

Nanotechnology for Air and Land Pollution: A short Review

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Abstract: Nanotechnology has sped up the development and application of innovative technologies that are both cost-effective and cutting-edge. These technologies have applications in air pollution rectification, catalysis, the detection of pollution, and other areas. The use of nanoparticles in a variety of fields, as well as the impact that they have on the environment, has been confirmed by several studies. As a result of their one-of-a-kind qualities and attributes, nanomaterials are excellent candidates for the prevention of pollution. Reducing the release of industrialized hazardous waste and other toxins can help with this. Higher electrical conductivity, higher strength-to-weight ratios, and dramatically enhanced surface areas and reactivities are only a few of the extraordinary and advantageous characteristics of nanomaterials. Nanomaterials can be found in a wide range of applications. Nanotechnology and nanomaterials have contributed to the development of a method that is preeminent in its ability to detect and treat trace environmental contaminants. Within the context of cleaning up air pollution, this chapter explores how a variety of nanomaterials can be put to use. Nanomaterials are being investigated in this research project in the form of nano adsorbents, nanocatalysts, nanofillers, and nanosensors respectively. It has been suggested that several different nanostructures, such as nanoparticles, nanofibers, nanorods, nanosheets, and nanowires, could be utilized in the process of cleaning the air.

Keywords: Nanomaterials; Environmental contaminants; Nanoadsorbents; Nanocatalysts; nanosensors;

1. Introduction

Unintended emissions of gases, particles, and aerosols into the inferior atmosphere are referred to as air pollution. [1]. such pollution is due to both sources viz; artificial and natural (such as wind-borne dust, volcanic eruptions, and forest fires). The gases and particles that pollute the air result in risk to human health. Nitrogen oxides, sulphur oxides, hydrogen sulphides, small powder particles (aerosols), and volatile organic compounds are the most common types of air contaminants (VOCs). According to the World Health Organization (WHO), lung cancer, chronic obstructive pulmonary disease, cardiovascular disease, stroke, and acute respiratory infections are among the seven million people who die each year from the combined effects of interior and outside air pollution. WHO data confirms that nine out of ten people breathe in air that exceeds WHO's guidelines for contaminant levels, with the highest exposures occurring in middle-income and low-income countries [2]. Additionally, the WHO is assisting a number of nations in combating air pollution. From urban smog to indoor smoke, there is significant risk to health and climate. For the purpose of environmental protection from adverse effects of pollution, a number of nations have enacted legislation regulating numerous pollution groups and justifying their adverse effects. At the nanoscale use of science, engineering, and technology, which ranges from one to one hundred nanometers, is known as nanotechnology. In general, nanotechnology, which often refers to structures with dimensions of 100 nm or less, involves the creation of substances and devices that fit inside this size range. Nanotechnology is incredibly diverse, ranging from completely new methods based on molecular self-assembly for the creation of nanoscale-sized sophisticated materials for the development of nanoscale-sized advanced materials. It is also feasible to directly influence matter using nanotechnology at the atomic level.

Recent research has focused on nanotechnology's potential to offer innovative clarifications to succeed and

decrease pollution in water, air, and land, along with improvement in performance of conventional remediation practices. It is believed that environmental nanotechnology plays a significant role in shaping contemporary environmental engineering and science. Nanotechnology has expedited the creation and application of cost-effective and innovative skills for cleaning air pollution, catalysis, pollution detection, and other applications. Many reviews have established that nanoparticles are used in diverse areas and that they have an effect on the environment. Nanomaterials are a great way to stop pollution by reducing the amount of industry waste and other contaminants that are released into the environment due to their unique properties and characteristics. Nanomaterials' exceptional and advantageous properties include significantly greater reactivity and surface area, greater electrical conductivity, and increased ratio of strength-weight. Nanotechnology and nanomaterials are the best way to find and treat small amounts of pollution in the world. The current chapter involves the use of several nanomaterials in the remediation of contamination of air. The current study involves the investigation of nanomaterials in sense of nano adsorbents, nanocatalysts, nanofilters, and nanosensors. Various nanostructures, including nanoparticles, nanofibers, nanorods, nanosheets, and nanowires, have been stated for use in air purification. We primarily investigate materials based on carbon and metal-based nanomaterials for the removal of airborne contaminants. In conclusion, the potential environmental effects of nanomaterials (metal-based nanomaterials and carbon-based nanomaterials) are discussed. Clearly, research studies are devoted to advancing the application of nanomaterials in a variety of environmental remediation applications.

