Journal of Chemical Health Risks

www.jchr.org

JCHR (2023) 13(5), 473-490 | ISSN:2251-6727

"Nanotechnology in Environmental Applications: Nanoparticles Synthesis for Water Pollution and Wastewater Treatment"

Sandhya Chandrakar[1*] Jayshankar sahu[2], Sangeeta Sahu[3], Shilpa Sharma[4], Kalpana Pandey[5], Madhurima Pandey[6]

[1*]Department of Chemistry, GD Rungta College of Science & Technology, Kohka, Kurud, Bhilai, Chhattisgarh, India, sandhyachandrakar1996@gmail.com
[1,5]Department of Applied Chemistry, University Teaching Department, CSVTU, Bhilai, Chhattisgarh, India
[2]Department of Computer Application, Shri Shankaracharya institute of Professional Studies, Raipur, Chhattisgarh, India
[3,4]Department of Engineering Chemistry, Bhilai Institute of Technology, Raipur, Kendri, New Raipur – 493661, Chhattisgarh, India
[5]Department of Chemistry, KD Rungta College of Science & Technology, Raipur, Chhattisgarh, India
[6]Department of Engineering Chemistry, Bhilai Institute of Technology, Bhilai House, Durg491001, CG, India

***Corresponding Author:** Sandhya Chandrakar
*Department of Chemistry, GD Rungta College of Science & Technology, Kohka, Kurud, Bhilai, Chhattisgarh, India, sandhyachandrakar1996@gmail.com

Keywords:

Nanotechnology, Environmental pollution, Nanoparticles, water pollution, wastewater treatment.

Abstract

Global population growth is causing an increase in energy and the material consumption, which has an impact on the environment. Increased generation of solid waste, increased air pollution from cars and factories, and contamination of surface and groundwater are a few of these effects. The integration over the previous 20 year has changed of materials with artificial nano-scales. The nanotechnology market environmental applications are growing quickly rising, demonstrating the significance of such developments in both research and practices. By manipulating the shape and size of the materials at the nanoscale, nanotechnology is an emerging technology that can help combat pollution. Through the direct use of Nanomaterials for the detection, prevention and removal of pollutants as well as through the use of superior industrial design techniques and the creation of environmentally friendly goods, nanotechnology has the potential to improve the environment. Because of their small size and high surface area, nanoparticles exhibit increased reactivity. Although this trait has a variety of advantages and uses. This review provided comprehensive details on the use of nanotechnology in pollution control, including source reduction or pollution prevention, remediation or degradation of pollutants. Examined how to synthesized nanoparticles and nanotechnology is used in control and reduction of water pollution.

Introduction

One of the numerous definitions for the term "pollution" is "the existence of a material in the environment whose chemical make-up or amount inhibits the operation of natural processes and has negative impacts on the environment and human health [1]."Pollution, a major environmental concern, has increased due to urbanization and population growth. As technology advances, new toxins emerge, posing a serious threat to human life and the environment. Industrialized nations release pollutants like carbon monoxide, heavy metals, hydrocarbons, nitrogen oxides, organic compounds, sulphur dioxide, and particulates. Acid rain is primarily caused by burning fossil fuels. Water pollution is also a concern, resulting from garbage disposal, fertilizer leaks, oil spills, herbicide use, industrial processes, and natural fossil fuel extraction [2-6].Every sector of the environment is experiencing major issues as a result of growing anthropogenic activities, whether it be in the areas of air, water, or soil, as a result of persistent and inappropriate changes made to their natural states. Environmental contaminating agents are randomly added to the environment by industrial, residential, and agricultural processes that are necessary for the human populations[7]. According to estimates from the World

Journal of Chemical Health Risks
www.jchr.org
JCHR (2023) 13(5), 473-490 | ISSN:2251-6727

Health Organization, air pollution claimed the lives of more than six million people in 2016(WHO 2018). In the same year, water contamination contributed to nearly 108 million fatalities worldwide. In 2016, there were around 13.7 million fatalities worldwide that might be attributed to the hazardous environment[8].Air pollution in India claimed the lives of over 1.6 million people in the same year. Nanotechnology has significantly advanced technology, particularly in environmental remediation. Nanomaterials have larger surface-to-volume ratios, improved reactivity, and can be functionalized to target specific contaminants. The deliberate tinkering of nanoparticles' physical qualities can also enhance their effectiveness in pollutant cleanup. This technology has transformed the field of environmental remediation [9-13]. This review focuses on the detrimental impacts of pollutants on human health and environmental pollution remediation techniques. On the use of various kinds of nanomaterials for eliminating contaminants. Additionally, a general overview of nanoparticles synthesis processes, their characterization methods, and applications in many domains has been provided.

Nanotechnology

Nanotechnology studies particle size and structure, producing nanomaterials ranging from 1 to 100 nm. Rapid technological advancements enable the development of nanomaterials for environmental pollution remediation. Nanoparticles have been developed to clean up polluted water, air, and soil from biotic and abiotic factors. By using nanotechnology, toxins in soil, water, and air can be reduced [14-16]. Nanoparticles are increasingly used in various disciplines, including material science, chemistry, physics, and medicine. Originating from the Greek word "nano," they have distinct granular phases and solute characteristics, with a surface to volume ratio of 35-45%. Their specific surface area influences intrinsic properties [17-18].

Methods of Nanoparticles Synthesis

Top-down and bottom-up approaches are two methods for synthesizing nanoparticles, used in fields like nanotechnology, materials science, and chemistry. Top-down methods break down bulk materials into tiny pieces using physical, chemical, and mechanical techniques. Bottom-up approaches use small components to create complex structures, self-assembling under specific conditions. Biosynthesis of nanoparticles uses bottom-up methods, utilizing a biological system for oxidation-reduction at room temperature and pressure [19-22]. **Figure 1** shows that different approaches and techniques using for nanoparticles synthesizing.

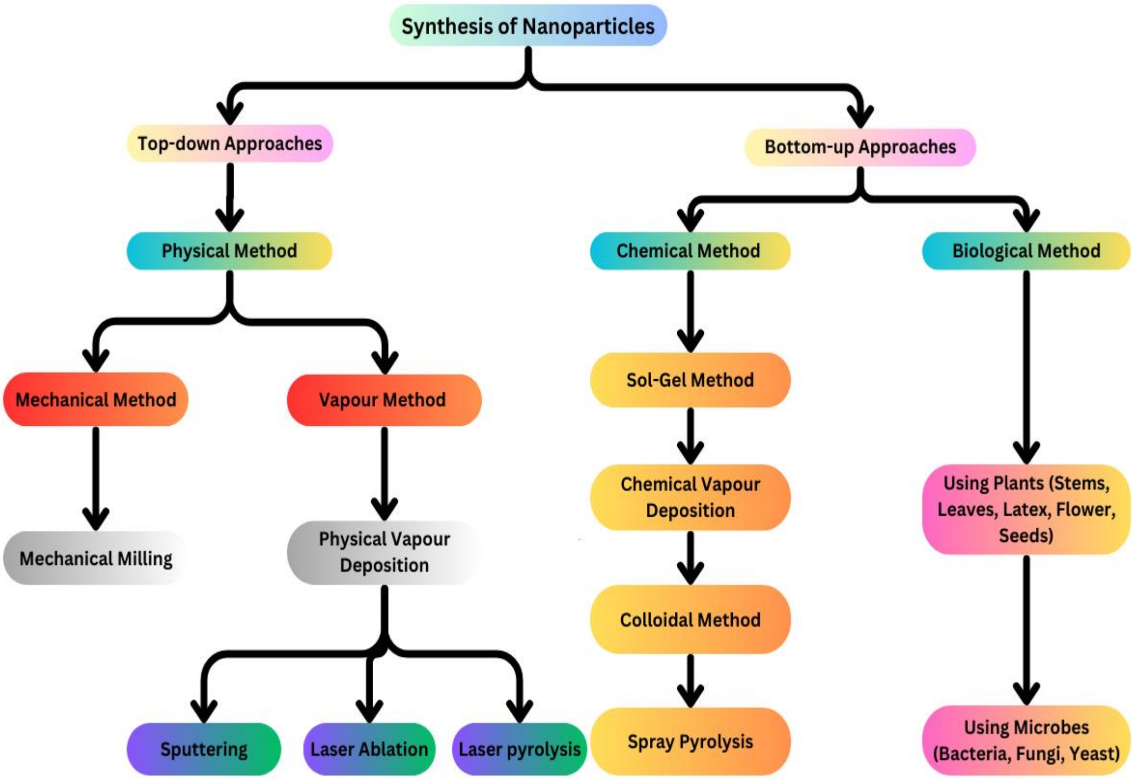

Fig1. Different approaches and techniques for nanoparticles synthesis [20,22]

Physical method

There are various physical methods for synthesizing nanoparticles. These methods rely on physical processes to create nanoparticles and are often chosen for their ability to produce highly controlled and well-defined nanoparticles. Some common physical methods for nanoparticles synthesis include:

Mechanical milling's

Mechanical milling, invented by John Benjamin in 1970, involves using high-energy ball milling to reduce particle size. The effectiveness of this process depends on the method of operation and the properties of the milling powder.

There are two types of milling: low energy and high energy milling. Intense ball milling is commonly used to produce nanoparticles, particularly inter-metallic nanoparticles [23,24].

Laser ablation

The laser ablation method uses laser irradiation to reduce particle size to nanoscale. It involves pulsed laser irradiation on a solid material, typically using Ti: Sapphire, copper vapour lasers, and Nd: YAG (neodymium-doped yttrium aluminium garnet) lasers. The material breaks down into nanoparticles, which remain in the liquid around the object, creating a colloidal solution. The amount of ablated atoms and particles is determined by the laser pulse duration and energy [25].

