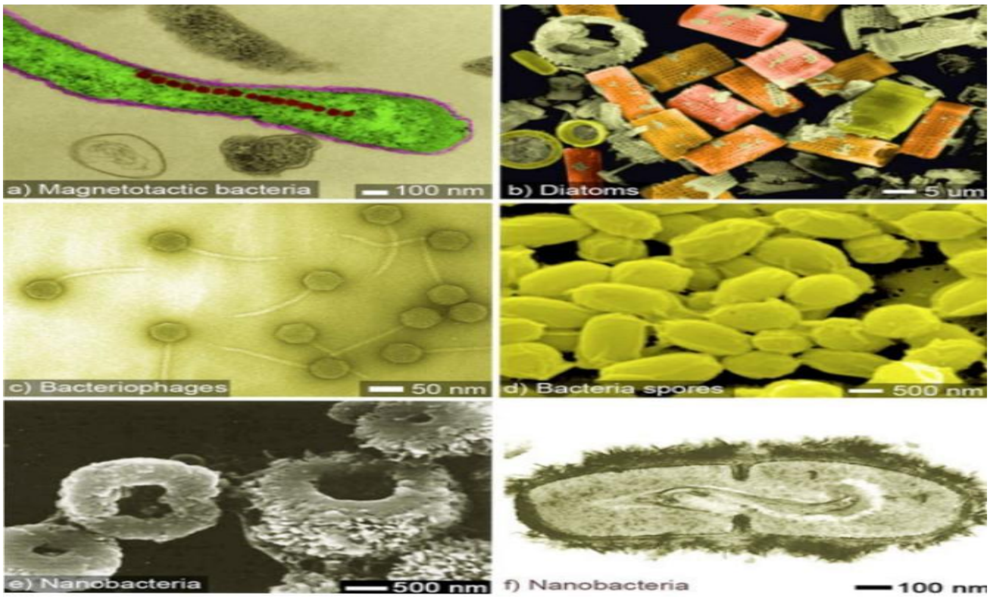

Figure 4*: *Nanoscale organisms or those generating solid-state nanoscale waste

Anthropogenic nanomaterial

Nanomaterials, both naturally occurring and man-made, have been part of human activities for millennia. Early examples include combustion in processes like cooking, smelting, and welding, where nanoparticles were unintentionally produced. In modern times, man-made nanomaterials are intentionally engineered for use in various industries, including cosmetics (e.g., sunscreens), sports goods, and food additives. Common examples include carbon black in tires and fluorescent quantum dots in biological imaging. Despite their wide use, these materials represent just a tiny portion of the environmental nanoparticles, most of which result from industrial processes like power generation and combustion.

Health impacts of engine and diesel exhaust nanoparticles

Automotive exhaust and diesel are significant sources of micro and nano-particles in environments. Diesel engine exhaust particles typically range from 20-130 nm, while gasoline engine particles range from 20-60 nm, with both types commonly being spherical in shape. Research has also identified the presence of carbon nanotubes and fibers in diesel engine exhaust, as well as in areas around gasoline combustion sources. These particles, especially carbon nanotubes, are of particular interest in toxicological studies due to their potential health risks. [14] Exhaust fibers have a similar aspect ratio to lung-retained asbestos, indicating the presence of potentially harmful carcinogens. Prior to the announcement of these results, materials experts believed they did not exist in nature and ascribed their existence only to engineering. Diesel-generated particles contain more than 90% nanoparticles, although accounting for just 20% of their bulk. Recent health concerns led to investigations on particle size distribution and concentrations in cities across continents.

Health effects

The severity of harmful health consequences from engine exhaust varies among cities, perhaps due to the particle's complexity and structure mixes. Diesel exhaust is considered harmful due to its high quantities of polynuclear aromatic hydrocarbons, such as benzo-a-pyrene, which is carcinogenic. Car exhaust pollution of particles has a significant impact on death rates, with a substantial correlation between residing near major roadways and higher cardiopulmonary mortality [15]

This epidemiological study supports observations of nanoparticle concentrations near roads, which show an exponential decrease over several hundred meters from traffic. Exposure to combustion gases derived from oil, especially engine exhaust, during pregnancy or the early postnatal period, has been linked to a high risk of childhood malignancies. Professional drivers have a higher risk of experiencing a myocardial infarction or heart attack. [16]

The impact of indoor pollution on health

Compared to outdoor air indoor air can be moe polluted, with human activities like cooking, smoking, cleaning, and burning candles or fires generating significant amounts of particulate matter, including harmful nanoparticles. These indoor particles include skin particles, spores, chemicals, textile fibers, and dust mites from various sources. Some particles also enter buildings through ventilation systems from outside. Given that people spend indoor time more than 80%, the pollution indoor air is directly affecting health of human.

