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AN OVER VIEW OF NANO TECHNOLOGY IN WASTE MANAGEMENT

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ABSTRACT

The industrial intervention had a profound impact on our environment and the amount of damage it has bestowed is in the form of polluted water and solid waste accumulation. With upgradation of technologies in the industrial upfront there is also an increase in the robust nature of industrial waste. Keeping in view of the various environmental aspects, advanced techniques were developed by the inculcation of nanotechnology. Among the diverse technologies that have gained prominence is the use of nanoparticles as a medium to monitor and treatment process. One of them is the use of organic techniques, i.e., the use of nano-chitosan. The review article focuses on the new data pertaining to the study and improvement of various nano-scale treatment technologies implemented for wastewater treatment with an environment friendly biodegradation. The eradication of harmful toxicants is an exhaustive process, but this is required to invigorate the sustainable development. Various strategies were promulgated but the inculcation of nanomaterial provided a low-cost, efficient and simple method for removal of contaminants by adsorption. These nanomaterials provide the best adsorbent due to its simple structural properties that provide a better surface area with high absorption capacity. This comprehensive review gives a glimpse of the various green and other nanotechnologies used for wastewater and contaminated soil treatments.

Keywords: Wastewater, nanotechnology, solar, biodegradation, Waste Water (sewage) treatment (WWT)

INTRODUCTION

The word “nano” is Greek in origin, and it is used to describe one billionth of a meter. The term Nanotechnology was coined by Norio Taniguchi (1974) to describe the manufacturing of materials at the nanometre scale. Nanotechnology is a drastically growing research area with the utilization to implement nanoscale materials in the area of science and technology. It is a multidisciplinary scientific undertaking, involving creation and applications of materials, devices or systems that function at nanoscale. Nano phasic and nanostructured materials are drawing in more consideration because of its distinctness and selectivity related to biological and pharmaceutical applications[1]. More than this it also caters to the pollution through various techniques that help in monitoring and assessing the environmental risk. It is likewise put on in cosmetics, electronic and energy associated utilities[2].

The synthesis of various Nano structures and particles are mainly categorized into two perspectives. The first is top to down perspective and second is bottom to top up perspective. Both the perspectives consist of various methods to produce nanoparticles. In the top–down perspective, particles are generated from the bulked (grouped) materials and in the bottom–up approach the nucleation sites are first formed then it grows into a nano sized particle. The examples of top-down (physical) approach are ball milling, laser ablation, evaporation–condensation, electromagnetic levitation gas condensation (ELGC), ultra-sonication, lithography, spray pyrolysis, radiolysis, arc discharge, and photo–irradiation. Physical approach is generally applied for high scale production in a minimal time. The bottom-up approach, however, relies mostly on the use of reducing and stabilizing agents to produce the various types of nanoparticles and its subcategories in organic and inorganic (it depends upon the use of reactive agents) methods. In this type of synthesis various methods like chemical vapour deposition, sol-gel process, spinning, pyrolysis, etc. are used[3]. The biosynthesis of nanoparticles is done using microorganisms as an alternative for the conventional methods (i.e., physical and chemical methods). Prokaryotes and eukaryotes are applied for production of metallic nanoparticles (viz. silver, gold, platinum, zirconium, palladium, iron, cadmium) and metal oxides (such as titanium oxide, zinc oxide, etc). These microbial organisms incorporate bacteria, fungi, algae and actinomycetes. The synthesis of nanoparticles may be intracellular or extracellular as indicated by the place of nanoparticle development. Biosynthesis processes are environment friendly, effectual, economic, and scalable with desirable controlled features like size and morphology of nanoparticles[4].

Rapid population growth, industrialization, and urbanization have been associated with extensive use of various pollutant-containing products and by-products, these product manufacturing industries are omitting numerous wastes that lead to the accumulations in various ecosystems and environment. World is suffering from the shortage of freshwater and the demand is continuously increasing day by day. It estimated that nearly 3.6 billion people scarce at least 1 month in a year. Again, with fast populace development and growth of the urban areas, yearly waste production is projected to increase by 70% from 2016 levels to 3.40 billion tons in year 2050.

The most common method implemented for solid waste is through sanitary landfill. They generate large quantities of leachate; the term leachate is elucidated by the liquid that comes out of the landfill and extracted dissolved along with suspended matter. The overproduction of leachate often leads to harmful effects on humans and the environment. As a solution various nanotechnology-based processes are used to treat leachate like nano-filtration[5].

Wastewater treatment plants are used to remove the water-based pollutants from the industrial, sewage and other wastewater systems. The diverse range of nanoparticles made from noble metals are gold, silver etc. They are initially reproduced and utilized in catalytic reduction processes, which has a high surface to volume ratio and decipher a huge catalytic activity towards the reduction of numerous organic pollutants in wastewater treatment plants.

In this mini-review, the implementation of green-synthesised nanoparticles used for wastewater and soil treatment are mentioned and their economical way to meet the need of renewable energy goal was also highlighted.

Use of Waste Materials as Nanoparticle Production and Application :

Waste materials from the different sources like the industries or consumer is the highlighted problem, waste may have value added materials or basic structures that can be utilized to produce the nanoparticles e.g., waste from the rubber/tires, large batteries, wastewater, bio-solids etc. contains the carbon, copper, zinc, lead that can be potential source for the nanoparticles construction. Added to this consumer's waste may also contain different metallic compounds which can be recovered by various methods and as an end product we can get a good amount of metallic nanoparticles or composite materials (Table 1). The various physical and chemical methods like reduction with sodium borohydride, solvent thermal method with grinding and milling pre-treatment.