Laser pyrolysis

Laser pyrolysis is a method for producing nanoparticles by activating laser energy, promoting homogeneous nucleation processes. This results in extremely localized heating and cooling, with the most popular type being infrared CO_2 laser. Once the condensable product reaches super saturation, nanoparticle production begins in CO_2 pyrolysis [26].

Physical vapour deposition

Physical deposition involves placing material on a surface as nanoparticles or thin sheets, vaporizing it using controlled vacuum techniques like thermal evaporation and sputtering deposition. Lanthanum strontium cobalt thin sheets are often synthesized using pulsed vapour deposition, where a solid target is subjected to laser ablation, generating plasma and depositing the ablated species on the base material[27].

Chemical method

Chemical reactions are popular methods for creating nanoparticles, allowing precise control over size, shape, composition, and surface characteristics. Popular chemical techniques include chemical synthesis, synthesis of nanoparticles, and synthesis of nanoparticles.

Colloidal method

The process of producing gold, iron, molybdenum, and silver nanoparticles involves the use of reducing agents like $Na_3C_6H_5O_7$. This technique was first proposed by Turkevich in 1951 for producing Au monodisperse colloidal solutions. The process involves reducing a metal salt in a liquid solution, yielding nanoparticles as residues. After boiling Chloroautic acid and trisodium citrate, seed crystals transform into gold nanoparticles [28-29].

Chemical vapour deposition method

In the late 19th century, chemical vapour deposition was first documented and patented for creating carbon fiber threads and carbon powder colour pigments for electric lamps. This technique involves the chemical reaction of gaseous molecules with atoms to deposit a thin film of the target substance on an outer layer, often resulting in atomic layer deposition (ALD) thin films [30-31].

Sol-gel method

Livage et al. (1988) reviewed a sol gel chemistry method for transition metal oxides, involving direct metal blending with oxide or nanoparticles in prehydrolyzed silica sol, matrix-forming colloids, or reduction and complexation with silane before hydrolysis, resulting in the production of nanoparticles [32].This method uses gelatine and colloidal suspension to create continuous-flowing networks in a liquid phase. Colloidals are created using metal ion precursors like alkoxysilanes and alkoxides. Teramethoxysilane and tetraethoxysilane are commonly used for silica gel. Metgal alkoxides are water-immiscible precursors for various metals. Alcohol is used as a universal solvent. The process involves particle expansion, accumulation, hydrolysis, and precipitation [24].

Spray pyrolysis

Spray pyrolysis is a process where a hot reactor is heated to evaporated nanoparticle precursors, typically in the form of acetate, nitrate, or chloride. The apparatus consists of a fluid nebulizer, a thermostatically controlled vertical tubular reactor, and a precipitation device. Atomized methods, such as two fluid nozzles, vibrating orifice, spinning disk, ultrasonic sound, air-assisted pumps, or sprayers, can be used. Ultrasonic spray pyrolysis creates atomized droplets from the precursor solution, which are then carried to the reactor furnace and collected through a collection system [33-34].

Biological method

Green synthesis techniques are a growing trend in nanotechnology, addressing safety, high cost, and reaction-related challenges. These methods combine clean chemistry, atomic economy, environmentally friendly chemistry, and benign by design chemistry to reduce environmental and public health risks and improve chemical applications.Anenvironmentally responsible technique create nanoparticles is by using the biological method, which is provided as an alternative to chemical and physical methods. The biological technique, which involves the use of bacteria, fungi, yeasts, molds, algae, and plants, enables the synthesis of metallic nanoparticles with various sizes, shapes, compositions, and physicochemical characteristics in a single step. This process involves the reduction of molecules found in plants and microorganisms, including proteins, enzymes, phenolic compounds, amines, alkaloids, and pigments [35-37].

Nanoparticles synthesis using bacteria

Bacteria are crucial in the production of nanoparticles due to their ability to reduce metal ions. Green synthesis technology offers a safe, nontoxic, and environmentally acceptable solution. Prokaryotes are also attractive for synthesizing metallic nanoparticles due to their abundance and adaptability. Bacteria are easy to grow and control, as they multiply quickly and can be controlled by regulating factors like oxygenation, temperature, and incubation time. This allows for the production of nanoparticles of various sizes and shapes, demonstrating the growing interest in using naturally available resources for nanoparticle synthesis [38-39]. Here are a few instances of bacteria that have been employed to create nanoparticles **(Table1)**.

Table1 List of microorganism (Bacteria) that synthesize metal nanoparticles

S.No	Microorganism	Nanoparticles	Size (nm)	Techniques used for characterization	References

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1	Aspergillus terreus	Lead selenide	20-50	TEM, SEM, XRD, UV-Vis, FTIR	[40]
2	Pseudomohasstutzeri	Ag	20-100	TEM, UV- Vis	[41]
3	Lactobacillus casei subsp.	Ag	25-50	TEM, UV- Vis	[42]
4	E. coli	Cd telluride	2-3	TEM, XRD, UV- Vis	[43]
5	Rhodococcus species	Au	~20	TEM, UV- Vis	[44]
6	Sachharomycescerevisae	Cds	2.5-5.5	TEM, XRD, UV- Vis	[45]
7	Azospirillumbrasilense	Au	5-50	TEM, DLS, UV- Vis	[46]
8	Helminthosporumsolani	CdSe	5.5	TEM, UV- Vis, FL, EDS, XPS	[47]
9	Klebsiella pneumonias	Ag	50	TEM, EDS, UV- Vis	[48]
10	Shewanelloneidensis	Cu	20-40	TEM, STEM, XANES, EELS, SBFSEM	[49]

Nanoparticles synthesis using Fungi

Fungi are an eco-friendly method for creating metal/metal-oxide nanoparticles due to their variety of enzymes. They can produce more nanoparticles than bacteria, and their enzyme and protein can be used as a reducing agent to create metal nanoparticles from metal salt. Metals like Ag can attach to cytoplasmic membranes and decrease, creating silver nuclei and nanoparticles. Common fungi like Fusarium oxysporum, Aspergillus fumigates, and Trichoderma reesei secrete specific reducing agents to eliminate these metal ions **(Table2)** [50-51].

Fungi are superior microbes due to their ability to withstand various conditions in bioreactors, grow slowly, and be easily handled. They also grow slowly and are simple to manufacture. Reductive proteins secrete more nanoparticles, which can be processed later. The nanoparticles, precipitated outside the cell, are free of extraneous cellular components, making them suitable for various applications [52,55].

Table2 List of microorganism (Fungi) that synthesize metal nanoparticles

S. No.	Microorganism	Nanoparticles	Size (nm)	Techniques used for characterization	References
1	Fusarium oxysporium	Ag	5~15	TEM, UV-Vis	[51]
2	Schizophyllum commune	Ag	54-99	SEM, FTIR, SDS-PAGE, UV-Vis	[52]
3	Hormoconisresinae	Au	3-20	TEM, EDS, XRD, UV-Vis	[53]
4	Saccharomyces cerevisiae	CdSe	15-20	TEM, EDS, FL, laser scanning microscpoe	[54]
5	Aspergillus flavus fungus	PbS	35-100	TEM, UV-Vis, FL, XRD, EDS	[55]
6	Sachharomycescerevisae	TiO_2	~12.6	XRD, TEM, SAED	[56]
7	Trichoderma viride	Ag	5-40	FTIR, TEM, EDS	[57]
8	Endophytic fungus	Ag	25-30	TEM, FTIR, UV-Vis	[58]

Nanoparticles synthesis using yeast

Research explores the use of yeast in manufacturing metallic nanoparticles due to their advantages over bacteria, including bulk production, ease of regulation, enzyme creation, and quick growth. S.pombe's sulphide nanoparticles were used to create a calcium diode, and standardization and documentation of suitable conditions for Ag nanoparticle preparation were established **(Table3)** [59, 60]. Yeasts, including Sacchromyces cerevisiae, are categorized into various kingdoms and have around 1500 known species. They are used in fermentation of dough, beer, and alcohol, and have significant industrial value. Using yeast cells as NP-carriers allows for straightforward encapsulation methods, eliminating the need for stabilizers. NPs biosynthesis aims to reduce cytotoxicity through cellular defense mechanisms, using substances like phytochelatins and glutathione to bioreduce metal ions [61, 62].

Table3 List of microorganism (Yeast) that synthesize metal nanoparticles

S.No	Microorganism	Nanoparticles	Size (nm)	Techniques used for characterization	References
1.	Candida glabrata	CdS	20-29 Å	X-ray analysis	[63]
2.	S. cerevisiae	Ag	2.5-20	TEM, UV-Vis	[64]
3.	Schizosacchromyces pombe	CdS	1-1.5	TEM, XRD, UV-Vis	[59]
4.	Yeast strain MKY3	Ag	2-5	TEM, XRD, X-ray photoelectron spectroscopy	[60]
5.	Yeasts cell	TiO_2	<12	SEM, TEM, XRD, EDX, UV-Vis	[65]
6.	Yarrowialipolytica	Au	-	SEM-EDS, XRD, FTIR, UV-Vis	[66]
7.	Pichia jadnii	Au	100	SEM, TEM	[67]

Nanoparticles synthesis using plant extract

Plants are a cost-effective and easy-to-maintain chemical manufacturing source, known for their ability to detoxify heavy metals, addressing environmental pollution. Plant-assisted nanoparticle synthesis is faster than chemical nanoparticles, thanks to the

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JCHR (2023) 13(5), 473-490 | ISSN:2251-6727

phytochemicals found in various plant parts like fruit, stems, leaves, and roots. This environmentally friendly method is widely used in the production of nanoparticles **(Table4)** [68,69].Plant leaf extracts, rich in essential phytochemicals like flavones, terpenoids, sugars, ketones, aldehydes, carboxylic acids, and amides, are used to create nanoparticles under various experimental conditions, influencing their output and stability [70].The plant portion for nanoparticle creation can be cleaned, boiled in distilled water, and then pressed, filtered, and added with appropriate metal solutions, revealing their production, and allowing us to separate them, as shown in **Figure 2.** The synthetic procedure is completely eliminated by using natural plant extract, which is both cost-effective and environmentally friendly [71].