Impact of health

Indoor cooking emissions can have negative health impacts owing to particulate matter inhalation, especially over time. Cooking generates almost 10 times more particulate matter than non-cooking hours.ndoor smoke from solid fuels is a major cause of death globally, particularly in Africa and Asia.

An estimated 1.6 million people die yearly from illnesses related to indoor air pollution, with over half of these deaths being under the age of 5 children. The reports of WHO more than 50% of the population of global relies on fuels that are solid like biomass for heating and cooking. While burning of wood is often viewed as environmentally friendly due to its renewable nature, it is a significant source of nanoparticles and air pollutants, contributing to health risks, particularly in developing countries.

The impacts of cigarette smoke on health

Tobacco smoke is a complex aerosol consisting of a specific range of chemical compounds and nanoparticles. The nanoparticles in tobacco smoke typically size range from 10 nm to 700 nm, with the highest concentration around 150 nm. These nanoparticles are primarily made up of carbon and other substances, and they play a role in delivering harmful chemicals to the lungs. In addition to nanoparticles, tobacco smoke contains approximately 100,000 different chemical components, including toxic gases (such as carbon monoxide, formaldehyde, and ammonia) and particulate matter. These chemicals contribute to the harmful health effects of smoking, such as cancer, respiratory diseases, and cardiovascular issues.

Nanoparticle source	Concentration (Nanoparticles/cm3)	Estimated source strength (Particles /min×10)
Pure wax candle	241500	3.65
Radiator	218400	8.84
Cigarette	213300	3.76
Frying meat	150900	8.27
Heater	116800	3.89
Gas stove	79600	1.3
Scented candles	69600	0.88
Vaccum cleaner	38300	0.38
Air freshener Spray	29900	0.34
Ironing a cotton sheet	7200	0.007

TABLE 1*: *Nanoparticle concentrations measured as a result of various common indoor household activities

Health impacts

The smoke from tobacco is harmful due to its gas phase and nanoparticles. Numerous research has examined the negative health impacts of ambient cigarette smoke. Adults who smoke cigarettes, whether first-hand or second-hand, are more likely to develop chronic respiratory illnesses such as lung cancer, nasal cancer, cardiovascular disease, pancreatic cancer, and genetic changes. Cigarette smoke exposure in children increases the incidence of SIDS lower respiratory tract infections, middle ear issues, and increased asthma. Compared to nonsmokers, cigarette smokers are more likely to develop a number of illnesses, such as cancer and heart disease. Quitting smoking significantly reduces the incidence of myocardial infarction within two years, indicating that the susceptibility caused by inhaled nanoparticles is reversible [17]

Building destruction and its impact on health

When major buildings are demolished, Respirable particulate matter particles concentration dramatically rises less than 10 m. Demolition sites frequently contain hazardous materials such as asbestos fibers, lead, glass, wood, and paper. Furthermore, dust clouds may travel long distances and impact nearby areas.

Health effects

The impact of health exposure to soot and demolition particles from the WTC (World Trade Center) disaster on 11 September 2001, are not fully understood. Early epidemiological and clinical studies at the site of firefighters showed short-term respiratory issues such as bronchial hyperactivity and cough. However, the long-term health implications of such exposure, including the potential for chronic diseases or cancer, remain uncertain and require further research.

Other consumer products and cosmetics, and impact of health

Nanotechnology has significantly advanced the cosmetics industry by enabling the engineered nanoparticles use in a variety of products. Some key applications include:

Skin Penetration and Delivery

Nanoparticles can penetrate deeper into the skin, delivering active ingredients like peptides that stimulate cell regeneration, improving skin health.

Antioxidant Properties

Nanoparticles such as functionalized fullerenes have antioxidant benefits, helping to neutralize free radicals and reduce signs of aging, often found in creams and lotions.

Optical Effects

Nanoparticles like alumina nanopowder are used to optically conceal wrinkles and fine lines by reflecting light, giving the skin a smoother appearance.

