A COMPREHENSIVE REVIEW ON NANOMATERIALS AND IT'S WATER REMEDIATION APPLICATIONS

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Abstract

There is a serious ecological threat to all living species because of the ever-increasing pollution levels in drinking water. In order to efficiently remove a wide spectrum of heavy metals from polluted water, numerous conventional and non-traditional approaches have been utilised. Restriction of huge substrates will be an important advance towards the real usage of various nano-biomaterials in water purification systems. To remove the excess fluoride, heavy metals, and fluoride-like heavy metals in the water, researchers have developed new, novel, cost-effective, and easily available technologies. Future research will be dependent on the excluded interaction between the effects of nanoconfinement and water purification improvements as a result of this key notion. There are several effective adsorbents that can remove excessive levels of heavy metals, and these adsorbents are easy to get and accessible to the general public, as demonstrated in this review.

Keywords: Fluorosis; Nanotechnology; Defluoridation; Nanoconfinement; Adsorption.

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1. Introduction

Water is world's wide resource and constituent lives. It acts chief role in the global economy, where about 70-80% of freshwater is used in cultivation of crops. Water pollution is one of the biggest environmental harms faced by the planet and has a tendency for affecting human health, plants, trees and livestock, as well as water shortages. Due to the shortage of fresh water supplies, waste management has become an elegant way to conserve and increase the water accessible sources. In recent decades, the presence in the marine ecosystem of numerous newly detected substances of anthropogenic or natural origin has become a global concern for the environment. The compounds are referred to by various groups as "emerging contaminants (ECs), micro-pollutants, emerging pollutants (EPs), emerging concern contaminants (CECs), or trace organs compounds (TrOCs). Recycle of polluted water posses' wide range of applications, including agricultural soil management, environmental activities, manufacturing, recreational, aquaculture, and artificial groundwater recovery[1]. Waste water management provided proper processing is taken to restore its acceptable water quality for the intended use. Except for a small number of countries, the water supply is limited mostly to non-potable sources or to indirect, drinking water use. Any conditions and parameters including content of heavy metals, electrical conductivity and subsequent condensation organic matter should therefore be tested after application before wastewater[2].

Nanotechnology enables the production of new high-tech materials, such as functionalized surfaces, adsorption materials, coatings, nano catalysts, membranes. and reagents, for effective water and waste water repair processes[3-5]. Nano sorbent materials are nevertheless regarded as the most appropriate form of water and wastewater remediation due to their simple application and the wide variety of adsorbents available[6]. Nanomaterials historically had an unprecedented impact on the water and wastewater treatment process. Because of its special feats, such as increased surface area and enhanced adsorption potential, nanomaterials are the smartest way to handle both organic and inorganic pollutants. In addition, physisorption or chemisorption can rely on the functionalization of nanomaterials to communicate between nano adsorbents materials and pollutants[7].

Nanomaterials can offer a wide variety of uses due to their specific and novel surface area, such as reactant films, nano sponges, pinch, silver and TiO2. As some master evaluations show, by 2050, the total population will grow to nine billion. Totally 77 percent of the national population is concentrated. The obtained results were interpreted with Water Consultative Council reports which are considered as semiarid or 2/3 of territory monitoring. The relationship between organic and inorganic contaminants with materials containing nano sorbent. In order to extract methyl orange tint from water by the use of carbon nanotubes to remove diazinon pesticide[8,9]. The role of Cu\\Fe binary oxides in water removal of hexavalent chromium. The importance of new hybrid material in the removal of arsenic from water (III). However, by implementing potential activated alumina significantly modified by zirconium, fluoride and calcium removed[10].