1.1 Nanotechnology for Air pollution control and treatment

Photocatalysts become active in breakdown different dangerous air pollutants into less toxic or environmentally favorable products when they are exposed to ultraviolet light. The development of novel photocatalytic materials and their modifications by impregnation might eventually lead to economical technology for modification of environmental concerns. Titania is significantly changed using metallic and non-metallic dopants to increase its catalytic activity even more. The Novel catalyst, numerous types such as WO₃ decorated ZnO, was further included in the list of photocatalysts to harvest solar light. These many catalysts have been tested to treat various substances and have been used in various situations for pollution remediation [3]. Metal-organic frameworks (MOFs) are innovative tools for gas storage and separation, water harvesting from the atmosphere, chemical sensing, energy storage, drug delivery, and food preservation. MOFs have considerable potential for green applications such as air and water pollution remediation due to their diverse structural motifs that may be changed during synthesis. The desire to employ MOFs for environmental applications motivated the addition of metal and functional groups to their structures, as well as the formation of heterostructures by combining MOFs with other nanomaterials to efficiently remove dangerous chemicals from wastewater and the atmosphere [4]

Air pollution, particularly solid particle pollution, poses a major threat to people's physical and mental health. As a result, air filtration membrane performance and stability are becoming increasingly important. Cheng et al. designed membranes in an in-situ growth method, nanosized polypropylene@zeolitic imidazolate framework-8 (PP@ZIF-8) membranes, and polypropylene@copper (II) benzene-1,3,5-tricarboxylate (PP@Cu-BTC). In a realistic context, these membranes can accomplish effective and stable filtering of (PM_{2.5}) particles [5]. Toxic volatile organic compounds (VOCs) and fine particulate matter (PM_{2.5}) in indoor air constitute a hazard to strength of human being, including cancer, leukemia, fetal malformation, and abortion. As a result, developing technology to reduce inside contamination of air is critical to circumvent negative consequences. Adsorption and photocatalytic oxidation are the current high-efficiency methods for removing VOCs and PM_{2.5}. Fine particulate matters are particles in the air that are smaller than or equal to 2.5 microns in diameter PM_{2.5} are formed inside during fuel combustion, metallurgy, power generation, textile printing, smoke and dust discharged from coal and gas or fuel oil during heating and cooking, and exhaust gas released into the atmosphere when various vehicles utilize fuel in the interior operating operations. Biochar reduces VOCs primarily through two mechanisms: adsorption in the carbonized regime and partitioning in noncarbonized organic matter.[6]

1.2 Nanotechnology for water treatment

Rapid urbanization and industrialization have threatened water resource systems, limiting the sustainable development of society and economies. Water pollution, climate change, and high-intensity human activities

have a significant impact on watersheds. Around 40% of the population is facing water scarcity. In many countries, the major rivers and lakes are generally subject to different levels of heavy metal contamination. Heavy metal pollution mainly comes from a combination of factors [7] Although natural phenomena such as excessive rainfall can contribute to increased water pollution, manmade activities are the primary causes of heavy metal contamination. The direct flow of dirty water into rivers and lakes, in particular, has expanded dramatically, resulting in heavy metal contamination. Heavy metal contamination exacerbates aquatic pollution and has a direct impact on drinking water safety, food production, and agricultural safety, eventually threatening human health [8]. The present water and wastewater management practice might be considerably improved by introducing nanoparticles into the system, taking advantage of these dimensional effects of Nanomaterials, particularly membranes [9], adsorption [10], catalytic oxidation [11], disinfection, and sensing [12] offer a wider potential and capacity for water and wastewater remediation.

