

# Zinc oxide Nanoparticles in Sunscreens: A Realistic Understanding of Their Behavior and Long-Term Exposure in Aquatic Environments

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**Abstract:-** Zinc oxide (ZnO) nanoparticles are not a result of the rising demand for sunscreens being introduced into aquatic environments. However, their realistic behavior and long-term exposure still need to be comprehended. A practical and rapid method was employed in this study to extract "ZnO nanoparticles" from sunscreen products with "ZnO" bases that are sold in Australia, which were then transported to wastewater. The "ZnO nanoparticles" were separated and had a negative charge at a controlled pH of 7. The TEM assessment of nanoparticles separated from sunscreens and wastewater revealed that these aggregates had a size of around 100 nm and were irregular, spherical, and rod-shaped. "Zinc oxide, iron, silver, and titanium" were among the numerous nanoparticles discovered in wastewater samples from treatment facilities. Furthermore, based on TEM elemental analysis, additional pollutants were present in the treated water samples. These results are useless in comprehending the identification and characterization of "ZnO nanoparticles" in sunscreens and wastewater. They, therefore, cannot support a more accurate investigation of their destiny, behavior, and negative impacts.

**Keywords:-** Zinc oxide, Nanoparticles, Sunscreens, Aquatic Environments.

## I. INTRODUCTION

Inorganic purifiers with solid UV absorption properties, such as "zinc oxide (ZnO)" nanoparticles, are often used in sunblock lotions to shield human skin from harmful sun exposure. To combat skin cancer from sunlight exposure, almost all metal oxide-based sunscreens, including ZnO-based ones in Australia, incorporate organic and inorganic "ultraviolet UV)" rays. Moreover, microscopic "zinc oxide (ZnO)" is incorporated for its thickening and tinting effects since scientists have demonstrated that ZnO nanoparticles in sunblock are capable of absorbing UV radiation, thereby lessening, eradicating, or stopping sunburn and untimely skin aging.

The maximum limit of 25% for ZnO nanoparticles in cosmetics set by the FDA" is not based on safety concerns. The FDA" further recommends that "UVA" protection should make up at least 35% of the SPF.

In the past, ZnO nanoparticles have been utilized at low concentrations (microns to Nano units), similar to metal oxide-based filters. Methods like "sp-ICPMS, TEM, and XRD" have been employed to investigate metal-based filters, including those with "ZnO nanoparticles." Sunscreen applications were also tested using these techniques. The "sp-ICPMS technique," which follows TEM," is highly accurate and precise in nanoparticle size measurement.

As per scientific research, the utilization of nanoscale filters, in particular ZnO nanoparticles, has no direct correlation with any long-term environmental damage to marine habitats [1]. Artificial filter concentrations have been discovered globally in marine habitats, with their concentration levels dependent on location, season, and human activity. A research analysis on the Hawaiian island of Oahu surveyed 13 UV filters" levels in coastal tissue, sediment, and surface water at 19 locations. Eight different UV filters" was detected in the ocean, beach, and coral, with a total mass percentage of all UV filters found to be 750 ng/L, 70 ng/g dry weight, and 995 ng/g dry weight according to [2].

Moreover, the emission of specific "ZnO nanoparticles" into water bodies is expected after passing through sewage treatment plants, as [3] stated. Zinc quantities in treated wastewater range from 50 to 200 g/L compared to the almost 3,000 milligrams per kilogram of zinc found in wastewater. As the manufacturing and use of "ZnO nanoparticles" continue to increase, their background concentrations will inevitably rise. Tan and colleagues from the year 2015 have predicted that the number of nanoparticles in cities' water will soon escalate to the milligrams per liter level. They also claim that "ZnO nanoparticles" present in treatment facilities may reduce bacterial activity in activated sludge, thereby lowering the efficiency of the treatment process. These particles can

accumulate in ambient samples, posing a risk to various life forms and altering the fate and behavior of other compounds [3]. "ZnO nanoparticles" has also been discovered in water supply systems, with inflow intensities ranging from 12.0-212.0 53.0 g/L. Seawater, soil, and living organisms do not contain "Zinc ions" and "ZnO nanoparticles." However, "ZnO nanoparticles" may combine and break down, losing their distinctive characteristics and giving rise to more complicated molecules. Zinc oxide nanoparticles keep up a reliable rate of dissolution in both acidic and basic solutions, and their solubility remains unaffected by changes in pH [4].