Table 1. Different strategies for production of a variety of nanoparticles

Chemical Methods	Physical Methods	Biological Methods
Hydrothermal Preparation •Metal NPs - Zr, Au, Pt & Ag. •Metal oxide NPs - αFe_3O_4, ZnO, CuO & Fe_3O_4.	**Inert Gas Condensation** •Metal NPs-Mn,Cu & Pt. •Core shell NPs - FeAg(Core)-Si(Shell) •Inter metallic NPs-AuPd	**Plant Extracts mediated Biogenesis** • Metal NPs - Au, Pd& Ag

Micro-EmulsionTechnique Inorganic Nanoparticles •Metal NPs - Pd, Au, Rh, Ag, Ir, Pt & Ni. •Metal salts NPs - CaCO3, BaCO3 & SrCO3.	**Pulse Vapor Deposition Sputtering** •Metal NPs - Ag, Au, Y, Pt & Fe. Metal oxide NPs - TiO2, ZrO2, magnetic (Fe-Pt), semiconductors (Ge) & quantum dots (Ge)	**Microorganisms mediated Bio synthesis** • Metal NPs - Au, Pt, Ag, Cu, Hg, Pd &Cu • Metal sulphide NPs - Cds, magnetite NPs, PbS & quantum dots (CdTe, Cds).
•Magnetic NPs - (Zn,Mn,)Fe2O4)& BaFe212O19). •Metal sulphite NPs - (CdS, CuS & CdSe). Organic NPs •**Organic molecules** (Cholesterol, retinol, rhodiaarome, rhovanil), conducting polymers (Polyaniline, polypyrrole, polythiophene), Polymers (Latex, polystyrene, PMMA),	**Electron Beam Evaporation.** •Inter metallic NPs - PtMWCNT & CoPtgraphene. •Metal NPs - Ag, Au & Pt **Laser Ablation** •magnetic NPs – FePt, metal oxide (ZnO), FeCo, metal sulphide (PbS). •Metal NPs - Ag, Se & Fe, Ni.	• **Metal oxide NPs**- TiO_2, ZrO_2 & SiO_2.
Co-Precipitation •MnO2, Fe2O3, Fe2O3- ZrO2, Fe3O4, Fe2O3- SnO2 & Organic inorganic hybrid composites	**Electro-Spraying** •Metal NPs – Ti, Au, Ni, SiO2, Ag, TiO2 & ZrO2. •Polymeric NPs -PMMA, PCL, chitosan, PLGA.	**Bio-Templates mediated Bio synthesis** • Metal NPs - Pt, Ag &Au.
Plasma Chemical Vapor Deposition •GaN NPs, silica and Carbon.	**Melt assimilation** •Nanocomposites NPs (Polypyrrole polyprpylen	

In addition, experiments have been conducted to study the application of available nano adsorbents materials in contaminated water management strategies. For example, eminent investigators applied various nano sorbent such as metal oxides and carbon, which were used to remove heavy metals from waste water[11]. Moreover, following the modification of mesoporous silica, synthetic superparamagnetic nano sorbents (iron oxide) have a major impact in removing of pollutants by exceedingly increased surface area. investigation offer the impact and sources of different types of nanomaterials and adsorbents towards bioremediation of wastewater comparatively investigate with available literatures and research.

Effect of Toxic Dyes on Living Organisms

The availability of dyes (RB, MB, MV, CR & CV) and its structures and non-biodegradable existence, are major concerns for society and are harmful to living organisms. These dyes are carcinogenic and damage the environment. These dyes not only devastate aesthetic feature but also limit the dissemination of sunlight into water, which gives negative impact on organisms which living in water. Among different contaminants MV and MB are the most harmful to living creatures. Acidic dyes have adverse impact on the eyes, breathing system, skin and can increase the risk of cancer and human mutagenicity. Basic coloring dyes are also poisonous, can result in allergies, inflammation of the skin, mutations and even cutaneous cancer, improve heart health. Wastewater from different textile factories often includes metal ions that are impurities entirely depends on hexavalent chromium[12-15].