These nanoparticles are found in a specific range of product of personal care, including deodorants, shampoos, toothpastes, sunscreens, makeup (foundation, blush, eye shadow, etc.), and fragrances. The use of nanotechnology helps improve product efficacy, enhance aesthetic properties, and create novel formulations for various cosmetic needs.

Health impacts

The Environmental Effects of Particles in consumer items are unknown, however nanotoxicology has shown that previously regarded benign compounds can cause harm. Silver, a commonly used antibacterial agent, may be hazardous to human or cells from animals in particle form, with toxicity higher than arsenic. Silver nanoparticles can travel to the olfactory bulb, mitochondria, liver, circulatory system, heart, and kidneys, following inhalation. In blood of patient Particles of silver have been found with problems of blood, as well as in the colons of those with cancer of the colon.

Effect of nanoparticles on lungs

Inhaled particles, both organic and inorganic, are cleared from the airways through mechanisms like mucus retention and macrophage phagocytosis. The mucociliary escalator moves these particles to the throat for swallowing or expectoration. Relative to their mass the smaller particles (typically less than 100 nm in diameter, known as nanoparticles) have a much higher surface area compared to larger particles. This surface area increases enhances their reactivity, allowing them to interact more readily with lung tissues or be engulfed by macrophages. [18]

Nano-sized materials, with their high surface reactivity, can effectively target the pulmonary epithelial surface even in small quantities. Due to their small size, a nanoparticle of large concentration can deposit in respiratory units, particularly the alveolar region, where they can interact with the sensitive barrier between alveolar epithelium and endothelium. These particles may be able to translocate into deeper tissues due to the near alignment of the capillary endothelium and alveolar epithelium, which might either allow for focused therapy or provide toxicity hazards.[19]

What are the effects of nanoparticles on respiratory health?

Studies in rats show that ultrafine or nanoparticles cause more severe lung inflammation and tumor formation than larger particles of the same chemical composition at equal mass concentrations. This heightened toxicity is attributed to factors like surface area and chemistry, which play a significant role in nanoparticle behavior. When inhaled as single particles rather than aggregates, nanoparticles deposit more efficiently in the lungs. Once in the alveolar regions, these particles can bypass the lung's defense mechanisms and migrate into the interstitial areas, a vulnerable part of the respiratory system, increasing the risk of harm.

To determine the possible dangers of nanomaterials, hazard studies with different types of nanoparticles are necessary due to a lack of evidence on their health, safety, and environmental impact. Different nanoparticle kinds, like other particles and fibers, may provide varying toxicity outcomes. Not all nanoparticles are dangerous or benign.

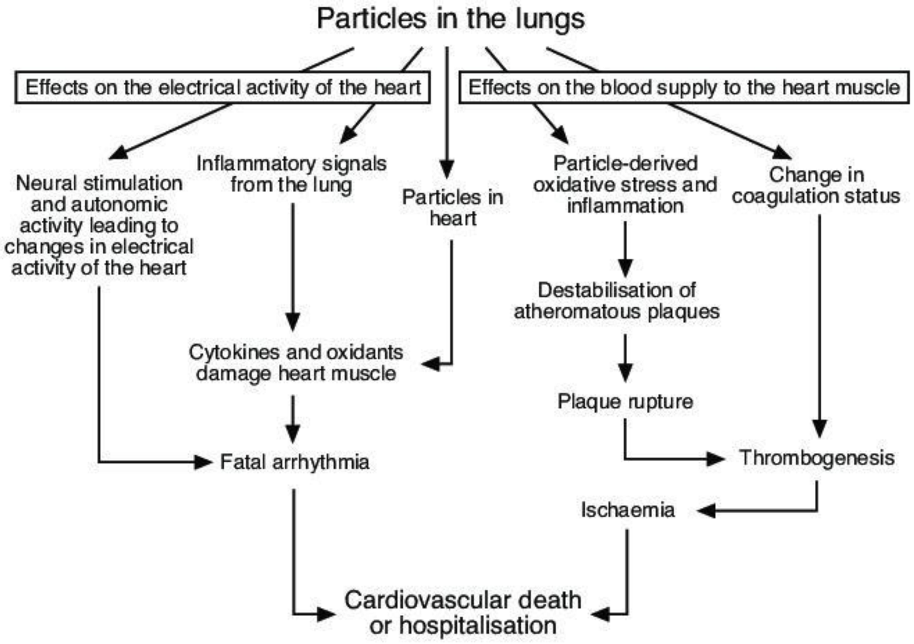

Figure 5: *Particles in the lungs*

Physicochemical properties of NPs

These properties include

Large Surface Area

NPs have a high surface-to-volume ratio, which enhances their reactivity and makes them ideal for catalysis, drug delivery, and surface modification.