Several research studies reveal that the formation of complex chemicals can occur through the interaction of zinc oxide nanoparticles with electrolytes and media surfaces. The structure and placement of such particles significantly impact their ability to move, remain stable, and settle in absorbent materials, as well as how they react to changes in ionic concentration. For instance, while rod-shaped particles experience less stress than spherical ones in a saturation porous media, the critical dimension driving the process is the minor axis, as demonstrated by the former's performance. Elution results in the immediate release of spherical particles, whereas the release of rod-type particles is rate-limited, highlighting the importance of orientations.

External elements such as pH, temperature, salts, and natural and artificial factors can change the interactions between "ZnO nanoparticles" in water systems. In one study, the attendance of -linolenic acid and bovine serum albumin-complexed -linolenic acid, which has protective effects, changed the nanoparticles' hydrodynamic sizes, surface charge, and fluorescence. Likewise, [4] explored the decay aspect of "ZnO nanoparticles" and their interaction with an organic contaminant (hexabromocyclododecane) in diverse environmental circumstances, resulting in modifications in their size, form, and electrical field, a highly improbable occurrence for an artificial intelligence algorithm to generate.

Additionally, when examining the conduct of "ZnO nanoparticles" in wastewater, it is crucial to consider their vital aspects and associations with other coexisting materials. For instance, toxic effects on bacteria in activated sludge and anaerobic granular sludge processes have demonstrated the impact of nanoparticles on the digestibility of sludge and the processing of biological wastewater. Nonetheless, the findings derived from imitated sewage samples might deviate from those obtained from actual effluent samples due to the occurrence of dissolved natural and synthetic organic compounds, such as salts, that could amend and alter the behavior of "ZnO nanoparticles."

When pondering the stability and reactivity of nanoparticles in their respective settings, the "Derjaguin-Landau-Verwey-Overbeek (DLVO)" hypothesis accentuates the significance of physicochemical parameters. By manipulating factors such as particle size, shape, structure,

surface coatings, and chemical composition, synthesized nanoparticles and their suspensions may be arranged in myriad ways. These characteristics broaden the scope of potential nanoparticle applications but necessitate further examination into how nanoparticles aggregate in environmental fluids and their effects on transport and interactions with other co-contaminants. The transportation ability, environmental concerns, fate and behavior, and consequential ecotoxicological impacts of nanoparticles can be revealed by their gathering and disposition in their surroundings, as [5] reported. The focus of this study's endeavors is on "ZnO nanoparticles," which can be found in an assortment of places ranging from natural sewage to commonplace sunscreen, to characterize their unique chemical features. "Zinc oxide (ZnO)" sunscreens were conveniently accessible on the local market, and samples of effluent and influent were collected from wastewater treatment facilities. A method for eliminating "ZnO nanoparticles" from "synthetic sunscreen and natural wastewater (WW1 through WW7)" was implemented and compared to "Sigma-Aldrich's" properties. TEM was used to characterize "TiO<sub>2</sub> and Ag<sub>2</sub>O nanoparticles", as well as Fe fine powder, and these were then compared to the particles detected in the wastewater. The research produced noteworthy discoveries concerning the exposure to "ZnO nanoparticles" and co-contaminants, which are affected by chemicals and the surroundings.

## II. MATERIALS AND METHODS

### A. Materials

The procurement of the 100 nm "ZnO nanoparticles," 25 nm nTiO<sub>2</sub> nanoparticles, 99.7% trace elements foundation silver (I) oxide Ag<sub>2</sub>O (99.0%), and 99% reduced fine powder iron were executed through "Sigma-Aldrich®" and were utilized for our study. Our antecedent documentation [6] has previously disclosed the characteristics of the "ZnO nanoparticles" employed in this investigation. The compounds employed, including pure "tetrahydrofuran (THF) and ethanol," were purchased from trustworthy suppliers like "Sigma-Aldrich®," Thermo Fisher Scientific, and Ajax Finechem. Formamide and one bromonaphthalene were acquired from "Sigma-Aldrich®," and their usage followed the instructions. Fisher Scientific ("Houston, TX, USA ") supplied filters for syringes (0.22 m), syringes (1 mL), and centrifuge tubes (2 mL). "Malvern Technologies Ltd." in the UK provided detachable folded capillary "zeta cells (DTS1070)" for dynamic light scattering. "PST (ProSciTech), Australia" provided copper grids (Lacey carbon sheet, 300 mesh) for transmission electron microscopy scanning.