Nanomaterials have increased the competitiveness of water and wastewater cleaning by lowering prices. The use of depleted nanoparticles in water and wastewater treatment systems, on the other hand, remains cumbersome [13]. First, nanoparticles tend to agglomerate in a fluidized system or a stiff substrate, resulting in significant activity loss and pressure decrease [14]. Second, except for magnetic nanoparticles, separating most of the nanoparticles expelled from reused treated water remains a difficult task. It appears to be disadvantageous from a financial standpoint. [15] Thirdly, the actions and implications of nanoparticles in the treatment of water and wastewater are unknown; thus, it is a fundamental worry which can hinder the implementation of nanotechnology [16] that nanoparticles damage human health and the aquatic environment. To avoid or diminish the possible negative effects of using nanotechnology, it is desirable to create a device or material that may reduce the mobilization or release of nanoparticles while retaining their high reactivity. A successful and promising approach has been shown by the development of nano-composites. The most typical technique to create a nanocomposite is to load a range of supporting materials for depositing desired nanoparticles, such as membranes or polymers. It may be defined as a multi-phase material with a diameter of at least one phase of 100 nm [17].

1.2.1 Adsorption & Separation

The two most commonly utilized technologies for polishing water and wastewater are adsorbents and membrane-based separation. The cycle of adsorption regeneration considerably reduces the price-to-benefit ratio of conventional adsorbents. Many Nanosized adsorbents, i.e., metal oxides or Nanosized metal, graphene, nanocomposites, and carbon nanotubes (CNTs), are characterized by excellent selectivity and strong reactivity. They perform adsorption several magnitudes better than conventional adsorbents [18]. Membrane separation is also essential since it allows for the recycling of water from uncommon sources like wastewater. The contamination removal is mostly dependent on size exclusion. However, membrane selectivity/permeability issues still hamper the development of membrane technology, namely trade-offs in membrane selectivity and permeability [19]. By adding functional nanoparticles to the membrane, scientists were able to make nanocomposite membranes with advanced features. This new class of membranes had better mechanical or thermal stability, porosity, and hydrophilicity, such as higher permeability, anti-fouling, antibiotic, adsorbent, or photocatalytic properties. [20]. Currently, adsorption and separation nanotechnology are near maturity.

1.2.2 Catalysis

To eliminate trace contaminants and microbiological pathogens from water, the advanced oxidation process of catalytic or photocatalytic oxidation is applied. It's a better initiative to make both contaminants biodegradable form non-biodegradable components [21]. Organic molecules are being polished by photolysis [22]. High surface to volume ratio of nanocatalysts showed better catalytic performance than bulkier equivalents. Size-dependent behavior was observed in the band gap, and nanoscale semiconductors have a crystalline phase. Their photo-generated charge distribution and electron-hole redox potential changed with different diameters [23]. The immobilizing of nanoparticles onto diverse substances improved the nanocatalyst stability, and the resulting nanocomposites were suitable for contemporary photo-reactors [24].

1.2.3 Filtration and Membrane

Filtration is a physical separation process that allows polluted water to flow through a membrane when larger solutes are present. This method is widely preferred due to its high stability, process intensity, pollutant retention ability, automated process control, lower operational robustness, chemical mass, and filtration [25]. ultrafiltration (UF), a microfilter (MF), Forward Osmosis (FO), Reverse osmosis (RO), nanofiltration (NF), electrodeionization (EDI), electrodialysis (ED), pervaporation, and distillation are currently utilized membrane-based filtration technologies. The macroporous MF membrane traps microorganisms such as bacteria and protozoa as well as suspended particles. (50–1000 μm). The UF membrane with mesoporous holes rejects the majority of viruses and colloidal pollutants (5–50 μm). [26]. The nanoporous NF membrane (0.5–10 μm) is used to remove inorganic and organic pollutants, as well as the ED and EDI procedures are frequently utilized (metals and ions). Water desalination relies on RO and FO membranes with microporous pores (0.1– 1 μm). Desalination can be achieved using distillation or pervaporation, albeit both are less commonly used in practical applications. The downsides of these filtering approaches are low recrudescence, fixed solute selectivity, frequent fouling, and energy-intensive operations. After numerous cycles, most filtering membranes must be cleaned with chemicals and/or heated. [27]. As a result, utilizing NMs is required to get the most out of conventional filtration membranes. As proof, we look at the most widely studied (NMs, such as carbon nanotubes (CNTs), ceramic and grapheme, aquaporin, and zeolite membranes, as well as single thin-film composite (TFC) and mixed matrix (MM) membranes. Our goal is to investigate the basics of each NM-based disinfection approach, including the various NMs and production procedures, as well as current commercialization and separation performance attempts. [28].