Nano-technology has the potential to revolutionize waste management by offering innovative solutions to various waste-related challenges. Its unique properties at the nanoscale can be applied to enhance waste treatment, recycling, and pollution control. Here are some ways in which nano-technology can be utilized in waste management:

Table 1: The various waste derived nanoparticles and its applications

Sr No	Waste derived nano particle/materials	Source	Application	References
1	Ferrous	Mill scale	Magnetic separation and dye removal	Arfin et al., 2017
2	Graphene	Recycled polyethylene	Adsorption of methylene blue and other dyes	El Essawy et al
3	Bio-char	Eggshell waste	Pb^{2+} adsorption	Wang et al. (2018)
4	Organic aerogel	Paper, cotton, plastic bottles	Oil (and its similar) removal	Thai et al. (2019)
5	Silica nanoparticles	Agricultural waste	Removal of acid orange	Rovani et al. (2018)
6	Zinc and Cupper	Electrical waste (PCB)	Methylene Orange Degradation	Nayak et al. (2019)
7	Zero valent Ferrous	Pickling line of steel plant	Decomposition of Nitrobenzene	Lee et al. (2015)
8	Copper	Electrical waste	Enhance the electro chemical efficiency of electrode	Abdelbasir et al. (2020)
9	Porous silica nano particles	Rice husk	Co_2 Capture (absorption and desorption) in bottom and fly ash stream	Zeng and Bai, (2016)

Water purification :

Nano-sized materials, such as nanoparticles and nanocomposites, can be used as efficient adsorbents to remove pollutants and contaminants from water. These nano-materials have a high surface area and enhanced reactivity, making them effective at capturing and degrading various pollutants, including heavy metals and organic compounds.

Waste treatment and remediation :

Nanomaterials can be used to catalyze chemical reactions and break down harmful substances in waste streams. They can also be employed in soil and groundwater remediation to remove contaminants, such as heavy metals and organic pollutants.

Carbon Nanotubes (CNT) can be fabricated from plastic wastes after the application of autoclaves, crucible, muffle furnace and quartz tube. These methods disintegrate solid polymers into carbon precursors by pyrolysis. Other than this, polyethylene, polyvinyl alcohol, polypropylene and polyethylene terephthalate can also be utilized for the production of carbon nanotubes[6].

Graphene can also be reproduced by numerous plastic waste applying methods like waste polypropylene catalysed by montmorillonite than conversion of carbonized char and dissolved it with HNO3. The amorphous carbon can be obtained and repeated processes of same can give graphene flakes after the centrifugation and isolation process.

The mode of action approach of various nanoparticles changes with the native environment as the reaction, the medium and the characteristics alters with the availability of resources.

Silver nanoparticles generated from green synthesis using the neem leaf and banana peel is useful for the dye degradation and antimicrobial activity. The potential effects for dye degradation are also effectively applied for the hazardous dye removal.

Nanoparticles made from gum acacia and copolymer nanocomposite magnetite nanoparticles were used as an adsorbent for the aqueous solution in the wastewater treatment plant and effluent showed the removal of the different magnetic property containing waste materials.

ZnO nanoparticle synthesized from the peel of *Passiflorafoetida* fruit uplifted the removal percentage of methylene blue (93.25%) and Rhodamine B (91.06%) after 70 min of application of nanoparticles. The metallic nanoparticles have potential for removal of the antibiotic resistant bacteria and antibiotic resistant genes from wastewater treatment facilities.

Nanoparticles function as a reducing agent and work as an antimicrobial catalyst for the detoxification of pollutants like organic, inorganic, and heavy metals. It's environment friendly nature, cost effectiveness and potential reaction capability gives an extra edge over the available treatment materials[7].

Nanomaterials from Chitosan Used for Removal of Dyes :

Chitosan nanoparticles possess relatively larger surface area and higher adsorption potency. These two qualities make it an effective adsorbent material for the decomposition of various dyes in textile wastewater.

The capacity to adsorb and select the chitosan nanoparticles is further enhanced when surface is modified by some functional groups or by an appropriate grafting compound. The advantage of using magnetic chitosan lies in the simplicity of segregation done via magnet with better recyclability.

A prepared concoction nanoparticle of chitosan/Al_2O_3/magnetic iron oxide and applied it for the removal of methyl orange dye. Apart from this the researchers have also prepared simple magnetic chitosan. The magnetic chitosan is good adsorbent for the dye removal, and it was further seen through the experiment results for methyl orange removal.

Glutaraldehyrade crosslinked magnetic chitosan nanocomposites prepared by reduction precipitation process are often applied for the elimination of Acid Red 2 and it gives an adsorption potency of 90.06 mg g^{-1}. The production process does not involve in use of any hazardous chemicals or extreme heat. The mechanism of adsorption is established on electrostatic interaction of anionic Acid Red 2 dye. This has a positive surface charge for magnetic chitosan nanocomposite and occurs as a consequence of protonation of amine group.

Nanomaterials Made From Chitosan in Removal of Pesticides:

The barriers in the crop productivity are the pests, weeds and harmful substances disposed on the land. In order to eradicate these problems pesticides are used but there is also a problem when these are used as they leach out in the nearby water bodies and promulgates rapid algal growth. Being toxic they often harm the aquatic ecosystem so they need to be removed from the environment with the help of adsorbents. The chitosan nanoparticles are used for the removal of pesticides is the new avenue where very few researchers have worked upon. In a study conducted by various methods used the chitosan mixed with zinc oxide nanoparticles to remove the pests.

Chitosan Infused Nanomaterials for the Removal of Other Organic Pollutants :

The nanomaterials infused with chitosan have given very good results for the elimination of pollutants and many researchers have applied the nanochitosan for the eradication of polyaromatic hydrocarbons (pH 5, 30°C)[5] .

The magnetic chitosan nanoparticle was prepared by one-step *in situ* co-precipitation technique. The Quasi-spherical shaped nanoparticles are formed with size 10 nm. The magnetic chitosan nanoparticles prepared removed humic acid from water solution at pH 7 and 25°C. It has a reclaimable property which helps it to be used for a long term[14]. The capacity to adsorb for the chitosan-based nanoparticles for organic pollution has been widely used due to its effective sorbent properties, economic feasibility and biodegradable nature which is a boon to the environment and its dwellers.