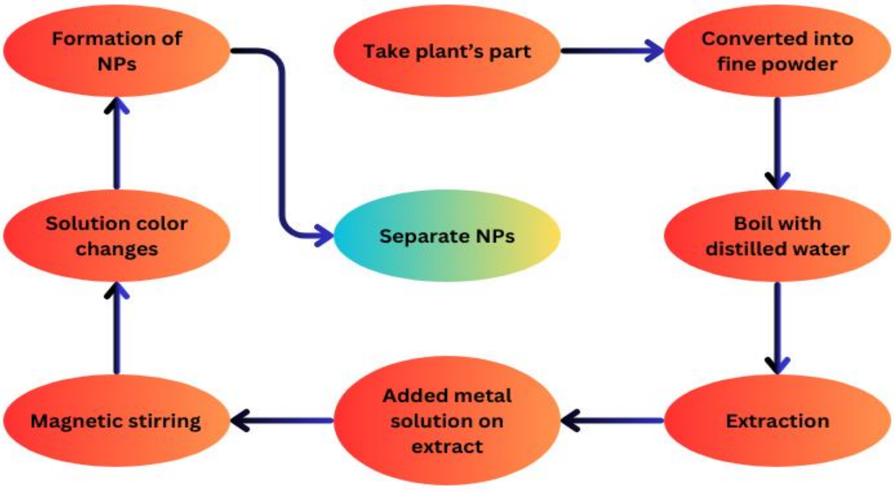

Fig-2 Process of Nanoparticles synthesis [69, 71]

Table4 List of plants that synthesize metal nanoparticles

S.No	Plants	Source of NPs	Nanoparticles	Size (nm)	Techniques used for characterization	References
1	Gelidiumpusillum	Seaweed extract	Au	12 ± 4.2	TEM, UV-Vis, FTIR, XRD, DLS	[72]
2	Dionaea muscipula	Plant tissue	Ag	5 - 10	SEM, TEM, DLS, XPS, EDS	[73]
3	Citrum limon	Outer peels	TiO_2	80 -140s	XRD, EDX, SEM, TEM	[74]
4	Ficus carica (Lemon)	Leaf	Fe_2O_4	43 - 57	SEM, EDX, XRD, FTIR, UV-Vis	[75]
5	Ananas comosus (Pineapple)	Peel	Ag	12.4	TEM, FTIR, UV-Vis	[76]
6	Hageniaabyssinica	Leaf	Cu	34.76	UV-Vis, XRD, FTIR, SEM, EDXA, TEM, SEAD	[77]
7	Carica papaya (papaya)	Peel	CuO	85 - 140	XRD, EDX, FTIR,	[78]
8	Artocarpus heterophyllus (Jack fruit)	Peel	Fe	33	FTIR, SEM, TEM, XRD, EDX	[79]
9	Banana	peel	Ag	-	SEM, XRD, FTIR, EDS, UV-Vis	[80]
10	Walnut	Shell	Cu	15 - 22	TEM, EDX, FTIR	[81]
11	Mentha arvensis	Leaves	TiO_2	20 - 70	UV-Vis, XRD, FTIR, SEM	[82]
12	Ganoderma lucidum	Reishi mushroom	Ag	15 - 22	XPS, XRD, TEM, FTIR, UV-Vis	[83]
13	Cotton bolls	peel	Pd	275	XRD, TEM, UV-Vis, FTIR	[84]
14	Grape	Stalk	Ag	27.7 ± 0.6	UV-Vis, EDX, FTIR,	[85]
15	Azadirachta indica (neem)	Leaf	ZnO	9.6 – 25.5	TEM, XRD, EDX, FTIR, UV-Vis	[86]

Characterization of NPs

Nanoparticle characterization is crucial for understanding and managing their production and applications. Techniques like SEM, FTIR, XPS, AFM, DLS, XRD, and UV-Visible spectroscopy are used to analyze characteristics like pore size, surface area, crystallinity, particle size, shape, and fractal dimensions [87, 88]. Scanning electron microscopy (SEM) is a technique used to study nanoparticles, providing detailed images of their surface characteristics, morphology, and size. It can be combined with energy-dispersive X-ray spectroscopy (EDS) to investigate the elemental composition. Transmission electron microscopy (TEM) provides high-resolution images of nanoparticles, revealing their crystalline composition and lattice spacing. Fourier transform infrared spectroscopy (FTIR) reveals the combination of chemicals and functional groups on the nanoparticles' surface, while X-ray photoelectron spectroscopy (XPS) reveals the chemistry of nanoparticles' surfaces. Atomic force microscopy (AFM) evaluates the topography and surface characteristics of nanoparticles, while dynamic light scattering (DLS) determines size distribution in liquids. X-ray diffractometry (XRD) ascertains the crystalline structure of nanoparticles [72,80,86,88].

Review of Nanotechnologies and Nanoparticles used for Environmental Applications

Nanotechnology significantly impacts production techniques, replacing machinery, and reformulating components, reducing energy and material consumption, and reducing environmental harm. It provides innovative solutions to environmental contamination problems **Figure 3**[89].

Fig3- Environmental applications of nanotechnology and nanoparticles [89, 91]

Nanomaterials offer numerous applications in various fields, including adsorption, sensors, membranes, and disinfectants. They have been synthesized into complex structures to enhance their adaptability. This paper emphasizes the benefits of nanotechnology in wastewater treatment systems, emphasizing the need for green, reliable, and economical environmental restoration procedures [90, 91].

Water pollution

Water is a vital resource for the global economy, ecology, and health. However, a lack of clean water is causing issues like 1.2 billion people lacking access,

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JCHR (2023) 13(5), 473-490 | ISSN:2251-6727

2.6 billion lacking basic hygiene, and millions of deaths from contaminated water. Population growth, pollution, flooding, and increasing demand for water strain human society. Water scarcity is a global issue due to population growth, excessive surface and groundwater use, and rising waste. To prevent future water stress, it is essential to control existing water supplies, particularly groundwater, which is the most crucial water resource.Worldwide, aquifers provide drinking water for over 2 billion people, according to United Nations Environment Programme (UNEP) research. Irrigated agriculture, which mostly uses groundwater, produces 40% of the world's food [92-95].

Wastewater

Wastewater from industries like mining, electroplating, and battery manufacturing is contaminated and harmful to the environment and living things. The type of pollutants in industrial wastewater depends on production methods and can include organic chemical components, high salinity, hazardous heavy metals, high pH, and toxins. Wastewater composition varies and includes complex organic substances, inorganic compounds, and hazardous wastes. Nonhazardous wastes, such as organic waste, cardboard, plastic, iron, glass, and stone, pose no environmental or public health risks [96-99].Nanoscale science and engineering advancements are paving the way for innovative water purification systems that meet specific specifications [100]. Nano-science investigates molecular, atomic, and macromolecular interactions, focusing on nanotechnology. It involves creating, describing, and using nanostructured materials for adsorption, catalysts, and wastewater treatment, attracting attention in recent times[94]. Nanoparticles can effectively detoxify trichloroethene, a hazardous industrial effluent, making them ideal for hydro dehalogenation and reduction in various inorganic and organic groundwater contaminants [99]. Nanotechnology advancements offer affordable, effective treatment solutions, addressing current issues and demonstrating potential for expanding water supplies and creating future water supply systems [90].

Adsorption

Sorption is the process of a substance adhering to a surface, forming interactions between the sorbent and the sorbate. It can be physical, chemical, or electrostatic, depending on the interactions. Physical sorption involves weak physical contacts, while chemical sorption creates new chemical bonds. Electrostatic sorption involves electron exchange between the surface site and adsorbed molecules. Adsorption refers to the uptake of an adsorbate on solid surfaces [101-103].Nanoadsorbents offer significant advancements in water treatment due to their high adsorption kinetics, short intra-particle dissemination distance, high specific surface area, and adjustable pores. Their highly mobilized adsorption sites and large specific area make them effective. Current methods include metal-based, polymeric, carbon-based, plant-based, and zeolites **(Table5)** [104,105].