Mechanical Strength

Due to their small size and high surface energy, NPs often exhibit exceptional mechanical strength and durability, which is beneficial for materials science and engineering.

Optical Activity

NPs can exhibit unique optical properties, such as surface plasmon resonance (SPR), which makes them useful in imaging, sensing, and photonic devices.

Chemical Reactivity

The increased surface area and reactivity of NPs make them highly effective in chemical reactions, such as catalysis, environmental remediation, and sensors.

These characteristics enable NPs to be employed in a specific range of including medicine, energy, electronics, fields, and environmental applications.

Electronic and optical characteristics

The size-dependent optical characteristics of Nobel metal (NP) nanoparticles include a discernible UV-visible extinction band that is absent from bulk metals. This band, called LSPR (localized surface plasmon resonance), is created when conduction electrons collectively oscillate in response to incoming light. LSPR leads to selective absorption at specific wavelengths and enhances the molar absorption coefficient. Additionally, NPs can scatter light efficiently, with scattering intensity comparable to 10 fluorophores, while also generating strong local electromagnetic fields at their surface. These properties make NPs useful for enhancing spectroscopy and sensing applications [20]

Gold and silver nanoparticles (NPs) exhibit distinctive colors because their localized surface plasmon resonance (LSPR), which occurs when free electrons on their surfaces oscillate in response to light. Gold NPs often appear rusty, while silver NPs appear yellow. The LSPR effect is influenced by the movement of d-electrons in these metals, and their mean free path (about 50 nm) is larger than the NP size, preventing bulk scattering. When light interacts with these NPs, it induces a resonant oscillation of surface electrons, leading to the characteristic colors and optical properties.

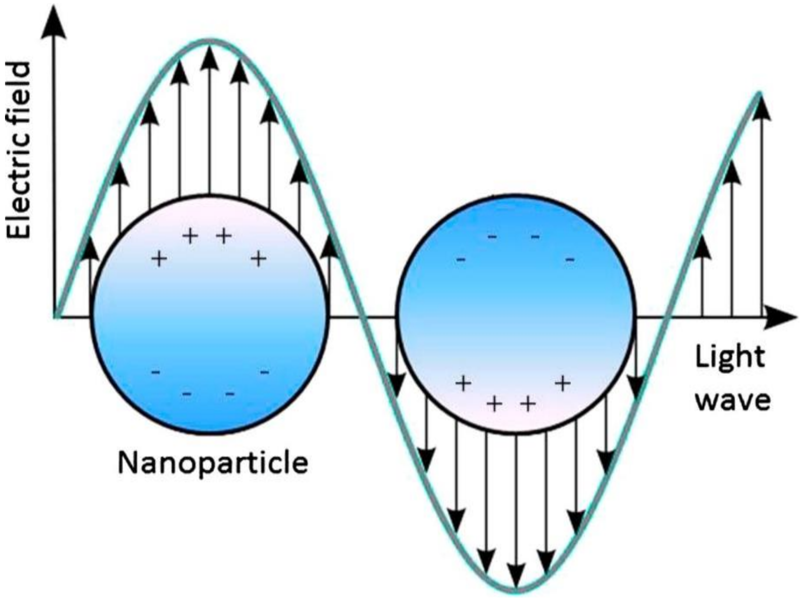

Figure 6: *On nanoparticle outer surface Graphical representation showing the LSPR (localized surface Plasmon response*

Magnetic properties

Magnetic nanoparticles (MNPs), typically sized between 10-20 nm, have garnered significant interest across various fields because their specific magnetic characteristics at the nanoscale. According to Reiss and Hutten (2005), this size range is optimal for maximizing the magnetic characteristics of the particles, which make them valuable in applications like data storage, biomedicine, homogeneous and heterogeneous catalysis, MRI, magnetic fluids, environmental remediation.Their small size allows for high surface area, enhanced reactivity, and the ability to respond to external magnetic fields, contributing to their versatility and efficiency in these diverse fields.