The Use of Nanotechnology for Pesticides and POP Remediation from Soil :

The soil pollution is prevalent through the unsurmountable use of pesticides and persistent organic pollutants (POPs) by human activities that lead to the restriction of chemical pollutants use in the Stockholm convention on persistent pollutants (POPs) held in 2004. With the awareness through convention, there was a widespread need to wipe out these contaminants persistent in the soil via proper bioremediation and administration of contaminated soil areas that has been disrupted due to deposition of toxic chemical pollutants. There are eight pesticides out of the total 12 banned POP chemicals and the rest are either from factory-exhaust chemicals and pharmaceuticals[8]. The biomagnification and bioaccumulation of these toxic compounds pose a greater risk for the cycle of food chain and more persistent in the tertiary consumers so there is a need to remove these pollutants at the initial stage itself. Since these POPs are lipophilic, they tend to deposit as fatty tissues in the living beings and pose an acute and chronic risk. Many pesticides have recently been banned as they pose threats to the health even after it has been abandoned for many years. The problem with POPs arises when they are prevalent by the means of vaporization and are settled at the site far from the origin. The recalcitrant nature of the POPs tends to contaminate the soil for decades and they take several years to degrade from the environment. Photocatalysis is the means for degradation of these pesticide pollutants. The nanoparticles in the process of photolysis acts as catalyst and go through response with chemical contaminants i.e., pesticides and POPs. These nanophotocatalysts transform the hazardous persistent pollutants into simple compounds such as CO_2, N_2, and H_2O. According to Fujishima et al., 2008, the nanoscale titanium dioxide (TiO_2) and zinc oxide (ZnO) are better photocatalysts and it was further elucidated by[9] , by his study on the degradation of organochlorine pesticides such as α-, β-, γ-, and δ-hexachlorobenzene; dicofol; and cypermethrin through use of nano-TiO_2. The pesticides with nano-TiO_2 on its surface attract the peroxide or hydroxyl radicle and helps in electron transfer. The photocatalytic degradation of organophosphorus and carbamate with the use of nano-TiO_2 with rhenium (Re^{+3}) have been reported for the leaves of tomato plantsand around 15–30% photocatalytic degradation was found for organophosphorus and carbamate pesticides. The use of nano-TiO_2 for photocatalysis is also found effective in reducing the half-lives of pesticides as defined by [10].

The application of carbon nanofibers has expedited as they provide complete mineralization of metolachlor which is used as an herbicide and are capable of giving rise to innumerable by-products in the form of organic acids and aromatic compounds which are harmful and persistent.

The nanozerovalent iron (nZVI) has a better degradative effect on the soil contaminated with Dichlorodiphenyltrichloroethane (DDT). The degradation rate was found around 50% for DDT induced soil and 24% for POP polluted soil.

The application of nZVI has conducted on remediation of soil contaminated with organochlorine. The disturbance on soil bacterial community after application of nZVI has been noticed along with the depletion in pursuit of chloroaromatic mineralizing microbial organisms.

The initiation of photodegradation of malathion was done with the incorporation of the semiconductor synthesized nanoparticles attached with various metal core-shell nanocomposites such as TiO_2, Au/TiO_2, ZnO, and Au/ZnO as they acted as catalyst. The prepared nanocomposite with a coalescence of metal core and semiconductor further improvised the photocatalytic effect and boosted the malathion decomposition in a stipulated time[11]. The Tio_2 nanoparticles remains unaffected during degradations process. It possess low toxic effects and low manufacturing cost[12].

The effect of nano-TiO_2 (anatase) on photocatalytic decomposition of phenanthrene (a poly aromatic hydrocarbon) was studied by[13]. They found that half-life of phenanthrene was brought down by 14 h (from 46 to 31 h) when TiO_2 was loaded at 0 and 4 percentage weight. A significant degradation process was witnessed on the soil surfaces when TiO_2 was used. The factors such as the concentration of H_2O_2, intensity of light and humic acid enhanced the degradation process as depicted in Table 2.

Table 2: The use of Nanotechnology for pesticides and POP remediation

Nanomaterial	Pesticide on focus	Remarks	References
MWCNTs	Metolachlor	Pesticide mineralization due to catalytic ozonation	Restivo et al. (2012)
Nanoscale zerovalent iron (nZVI)	DDT	Reduction of pesticide due to complete oxidation and elevated electron release	El-Temsah et al., 2016
	Aroclor 1242	The chloroaromatic mineralizing microorganisms showed reduced rate of educed rate of PCB activity	Tilston et al. (2013)
	Organochlorine pesticides and PCBs	Detoxification and decomposition of chlorinated organic solvents	Pan and Xing (2012)
TiO2, Au/TiO2, ZnO, and Au/ZnO Nano-TiO2- coated film	Malathion Organochlorine pesticides— α-, β-, γ-, and δ-hexachlorobenzene; dicofol; and cypermethrin	Photocatalytic degradation With the Hydroxyl radical and electron transfer, photocatalytic decomposition of pesticides on TiO_2 surface occurs	Fouad and Mohamed (2011); Yu et al. (2007)
Anatase TiO2	Phenanthrene (PAHs)	The use of TiO_2 with H_2O_2 and humic acid (in presence of light) led to degradation	Gu et al. (2012)
Rhenium (Re^{+3})-doped nano-TiO2	Carbofuran	Pesticide decomposition through photocatalysis	Rui et al. (2010)
nZVI and Pd/Fe bimetallic NPs	Polychlorinated biphenyls (PCBs)	Undergoing Hydro-dechlorination	Chen et al. (2014)

Nanosensors for waste monitoring :