Table 5 List of adsorbents used for the removal of pollutants removal

Adsorbents	Target pollutants	Performance	Adsorption isotherms	Remarks	Reference
Titanate nanotube TNTs	Pb (II), Cd(II), Cu(II), Cr(II)	TNTs according to the order of - Cr^{3+}(1.37 mmol/g) << Cu^{2+} (1.92 mmol/g) < Cd^{2+} (2.13 mmol/g) << Pb^{2+} (mmol/ g)	-	Given its ability to efficiently absorb cations, TNTs are regarded as useful heavy metal adsorbents. Because of their high surface hydroxyl groups (OH) and low point of zero charge (pHPZC) through ion exchange	[132]
Magnetite Fe_3O_4	Cd(II), Zn(II), Pb(II), Cu(II)	At pH 5.5, 95% of the metal ions were absorbed in around 30 minutes	Langmuir	Throughout the four cycles. The adsorption capacity was nearly constant; however, as the concentration of coexisting ions (Na^+, K^+, or Mg^{2+})increased, Cu^{2+} adsorption capacity declined	[133]
NiO nanoparticles	Cd(II) and Pb(II)	The greatest adsorption capabilities for Pb(II) and Cd(II) ions were 625 mg/g and 909 mg/g, respectively.	Langmuir	The adsorption was endothermic and spontaneous, occurring in response to boundary layer diffusion or external mass transfer.	[134]
Magnetite Iron oxide nanoparticle (MION-Tea) Fe_3O_4	As(III) and As(V)	High adsorption capacities for As(III) and As(V) at 188.69 and 153.8 mg/g, respectively.	Langmuir	Thermodynamics shown that adsorption is endothermic. MION-Tea can be recycled with NaOH and used again for up to five adsorption cycles.	[135]
Amorphous zirconium oxide (am-ZrO_2)	phosphate	At pH 6.2, the adsorption capacity was approximately 99.01	Langmuir	The surface hydroxyl groups were crucial to the phosphate's adsorption process. It would be	[136]

		mg/g.		simple to generate am-ZrO_2 nanoparticles with 0.1 M NaOH	
Graphitized, carboxylized, and hydroxylized CNTs	Ciprofloxacin pharmaceuticals	-	Freundlich and dubenin-Astakhov	Since MH and MC have different electron donor-acceptor interactions, sorption on MH was greater than on MC.	[137]
CNTs carboxylized with HNO_3	Epirubicin pharmaceuticals	-	Freundlich	CNTs were able to create supramolecular complexes with EPI and beneficial loading properties as drug carriers by π-π stacking.	[138]
Nano ZnO	Pb(II)	Pd adsorption is nearly entirely present in nano ZnO at lower beginning	Langmuir and Freundlich	The powder had a surface area of 80.425 m^2g^{-1}, which was higher than that of typical zinc oxide.	[139]
CNTs loaded with magnetite	Methylene blue (MB) organic dyes	-	Langmuir	The high adsorption capacity was caused by π-π stacking interactions and electrostatic attraction between (MB) and CNTs.	[140]
Sunflower straw	Uranium	251.52 mg/g	Langmuir	1000 mg/L initial concentration of uranium taken	[141]

Adsorption process

Select high surface area Nanomaterials for adsorption, functionalizing or pre-treating to remove contaminants. Fill reactors with contaminated water, and the nanoparticles attract pollutants. Adsorption and desorption kinetics are influenced by temperature, contact duration, and initial pollutant concentration. Water is separated from nanoparticles using filtration or sedimentation, and desorption regenerates Nanomaterials. This is an example of a simplified schematic diagram **Figure 4** that shows how Nanomaterials are used in the adsorption process to remove contamination from water[106-108].

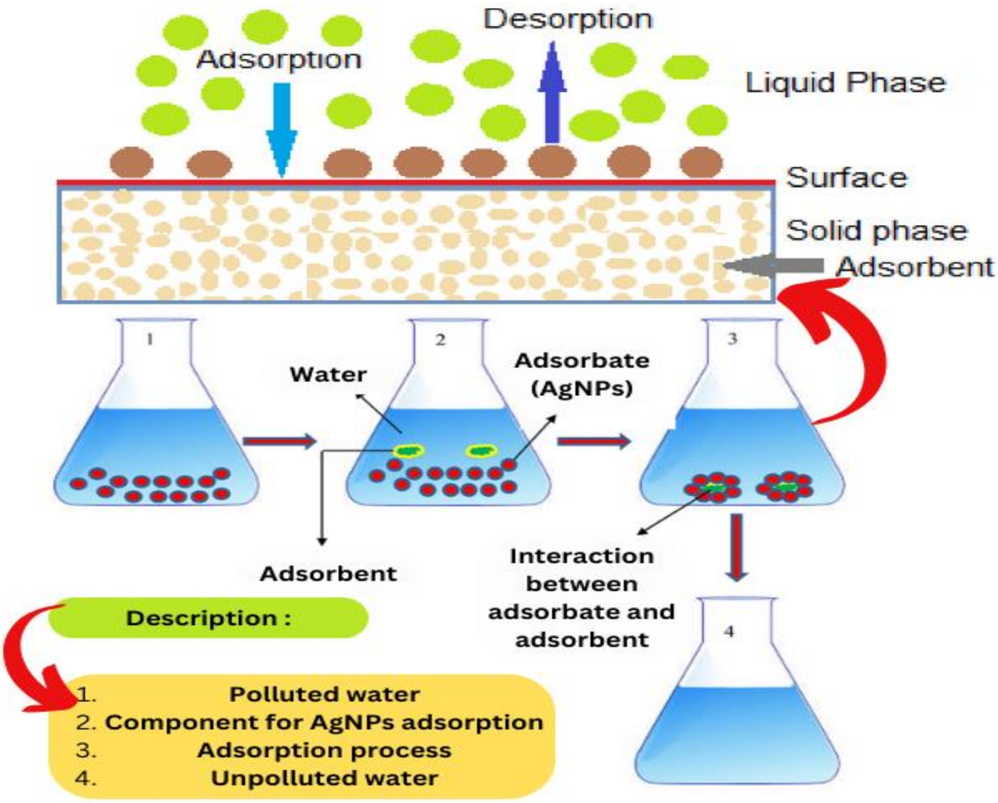

Fig 4 – Nanoparticle used for the removal of pollutants from water by adsorption process [107]

Membrane Process

Membranes are porous layers that allow water molecules to pass while obstructing metals, salts, bacteria, and viruses. They can be used electrically or pressure-driven for water purification. Membrane separation techniques are advanced for wastewater treatment [109,107].The membrane process is effective in water remediation due to its segregation, ease of use, and lack of secondary contamination. Common membrane materials include polymers like poly-acrylonitrile (PAN), polyamide (PA), and cellulose acetate (CA). Membrane methods include microfiltration, ultrafiltration, nano-filtration, and ultrapure water production, desalination, and water reuse **Figure 5** [110-112].

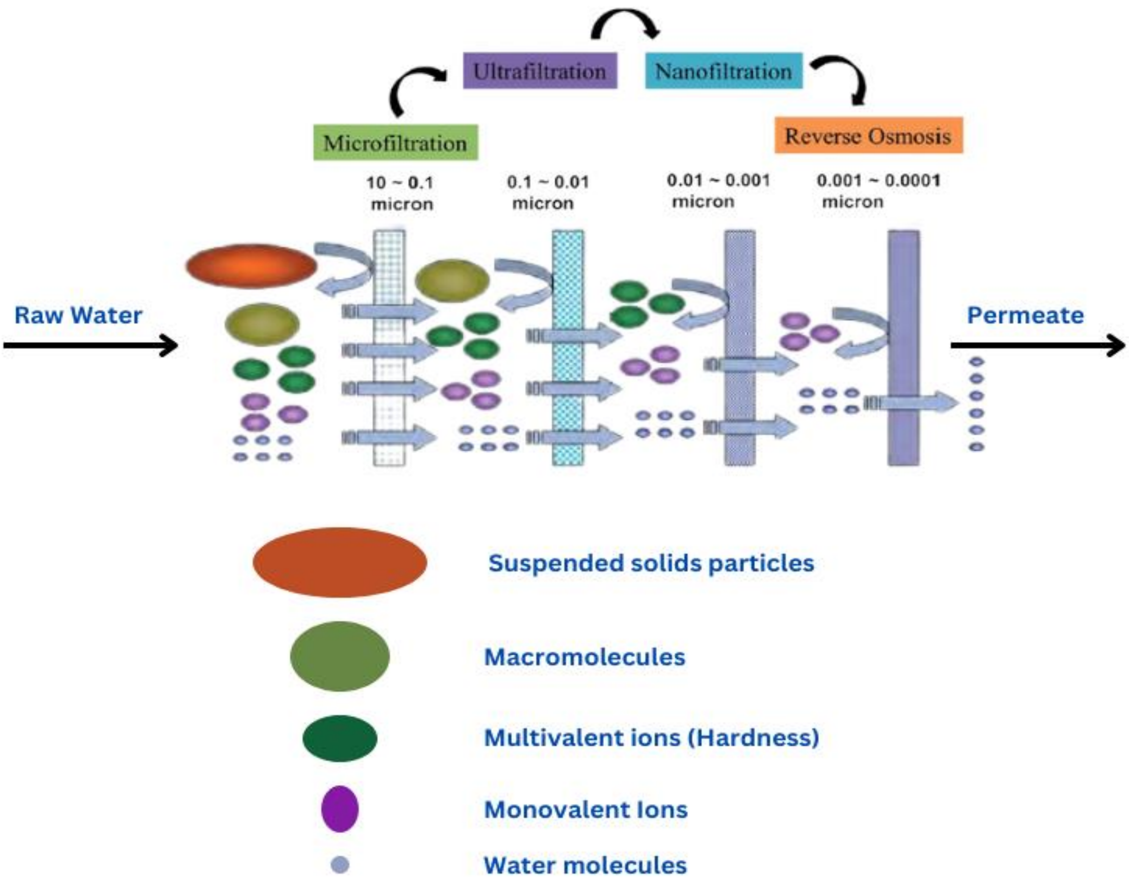

Fig 5 – Water purification process using different types of nano membranes [111, 113]

Nanotechnology has developed novel water treatment membranes with high catalytic activity, transparency, and control over fouling. Mesoporous carbons in thin film polymeric matrices serve as nano-composite membranes, enhancing water permeability. Thin-film nano-composites with nano-NaX zeolite and polyamide are used for purifying water and allowing impurities to pass through, enhancing water quality [113-115].