1.3 Nanotechnology for degradation of land waste

Nanotechnology can be applied to contaminated soil, in which pollutants viz; heavy metals and metalloids to organic compounds. The technologies included for the removal of impurity are immobilization, reduction reaction, photocatalytic degradation, Fenton and Fenton- like oxidation, and various combinations of the abovementioned mechanisms. The combination of nanotechnology and bioremediation (e.g., phytoremediation and micro-remediation) has also become popular in recent years [29-30]. The organic pollutants are often detached by catalytic degradation and reduction reaction, whereas pollutants like heavy metals and metalloids are removed by an adsorption mechanism. Some researchers adopted methods and materials that can simultaneously remove multiple pollutants [31]. In a simultaneous adsorption and oxidation scenario, the presence of ENMs could facilitate both adsorption and redox degradation of micropollutants [32]. The demand for these multifunctional Nanomaterials is increasing due to the efficient removing capacity, time consumption, avoid sequential processing of pollutants.



Fig. 1. Soil Pollution Remediation Classification

The researchers have worked out on heavy metals and organic compounds such as carbon nanomaterials, metal oxides Fe_3O_4 , TiO_2 , ZnO , nanoscale zero-valent iron (nZVI) nanoparticles, and nanocomposites. Figure 1. shows classification according to their pollutant removal mechanisms. Nanotechnology has proved extensive attention in the removal of soil contaminants. The Nanoscale metal oxide such as iron-free, Fe_2O_3 ,

cerium oxide, Al_2O_3 , Mn_xO_y , TiO_2 , and MgO shows the good result for soil remediation [33]. Recently magnetic nanosized adsorbents have been used for removing magnetic impurities from soil [34]. Several researchers found that nanomaterials are extremely adsorbent properties towards heavy and toxic metals arsenic, cadmium, chromium, and uranium. Besides these, they outdo the high capacity and selectivity of other common contaminants, such as organic and phosphate. Emulsified nanoscale zero-valent iron (ZVI) nanoparticles are environmentally safe treatment particles that eliminate contaminants from water. Compared to conventional treatment methods, EZVI requires less treatment time and produces less waste. EZVI is a viable solution for polluted areas that have a high contaminant load. Currently, EZVI is used at several sites, including dye manufacturing facilities, pharmaceutical and chemical manufacturing facilities, dry cleaners, and metal cleaning and degreasing facilities. Several government-owned sites have also begun using EZVI to remove contaminants from groundwater. [34-37]. The effectiveness of EZVI depends on several factors, including the soil pH and the concentration of the contaminant. The nanoscale particles are attracted to each other, promoting efficient transport. In addition, nZVI nanoparticles can agglomerate into larger micron-sized particles. However, the lack of toxicological information poses a major challenge. It is crucial to identify methods of controlling migration that minimize the risk of toxicological effects. The use of nZVI in environmental clean-up is a promising approach for removing pollutants from groundwater. Moreover, it is inexpensive. EZVI is the only commercially available agent with these features. For example, nanohydroxyapatite particles are effective in controlling soil surface crust formation. This technology is the future of environmental clean-up. Although the potential benefits of using engineered nanomaterials in environmental clean-up are enormous, concerns about their safety and sustainability still surround their widespread use. While engineered nanomaterial (ENMs) can improve food production and produce more energy and clean water, they have raised significant environmental concerns. Many studies have found adverse effects in the soil, air, and water. Furthermore, their use has led to a plethora of misleading information and misunderstanding. The benefits of engineered nanomaterials for environmental clean-up include the potential to remove contaminants from the surface and groundwater. ENMs can be designed to perform chemical reduction, sorption, and complexation. When synthesized at the nanoscale, ENMs exhibit altered properties, which make them highly effective in decontamination [38]. These nanomaterials are also highly efficient at decontamination because they have large surface areas and catalytic activity. Nanomaterials can be used to remove pollution from soil and water and are also effective for removing pesticides, dyes, and heavy metals.