Nanoscale sensors can be used to detect and monitor various waste parameters in real-time. For instance, they can monitor air and water quality, providing valuable data for waste management decision-making and pollution control. Nanotechnology offers promising solutions in waste management by enhancing processes such as waste treatment, recycling, and pollution control. Nanosensors can detect and monitor pollutants in real-time, aiding in waste management and pollution control. Nanosensors have shown great potential for waste monitoring applications due to their high sensitivity and ability to detect a wide range of pollutants Real-time Monitoring: Nanosensors can provide real-time data on various waste-related parameters, such as pH levels, chemical composition, and the presence of specific pollutants. Nanosensors can be designed to be highly selective and specific to particular pollutants, reducing the chances of false readings. Wireless Connectivity: Some nanosensors can be integrated with wireless technology, allowing for remote monitoring and data transmission, enhancing waste management efficiency. Nanosensors are continually evolving, offering promising solutions for effective and efficient waste monitoring, which is crucial for maintaining environmental health and safety standards[15-18].

Nanotechnology in waste recycling :

Nano-engineered materials can improve the efficiency of recycling processes. For example, nano-catalysts can enhance the breakdown of complex waste materials, making it easier to extract valuable resources from waste streams. Nanotechnology offers several potential applications in waste recycling processes, including improving material separation, enhancing recycling efficiency, and reducing environmental impact. Nanotechnology can enhance the recycling of materials by improving the sorting and separation of different components in waste streams. However, it's essential to consider the potential environmental and safety concerns associated with nanomaterials in waste management. Proper regulations and risk assessments are crucial to ensure safe and sustainable implementation.

It includes:

Enhanced Sorting: Nanotechnology can improve the precision of sorting materials in recycling facilities, leading to more effective separation of recyclables from waste.

Nanomaterials for Recycling: Nanomaterials can be used to create more efficient catalysts for chemical recycling or to improve the properties of recycled materials.

Advanced Sensors: Nanosensors can be employed to monitor and control recycling processes, ensuring better quality control and resource efficiency.

Waste-to-Energy Conversion: Nanotechnology can enhance waste-to-energy processes, allowing for more efficient and environmentally friendly energy recovery from waste.

Reduced Environmental Impact: By enabling more efficient recycling and reducing waste, nanotechnology can contribute to lowering the environmental footprint of recycling processes.

Improved Recycling of Composite Materials: Nanotechnology can aid in the recycling of complex materials like electronic waste or composite materials by breaking them down into their constituent parts more effectively.

Reduced Waste Generation: Through innovations in packaging and materials design, nanotechnology can help reduce the generation of waste in the first place [19-23].

Nanoscale coatings for waste containment :

Nano-engineered coatings can be applied to waste storage containers to improve their resistance to leakage and corrosion. This can help prevent hazardous waste from seeping into the environment and causing pollution.

Nano-bioremediation :

Nanotechnology can also be combined with bioremediation techniques to enhance the removal of pollutants by microorganisms. Nanomaterials (NM) can act as carriers for beneficial bacteria, allowing them to efficiently target and degrade specific waste components. The type of NM selection based on the nature of the contaminant. A nano iron material is used for heavy metals separation in soils or water through its magnetic properties. Also, carbon-based NMs are used to trap organic pollutants or heavy metals from water, soil or air.

Energy recovery from waste :

Nanotechnology can play a role in improving energy recovery from waste through advanced materials and catalysts used in waste-to-energy processes, such as gasification and pyrolysis. Despite the many potential benefits, it's essential to consider the potential risks and safety aspects associated with the use of nanomaterials. Proper regulation and guidelines should be in place to ensure the responsible and safe application of nanotechnology in waste management. Additionally, ongoing research and development are needed to fully explore and optimize the use of nanotechnology in this field.

Nanomaterial-based filters :

Nano-engineered filters can be used in air and water treatment systems to capture and remove particulate matter, microorganisms, and harmful pollutants more effectively than conventional filters. The carbon nanomaterials are used in several water treatment applications such as dye removal, oil separation from water, and heavy metal ions removal. Nanomaterials have emerged as the new future generation materials for high-performance membranes that are expected to solve the water crisis issue. Nanofiltration membranes can improve the separation and purification of liquids and gases in waste treatment.

Nanocatalysts for waste-to-energy processes :

Nanocatalysts can improve the efficiency of waste-to-energy conversion technologies like anaerobic digestion and fermentation, leading to increased biogas production and energy generation. Calcium oxide is a common nanocatalyst for biodiesel production due to its inexpensive cost and strong catalytic activity. CaO can be utilized either alone or in conjunction with other materials to produce biodiesel. By the use of nanocatalyst, production of biodiesel from various sources such as palm, sunflower, soybean, olive, maize, rapeseed, safflower, peanut, and coconut oil, vegetable oil, waste cooking oil (WCO) extracted from animal fat and algal oil. Nanocatalysts can significantly increase biodiesel yield. The main advantage of using nanocatalyst in biodiesel production is reusability and recovery without losing its catalytic activity. Thus, Nanocatalysts can improve the efficiency of waste-to-energy processes, converting waste into electricity or fuel[24].