Photo catalysis

Advanced oxidation processes, such as photo-catalysis, are being explored as a sustainable and affordable solution for water treatment, aiming to reduce resistant organic pollutants and eliminate microorganisms. Photo-catalytic oxidation is a reaction involving chemicals, light, or energy, requiring the creation of reactive radicals like hydroxyl radicals and H_2O_2, O_2, and O_3. Homogenous photo-catalysis methods can be divided into photo-Fenton and Fenton reactions, with photo-Fenton having a 600 nm light wavelength and Fenton having no light exposure. Both techniques can be irradiated with solar or UV light, but require pH rectifications [116-120].Research groups are exploring the use of membrane photo-catalytic reactors to make water cleaner and retain catalytic particles. However, high-pressure pumps are expensive and energy inefficient. Coating techniques like vapor deposition and wet chemical coating can be used for immobilizing nanoparticles. TiO_2 nanoparticles and silver-coated antibacterial filters are promising options. Exposure to UV radiation activates electron-hole pairs, enhancing the biodegradability of decomposable materials [107, 121, 122].

Disinfection and Decontamination

Disinfections in sewage water effectively inhibit microbial growth but can produce harmful disinfection byproducts (DBPs) with short half-life. Over 600 DBPs have been identified worldwide, mostly carcinogenic. Technological innovation is needed to provide effective disinfection without DBPs. Nanomaterials like fullerenes, CNTs, nano-Ag, nano-ZnO, and nano-TiO_2 exhibit strong antibacterial qualities, making them a promising alternative to traditional disinfection techniques [123-126].Nanotechnology advancements have sparked interest in researching antibacterial properties of Nanomaterials (NMs) for water disinfection. Solar light-emitted NMs show potential as substitutes or combined with photo-excitation technologies [127]. Nanoparticles like ZVIn and carbon-based nanomaterials like fullerene and CNTs exhibit high antibacterial activity without significant oxidation. These properties are initiated by contact with bacteria, with SWCNTs having the greatest antibacterial activity. Fullerene interaction requires immediate interaction [128-131].

Constraints and the Need for Research

Nanotechnology-based water and wastewater treatment methods hold significant promise, but more research is needed to expand their commercialization and ensure safety and affordability. Long-term effectiveness of existing technologies is another area that requires further research. Adoption of novel technologies is influenced by affordability and associated hazards, with nanomaterials currently being relatively expensive. Reuse and regeneration of nanoparticles can lead to cost-effectiveness, but risk assessment and management are difficult due to their nanoscale nature. Researchers must be aware of potential risks associated with these substances while treating wastewater and water [122,142].

Conclusion

Human activity is disrupting the ecosystem by releasing toxic substances that contaminate land, atmosphere, and water, endangering public health. Water safety is crucial due to factors like population growth, droughts, and changing climate conditions. Nanomaterials are gaining popularity in water treatment and wastewater treatment. While our world is superior due to water, many parts of the world lack sufficient drinking water. Researchers and scientists need to develop new strategies to address these limitations. Nanotechnology has shown success in removing contaminants from water, managing challenges, and advancing certain areas. Nanostructured catalytic membranes and nanosorbents are effective, time-efficient, ecologically benign, and low energy consumption. However, these methods are currently not widely used due to their high cost. Nanomaterials exhibit efficiency due to their rapid reactivity. However, there are no automated digital monitoring techniques for assessing nanoparticle prevalence in water. Ultimately, nanotechnology will lead to dynamic and adaptable systems for detecting and tracking various toxins and hazardous chemicals in environmental media.

Reference

1. Mehndiratta, P., Jain, A., Srivastava, S., & Gupta, N. (2013). Environmental pollution and nanotechnology. *Environment and Pollution*, *2*(2), 49.
2. Tratnyek, P. G., & Johnson, R. L. (2006). Nanotechnologies for environmental cleanup. *Nano today*, *1*(2), 44-48.
3. Kumar, L., Ragunathan, V., Chugh, M., & Bharadvaja, N. (2021). Nanomaterials for remediation of contaminants: a review. *Environmental Chemistry Letters*, *19*, 3139-3163.
4. Panahi, Y., Mellatyar, H., Farshbaf, M., Sabet, Z., Fattahi, T., &Akbarzadehe, A. (2018). Biotechnological applications of nanomaterials for air pollution and water/wastewater treatment. *Materials Today: Proceedings*, *5*(7), 15550-15558.
5. Yunus, I. S., Harwin, Kurniawan, A., Adityawarman, D., &Indarto, A. (2012). Nanotechnologies in water and air pollution treatment. *Environmental Technology Reviews*, *1*(1), 136-148.
6. Krantzberg G, Tanik A, do Carmo J.S.A., Indarto A, Ekda A. Advances in water quality control. Scientific Research Publishing 2010.
7. Baruah, S., & Dutta, J. (2009). Nanotechnology applications in pollution sensing and degradation in agriculture: a review. *Environmental Chemistry Letters*, *7*, 191-204.
8. Prüss-Ustün, A., Wolf, J., Corvalán, C., Neville, T., Bos, R., & Neira, M. (2017). Diseases due to unhealthy environments: an updated estimate of the global burden of disease attributable to environmental determinants of health. *Journal of public health*, *39*(3), 464-475.
9. Losada-Garcia, N., Rodriguez-Otero, A., & Palomo, J. M. (2019). Fast degradation of

Journal of Chemical Health Risks
www.jchr.org
JCHR (2023) 13(5), 473-490 | ISSN:2251-6727

bisphenol a in water by nanostructured cunps@ calb biohybrid catalysts. *Nanomaterials*, *10*(1), 7.
10. Linley, S., & Thomson, N. R. (2021). Environmental applications of nanotechnology: nano-enabled remediation processes in water, soil and air treatment. *Water, Air, & Soil Pollution*, *232*, 1-50.
11. Guerra, F. D., Smith Jr, G. D., Alexis, F., & Whitehead, D. C. (2017). A survey of VOC emissions from rendering plants. *Aerosol and Air Quality Research*, *17*(1), 209-217.
12. Campbell, M. L., Guerra, F. D., Dhulekar, J., Alexis, F., & Whitehead, D. C. (2015). Target-specific capture of environmentally relevant gaseous aldehydes and carboxylic acids with functional nanoparticles. *Chemistry–A European Journal*, *21*(42), 14834-14842.
13. Shah, K. J., &Imae, T. (2016). Selective gas capture ability of gas-adsorbent-incorporated cellulose nanofiber films. *Biomacromolecules*, *17*(5), 1653-1661.
14. Heiligtag, F. J., & Niederberger, M. (2013). The fascinating world of nanoparticle research. *Materials today*, *16*(7-8), 262-271.
15. Al Saber, M., Biswas, P., Dey, D., Kaium, M. A., Islam, M. A., Tripty, M. I. A., ... & Kim, B. (2021). A comprehensive review of recent advancements in cancer immunotherapy and generation of CAR T cell by CRISPR-Cas9. *Processes*, *10*(1), 16.
16. Malik, S., Muhammad, K., & Waheed, Y. (2023). Nanotechnology: A revolution in modern industry. *Molecules*, *28*(2), 661.
17. You, H., Yang, S., Ding, B., & Yang, H. (2013). Synthesis of colloidal metal and metal alloy nanoparticles for electrochemical energy applications. *Chemical Society Reviews*, *42*(7), 2880-2904.
18. Auffan, M., Rose, J., Wiesner, M. R., &Bottero, J. Y. (2009). Chemical stability of metallic nanoparticles: a parameter controlling their potential cellular toxicity in vitro. *Environmental Pollution*, *157*(4), 1127-1133.
19. Pacioni, N. L., Borsarelli, C. D., Rey, V., & Veglia, A. V. (2015). Synthetic routes for the preparation of silver nanoparticles: A mechanistic perspective. In *Silver Nanoparticle applications: in the fabrication and design of medical and biosensing devices* (pp. 13-46). Cham: Springer International Publishing.
20. Zamare, D., Vutukuru, S. S., & Babu, R. (2016). Biosynthesis of nanoparticles from agro-waste: a sustainable approach. *Int J Eng Appl Sci Technol*, *1*(12), 85-92.
21. Jamkhande, P. G., Ghule, N. W., Bamer, A. H., &Kalaskar, M. G. (2019). Metal nanoparticles synthesis: An overview on methods of preparation, advantages and disadvantages, and applications. *Journal of drug delivery science and technology*, *53*, 101174.
22. Aswathi, V. P., Meera, S., Maria, C. A., & Nidhin, M. (2023). Green synthesis of nanoparticles from biodegradable waste extracts and their applications: a critical review. *Nanotechnology for Environmental Engineering*, *8*(2), 377-397.
23. Ullah, M., Ali, M. E., & Abd Hamid, S. B. (2014). SURFACTANT-ASSISTED BALL MILLING: A NOVEL ROUTE TO NOVEL MATERIALS WITH CONTROLLED NANOSTRUCTURE-A REVIEW. *Reviews on Advanced Materials Science*, *37*.
24. Rajput, N. (2015). Methods of preparation of nanoparticles-a review. *International Journal of Advances in Engineering & Technology*, *7*(6), 1806.
25. Simakin, A. V., Voronov, V. V., Kirichenko, N. A., &Shafeev, G. A. (2004). Nanoparticles produced by laser ablation of solids in liquid environment. *Applied Physics A*, *79*, 1127-1132.
26. Swihart, M. T. (2003). Vapor-phase synthesis of nanoparticles. *Current opinion in colloid & interface science*, *8*(1), 127-133.
27. Pandey, P. A., Bell, G. R., Rourke, J. P., Sanchez, A. M., Elkin, M. D., Hickey, B. J., & Wilson, N. R. (2011). Physical vapor deposition of metal nanoparticles on chemically modified graphene: observations on metal–graphene interactions. *Small*, *7*(22), 3202-3210.
28. Cavaliere, P. D., Perrone, A., &Silvello, A. (2021). Water electrolysis for the production of hydrogen to be employed in the ironmaking and steelmaking industry. *Metals*, *11*(11), 1816.
29. Roy, A., Sharma, A., Yadav, S., Jule, L. T., &Krishnaraj, R. (2021). Nanomaterials for remediation of environmental pollutants. *Bioinorganic Chemistry and Applications*, *2021*.
30. Pedersen, H., & Elliott, S. D. (2014). Studying chemical vapor deposition processes with theoretical chemistry. *Theoretical Chemistry Accounts*, *133*, 1-10.
31. Miikkulainen, V., Leskelä, M., Ritala, M., & Puurunen, R. L. (2013). Crystallinity of inorganic films grown by atomic layer deposition: Overview and general trends. *Journal of Applied Physics*, *113*(2).
32. Cushing, B. L., Kolesnichenko, V. L., &O'connor, C. J. (2004). Recent advances in the

liquid-phase syntheses of inorganic nanoparticles. *Chemical reviews*, *104*(9), 3893-3946.