Plastics' exponential use and refractory characteristics result in their massive environmental build-up, a severe environmental concern that modern cultures are presently confronted with. The environment with plastic garbage can have major consequences for living forms, ecosystems, and the economy. Additionally, plastic trash can degrade into tiny particles known as microplastics (MPs) and neoplastic (NPs), resulting in environment and living beings collaboration. As a result, there is an urgent need to create long-term and cost-effective mitigating options. Because plastic-degrading enzymes may selectively target the polymer structure for subsequent breakdown, enzymatic techniques stand out as viable, sustainable strategies for microplastic degradation. Because plastic-degrading enzymes may selectively target the polymer structure for subsequent breakdown, enzymatic techniques stand out as viable, sustainable strategies for microplastic degradation [39-41]. Extracellular hydrolase enzymes that break down long-chain polymers into smaller molecules include lipases, proteases, and cellulases. These enzymes, in general, promote hydrolytic cleavage of lengthy chains, resulting in smaller units that are simpler to transport and absorb into the cell for further enzymatic destruction and, eventually, the release of ecologically innocuous chemicals [42]. Different enzymes have also been immobilized on inorganic nanostructures. For instance [43] Covalent bonding immobilized lipase and cutinase on SiO_2 nanoparticles and $\text{Fe}_3\text{O}_4@ \text{SiO}_2$ nanostructures. The constructed catalytic systems degraded polycaprolactone with remarkable stability and efficiency. Carbon-based materials, on the other hand, have shown promise as a support for plastic-degrading enzymes. Cadmium (Cd) contamination in paddy soil has harmed human health significantly. Because of their outstanding adsorption efficiency and mechanical robustness, nano-ferrous sulfide@lignin hydrogel ($\text{FeS}@ \text{LH}$) composites might be an appropriate material for paddy soil Cd removal. However, the $\text{FeS}@ \text{LH}$'s performance in a paddy field is unknown. In this investigation, $\text{FeS}@ \text{LH}$ was used to establish water spinach in a Cd-contaminated paddy area (*Ipomoea aquatica* Forssk). After 30 days, $\text{FeS}@ \text{LH}$ efficiently eliminated Cd from the soil (37.6%) and water spinach

(34.5%). Pb, Zn, Cu, and other metal concentrations in soil and water spinach were determined [44].

1.3.1 Nano-Particles as adsorbent

Advanced nano adsorbents are much better at removing gases, bacteria, and other organic molecules from the environment than traditional adsorbents, which are not very effective and have a small amount of active site surface area. Adsorption mainly depends on adsorbent properties viz; porosity and surface area.