Nanocomposites for waste packaging :

Nano-additives can be incorporated into plastics and other packaging materials to enhance their strength, durability, and biodegradability, reducing the environmental impact of packaging waste. The various nanomaterials are used for food packaging such as silver NPs, copper NPs, zinc oxide NPs, titanium dioxide NPs, silicon dioxide NPs, nanocellulose, nanoclays, chitosan NPS, etc. Oxygen scavengers such as ZnO can be used for the packaging of cooked meat products, cheese, bakery products, fruit, vegetable, seeds, nuts, etc. to prevent discoloration, mold growth, rancidity, and for the retention of vitamin C. Ethylene absorbers such as Zeolite, Ag, TiO_2, ZnO can be used for climacteric fruits and vegetables food packaging by the reduction in ripening and senescence, thereby enhancing the quality and prolonging shelf-life. Antioxidant releasers such as Ag, ZnO, CuO, Graphene are mostly used for fresh fatty fish, meat, seeds, nuts, and fried products packaging to improve the oxidative stability of the product. Finally, nanoparticles (NPs) (such as Ag, TiO_2, ZnO, Cu, Graphene) with antimicrobial activity are used for fresh meat, fish, vegetable, fruits, dairy products, grain, cereals, and bakery products, ready-to-eat meals packaging to prevent microbial growth. There are about 400 companies in the world that focus on nanoparticles in food and food packaging. Nanocor is a USA-based AMCOL International Corporation which is specialized in the production of nanoclay-based plastic bio-nanocomposites with the trademark Nanomer®. These products have improved thermal, barrier, and physical properties. However, Plantic Technologies Limited, Australia designed starch-nanoclay-based 'thermoformed plantic trays' for Cadbury, Dairy Milk, and Mark & Spencer Swiss chocolate. These packaging materials are biodegradable, non-toxic, have improved rheological, mechanical, and moisture properties[25]

Nanotechnology for hazardous waste immobilization :

Nanomaterials can be used to stabilize and encapsulate hazardous waste, preventing its leaching into the environment and reducing the risk of contamination. Nanoscale particles have gained a great interest for heavy metal immobilization in soil and groundwater[26].

Nano-enabled waste tracking and sorting :

Nanotags or nanomarkers can be applied to waste items to facilitate better tracking and identification throughout the waste management process. This can improve recycling efficiency and reduce the amount of non-recyclable waste. Many of the current solid waste and recyclable sorting and separation methods are tedious and can often be expensive, leading to inefficiencies. Nanotechnology affords new opportunities to interact with and gain insight into the products and materials with which people interact. One novel application is the capability to tag and track materials from manufacture to end-of-life. Nanoscale materials and structures can be utilized as "tags" and can be directly incorporated into or onto the product during the manufacturing process.

The small size of the materials and structures renders them invisible to the naked eye without altering the "macro" properties of the system. The nanoscale material and structures can be robust and can be used to "track" a material through it. Nanomaterials and nanostructures can be added into or onto plastics, electronics, and other consumer items as nano-sized physical tags with unique property signatures. The nano-sized tag cannot be easily removed and can be interrogated using various optical, electronic, and magnetic detection methods at any point during the lifecycle of the tagged product for authentication in order to allow easier tracking. Since such tags can be tuned to have a unique property signature, they can be used by chemical and product manufacturers to uniquely identify and track their products throughout their lifecycles. Products entering the waste stream at their end-of-life can be effectively separated and sorted by the different identifying tags used by each chemical and product manufacturer and can then be sent to the appropriate chemical and product manufacturer for recycling and reuse. This ready identification process will minimize and reduce the amount of potential recoverable and recyclable waste ending up in landfills[27].

Nanotechnology for electronic waste (e-waste) recycling :

Nanoscale processes can aid in the recovery of valuable metals from electronic waste, which often contains valuable resources but is challenging to recycle using traditional methods. A large range of airborne natural particles including airborne particles which is rich in natural minerals have been used as interfaces to remove airborne pollutants, including many of which that are produced from e-waste deposits as well as during the e-waste industrial processes. Since airborne nanoparticles and microparticles are quite diverse, several studies have focused on those that uptake airborne pollutants through physisorption processes which require much less energy (~10–15 kcal/mol) for their recycling-recovery processes, in comparison to chemisorption procedures (>15 kcal/mol). For instance, various iron oxides were used as interface to remove a variety of organic compounds (e.g., BETX), as well as trace metals such as mercury, which is commonly used in several e-waste products such as energetically efficient fluorescent lamps. Interestingly, the usage of magnetism of particles (e.g., magnetite, Fe_3O_4) allowed researchers to transport particles without much energy, while removing very effectively and efficiently the pollutants emitted from e-waste materials. Furthermore, various different natural coatings such as cellulose products which are known natural waste (e.g., carboxymethyl cellulose) to selectively remove gas-phase pollutants, or to increase their uptake at various humidity levels or control competitive adsorption in presence of several co-pollutants. There have been additional efforts to combine natural nanoparticle physisorption processes for e-waste material, with solar-run operated salt-based electrochemistry to remove both organic and metal contaminants. Another method that has been the use of natural minerals such as clay mineral and montmorillonite nano and micro-traps to remove and recycle the pollutants including toxic compounds produces in e-waste. Many E-waste treatment processes use fossil fuel combustion that generate gaseous emissions that contain a number of toxic organic pollutants and carbon dioxide (CO_2) that lead to climate change and atmospheric pollution. There are new development of hybrid technologies, for instance integrated bioreactor combined with recyclable iron oxide nano/micro-particle adsorption interfaces, to remove CO_2, and undesired organic air pollutants using natural particles. Such hybrid technologies allow keeping the existing technology with novel features, to remove the toxicants while allowing the efficiency and effectiveness of the processes, which should be considered in e-waste management[28].

Nanoscale smart sensors for waste bins :

Nanosensors integrated into waste bins can monitor waste levels, detect odours, and optimize waste collection schedules, leading to more efficient waste collection and transportation.

Nanocoatings for waste containers :

Nanocoatings can be applied to waste containers to make them more resistant to fouling, corrosion, and odour, improving sanitation and extending their lifespan. Nanomaterials possess improved thermal, mechanical, physical, chemical, magnetic, electronic, and optical properties. Nanocrystalline structures are superior over microstructures for corrosion enhancement due to the fine grain sizes, which provide better space filling and a higher integrity of the coated surface. Applying nanocoating onto the surface of the substrate makes it harder, tougher, and improves its adhesive properties. However, the coating thickness and composition should be designed so as not to decrease its protective characteristics towards corrosive and eroding influences[29].