Chromium mediated multifarious dyes are generally severe carcinogenic and have damaging effects on marine organisms. The key explanation for the improved toxicity of azo dyes is the group of amines found in azo dyes. Reactive dyes in water soluble can be a reason for severe water problems[16,17]. Thus, the variety of dyes are a more hazardous organic pollutants in the atmosphere which are directly and indirectly exposed into water supplies, making polluted water or portable drinking water therapy a major ecological concern. The removal of fungi flocculation and anaerobic digestion, many methods are used, e.g. physical method, chemical, and biological methodology. These methods are effective and have accurate results to remove radioactive dyes from water[18]. They have however also some disadvantages, such as high processing loads, which are less efficient at low concentration and hard to manage. Adsorption, in terms of its ease, cost efficiency, simple handling protocol and service, is the best for the elimination of toxic dyes from contaminated water. Adsorption is a multi composition of fluids surface process in which a molecule (solute) is fixed by chemical and physical bonds to the surface of a solid material[19].

These surface compounds are known as adsorbents, whereas the molecule extracted from the liquid process is called as adsorption. Today, the adsorption phenomenon is useful for the purification of water. Dyes have the chromogenic group that makes the dye molecules adsorb easily on the adsorbent surfaces[20]. Schematic display of elimination of toxic dyes in the wastewater by adsorbent is shown in Fig (1).[21]

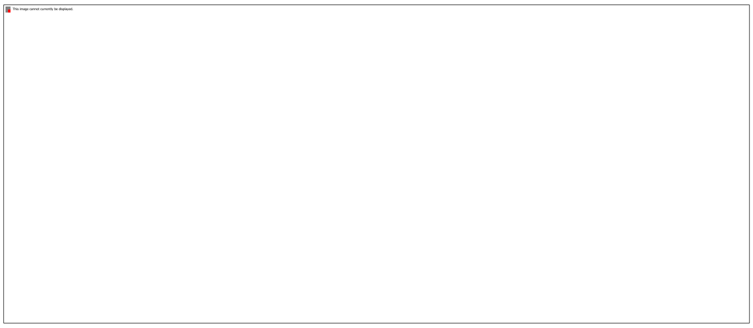

Figure 1: Dye adsorption process.

There are several factors responsible for the pollutant removal was represented in Fig. 2. Detailed studies of these tailored parameters will help to efficiently remove dyes and improve industrial water treatment processes. Recently, nanoparticles (NPs) are used as water adsorbents for water purification, which has a wide range of water treatment. These attractive NPs posses' wide applications and properties, like improved surface-to-volume ratio, active surface characteristics in the treatment of toxic contaminants[22,23].

Figure 2: Factors influencing the adsorption efficiency

Nano Adsorbent (NA)

Nano-adsorbent adsorbents are often used to remove heavy metals from wastewater. The most widely used nanoparticles for the removal of heavy metals from aqueous solutions are CNTs and metal oxides. These nano-particles have certain main characteristics, such as large BET surfaces, microporous structure, high dispersion ability, and are economic and environmentally friendly. Less particles and difficulties in separating them from aqueous solutions can, however, contribute to secondary contamination. This also impacts the bioavailability and mobility of heavy metals and contributes to environmental toxicity. The cost and feature property such as the size of the particle, probability distribution of particles, shape, crystal structure, distribution of composite material, purity, aggregation checks, stabilisation, repeatability and higher NP increased manufacturing made it suitable for various applications such as sensor, biomedical, and water treatment in particular fig 3.[24,25]