Mechanical properties

Nanoparticles (NPs) exhibit unique mechanical characteristics that differ from bulk materials and microparticles, making them valuable in technique such as nanofabrication, and nano-manufacturing tribology, surface engineering. Key mechanical properties, like stress, strain, adhesion, and friction, elastic modulus, hardness, help define their behavior. Surface treatments like coating, coagulation, and lubrication enhance these properties When there is lubricated contact, rigidity occurs difference between the external surface and NPs influences how NPs deform under pressure—whether they indent or distort the surface. Understanding and controlling these mechanical properties is necessary for improving material and surface quality removal in various applications.

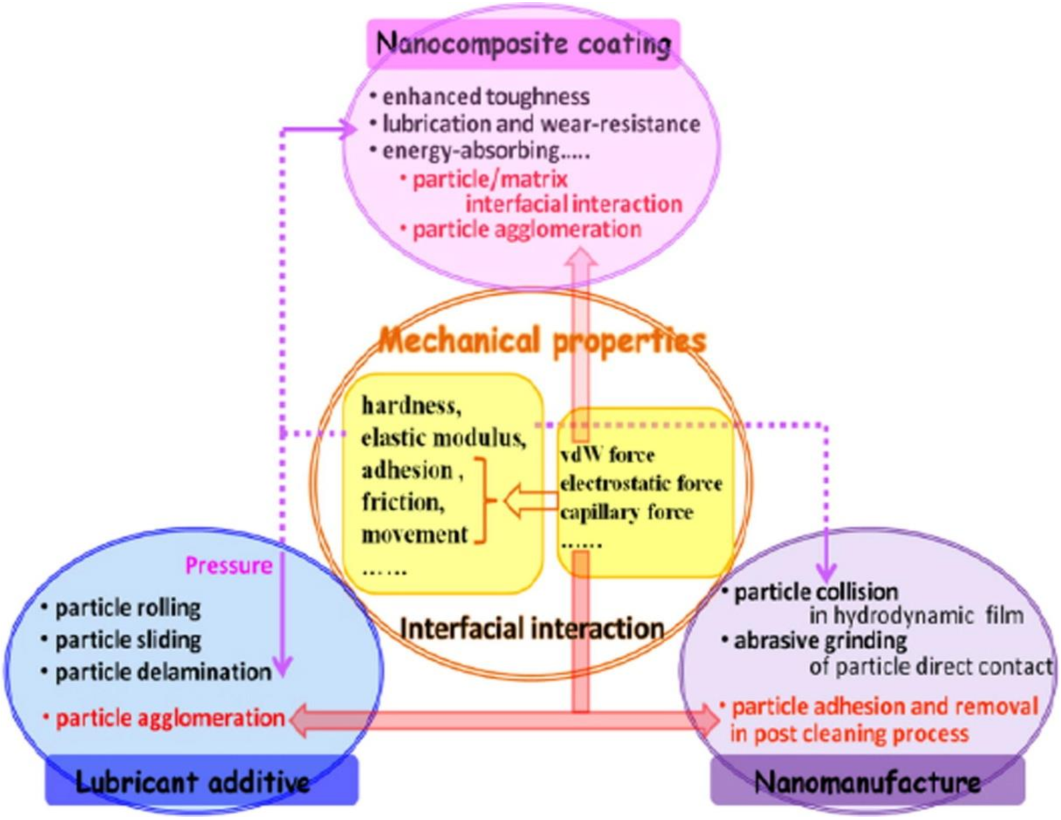

Figure 7: A diagrammatic representation of mechanical properties and their applications

Thermal properties

When metal nanoparticles, like copper, are solid, their thermal conductivity is much greater than that of fluids. For example, the thermal conductivity of copper is approximately 700 times that of water and 3000 times that of motor oil. The heat conductivity of metal oxides, such as alumina (AlO_3), is greater than that of water. It is anticipated that fluids with suspended solid particles, or nanofluids, would have far higher thermal conductivities than traditional heat transfer fluids, increasing their efficiency [21]