Nanotechnology in wastewater treatment :

Nanomaterials like graphene oxide and nanoscale membranes can enhance the removal of contaminants from wastewater, improving the overall efficiency of wastewater treatment processes. **Water Purification:** Nanomaterials like carbon nanotubes and nanoparticles can remove contaminants from water, making it more efficient and cost-effective.Magnetic nanosorbents also helps in treating waste water and is proved very interesting tool especially for organic contaminants removal. Nanocatalysts are also widely used in water treatment as it increases the catalytic activity at the surface due its special characteristics of having higher surface area with shape dependent properties. It enhances the reactivity and degradation of contaminants. The commonly used catalytic nanoparticles are semiconductor materials, zero-valence metal and bimetallic nanoparticles for degradation of environmental contaminants such as PCBs (polychlorinated biphenyls), azo dyes, halogenated aliphatic, organochlorine pesticides, halogenated herbicides, and nitro aromatics. The catalytic activity has been proved on laboratory scale for various contaminants. Since hydrogen is used in making active catalyst in large scale by redox reactions, there is need in reducing its consumption and maintain hydrogen economy by directly making catalysts in metallic form. Silver (Ag) nanocatalyst, AgCCA catalyst, N-doped TiO_2 and ZrO_2 nanoparticles catalysts have been made which is highly efficient for degradation of microbial contaminants in water and are reusable as well. TiO_2-AGS composite is very efficient for Cr (VI) remediation in waste water due to the modification done in TiO2 nanoparticles leading to absorption band shift from UV light activity to natural light degradation. Palladium incorporated ZnO nanoparticles were found to be having very high photocatytic activity for removal of E.coli from water[30].

Nanotechnology for plastic degradation:

Researchers are exploring the use of nanomaterials and enzymes to break down plastic waste into smaller, more manageable components, potentially enabling more efficient plastic recycling or biodegradation.

Nanotechnology's versatile and customizable nature holds great promise for addressing various waste management challenges. However, it is crucial to continue research on the potential environmental and health implications of using nanomaterials in waste management to ensure their safe and responsible deployment. Nanoparticles offered Energy-efficient large-scale implementable methods to tackle the world's plastic accumulation problem[31].

Nanoscale adsorbents for heavy metal removal:

Nano-engineered materials, such as graphene-based nanocomposites and metal-organic frameworks (MOFs), have shown high efficiency in adsorbing heavy metals from industrial wastewater and contaminated soils. Nanomaterials can be used as highly effective adsorbents for removing pollutants and heavy metals from industrial and municipal waste streams. A novel functionalized silica nanoadsorbent was made with surface modification for the removal of heavy metal ions from waste water[32].

Nanoscale bioremediation :

Nanotechnology can enhance bioremediation processes by encapsulating and protecting beneficial microorganisms, such as bacteria or fungi, and delivering them to the contaminated sites for targeted pollutant degradation[33]. The microbial integration with the nanoparticles enables the adsorption and degradation of the contaminants at a greater level. The enzymes of the microbes even dissolve the pollutants to make them available to the nanoparticles for degradation. Integration MCNTs ("Multi-walled carbon nanotubes") with bioremediation techniques reduced the toxicants at a greater level[34].

Nanomaterials for waste-derived product development:

Nanotechnology can be employed to create new materials with enhanced properties from waste materials. For example, nanoparticles can be used as additives in cement or concrete to improve their strength and durability.

Nanoscale sensors for landfill monitoring:

Nanosensors can be embedded in landfill sites to monitor the decomposition process, gas emissions, and leachate quality, helping to optimize landfill management and reduce environmental impacts.

Nanotechnology for plastic waste upcycling :

Nanocatalysts and nanocomposites can be used to convert plastic waste into higher-value products, such as fuels or chemicals, through advanced pyrolysis or chemical recycling techniques.

Nanotechnology in waste composting :

Nanomaterials can enhance the composting process by accelerating the decomposition of organic matter and improving the quality of the compost produced.

Nanoscale robotic systems for waste collection and sorting :

Nanobots or nano-robots can be designed to autonomously navigate and sort waste items, making waste collection and recycling processes more efficient.

Nanotechnology for landfill gas management :

Nanomaterials can improve the capture and utilization of landfill gas (methane) by enhancing the efficiency of gas separation and purification processes.

Nanotechnology for textile waste treatment:

Nano-engineered coatings and finishes can improve the biodegradability and recyclability of textiles, reducing the environmental impact of textile waste. Nanofiber membranes have been employed for filtration and separation processes in textile wastewater treatment. Nanoparticles can be incorporated into textile fibers to enhance their recyclability. These nanoparticles enable easier separation of materials during recycling processes. Nanotechnology is also being used to develop biodegradable and sustainable textiles. Nanomaterials can enhance the strength and properties of biodegradable fibers, reducing the environmental impact of textile disposal.

Nanotechnology for waste reduction in manufacturing processes:

Nanotechnology can be integrated into industrial processes to minimize waste generation, optimize material usage, and enhance process efficiency. It's essential to emphasize that while nanotechnology offers numerous potential benefits in waste management, its safe and sustainable implementation requires thorough research, risk assessment, and regulatory oversight. Responsible development and application of nanotechnology will be key to ensuring positive impacts on waste management and the environment.

Nanomaterials for odour control :

Nano-engineered materials can be used to capture and neutralize odorous compounds from waste streams, reducing unpleasant smells in waste treatment facilities and landfills.

Nanoscale robotic systems for microplastic cleanup :

Nanobots equipped with sensors and nanoscale arms can be designed to target and remove microplastics from water bodies, helping to mitigate the growing problem of microplastic pollution.