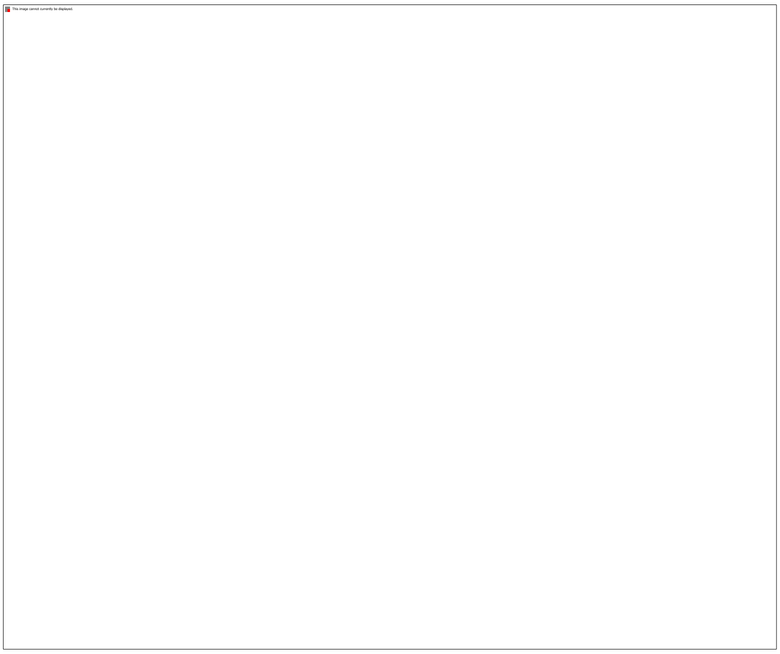

Figure 3: Water and wastewater treatment techniques

The present literature review has been carried out to upgrade nano adsorbent status in the water handling protocols and to examine the color sorption by a variety of nanomaterial, the sorption efficiency of which is described in Tables 1 and 2. Null-valent iron, iron oxides, hydroxides, aluminum oxide, zinc oxide, titanium oxide and Copper Oxide NPs are also used as an adsorbent in dye degradation[26].

Table 2: Elimination of dye with its absorbent name and method of synthesis

S.No	Dye	Adsorbent Name	Method of Synthesis
1	VG	Fe-NPs	Borohydride Chemical reduction
2	MB & MB	Copper-oxide nanoparticles	Precipitation method
3	MO	AgNPs doped activated carbon	1-step reduction process
4	Azo dyes	Nano zerovalent iron nanoparticle nanoparticles	$NaHBO_4$ chemical reduction reduction
5	VG	Iron nanoparticle loaded Ash	Borohydride chemical reduction chemical reduction
6	MO, MB & RB	Ag nanobiocomposite	One pot microwave method method

7	CV	cobalt nanoparticles	Combustion method
8	MG & CR	Fe-Zn nanoparticle	Precipitation method
9	DG, DR & AB	$CoFe_2O_4$	Simple precipitation
10	MB	Copper oxide nanoparticles	Reduction method
11	AB	Ni-SiO2/Tio2 nanoparticles	Hydrolysis process
12	Auramine O, MB & chrysoidine G	Nano-hydrogel	emulsion method
13	Direct blue 78, AR 18, RB 5, AO 7 & AB 113,	Chitosan	Inverse polymerisation
14	MV & MG	Magnetic NPs	distillation precipitation method
15	Dyes	TiO_2 nanostructures	Metal-assisted wet etching
16	MB, MO, OG, Orange G	Plant-mediated nanoparticle	chemical reduction method
17	RB	Pyrrole iron oxide	Chemical precipitation

General strategies used in wastewater treatment

Ion exchange

An "exchange site" of an immovable solid atom. Certain particles such as zeolites and clay minerals occur naturally, while others are synthesized. Ion exchange techniques in water and wastewater were successfully used to remove various heavy metal cations[27,28]. Some researchers have found that it is difficult to remove such heavy metals such as plum, given the rivalry between the active ion replacement sites and the naturally occurring sites. The efficacy of the removal of variety of heavy metals in 18 hours in batch containers with enhanced acidic pH removal efficiency (N95%)[29-31].