33. Ghaffarian, H. R., Saiedi, M., Sayyadnejad, M. A., & Rashidi, A. M. (2011). Synthesis of ZnO nanoparticles by spray pyrolysis method.
34. Majerič, P., Friedrich, B., & Rudolf, R. (2015). Au-nanoparticle synthesis via ultrasonic spray pyrolysis with a separate evaporation zone. *Materiali in tehnologije*, *49*(5), 791-796.
35. Nadaroglu, H., Onem, H., &Alayli Gungor, A. (2017). Green synthesis of Ce2 O3 NPs and determination of its antioxidant activity. *IET nanobiotechnology*, *11*(4), 411-419.
36. Cicek, S., Gungor, A. A., Adiguzel, A., &Nadaroglu, H. (2015). Biochemical evaluation and green synthesis of nano silver using peroxidase from Euphorbia (Euphorbia amygdaloides) and its antibacterial activity. *Journal of Chemistry*, *2015*.
37. Nadaroglu, H., Gungor, A. A., Ince, S., &Babagil, A. (2017). Green synthesis and characterisation of platinum nanoparticles using quail egg yolk. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *172*, 43-47.
38. Iravani, S. (2014). Bacteria in nanoparticle synthesis: current status and future prospects. *International scholarly research notices*, *2014*.
39. Pantidos, N., & Horsfall, L. E. (2014). Biological synthesis of metallic nanoparticles by bacteria, fungi and plants. *Journal of Nanomedicine & Nanotechnology*, *5*(5), 1.
40. Jacob, J. M., Balakrishnan, R. M., & Kumar, U. B. (2014). Biosynthesis of lead selenide quantum rods in marine Aspergillus terreus. *Materials Letters*, *124*, 279-281.
41. Joerger, R., Klaus, T., & Granqvist, C. G. (2000). Biologically produced silver–carbon composite materials for optically functional thin-film coatings. *Advanced Materials*, *12*(6), 407-409.
42. Korbekandi, H., Iravani, S., & Abbasi, S. (2012). Optimization of biological synthesis of silver nanoparticles using Lactobacillus casei subsp. casei. *Journal of Chemical Technology & Biotechnology*, *87*(7), 932-937.
43. Bao, H., Hao, N., Yang, Y., & Zhao, D. (2010). Biosynthesis of biocompatible cadmium telluride quantum dots using yeast cells. *Nano Research*, *3*, 481-489.
44. Park, Y., Hong, Y. N., Weyers, A., Kim, Y. S., & Linhardt, R. J. (2011). Polysaccharides and phytochemicals: a natural reservoir for the green synthesis of gold and silver nanoparticles. *IET nanobiotechnology*, *5*(3), 69-78.
45. Prasad, K., & Jha, A. K. (2010). Biosynthesis of CdS nanoparticles: an improved green and rapid procedure. *Journal of colloid and interface science*, *342*(1), 68-72.
46. Kupryashina, M. A., Vetchinkina, E. P., Burov, A. M., Ponomareva, E. G., & Nikitina, V. E. (2013). Biosynthesis of gold nanoparticles by Azospirillumbrasilense. *Microbiology*, *82*, 833-840.
47. Suresh, A. K. (2014). Extracellular bio-production and characterization of small monodispersed CdSe quantum dot nanocrystallites. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *130*, 344-349.
48. Shahverdi, A. R., Minaeian, S., Shahverdi, H. R., Jamalifar, H., & Nohi, A. A. (2007). Rapid synthesis of silver nanoparticles using culture supernatants of Enterobacteria: a novel biological approach. *Process Biochemistry*, *42*(5), 919-923.
49. Kimber, R. L., Lewis, E. A., Parmeggiani, F., Smith, K., Bagshaw, H., Starborg, T., ... & Lloyd, J. R. (2018). Biosynthesis and characterization of copper nanoparticles using Shewanellaoneidensis: application for click chemistry. *Small*, *14*(10), 1703145.
50. Mohanpuria, P., Rana, N. K., & Yadav, S. K. (2008). Biosynthesis of nanoparticles: technological concepts and future applications. *Journal of nanoparticle research*, *10*, 507-517.
51. Ahmad, A., Mukherjee, P., Senapati, S., Mandal, D., Khan, M. I., Kumar, R., & Sastry, M. (2003). Extracellular biosynthesis of silver nanoparticles using the fungus Fusarium oxysporum. *Colloids and surfaces B: Biointerfaces*, *28*(4), 313-318.
52. Arun, G., Eyini, M., & Gunasekaran, P. (2014). Green synthesis of silver nanoparticles using the mushroom fungus Schizophyllum commune and its biomedical applications. *Biotechnology and Bioprocess Engineering*, *19*, 1083-1090.
53. Mishra, A. N., Bhadauria, S., Gaur, M. S., & Pasricha, R. (2010). Extracellular microbial synthesis of gold nanoparticles using fungus Hormoconisresinae. *JOM*, *62*, 45-48.
54. Wu, S. M., Su, Y., Liang, R. R., Ai, X. X., Qian, J., Wang, C., ... & Yan, Z. Y. (2015). Crucial factors in biosynthesis of fluorescent CdSe quantum dots in Saccharomyces cerevisiae. *RSC advances*, *5*(96), 79184-79191.
55. Priyanka, U., KM, A. G., Elisha, M. G., & Nitish, N. (2017). Biologically synthesized PbS nanoparticles for the detection of arsenic in water. *International Biodeterioration & Biodegradation*, *119*, 78-86.

56. Jha, A. K., Prasad, K., & Kulkarni, A. R. (2009). Synthesis of TiO2 nanoparticles using microorganisms. *Colloids and Surfaces B: Biointerfaces*, *71*(2), 226-229.
57. Fayaz, A. M., Balaji, K., Girilal, M., Yadav, R., Kalaichelvan, P. T., &Venketesan, R. (2010). Biogenic synthesis of silver nanoparticles and their synergistic effect with antibiotics: a study against gram-positive and gram-negative bacteria. *Nanomedicine: Nanotechnology, Biology and Medicine*, *6*(1), 103-109.
58. Singh, D., Rathod, V., Ninganagouda, S., Hiremath, J., Singh, A. K., & Mathew, J. (2014). Optimization and characterization of silver nanoparticle by endophytic fungi Penicillium sp. isolated from Curcuma longa (turmeric) and application studies against MDR E. coli and S. aureus. *Bioinorganic chemistry and applications*, *2014*.
59. Kowshik, M., Deshmukh, N., Vogel, W., Urban, J., Kulkarni, S. K., &Paknikar, K. M. (2002). Microbial synthesis of semiconductor CdS nanoparticles, their characterization, and their use in the fabrication of an ideal diode. *Biotechnology and bioengineering*, *78*(5), 583-588.
60. Kowshik, M., Ashtaputre, S., Kharrazi, S., Vogel, W., Urban, J., Kulkarni, S. K., &Paknikar, K. M. (2002). Extracellular synthesis of silver nanoparticles by a silver-tolerant yeast strain MKY3. *Nanotechnology*, *14*(1), 95.
61. Martínez, B. F., Contreras, A. A., & González, E. Á. (2010). Use of Saccharomyces cerevisiae cell walls in diets for two genetic strains of laying hens reared in floor and cages. *International Journal of Poultry Science*, *9*(2), 105-108.
62. Roychoudhury, A. (2020). Yeast-mediated green synthesis of nanoparticles for biological applications. *Indian J Pharm Biol Res*, *8*(03), 26-31.
63. Dameron, C. T., Reese, R. N., Mehra, R. K., Kortan, A. R., Carroll, P. J., Steigerwald, M. L., ... & Winge, D. R. (1989). Biosynthesis of cadmium sulphide quantum semiconductor crystallites. *Nature*, *338*(6216), 596-597.
64. Niknejad, F., Nabili, M., Ghazvini, R. D., &Moazeni, M. (2015). Green synthesis of silver nanoparticles: advantages of the yeast Saccharomyces cerevisiae model. *Current medical mycology*, *1*(3), 17.
65. Peiris, M. M. K., Gunasekara, T. D. C. P., Jayaweera, P. M., & Fernando, S. S. N. (2018). TiO2 nanoparticles from Baker's yeast: A potent antimicrobial.
66. Pimprikar, P. S., Joshi, S. S., Kumar, A. R., Zinjarde, S. S., & Kulkarni, S. K. (2009). Influence of biomass and gold salt concentration on nanoparticle synthesis by the tropical marine yeast Yarrowialipolytica NCIM 3589. *Colloids and Surfaces B: Biointerfaces*, *74*(1), 309-316.
67. Gericke, M., & Pinches, A. (2006). Biological synthesis of metal nanoparticles. *Hydrometallurgy*, *83*(1-4), 132-140.
68. Shahid, M., Dumat, C., Khalid, S., Schreck, E., Xiong, T., & Niazi, N. K. (2017). Foliar heavy metal uptake, toxicity and detoxification in plants: A comparison of foliar and root metal uptake. *Journal of hazardous materials*, *325*, 36-58.
69. Iravani, S. (2011). Green synthesis of metal nanoparticles using plants. *Green Chemistry*, *13*(10), 2638-2650.
70. Mittal, A. K., Chisti, Y., & Banerjee, U. C. (2013). Synthesis of metallic nanoparticles using plant extracts. *Biotechnology advances*, *31*(2), 346-356.
71. Carolin, C. F., Kumar, P. S., Saravanan, A., Joshiba, G. J., & Naushad, M. (2017). Efficient techniques for the removal of toxic heavy metals from aquatic environment: A review. *Journal of environmental chemical engineering*, *5*(3), 2782-2799.s
72. Jeyarani, S., Vinita, N. M., Puja, P., Senthamilselvi, S., Devan, U., Velangani, A. J., ... & Kumar, P. (2020). Biomimetic gold nanoparticles for its cytotoxicity and biocompatibility evidenced by fluorescence-based assays in cancer (MDA-MB-231) and non-cancerous (HEK-293) cells. *Journal of Photochemistry and Photobiology B: Biology*, *202*, 111715.
73. Banasiuk, R., Krychowiak, M., Swigon, D., Tomaszewicz, W., Michalak, A., Chylewska, A., ... &Krolicka, A. (2020). Carnivorous plants used for green synthesis of silver nanoparticles with broad-spectrum antimicrobial activity. *Arabian Journal of Chemistry*, *13*(1), 1415-1428.
74. Nabi, G., Ain, Q. U., Tahir, M. B., Nadeem Riaz, K., Iqbal, T., Rafique, M., ... & Rizwan, M. (2022). Green synthesis of TiO2 nanoparticles using lemon peel extract: their optical and photocatalytic properties. *International Journal of Environmental Analytical Chemistry*, *102*(2), 434-442.
75. Üstün, E., Önbaş, S. C., Çelik, S. K., Ayvaz, M. Ç., & Şahin, N. (2022). Green synthesis of iron oxide nanoparticles by using Ficus carica leaf extract and its antioxidant activity. *Biointerface Res. Appl. Chem*, *12*, 2108-2116.