Module 3: Nanoparticles Application

Application in drug and medication

Complex or Simple, inorganic nano-sized particles have special chemical and physical characteristics that make them essential for creating novel nanodevices with a variety of uses in the biological, pharmacological, biomedical, and physical domains. Nanoparticles' (NPs') optical characteristics are very useful for improving contrast in photothermal treatment and biological and cell imaging. For widely utilized NPs, such as gold (Au) nanoparticles, silica-Au NPs, and gold nanorods, methods such as Mie theory and the discrete dipole approximation are used to calculate absorption and scattering efficiencies as well as optical resonance wavelengths in order to assess their optical behavior. Drugs can be better dissolved, stabilised, and released under regulated conditions by being Encapsulated in nanoparticles and liposomes.[22]

The Medication is in the distribution area and the medication is absorbed into the body.[23]

Applications for manufacturing processes and materials

Nanocrystalline materials are of great interest in material science because their properties change with size, differing significantly from bulk materials. Manufactured nanoparticles (NPs) exhibit unique electrical, mechanical, optical, and imaging characteristics, making them valuable in various applications across medical, commercial, and environmental sectors. NPs are designed to create and enhance both biological and non-biological systems with specialized functional capabilities. The potential benefits of nanotechnology are well recognized, and many commercial products are already being mass-produced in industries such as microelectronics, aerospace, and pharmaceuticals.[24]

Application in environment

Engineered nanoparticles (NPs) are being released into the environment as a result of their increasing use in consumer and commercial products. Evaluating NPs' mobility, reactivity, ecotoxicity, and persistence is necessary to comprehend the environmental dangers they pose. NP concentrations in soil and groundwater, two important exposure routes for environmental effect, might rise as a result of engineering uses. Environmental applications of nanotechnology generally fall into three groups.:

Creation of ecologically friendly goods, including those for pollution control or green chemistry.
Maintenance of hazardous contaminants in particles.
Sensors for monitoring environmental conditions. [25]

Application in electronics

Because printed electronics have benefits over conventional silicon-based methods and provide the possibility of low-cost, large-area electronics appropriate for flexible displays and sensors, interest in printed electronics has increased recently. Metallic nanoparticles (NPs), organic electronic molecules, carbon nanotubes (CNTs), and ceramic NPs are among the functional inks used in printed electronics. It is anticipated that these materials would spur quick acceptance as a mass manufacturing technique for novel electronic device types, allowing for more flexible and economical manufacture.

Metals and One-dimensional semiconductors possess unique optical, electrical and structural properties, creating them ideal building blocks for next-generation electronic, sensor, and photonic materials. Their distinctive characteristics enable enhanced performance in applications like advanced electronics, sensing technologies, and optical devices, driving innovation in these fields.[26]

Application in harvesting energy

Scientists are concentrating on renewable energy sources as a result of recent studies showing the nonrenewable fossil fuels are becoming increasingly scarce. Because of their vast surface area, optical characteristics, and catalytic potential, nanoparticles (NPs) are thought to be the best candidates for this use. In order to produce energy, NPs are frequently employed in photocatalytic processes such electrochemical water splitting and photoelectrochemical (PEC). They are also utilized in energy storage technologies, offering efficient methods for energy conservation at the nanoscale level. The active component of nano-spheres is distributed in a matrix-like structure, whereas the drug in nanocapsules is protected by a polymeric membrane. [27]