The adsorbents viz; Carbon-based materials like CNTs, activated carbon, and carbon fiber composites are more likely to attract CO₂ [45]. Recently, there has been more interest in using CNTs to absorb CO₂ because they are reversible. When the temperature goes up, the CO₂ can be taken away from the CNTs by desorption. Amine-functionalized CNTs acts as promising way to capture CO₂. CNT is a good support for adsorbents because it has a larger surface area and is chemically stable. This makes it less likely that the adsorbent will lose its structure during the CO₂ absorption process. In a study by [46], better CO₂ adsorbents were made by amine-functionalizing multi-walled CNTs with (3-aminopropyl) triethoxysilane in two steps: acid pretreatment with sulfuric acid and nitric acid, then amine-functionalization with (3-aminopropyl)triethoxysilane. The amine-functionalized multi-walled CNTs performed better in the CO₂ adsorption test, play a vital role in CO₂ uptake of 75.40 mg CO₂ adsorbed/g adsorbent. Due to their exceptional chemical and physical properties, ZnO nanostructures have attracted a great deal of research interest, resulting in numerous opportunities for energy, environmental, and electrical applications. Because zinc oxide nanoparticles are stable at high temperatures for the non-catalytic suffixation reaction [47], they are being studied closely as a way to clear the air of hydrogen sulfide, especially at higher temperatures through an adsorption process. [48] They talked about a simple, one-step method for making ZnO nanoparticles that doesn't use surfactants and heat processes afterward. The nanoparticles can be used to remove H₂S from the air. The adsorption tests outcomes confirmed that the prepared zinc oxide Nano adsorbent had a greater capacity for hydrogen sulphide adsorption due to the enhanced treatment of air volume and more adsorption time. The aforementioned study proved that the prepared zinc oxide Nano adsorbent is a particularly promising component for various ecological applications. SO₂ is an odorless, nonexplosive, and noncombustible gas that can impart a taste to the air at concentrations between 0.30 and 1.0 ppm. Atmospherically, SO₂ will transform into extremely stable byproducts. SO₂ is emitted into the atmosphere by the combustion of sulfur-containing fossil fuels and other industrial processes [49-50] reported results from single gas adsorption, confirming that zeolites are highly effective at removing CO₂, SO₂, and nitric oxide [51]. established that iron nanoparticles with a size of approximately 3–4 nm enhanced the adsorption capacity of SO₂ by 80% through dispersed reactive centers. Sekhavatjou et al. [52] observed how nanoparticles of zinc oxide and iron oxide could be used to separate sulphur components from sour gas. Mahmoodi Meimand et al [53] investigated how clinoptilolite zeolite with iron oxide nanoparticles and natural clinoptilolite zeolite could be used as nano adsorbents for SO₂. Due to the regenerative nature of the iron oxide nanoparticles, the modified zeolite with iron oxide nanoparticles exhibited greater SO₂ absorption efficiency than the unmodified zeolite. This could be considered an effective, trustworthy, and practical method for removing SO₂ from the air. Many researchers [54] on the use of MOFs as nanoadsorbents for removing nitrogen and sulphur from gas streams have been published. Among these MOF-based nanoadsorbents, NH₂-substituted UiO-66 exhibited a greater acid gas (e.g., CO₂, H₂S, NO₂, and SO₂) adsorption capacity. UiO-66-NH₂ has the capability of adsorbing noxious gases in a matter of minutes, making it a potential material for detoxification. UiO-66- NH₂ is a great material for acid gases removal owing to its different size pores, more holes and higher concentration.

Table 1: Nano adsorbents based on Carbon for environmental contaminants removal**1.3.2 Nano-Particles as catalysts**

Nano adsorbent	Contaminants	Sorption capacity	pH	Time	Kinetics	Isotherm models	References
MWCNT-TYR	Methylene blue	440 mg/g	6	7	Pseudo-second order kinetic	Langmuir isotherm model	56
MWCNTs(5–15nm)	Pb(II) Ni(II)	215.38±0.03 mg/g 230.78±0.01 mg/g	5	60	Pseudo-second order kinetics	Langmuir isotherm model	57
AminMag MWCNTs@SiO ₂	Pb(II) Cd(II)	98–104%	8	5	Pseudo-second order kinetics	Langmuir isotherm model	58
Single-walled carbon nanotubes magnetic nanoparticles (SWCNT-MN) hybrid adsorbent	Xylene	50 mg/g	8	20		Langmuir – Freundlich (GLF) isotherm	59
Nitrogen-doped graphene oxide nanosheets (N-GO)	Congo red	98–99%	2	360	Pseudo-second order kinetics	Langmuir isotherm model	60
Graphene oxide	Basic red 46	370.4mg/l	11	30	Pseudo-second order kinetics	Langmuir isotherm model	61

Nano-based photocatalysis is a possible way to purify pollutants in the air, and researchers have been looking into it more in recent year. Photocatalysis can be used to clean water, clean the air, and clean up polluted water, among other things. This is because it is better at turning photon energy into chemical energy, which is needed to quickly break down and mineralize persistent environmental pollutants. [62]. The separation efficacy of air contaminants is affected by the phase structure, texture of surface and nano based analysis of photocatalyst. Recent emphasis has been placed on the development of nano-based photocatalysts with a porous structure and explicit chemisorption toward target contaminants. This is because it allows low-concentration reactants to freely accumulate on the surface of nano-based photocatalysts, which could improve photocatalytic performance [63]. Photocatalysis with modified TiO₂ has the potential to enhance both air quality and health. Smart coatings, which are standard materials suitable for interior applications, are produced by modified TiO₂ by means of innovative photocatalytic properties below interior light irradiation. It is generally accepted that photocatalytic performance is affected by light absorption, surface reactivity, and charge creation/recombination rate. The use of photocatalytic materials and coatings based on TiO₂ as an exterior layer on building facades along high-traffic roads has proven effective at degrading significant air pollutants, such as nitrogen dioxide, produced by vehicle exhausts. Under controlled lighting, temperature, and humidity settings, the ability of paints with TiO₂ in them to separate nitric oxide is tested. On subsequent mineralization of substrates of inorganic and organic origin, photocatalysts based on titania have the potential