Journal of Chemical Health Risks
www.jchr.org
JCHR (2023) 13(5), 473-490 | ISSN:2251-6727

76. Emeka, E. E., Ojiefoh, O. C., Aleruchi, C., Hassan, L. A., Christiana, O. M., Rebecca, M., ... & Temitope, A. E. (2014). Evaluation of antibacterial activities of silver nanoparticles green-synthesized using pineapple leaf (Ananas comosus). *Micron*, *57*, 1-5.
77. Murthy, H. C., Desalegn, T., Kassa, M., Abebe, B., & Assefa, T. (2020). Synthesis of green copper nanoparticles using medicinal plant hageniaabyssinica (Brace) JF. Gmel. leaf extract: Antimicrobial properties. *Journal of nanomaterials*, *2020*.
78. Phang, Y. K., Aminuzzaman, M., Akhtaruzzaman, M., Muhammad, G., Ogawa, S., Watanabe, A., &Tey, L. H. (2021). Green synthesis and characterization of CuO nanoparticles derived from papaya peel extract for the photocatalytic degradation of palm oil mill effluent (POME). *Sustainability*, *13*(2), 796.
79. Jain, R., Mendiratta, S., Kumar, L., & Srivastava, A. (2021). Green synthesis of iron nanoparticles using Artocarpus heterophyllus peel extract and their application as a heterogeneous Fenton-like catalyst for the degradation of Fuchsin Basic dye. *Current Research in Green and Sustainable Chemistry*, *4*, 100086.
80. Bankar, A., Joshi, B., Kumar, A. R., &Zinjarde, S. (2010). Banana peel extract mediated novel route for the synthesis of silver nanoparticles. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *368*(1-3), 58-63.
81. Mehdizadeh, T., Zamani, A., &Froushani, S. M. A. (2020). Preparation of Cu nanoparticles fixed on cellulosic walnut shell material and investigation of its antibacterial, antioxidant and anticancer effects. *Heliyon*, *6*(3).
82. Ahmad, W., Jaiswal, K. K., & Soni, S. (2020). Green synthesis of titanium dioxide (TiO2) nanoparticles by using Mentha arvensis leaves extract and its antimicrobial properties. *Inorganic and Nano-Metal Chemistry*, *50*(10), 1032-1038.
83. Aygün, A., Özdemir, S., Gülcan, M., Cellat, K., & Şen, F. (2020). Synthesis and characterization of Reishi mushroom-mediated green synthesis of silver nanoparticles for the biochemical applications. *Journal of pharmaceutical and biomedical analysis*, *178*, 112970.
84. Narasaiah, B. P., & Mandal, B. K. (2020). Remediation of azo-dyes based toxicity by agro-waste cotton boll peels mediated palladium nanoparticles. *Journal of Saudi Chemical Society*, *24*(2), 267-281.
85. Bastos-Arrieta, J., Florido, A., Pérez-Ràfols, C., Serrano, N., Fiol, N., Poch, J., & Villaescusa, I. (2018). Green synthesis of Ag nanoparticles using grape stalk waste extract for the modification of screen-printed electrodes. *Nanomaterials*, *8*(11), 946.
86. Bhuyan, T., Mishra, K., Khanuja, M., Prasad, R., & Varma, A. (2015). Biosynthesis of zinc oxide nanoparticles from Azadirachta indica for antibacterial and photocatalytic applications. *Materials Science in Semiconductor Processing*, *32*, 55-61.
87. Jadoun, S., Arif, R., Jangid, N. K., & Meena, R. K. (2021). Green synthesis of nanoparticles using plant extracts: A review. *Environmental Chemistry Letters*, *19*, 355-374.
88. Ingale, A. G., & Chaudhari, A. N. (2013). Biogenic synthesis of nanoparticles and potential applications: an eco-friendly approach. *J NanomedNanotechol*, *4*(165), 1-7.
89. Bhawana, P., &Fulekar, M. (2012). Nanotechnology: remediation technologies to clean up the environmental pollutants. *Res J Chem Sci ISSN*, *2231*, 606X.
90. Aguilar, Z. P. (2013). Types of nanomaterials and corresponding methods of synthesis. *Nanomaterials for Medical Applications*, *50*.
91. Loos, M. (2015). Nanoscience and nanotechnology. *Carbon nanotube reinforced composites*, 1-36.
92. Morris, B. L., Lawrence, A. R., Chilton, P. J. C., Adams, B., Calow, R. C., & Klinck, B. A. (2003). Groundwater and its susceptibility to degradation: a global assessment of the problem and options for management.
93. Montgomery, M. A., & Elimelech, M. (2007). Water and sanitation in developing countries: including health in the equation. *Environmental science & technology*, *41*(1), 17-24.
94. Sayan, B., Indranil, S., Aniruddha, M., Dhrubajyoti, C., Uday, C. G., &Debashis, C. (2013). Role of nanotechnology in water treatment and purification: potential applications and implications. *Int J Chem Sci Technol*, *3*(3), 59.
95. Tlili, I., &Alkanhal, T. A. (2019). Nanotechnology for water purification: electrospun nanofibrous membrane in water and wastewater treatment. *Journal of Water Reuse and Desalination*, *9*(3), 232-248.
96. Ashraf, M. A., & Mohd Hanafiah, M. (2019). Sustaining life on earth system through clean air, pure water, and fertile soil. *Environmental Science and Pollution Research*, *26*, 13679-13680.