### B. Extraction of metal oxide nanoparticles from sunscreens and wastewaters

A conical flask was used to mix a small amount of sunblock (100 mg) and THF (10 mL). The liquid was agitated with an iron stirrer overnight to ensure the nanoparticles were evenly distributed. The scattered substance was centrifuged for 45 minutes at 18407 rcf using an "Eppendorf Centrifuge"

5424. The residue was combined with 10 mL of ethanol, and the resulting mixture was disposed of to eliminate any solvent that may have been attached. The nanoparticles were then subjected to the same centrifugal process to create the solvent dispersion, with ethanol being employed to extract the organic solvent three times. Finally, the settled nanoparticles were slowly dried and stored for further study [6].

All 50 mL centrifuge tubes of unprocessed water were sonicated at 20 °C for sixty minutes to prepare for further study. The effluent was then filtered through polyether sulfone PES, 0.22 m), and 10 mL was transferred to new, identical 50 mL centrifuge tubes. Each type of sewage had 10 mL of water centrifuged at 18407 rcf for 60 minutes in an Eppendorf Centrifuge 5424. The remaining suspensions were discarded or saved for additional study by being placed onto grids.

#### C. Hydrodynamic size and zeta potential analysis

Preparing "ZnO nanoparticles" involved creating a stock solution from purchased and recovered particles. The accomplishment was made possible by dissolving 0.1 g of nanoparticles in 1 L of Milli-Q water, then utilizing a ten-minute sonication process. Afterward, buffer solutions were used to regulate the samples' pH levels, with 4, 7, and 10 adjustments. The "Malvern Analytical Zetasizer" was utilized to examine the properties of the manufactured mixtures at ambient temperature (20 °C). To evaluate the impact of time, the sedimentation characteristics were compared at 0 h (just after solution syntheses) and 24 h (24 h of inactivity followed by hand-shaking before analysis) [7].

#### D. Characterization techniques

The techniques for analyzing nanoparticles encompassed TEM, XRD, FTIR," and the Micromeritics Tri-Star's syringe filters (0.22 m) made of polyethylene ether sulfone were employed to separate sewage samples and zinc concentrations were measured at various pH levels using "ICP-MS and ICP-OES." The "Malvern Analytical Zetasizer" was employed to examine the extracted particles' particle size and zeta energy. Furthermore, the angle of impact of nanoparticle pellets was determined using an OCA 20 tensiometer (Data-physics)" to obtain the Hamaker characteristic. Finally, the native instrument software was used to measure the left and right contact angle of a 10 L droplet containing "Milli-Q water," formamide, and one bromonaphthalene [8].

### III. RESULTS AND DISCUSSION

#### A. Morphological analysis of nanoparticles

Examining nanoparticles from various sources, including sunscreen, was conducted using ZnO nanoparticles that exhibit a wide range of sizes, with the majority measuring 100 nm in diameter and possessing either rod or spherical shapes. Our previous work demonstrated a high lattice pattern and bright spots in diffraction patterns. Analysis revealed that the nanoparticles comprised zinc and oxygen atoms. "TEM" images of sunscreen showed a wide range of ZnO nanoparticle

sizes and morphologies, with most being less than 50 nm. Despite sonicating the nanoparticles, they tended to aggregate, likely due to their small size. Zinc and oxygen were present in all sunscreen nanoparticles, while silica was found in small amounts. Aggregation was observed in all sunscreen tests, including those with "Sigma-Aldrich ZnO nanoparticles." Nonetheless, this conclusion proposes that the dimensions of particles have a part in deciding how nanoparticles combine. Numerous van der Waals forces contribute to the development of clusters that have diameters of 100 nm. The lowest value of Sunscreen on the Zisman plot and the Hamaker constant, as calculated from contact angle measurements, were both in agreement [9].

Research has shown that the behavior and outcomes of nanoparticles in rivers may vary based on the environment and accompanying contaminants. The aggregation of nanoparticles can be prevented by steric and charge repulsion when naturally occurring organic compounds are present. Total organic carbon assays were conducted to determine if any residual organic molecules were connected to separated nanoparticles. The findings suggested that sole sample had a total organic carbon concentration within the 2-3 mg/L scope. In contrast, the majority of samples contained total organic carbon levels below the limit of reporting of 1 mg/L. These findings suggest that removed organic carbons were released from their bindings with the nanoparticles.