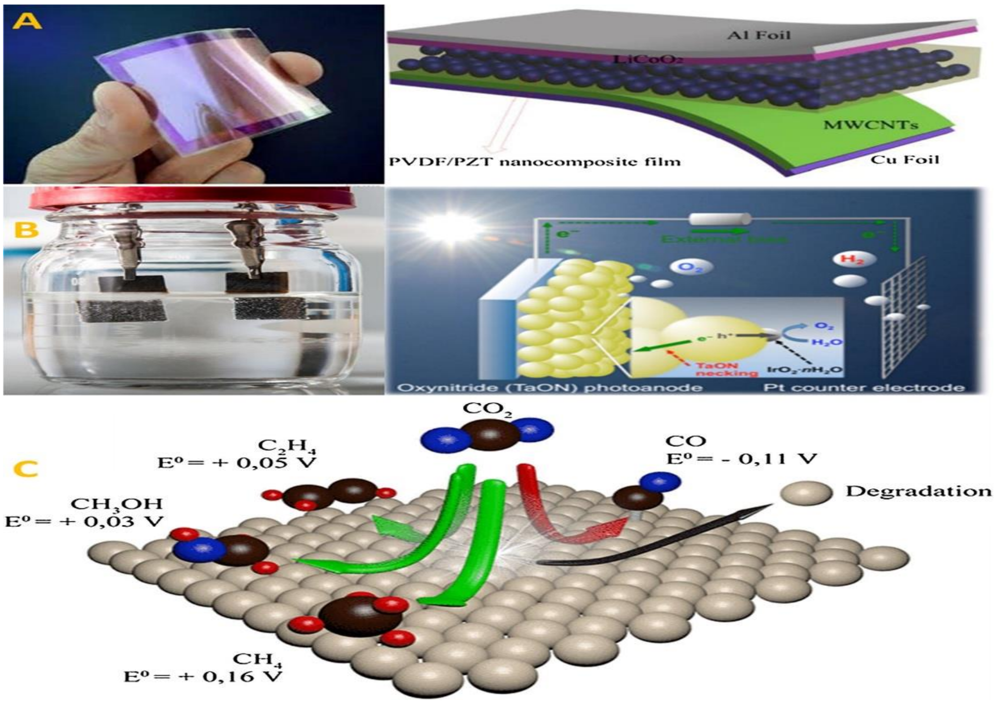

***Figure 8**: Approaches to energy creation include (A) piezoelectric actuators, (B) water splitting, and (C) carbon reduction Application in mechanical industries*

Nanoparticles (NPs) are increasingly used in mechanical industries for applications like coatings, lubricants, and adhesives because exceptional properties of mechanical, like high Young's modulus, stress, and strain resistance. By integrating NPs into metal and polymer matrices, the mechanical strength of materials can be enhanced at the nanoscale. NPs' behavior in lubricated contact zones, where they roll, can significantly reduce friction and wear, improving lubrication. Additionally, NPs like alumina, titania, and carbon-based materials are proven to enhance toughness and wear resistance in coatings, contributing to mechanically stronger and more durable materials.

Toxicity of nanoparticles

Nanoparticles (NPs) and other nanomaterials, while valuable for industrial and medical applications, pose toxicity risks to the environment and living organismsBecause of human activity, NPs can infiltrate the environment through the air, water, and soil. Their usage in environmental cleaning (such as injecting NPs into aquatic systems or soil) poses issues. Organic matter and other natural colloids, especially in freshwater systems, have an impact on the behavior of NPs, which tend to assemble in hard water or saltwater in aquatic settings. NPs' ecotoxicity is influenced by their dispersion state, and in order to fully comprehend their environmental impact, a number of abiotic parameters, including pH, salinity, and the presence of organic molecules, must be carefully investigated.[28]

CONCLUSION

An overview of nanoparticles is given in this review covering their types, production, characterization, and applications. NPs typically range in size 500 nm to a few nanometers, with varying morphologies. They are perfect for many applications because of their huge surface area resulting from their compact size, including photocatalysis due to their distinctive optical properties. Characterization methods like SEM, TEM, and XRD are used to analyze NP size and structure. Synthetic techniques allow precise control over NP shape, size, and magnetic properties. However, despite their benefits, unregulated use and disposal of NPs pose significant health and environmental risks, highlighting the need for safer, more sustainable practices in their application.