to eradicate a vast array of microbes [64]. Binas et al. [65-66] showed that it is possible to separate NO_x gases and VOCs in normal amounts of outdoor or indoor air using a photocatalytic method based on titania. In recent years, there has been a lot of interest in titania-based photocatalysts as disinfectants for a wide range of germs, including those that stay in the environment for a long time, like protozoan cysts, bacterial spores, and viruses. Both VOC and NO_x photodegradation are affected by humidity. Due to the competition between water molecules and contaminant molecules for adsorption sites, an increase in relative humidity stops photooxidation. Rezaee et al. looked into how gaseous formaldehyde breaks down when light hits nanoparticles of zinc oxide on bone char. Based on the results of the tests, the most formaldehyde could break down was about 73%. The findings showed that putting ZnO nanoparticles on bone char makes photocatalytic breakdown work better. This is because formaldehyde molecules stick to bone char better, which makes it easier for them to move to the catalytic zinc oxide and leads to a high photocatalytic rate. Vohra et al. [67] made a photocatalyst made of silver-ion-doped titania that kills microorganisms in the air better. In an experiment with moving air, a catalyst-coated filter is used to check how well a silver-ion-doped photocatalyst works. MS2 Bacteriophage, *Aspergillus niger*, *E. coli*, *Staphylococcus aureus*, and *Bacillus cereus* were used as indices to demonstrate the improved photocatalytic process's enhanced disinfecting capacity. Researchers found that this improved photocatalyst was one order of magnitude better at killing microorganisms than a normal photocatalyst made of titania. This improved photocatalysis process is effective against higher amounts of microorganisms in the air. This makes it a good option for protecting against bioterrorism.

1.3.3 Organic Contaminants Deduction by means of nanotechnology:

There are alcohols, carboxylic acids, phenolic derivatives, and chlorinated aromatic compounds among the organic contaminants in the environment. Photocatalytic degradation is one of the most acceptable methods for degrading hazardous organic contaminants. Through a process called photocatalytic breakdown, the organic pollutants can be turned into carbon dioxide and water. Organic paints made by factories are another major source of organic pollution. Through a process called photocatalysis, certain metal ions can break down these colors. Figure 1. illustrates the photocatalytic degradation of metal and organic contaminants.

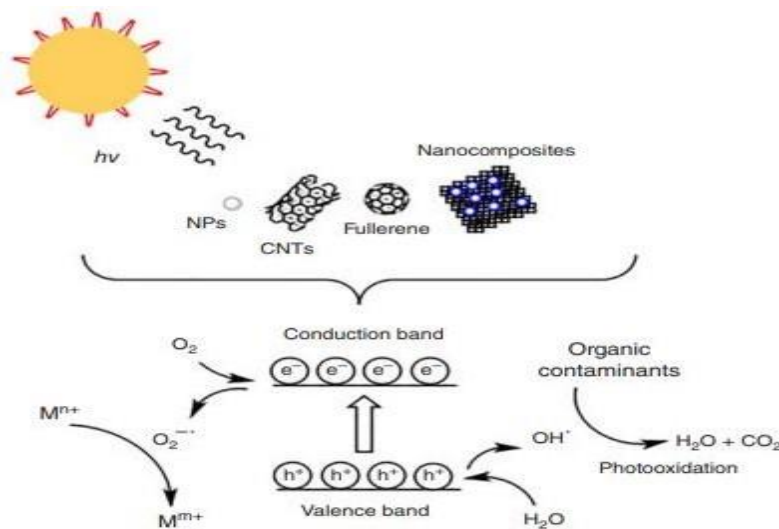


Fig. 2. metal and organic contaminants degradation mechanisms

Source: Guerra et al.[68] /MDPI/Licensed under CC BY 4.0.