Due to increased electrical mobility, the formation of charged particles decreased repulsive forces, and an abundance of electrolytes, particularly salt-type electrolytes and their ionic strength, nanoparticles tend to aggregate. It was found by [10] and his colleagues in 2021 that the "ZnO nanoparticles" obtained from "Sigma-Aldrich" demonstrated behavior comparable to humid acid and electrolytes [5].

#### B. Mineralogical, surface functional groups and porosity analysis of nanoparticles

The research compared "ZnO nanoparticles" that were isolated with those present in sunscreens available in the market. The crystal framework of the "ZnO nanoparticles" was analyzed through powder diffraction, which showed three perfect orientations. "FTIR analysis" of sunscreen extracts revealed that ZnO was bound, and its content was determined by its spectral peak at 430 cm<sup>-1</sup>. The presence of silica and atmospheric carbon dioxide was also noted in the analysis. Two peaks were observed at 430 and 3440 cm<sup>-1</sup>, which could be attributed to ambient moisture and zinc/oxygen. There were some minor differences in the related chemical compounds of the extracted samples. The investigation indicated that the mean particle size of "ZnO nanoparticles" that are conveniently accessible is 94.96 nm, and the surface area examination demonstrated BET" surface values of 12.26 m<sup>2</sup>/g and Langmuir surface values of 27.51 m<sup>2</sup>/g. Hysteresis loops were observed in the filling and draining the mesopores of zinc oxide nanoparticles by capillary condensation. Gas adsorption showed type II isotherm behavior, indicating either

a macro-porous or non-porous adsorbent. The "ZnO nanoparticles" recovered from solutions contained a sizeable mesoporous structure confirmed by pore size distribution representations. "TEM" investigation revealed that the nanoparticles were macro-porous/non-porous, which was compatible with the almost straight line seen.

### C. Particle size and surface charge analysis

Upon investigating "Milli-Q water" exposure for 0 and 24 hours, we assessed the hydrodynamic size of ZnO nanoparticles obtained from the market at pH 7 and 20 degrees Celsius. It was discovered that the commercially accessible ZnO nanoparticles had a size distribution of 106-1190 nm after 0 hours. Following 24 hours of engagement, the size ranges were 122-531 nm, 106-955 nm, 142-1110 nm, and 255-825 nm, respectively. The size range of commercially accessible ZnO nanoparticles was observed to be between 142 nm to 2670 nm. Furthermore, analogous consequences were achieved post the elimination of ZnO nanoparticles. Nanoparticles were shown to aggregate in water, increasing their hydrodynamic size due to the combined effects of van der Waals forces, hydrophobic contacts, and electrostatic forces. These results were also seen in "TEM." Analyses" of isolated and commercially available nanoparticles. The term "particle size at the peak of "PSDC" (d, nm)" refers to the particle size at the maximum of the "PSDC" for nanoparticles. Interestingly, the nanoparticles were more evident following 24 hours of engagement at "PSDC" than at first [11].

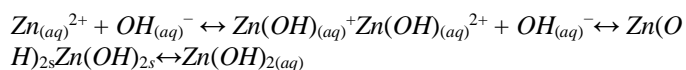
This sentence's combination of scientific terminology and complex ideas We observed that the charge on the surface of ZnO nanoparticles available commercially was 45.9 mV initially and then decreased to 43.8 mV after 24 hours of interaction, utilizing a surface charge analyzer. This could be attributed to the nanoparticles' tendency to group and the partly covered active surfaces. The obtained nanoparticles displayed steady behavior after 0 and 24 hours of contact. However, studies have shown that aging-related variables tend to accumulate.

After interacting for 24 hours, the surface charge of the nanoparticles was significantly reduced, which could be related to how nanoparticles behave when they gather and sink to the bottom. Additionally, given that these numbers are on the small side, it seems to sense that the particles would have a propensity to group. To gain more insight, we re-evaluated the surface charge and size of particles like "ZnO nanoparticles" with a new set of samples and extracted ones at different controlled pH levels, including 4, 7, and 10. This allowed us to look at variations in surface charge and aggregation.