REFERENCE

1. Yan Liu, Jin Choi, Nanomaterials and their Applications in Energy, Medicine, and Environmental Protection, Journal of Nanoscience and Nanotechnology,2016: 6(2): 143-156.
2. C. Arden Pope, Douglas W. Dockery, Health Effects of Fine Particulate Air Pollution: Lines that Connect, Journal of the Air and Waste Management Association, 2006:5(6): 709-742.
3. Günter Oberdorster , Eva Oberdorster, Jan Oberdorster, Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles, Journal of Environmental Health Perspectives,2005: 3(7): 823-839.
4. Ying Huang, Zhi Zeng, Guangming Chen, Nanoparticles: Classification, Properties, and Applications in Drug Delivery, Journal of Nano Today,2013: 8(5):423-440.
5. Suman Chakraborty, Siddharth Saha, Nanoparticles: Synthesis, Properties, and Applications in Drug Delivery, Indian Journal of Pharmaceutical and Health Technology, 2018:8(1): 45-54.
6. Meera Kumari, Suman Singh, Surface Modification of Nanoparticles for Targeted Drug Delivery, Indian Journal of Pharmaceutical and Health Technology, 2017:6(4): 115-121.
7. Pooja Sharma, Ankita Gupta, Coating Strategies in Nanoparticle-based Drug Delivery Systems, Indian Journal of Pharmaceutical and Health Technology,2018: 7(1):55-63.
8. Praveen Kumar, Vikas Sharma, Nanoparticles: Synthesis, Applications, and Their Role in Pharmaceutical Sciences, International Journal of Pharmaceutics and Pharmaceutical Technology, 2017:8(4): 123-137.
9. Amit Kumar, Vikas Saini, Natural Nanoparticles: Sources, Formation, and Environmental Significance, Journal of Environmental Nanotechnology, Monitoring and Management,2019: 11(2):13-29.
10. Ying Zhu, Lijun Wang, The Contribution of Dust Storms to Environmental Nanoparticles and the Global Dust Cycle, Journal of Atmospheric Environment, 2021:5(6): 118-133.
11. Lynette L. Jaffee, Stephen D. Hayes, Smoke Inhalation and Respiratory Complications: Emergency Management and Treatment Strategies, Journal of Emergency Medicine, 2016:4(5): 595-602.
12. Margarita Rojas, Pablo Garcia, Health Effects of Chronic Exposure to Volcanic Ash and Fine Particles: Respiratory and Cardiovascular Risks, Journal of Environmental Health Perspectives, 2017:2(5): 540-548.
13. Xiaodong Zhao, Jun Zhou, Sea Salt Aerosols: Health Benefits and Risks in Respiratory Disorders, Journal of Environmental Science and Technology, 2018:2(14): 7925-7934.
14. David B. Kittelson, Engines and Nanoparticles, Journal of Aerosol Science, 1998:9(5): 505-532.
15. Darryl Krewski, Extended Follow-up and Spatial Analysis of the American Cancer Society Study Linking Particulate Air Pollution and Mortality, American Journal of Respiratory and Critical Care Medicine, 2009:7(5):383-390.

16. Julien Perron, Traffic-related Air Pollution and Myocardial Infarction Risk in a Population-based Cohort Study, Journal of Environmental Health Perspectives,2015: 5(4):358-365.
17. Alfonso G. Bertoni, Impact of Smoking Cessation on the Risk of Coronary Artery Disease, Journal of Circulation, 2009:9(3): 366-372.
18. Gunter Oberholster, Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles, Journal of Environmental Health Perspectives, 2005:3(7):823-839.
19. Wolfgang Moller, Pulmonary Effects of Inhaled Ultrafine Particles: The Role of Nanoparticle Deposition and Translocation, Journal of Aerosol Science, 2008:8(7): 590-597.
20. Stefan Schlucker, Surface-Enhanced Raman Spectroscopy: Concepts and Chemical Applications, Journal of Angewandte Chemie International Edition, 2014:3(9): 4756-4795.
21. James A. Eastman, Anomalously Increased Effective Thermal Conductivities of Ethylene Glycol-based Nanofluids Containing Copper Nanoparticles, Journal of Applied Physics Letters, 2001:7(6):718-720.
22. Sanjay K Bais, Vivek S Kolekar, Advancements in Ocular Drug Delivery Systems: A Comprehensive Review, International Journal of Pharmacy and Herbal Technology ,2024:2(1):699-708.
23. Jiwan P.Lavande, Sanjay.K.Bais,Shamal Lokhande,A Systematic Review On Nanoemulsion, International Journal of Pharmacy Herbal Technology ,2024:2(1):1129-1140.
24. George M. Whitesides, Nanotechnology: A Research Field with Significant Potential for Innovation, Journal of Science, 2007, 8(5): 1457-1461.
25. Sandeep K. Sahoo, Soma Praveen, Nanoparticles in Environmental Cleanup, Journal of Environmental Chemical Engineering, 2012:1(1):81-96
26. Douglas A. B. Miller, Photonic Materials for the Next-Generation Optical Devices, Journal of Nature Photonics, 2012:6(3): 159-168.
27. Shrinivas R. Mane, Sanjay K. Bais, Gauri Anuse, Review of Herbal Novel Drug Delivery System, International Journal of Pharmacy and Herbal Technology,2024:2(1):1021-1042.
28. Jian Liu, Influence of Natural Organic Matter on the Behavior of Nanoparticles in Aquatic Systems, Journal of Environmental Science and Technology, 2013: 7(4): 7766-7773.