1.4. Future Scope of Environmental Nanomaterials

Nanotechnology is regarded as the technology with the most rapid growth in the current decade [69]. Most likely, this rapid growth is due to the invention of instruments, like scanning tunneling microscopy, electron microscopy, etc., that allows scientists to study matter at the nanoscale level, then synthesize, describe, and change nanoscale materials [70]. Scientists and businesspeople say that intelligent nanomaterials have the ability to change almost every part of modern life. They think it is the best technology for the modern world

because of its economic potential, its ability to make better goods, and, most importantly, its ability to reduce stress on resources and the environment. When we look to the future of nanotechnology, it is clear that it will have many more useful applications [71] and lead to the creation of new diagnostic tools and industries, such as nanoenergy, nanofood, nanoagriculture, nanomedicine, nanobiotechnology [72], and nanoelectronics. [73]. It will also help solve problems in industry and help other technologies like biology, physics, computer science, psychology, and other scientific fields grow and develop at an unprecedented rate. Nanotechnology will also make all parts of our lives more sustainable because of its convergence nature [74].

It will open doors for nanoscale engineering [75] and make physical technologies smaller. It will also lead to new therapeutic inventions and better tracking and safety in the environment, Muhammad Irfan Sohail and others. Optimizing production processes and improving qualities. Nanotechnology's progress could also lead to a business revolution by making it easier to improve product designs, specs, and manufacturing. [76-77]. Since nanotechnology was invented in 1960, it has become popular among technological researchers and scientists. This has led to the creation of multiple platforms for nanomaterials research, the publication of about 2 million research articles, and the creation of 1 million registered applications, all while progressing at a rate of 10% per year. [78]. Many futurists say that we don't know nearly as much as we should about how this technology will affect the world and people's health [79]. Nanotechnology is a good way to solve problems that are related to each other in this century.

Nanotechnology is making new things, making life better, and making methods better. Nanotechnology makes nanoparticles that are smaller, smoother, stronger, faster, safer, and more reliable. [80-81]. As new applications to use nanomaterials with these unique properties are found, the number of goods that contain them and the number of ways they can be used keeps growing. ENPs are good for the environment and can be used in medical, agricultural, industrial, electrical, and cosmetic items. These nanoparticles are made up of many different types of metal NPs. Nanogold is used in Hyperthermia Cancer Therapy [HCT], diagnostics for heart and infectious diseases, sensors and electronics, and nanosilver is used in food packing as an antimicrobial agent. In the medical field, drug delivery ENPS is used in DNA transfecting agents, hydrogels, DNA chips, and as a treatment for prion illnesses. There are a lot of diagnostic tools and solar packs that use them. Nanomaterials are used to make fertilizers and poisons, which help get rid of pests and get the fertilizer to where it needs to be [82-84]. Gold nanoparticles are used as a catalyst in the chemical industry for some oxidation processes and fuel cells. Single-walled carbon nanotubes (SWCNT) are better at conducting heat and electricity and being pulled apart. SWCNT is 460 times stronger than steel for how much it weighs. Due to their tensile strength, CNT and materials made from it are used in the plastics, car, and aerospace industries. CNTs are released into the environment when polymers are burned, drilled dry or wet, or when epoxy resins and car parts are worn down or sanded. [85]. Metal oxide nanoparticles (NPs) are used in the paint industry. These include titanium dioxide (TiO_2), zinc oxide (ZnO), silicon oxide (SiO_3), aluminum oxide (Al_2O_3), and even pure silver (Ag) and tin (Sn). Titanium-based nanoparticles (TiO_2) are used in solar cells, sunscreens, makeup, and bottle coatings because of their unique ability to block UV light. Semiconductor nanoparticles like Cd-Se, Cd-Te, Cd-Se-Te, In-P, Zn-Se, Zn-S, Bi_2S_3 , etc. are very important in the industrial and technology business. In the cosmetics and coatings businesses, ZnO, SiO_2 , and Ag nanoparticles are used. Due to their unique qualities, these NPs are used in chemical and physical fields, such as microcapsules, nanolatex, colored glasses, chemical sensors, and modified electrodes. They are also released into the environment through industrial wastes [86-99].

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