97. Reddy, M. S., Sivaramakrishna, L., & Reddy, A. V. (2012). The use of an agricultural waste material, Jujuba seeds for the removal of anionic dye (Congo red) from aqueous medium. *Journal of hazardous materials*, *203*, 118-127.
98. Lakkaboyana, S. K., Soontarapa, K., Marella, R. K., & Kannan, K. (2021). Preparation of novel chitosan polymeric nanocomposite as an efficient material for the removal of Acid Blue 25 from aqueous environment. *International Journal of Biological Macromolecules*, *168*, 760-768.
99. Hanafiah, M. M., Mohamad, N. H. S. M., & Abd Aziz, N. I. H. (2018). Salvinia molesta and Pistia stratiotes as phytoremediation agents in sewage wastewater treatment. *Sains Malaysiana*, *47*(8), 1625-1634.
100. Shah, M. A., & Ahmad, T. (2010). *Principles of nanoscience and nanotechnology*. Alpha Science International.
101. Poulopoulos, S. G., &Inglezakis, V. J. (2006). *Adsorption, ion exchange and catalysis: design of operations and environmental applications*. Elsevier.
102. Lennard-Jones, J. E. (1932). Processes of adsorption and diffusion on solid surfaces. *Transactions of the Faraday Society*, *28*, 333-359.
103. Engates, K. E., & Shipley, H. J. (2011). Adsorption of Pb, Cd, Cu, Zn, and Ni to titanium dioxide nanoparticles: effect of particle size, solid concentration, and exhaustion. *Environmental Science and Pollution Research*, *18*, 386-395.
104. Qu, X., Brame, J., Li, Q., & Alvarez, P. J. (2013). Nanotechnology for a safe and sustainable water supply: enabling integrated water treatment and reuse. *Accounts of chemical research*, *46*(3), 834-843.
105. Chowdhury, S., & Balasubramanian, R. (2014). Recent advances in the use of graphene-family nanoadsorbents for removal of toxic pollutants from wastewater. *Advances in colloid and interface science*, *204*, 35-56.
106. Arshadi, M., Faraji, A. R., & Amiri, M. J. (2015). Modification of aluminum–silicate nanoparticles by melamine-based dendrimer l-cysteine methyl esters for adsorptive characteristic of Hg (II) ions from the synthetic and Persian Gulf water. *Chemical Engineering Journal*, *266*, 345-355.
107. Gehrke, I., Geiser, A., &Somborn-Schulz, A. (2015). Innovations in nanotechnology for water treatment. Nanotechnol Sci Appl 8: 1–17.
108. Ibrahim, R. K., Hayyan, M., AlSaadi, M. A., Hayyan, A., & Ibrahim, S. (2016). Environmental application of nanotechnology: air, soil, and water. *Environmental Science and Pollution Research*, *23*, 13754-13788.
109. Kumar, S., Ahlawat, W., Bhanjana, G., Heydarifard, S., Nazhad, M. M., &Dilbaghi, N. (2014). Nanotechnology-based water treatment strategies. *Journal of nanoscience and nanotechnology*, *14*(2), 1838-1858.
110. Buonomenna, M. G. (2013). Membrane processes for a sustainable industrial growth. *RSC advances*, *3*(17), 5694-5740.
111. Pendergast, M. M., & Hoek, E. M. (2011). A review of water treatment membrane nanotechnologies. *Energy & Environmental Science*, *4*(6), 1946-1971.
112. Balamurugan, R., Sundarrajan, S., & Ramakrishna, S. (2011). Recent trends in nanofibrous membranes and their suitability for air and water filtrations. *Membranes*, *1*(3), 232-248.
113. Vatanpour, V., Madaeni, S. S., Khataee, A. R., Salehi, E., Zinadini, S., & Monfared, H. A. (2012). TiO2 embedded mixed matrix PES nanocomposite membranes: Influence of different sizes and types of nanoparticles on antifouling and performance. *Desalination*, *292*, 19-29.
114. Fathizadeh, M., Aroujalian, A., &Raisi, A. (2011). Effect of added NaX nano-zeolite into polyamide as a top thin layer of membrane on water flux and salt rejection in a reverse osmosis process. *Journal of membrane science*, *375*(1-2), 88-95.
115. Kim, E. S., & Deng, B. (2011). Fabrication of polyamide thin-film nano-composite (PA-TFN) membrane with hydrophilized ordered mesoporous carbon (H-OMC) for water purifications. *Journal of membrane science*, *375*(1-2), 46-54.
116. Comninellis, C., Kapalka, A., Malato, S., Parsons, S. A., Poulios, I., &Mantzavinos, D. (2008). Advanced oxidation processes for water treatment: advances and trends for R&D. *Journal of Chemical Technology & Biotechnology: International Research in Process, Environmental & Clean Technology*, *83*(6), 769-776.
117. Gaya, U. I., & Abdullah, A. H. (2008). Heterogeneous photocatalytic degradation of organic contaminants over titanium dioxide: a review of fundamentals, progress and problems. *Journal of photochemistry and photobiology C: Photochemistry reviews*, *9*(1), 1-12.
118. Chong, M. N., Jin, B., Chow, C. W., & Saint, C. (2010). Recent developments in photocatalytic

water treatment technology: a review. *Water research*, *44*(10), 2997-3027.
119. Malato, S., Fernández-Ibáñez, P., Maldonado, M. I., Blanco, J., &Gernjak, W. (2009). Decontamination and disinfection of water by solar photocatalysis: recent overview and trends. *Catalysis today*, *147*(1), 1-59.
120. Wang, J. L., & Xu, L. J. (2012). Advanced oxidation processes for wastewater treatment: formation of hydroxyl radical and application. *Critical reviews in environmental science and technology*, *42*(3), 251-325.
121. Gehrke, I., Keuter, V., &Groß, F. (2012). Development of nanocomposite membranes with photocatalytic surfaces. *Journal of Nanoscience and Nanotechnology*, *12*(12), 9163-9168.
122. Qu, X., Alvarez, P. J., & Li, Q. (2013). Applications of nanotechnology in water and wastewater treatment. *Water research*, *47*(12), 3931-3946.
123. Li, Q., Mahendra, S., Lyon, D. Y., Brunet, L., Liga, M. V., Li, D., & Alvarez, P. J. (2008). Antimicrobial nanomaterials for water disinfection and microbial control: potential applications and implications. *Water research*, *42*(18), 4591-4602.
124. Richardson, S. D., Plewa, M. J., Wagner, E. D., Schoeny, R., & DeMarini, D. M. (2007). Occurrence, genotoxicity, and carcinogenicity of regulated and emerging disinfection by-products in drinking water: a review and roadmap for research. *Mutation Research/Reviews in Mutation Research*, *636*(1-3), 178-242.
125. Savage, N., & Diallo, M. S. (2005). Nanomaterials and water purification: opportunities and challenges. *Journal of Nanoparticle research*, *7*, 331-342.
126. Hossain, F., Perales-Perez, O. J., Hwang, S., & Román, F. (2014). Antimicrobial nanomaterials as water disinfectant: applications, limitations and future perspectives. *Science of the total environment*, *466*, 1047-1059.
127. Dizaj, S. M., Lotfipour, F., Barzegar-Jalali, M., Zarrintan, M. H., &Adibkia, K. (2014). Antimicrobial activity of the metals and metal oxide nanoparticles. *Materials Science and Engineering: C*, *44*, 278-284.
128. Kang, S., Mauter, M. S., & Elimelech, M. (2009). Microbial cytotoxicity of carbon-based nanomaterials: implications for river water and wastewater effluent. *Environmental science & technology*, *43*(7), 2648-2653.
129. Lyon, D. Y., & Alvarez, P. J. (2008). Fullerene water suspension (nC60) exerts antibacterial effects via ROS-independent protein oxidation. *Environmental science & technology*, *42*(21), 8127-8132.
130. Vecitis, C. D., Zodrow, K. R., Kang, S., & Elimelech, M. (2010). Electronic-structure-dependent bacterial cytotoxicity of single-walled carbon nanotubes. *ACS nano*, *4*(9), 5471-5479.
131. Yang, C., Mamouni, J., Tang, Y., & Yang, L. (2010). Antimicrobial activity of single-walled carbon nanotubes: length effect. *Langmuir*, *26*(20), 16013-16019.
132. Liu, W., Wang, T., Borthwick, A. G., Wang, Y., Yin, X., Li, X., & Ni, J. (2013). Adsorption of Pb2á+, Cd2á+, Cu2á+ and Cr3á+ onto titanate nanotubes: Competition and effect of inorganic ions. *Science of the Total Environment*, *456*, 171-180.
133. Ge, F., Li, M. M., Ye, H., & Zhao, B. X. (2012). Effective removal of heavy metal ions Cd^{2+}, Zn^{2+}, Pb^{2+}, Cu^{2+} from aqueous solution by polymer-modified magnetic nanoparticles. *Journal of hazardous materials*, *211*, 366-372.
134. Sheela, T., & Nayaka, Y. A. (2012). Kinetics and thermodynamics of cadmium and lead ions adsorption on NiO nanoparticles. *Chemical Engineering Journal*, *191*, 123-131.
135. Lunge, S., Singh, S., & Sinha, A. (2014). Magnetic iron oxide (Fe_3O_4) nanoparticles from tea waste for arsenic removal. *Journal of Magnetism and Magnetic Materials*, *356*, 21-31.
136. Su, Y., Cui, H., Li, Q., Gao, S., & Shang, J. K. (2013). Strong adsorption of phosphate by amorphous zirconium oxide nanoparticles. *Water research*, *47*(14), 5018-5026.
137. Li, H., Zhang, D., Han, X., & Xing, B. (2014). Adsorption of antibiotic ciprofloxacin on carbon nanotubes: pH dependence and thermodynamics. *Chemosphere*, *95*, 150-155.
138. Chen, Z., Pierre, D., He, H., Tan, S., Pham-Huy, C., Hong, H., & Huang, J. (2011). Adsorption behavior of epirubicin hydrochloride on carboxylated carbon nanotubes. *International journal of pharmaceutics*, *405*(1-2), 153-161.
139. Venkatesham, V., Madhu, G. M., Satyanarayana, S. V., & Preetham, H. S. (2013). Adsorption of lead on gel combustion derived nano ZnO. *Procedia Engineering*, *51*, 308-313.
140. Ai, L., Zhang, C., Liao, F., Wang, Y., Li, M., Meng, L., & Jiang, J. (2011). Removal of methylene blue from aqueous solution with magnetite loaded multi-wall carbon nanotube: kinetic, isotherm and mechanism analysis. *Journal of hazardous materials*, *198*, 282-290.

141. Ai, L., Luo, X., Lin, X., & Zhang, S. (2013). Biosorption behaviors of uranium (VI) from aqueous solution by sunflower straw and insights of binding mechanism. *Journal of Radioanalytical and Nuclear Chemistry*, *298*, 1823-1834.
142. Kunduru, K. R., Nazarkovsky, M., Farah, S., Pawar, R. P., Basu, A., & Domb, A. J. (2017). Nanotechnology for water purification: applications of nanotechnology methods in wastewater treatment. *Water purification*, 33-74.