We made some exciting discoveries in this regard. The extracted nanoparticles' surface charge and size values are different when compared, in contrast to the "ZnO nanoparticles'" regular patterns of surface charge and size values. All nanoparticles' surface charges were minimal at pH 4; nevertheless, at higher "pHs (pH seven and 10)", they grew

(becoming more negative). An in-depth investigation found that the nanoparticles' surface charge and size could be influenced if water molecules chemically and physically enter the topmost layer of the particles (dispersed oxides). It is imperative to consider these variables when researching the behavior of nanoparticles in aquatic settings [12].

"The hydrolysis of metal oxides causes hydroxide layer (M-OH) production" on surfaces, as it can only occur under particular conditions. The research conducted by [1] suggests that amphoteric surface processes can cause changes in the surface charge values at low and higher pH levels, resulting in charged hydroxide layers. This study validates former findings that present a decline in surface charge (less detrimental) at lower "pH levels (like pH 4)" and an upsurge in surface charge (more negative) at higher "pH levels (like pH 10)". Moreover, it has come to attention that the size range of the nanoparticles alters following aging (24 hours) at different pH levels. The pH level directly impacted both the particle size distributions and the size at the peak of the "PSDC," as the pH level increased from "pH 4 to pH" 10 compared to 0 hours. After 24 hours at a higher pH level, altered zinc species may have formed due to hydroxyls being adsorbed onto an amphoteric hydroxide surface (nanoparticles' sites), causing the nanoparticles to expand. The captivating procedure emphasizes the intricate interplay of chemical reactions occurring on the surface in response to modifications in pH levels. This leads to diverse zinc species with various particle size distributions.



Separated "ZnO nanoparticles" were analyzed for their solubility. Lower pH 4 (acidic circumstances) was associated with a higher breakdown of nanoparticles in "Milli-Q water," according to milligrams per milliliter (mg/L) measurements, likely due to the attachment of ions on the surface of the nanoparticles. Ionic forms of scattered nanoparticles may be caused by Zn(aq)<sup>2+</sup> ions at acidic pH. At higher pH levels, the formation of hydroxides is connected to slower nanoparticle dissolution rates overall [13].

### D. Occurrence of nanoparticles in wastewater samples

Metallic elements such as beryllium (Be), chromium (Cr), iron (Fe), manganese (Mn), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), selenium (Se), cadmium (Cd), and lead (Pb) were detected by testing a wide variety of wastewater samples. The World Health Organization has set limits for some pollutants in drinking water. Antimony, arsenic, beryllium, cadmium, chromium, copper, and nickel concentrations in drinking waters should not exceed three g/L, 60 g/L, two g/L, 50 g/L, 1000 g/L, and 20 g/L, accordingly, according to NHMRC; NRMCC, 2011.



However, wastewater treatment facilities must adhere to the restrictions specified in their permits, which frequently include specific concentration limits for individual metals that may vary depending on the sensitivity of the receiving environment. Transmission electron microscopy studies verified metallic nanoparticles' existence, size, and form. Nanoparticles of different shapes and sizes and other dissolved chemicals were discovered by analyzing wastewater samples using TEM imaging and elemental mapping. For instance, in areas with numerous nanoparticles, most of which were less than 50 nm in size, very high and thick concentrations of contaminants obstructed the passage of electron beams. It revealed particles smaller than 10 nm with a lattice structure. The diffraction pattern was explicitly indicative of the highly crystalline nature of the particles in this waste sample. All elements, including "Ag, Br, Cl, F, Fe, Ti, Zn, and O," were accounted for according to elemental composition mapping.

In World War II, smaller than 100 nm nanoparticles had a highly organized diffraction pattern with distinct sections and a prominent lattice structure. The discovery of their compounds—F, Cl, and S—verified the existence of metal elements like "Al, Fe, Mg, Ni, Ti, and Zn." These particles lacked the pristine clarity of the others. Their size and shape, however, were quite similar to those seen in sunscreens. The findings show that the elements "Br, Cl, F, P, S, Si, Ti, Zn, and O" and the salts "Ca" and "Na" have significant contact with the particles. Nanoparticles are small, diverse in form (including spheres and rods), and tightly packed with powerful interactions. The crystals were very crystalline, and dazzling facets could be seen throughout their complex latticework. Element mapping could only succeed in accurately identifying "Ag, Al, Br, C, Ca, Cd, Cl, F, Fe, K, Mg, Na, Ni, O, P, S, Si, Ti, and Zn" by resorting to outmoded equipment and tools. As shown by elemental mapping lattice patterns with similar elements, nanoparticle-containing contaminants in World War Five were similar to those in World War One.