Nanotechnology for hazardous waste treatment :

Nanoparticles and nanocomposites can be used in innovative treatment processes for hazardous waste, facilitating the breakdown of toxic compounds and reducing their environmental impact.

Nanoscale photodegradation of pollutants :

Nanocatalysts and nanomaterials can be employed in photocatalytic processes to degrade persistent organic pollutants and contaminants present in industrial waste and wastewater. They can detect trace amounts of contaminants, including heavy metals, organic pollutants, and microbial pathogens, making them valuable for assessing water and soil quality in waste management. Nanosensors are small and can be easily integrated into portable devices, making them suitable for on-site waste monitoring. They are used in monitoring industrial effluents, landfill leachates, and wastewater treatment processes to ensure compliance with environmental regulations.

Nanotechnology in waste-to-fuel processes :

Nanomaterials can enhance the efficiency of waste-to-fuel conversion technologies, such as converting organic waste into biofuels or producing hydrogen from waste biomass.

Nanotechnology for waste transport and containment :

Nanomaterials with high mechanical strength and barrier properties can be incorporated into waste containers and liners to prevent leakage and reduce the risk of environmental contamination.

Nanoscale monitoring of landfill stability :

Nanosensors can be used to assess the structural integrity of landfills continuously, identifying potential issues like settling or instability, and allowing for timely maintenance and remediation.

Nanotechnology for desalination of brine waste :

Nano-engineered membranes can improve the efficiency of desalination processes, enabling the recovery of valuable resources from brine waste generated during seawater desalination.

Nanomaterials for mercury capture :

Nanoscale sorbents can be used to capture and remove mercury from waste streams, particularly from industrial processes and coal-fired power plant emissions.

Nanomaterials acts as disinfectant for the control of pathogens :

Most of the diseases in developing countries caused by water contamination due to the presence of bacteria, viruses, fungi and several protozoa. There are some disinfection agents, numerous DBPs and equipments are used for the Wastewater treatment. Nanomaterials are endued for inactivate the pathogens in water by surface based electrostatic interaction and phytochemical reactions that brings about the production of reactive oxygen species (ROS). It disrupts the cell wall and delivered the disinfective agents. Hence, the pathogens present in water can be easily inhibited[14].

CONCLUSION

The eco-friendly synthesis through nanoparticles (NPs) offers clean, non-toxic, relatively cost-effective, and environmentally sustainable procedures. Nanotechnology promulgates an upgraded and innovative initiative to fabricate and analyse various novel formulations based on metallic NPs that have tremendous prospect in diverse areas. Various nanoparticles and their prospective applications have been discussed in this review. The increasing threats to human health and the surround emancipated by the NPs are a concern therefore the studies are conducted in order to characterize the toxicity and mechanisms of NPs. The contemporary use of NPs with added advantages has been an important and efficient efforts to improvise the synthesis efficiency. The effective use of chitosan as adsorbent nanomaterial has led to the low-cost treatment for the water apart from the augmentation of antibacterial properties.

The implementation and utilization of these technological approaches for scale up and the commercial applications in the various fields will be upheld in the coming years. In the upcoming years the promulgation of nanotechnology will be useful for the replacement for the present precarious means as it will be eradicated the harmful contaminates from the soil and preserve the environmental sanctity. The remediation with the inculcation of nanotechnology has showed tremendous possibilities for diminishing the total cost and reduction of time allocated for replenishing as well as restoring the contaminated niche on a large scale. The onsite remediation reduces the overall cost for transport, processing and soil dumping afterwards the area has been replenished. The long-term effects due to the use of nanoparticles is still under the cynosure as proper evaluation needs to be done before forging ahead with large scale implementation to curb the future potential environmental effects.

REFERENCES

1. Jeevanandam J, Barhoum A, Chan YS, Dufresne A, Danquah MK. Review on nanoparticles and nanostructured materials: history, sources, toxicity and regulations. BeilsteinJ Nanotechnol. 2018Apr3;9(1):1050-74. doi: 10.3762/bjnano.9.98, PMID 29719757.
2. Khalid M, Abdollahi M. Environmental distribution of personalcareproducts and theireffects on humanhealth. Iran J Pharm Res.2021Winter;20(1):216-53. doi: 10.22037/ijpr.2021.114891.15088, PMID 34400954, PMCID PMC8170769.
3. Baig N, Kammakakam I, NanomaterialsFW.A review of synthesis methods, properties, recent progress, and challenges. Materials advances. 2021;2(6):1821-71. doi: 10.1039/D0MA00807A.