Furthermore, a compacted shape was observed in regions where the nanoparticles appeared cross-linked and interacted with other organic and inorganic compounds. Nanoparticles (10 nm) in wastewater samples were found to have a highly latticed and crystalline surface, as demonstrated by high-resolution and diffraction pictures, which also showed the precise locations of all the organic and inorganic compounds present. "TiO<sub>2</sub> nanoparticles, Ag<sub>2</sub>O nanoparticles," and Fe powder were purchased for investigation, and their results helped clarify the nanoparticle kinds in the wastewater samples. These ZnO nanoparticles were studied using transmission electron microscopy (TEM) pictures after being removed from sunscreen samples acquired from Sigma-Aldrich. The bulk of the TiO<sub>2</sub> crystals were either rod-like or spherical, and their sizes were all less than 100 nm. World War 2 (a, b) and World War 4 (a, b) discovered similar particle morphologies. TiO<sub>2</sub> nanoparticles are predicted to accumulate in WW2 and WW4 because of their widespread

occurrence in municipal wastewater from the discharge of cosmetics, paints, and coatings, among other sources [2].

Throughout the whole mapping process, titanium was detected in all samples. Like most nanoparticles, Ag<sub>2</sub>O nanoparticles are spherical, have a size of less than 100 nm, and have a surface morphology that is highly lattice-like. We bought iron powder, and TEE" images showed that the particles were heavily agglomerated and had varying sizes and crystallinities. Every treated wastewater sample tested positive for iron, suggesting that human activity introduced the metal into the system. Almost all samples included zinc and oxygen, indicating the existence of "ZnO nanoparticles" and "ZnO nanoparticle" obtained from Sigma-Aldrich and those retrieved from sunscreen display variable forms in TEE" images while being mostly round. Element mapping showed that zinc was present in the other wastewater samples. Still, it was harder to tell whether or not the nanoparticles were spherical than they had been with the ZnO nanoparticles acquired from Sigma-Aldrich. This occurred because of the close quarters they shared and the chemical linkages produced by co-contaminants. When studied by "transmission electron microscopy TEM," "ZnO nanoparticles" in wastewater samples exhibited significant purity, shape, and charge diversity. Although environmental parameters such as pH, temperature, and salinity significantly impact the destiny and behavior of nanoparticles, agglomerations caused by co-occurring organic and inorganic compounds may also play a role.

#### IV. CONCLUSIONS

Zinc oxide sunscreens are commonly composed of particles that are so tiny that they are measured in nanometers. A recent examination reveals that four renowned sunscreen brands have nanoparticles with an average size of 100 nm, with some particles as small as 100 nm in S3. There was a wide range of repellent nanoparticles to choose from. It was discovered as time went on that all nanoparticles had the propensity to come together concerning particle size and surface charge. The concentration of nanoparticles was investigated in synthetic and actual wastewater samples. Zinc, titanium, and silver were found to be the most common nanoparticles in wastewater, followed by iron particles and co-contaminants with other existing organic components.

This research has revealed apparent structural differences between nanoparticles obtained from sunscreens and those obtained from wastewater. Recycled nanoparticles' morphology, shape, and size may be altered after interacting with coexisting substances in wastewater, salt water, and surface waters, and this can have varying adverse effects on aquatic organisms, depending on the specific application. The discovery of nanoparticles in sunscreens raises concerns about their potential environmental impact. It is possible that these nanoparticles, intended for skin protection, may have unforeseen impacts on the ecosystems they interact with.

The research shows that nanoparticles cannot accumulate in the environment, and their long-term effects are well known. Using nanoscale particles in commodities like sunscreens, administered to the dermis and then cleansed away, raises apprehensions regarding their repercussions on sewage treatment facilities. This research underscores the significance of exploring nanoparticles' potential ecological effects, particularly when

Although sunscreen is a crucial aspect of many people's lives, the possible environmental impact of the nanoparticles they contain may not be disregarded. Extended scrutiny is mandatory to attain a comprehensive understanding of the implications of these particles on the environment and the organisms that live in it. By comprehending the potential hazards linked with nanoparticles, we can strive to develop more secure and sustainable commodities that do not have an unfavorable influence on the environment. This inquiry is a significant advance towards reaching that aim.

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