4. Sharma D, Kanchi S, Bisetty K. Biogenic synthesis of nanoparticles: a review. ArabJ Chem. 2019Dec1;12(8):3576-600.doi: 10.1016/j.arabjc.2015.11.002.
5. Nakum J, Bhattacharya D. Various green nanomaterials used for wastewater and soil treatment: a mini-review. Front EnvironSci. 2022Jan28;9:724814. doi: 10.3389/fenvs.2021.724814.
6. Siracusa V, Blanco I. Bio-polyethylene (Bio-PE), Bio-polypropylene (Bio-PP) and Bio-poly (ethylene terephthalate)(Bio-PET): recent developments in bio-based polymers analogous to petroleum-derived ones for packaging and engineering applications. Polymers.2020Jul23;12(8):1641.doi:10.3390/polym12081641, PMID 32718011.
7. Khan I, Saeed K, Khan I. Nanoparticles: properties, applications and toxicities. ArabJ Chem. 2019Nov1;12(7):908-31. doi: 10.1016/j.arabjc.2017.05.011.
8. Raffa CM, Chiampo F. Bioremediation of agricultural soils polluted with pesticides: a review. Bioengineering (Basel).2021Jul2;8(7):92. doi: 10.3390/bioengineering8070092, PMID 34356199.
9. Hernández S, Hidalgo D, Sacco A, Chiodoni A, Lamberti A, Cauda Vet al.Comparison of photocatalytic and transport properties of TiO 2 and ZnO nanostructures for solar-driven water splitting. PhysChemChemPhys. 2015;17(12):7775-86. doi: 10.1039/c4cp05857g, PMID 25715190.
10. Zeng R, Wang J, Cui J, Hu L, Mu K. Photocatalytic degradation of pesticide residues with Re3+ -doped Nano-TiO2. Journal of Rare Earths.2010;28:353-6. doi:10.1016/S1002-0721(10)60329-8.
11. Fouad DM, Mohamed MB. Comparative study of the photocatalytic activity of semiconductor nanostructures and their hybrid metal nanocomposites on the photodegradation of Malathion.J Nanomater.2012Jan1;2012:1-8. doi: 10.1155/2012/524123.
12. Dermatas D, Mpouras T, Panagiotakis I. Application of Nanotechnology for waste management: Challenges and limitations. Waste Management & Research. 2018 Mar;36(3):197-9.
13. Gu J, Dong D, Kong L, Zheng Y, Li X. Photocatalytic degradation of phenanthrene on soil surfaces in the presence of nanometer anataseTiO2 under UV-light. J EnvironSci (China). 2012Dec1;24(12):2122-6.doi: 10.1016/S1001-0742(11)61063-2, PMID 23534208.
14. Jain K, Patel AS, Pardhi VP, Flora SJS. Nanotechnology in wastewater management: a new paradigm towards wastewater treatment. Molecules. 2021 Mar 23;26(6):1797. doi: 10.3390/molecules26061797, PMID 33806788.
15. M. K. Dehvari *et al.* Nanosensors for environmental and pollution monitoring: A review. Environ Sci Pollut Res. 2018.
16. Yang *et al.*, Nanoscale Advances. 'Nanotechnology and its applications in the food sector: A review' – S.S. Smitha and S. Rani. Adv Food Nutr Res. 2019."Nanosensors for water quality monitoring" - S;2019.
17. Nanomaterial-based sensors for environmental pollutant monitoring - N. Sharma et al. Sens Actuators B. 2019.
18. Nanosensors for the detection of environmental and biological contaminants - M. Z. Atashbar et al. Sensors. 2020.
19. Nanotechnology in recycling and waste treatment: present and future trends - C. Pagano et al. J Cleaner Prod. 2018.
20. Nanotechnology and waste recycling: A comprehensive review - M. Singh et al. J Hazard Toxic Radioact Waste. 2016.
21. Nano-based approaches to enhance plastics recycling: a review - M. Norouzi et al. J Cleaner Prod. 2019.
22. Nanotechnology in waste recycling: an innovative solution - S. M. Alhassani et al. Int J Environ Sci Technol. 2020.
23. C. F. Forero et al. Nanotechnology in the recycling of automotive shredder residue: a review. Environ Sci Pollut Res. 2021.
24. Bin Rashid A. Utilization of nanotechnology and nanomaterials in biodiesel production and property enhancement. Journal of Nanomaterials. 2023 Feb 13;2023:1-4. https://doi.org/10.1155/2023/7054045
25. Perera KY, Jaiswal S, Jaiswal AK. A review on nanomaterials and nanohybrids based bio-nanocomposites for food packaging. Food Chemistry. 2022 May 15;376:131912. https://doi.org/10.1016/j.foodchem.2021.131912
26. Ibrahim RK, Hayyan M, AlSaadi MA, Hayyan A, Ibrahim S. Environmental application of nanotechnology: air, soil, and water. Environmental Science and Pollution Research. 2016 Jul;23:13754-88. https://doi.org/10.1007/s11356-016-6457-z
27. Fitch BR, Buntel CJ, Wang YJ, Hau SK, Londergan TM. The recycling exchange and nanotechnology: towards a zero waste economy. Intellectual Ventures, Bellevue, WA. 2012. Available from: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=4070b090af3ef818d354bd656f122f8fcbc5d75d
28. Ghimire H, Ariya PA. E-wastes: bridging the knowledge gaps in global production budgets, composition, recycling and sustainability implications. Sustain Chem. 1: 154–182. Available from: https://www.mdpi.com/2673-4079/1/2/12.
29. Abdeen DH, El Hachach M, Koc M, Atieh MA. A review on the corrosion behaviour of nanocoatings on metallic substrates. Materials. 2019 Jan 10;12(2):210. https://www.mdpi.com/1996-1944/12/2/210/pdf
30. Madhuri B, Singh SP, Batra RD. Nanotechnology in wastewater treatment: a review. Novel Applications in Polymers and Waste Management. 2018 Jan 19:173-82. Available from: https://www.researchgate.net/publication/287840958_Nanotechnology_in_waste_water_treatment_A_review.
31. Chandran R. R, Thomson B. I, Natishah A. J, Mary J. Nanotechnology in Plastic Degradation. Biosci Biotech Res Asia 2023;20(1). http://dx.doi.org/10.13005/bbra/3068
32. Janani R, Gurunathan B, Sivakumar K, Varjani S, Ngo HH, Gnansounou E. Advancements in heavy metals removal from effluents employing nano-adsorbents: way towards cleaner production. Environmental Research. 2022 Jan 1;203:111815. https://doi.org/10.1016/j.envres.2021.111815
33. Singh R, Behera M, Kumar S. Nano-bioremediation: An innovative remediation technology for treatment and management of contaminated sites. Bioremediation of Industrial Waste for Environmental Safety: Volume II: Biological Agents and Methods for Industrial Waste Management. 2020:165-82. doi:10.1007/978-981-13-3426-9_7
34. Hemalatha I, Harika D, Karnena MK. Sustainable Nano-Bioremediation Approaches for the Treatment of Polluted Soils. Nature Environment & Pollution Technology. 2022 Dec 1;21(4). https://doi.org/10.46488/NEPT.2022.v21i04.036