Chemical precipitation

The formed solid is indicated as a precipitate and can be pelleted by a centrifuge. Supernatal or supernatant is the fluid residual overhead of the solid[32,33]. Owing to its low cost and its efficiency, chemical precipitation methods are widely used to elimination of heavy metal ions from water and waste water[34]. The following steps usually include the reduction of heavy metals by chemical precipitation techniques:

Reverse osmosis (RO)

This approach is extremely successful when all ionic forms are removed from the water and wastewater solution. The concentrated by-product solution (called retentate) is a major benefit of the technique, making the final recapture of metals cheaper. Furthermore, this method has been used both in small scales and in large scales for heavy metal removal. The membranes are therefore relatively costly to purchase and maintain. And the high stresses needed to operate a device have led to the cost and sensitivity of this process. Reverse osmosis (RO) is a molecular filter technique that removes N99 percent of all soluble salts in a aqueous feedstock. Solvent mobility balances the concentration of solute on either side of the different membranes to produce a pressure called a "osmotic gradient." The reverse osmosis was named by the use membrane to pass water or wastewater, but the dissolved and particular substances are too big compared with the diameters of the membrane pores and stay behind[35-38]. This approach is extremely successful when all ionic forms are removed from the water and wastewater solution. The concentrated by-product solution (called retentate) is a major benefit of the technique, making the final recapture of metals cheaper[39]. Furthermore, this method has been used both in small scales and in large scales for heavy metal removal. The membranes are therefore relatively costly to purchase and maintain. And the high stresses needed to operate a device have led to the cost and sensitivity of this process[40,41].

The adsorption method has therefore been the most frequently used water treatment by the world's ecologists for removing toxic and poisonous inorganic and organic pollutants. However, adsorption produces a material, like other treatment systems, which may pose challenges to the responsible disposal. These achievements have led to many more studies to identify effective and cheap wastewater treatment techniques which mitigate these negative effects[42-45]. Classification of nano-adsorbents

Nanoadsorbents are generally categorized in different classes according to their adsorption process. Nanocarbonate (CNMs) has been the latest production, with carbon nanoparticles, carbon nanoparticles and nanocarbon sheets included[46]. In addition, nano-adsorbents were used for different types of silicone nano-materials, including silicone nanoparticles, silicone nano-nano-sheets and silicone nanosheets. Nanoclays, nanomaterials from polymers like nano-adsorbent controls two main nanoparticular features that function in another compound, including titanium dioxide and alumina, efficiently and efficiently. In addition, some reagents can change nanoparticles to boost their capacity before metal ions[47-50.]

Oxide based nanoparticles

Nanoparticles based on oxide are usually made from variety of non metals & metals inorganic nanoparticles. These nano-particles are commonly used for wastewater treatment of dangerous contaminants. The elevated BET surface area and minimal environmental impact, the reduced solubility and no secondary contaminants are known as the oxide-backed nanoparticles[51-54]

Iron based nanoparticles.

Ferric oxide is a decreased material for adsorbing hazardous metals due to its natural appearance and its good biocompatibility. It is an ecological material that is readily available in a polluted area with a reduced likelihood of secondary exposure[55,56]. The pH, temperature, adsorbent dose and time of incubation of Fe_2O_3 nanoparticles are determined by the adsorption conditions for various heavy metals. Different researchers have developed the capability to absorb Fe_2O_3surface. Fe_2O_3 nano-particles with 3-aminopropyl trimethoxy silane to change their surface. The change in these nanoadsorbents shows a very near affinity to eradicate different wastewater contaminants[57].

Zinc oxide (ZnO) nanoparticles.
Zinc oxide (ZnO) has high-BET pore surface for heavy metal adsorption. The most frequent use of nano-adsorbents, for instance nano-assemblies, nanoplates, nano-plates and hierarchical ZnO nano-rubbers is to extract metal ions from wastewater. The updated nanoadsorbent compositions ZnO have a high deletion efficiency of heavy metals in comparison with Cu Wastewater Isolation
(II)[58]. These modified ZnO nanoadsorbents are more efficient than conventional ZnO because of their special micro/nanostructures for removal. In addition, a variety of heavy metals have been removed using nano-assemblies. Because of their electropositive existence, adsorption in microporous nanoassemblies of Pb^{2+}, Hg^{2+} and As^{3+} is higher. The use of mesoporous hierarchical nano-rods from elevated wastes is to strip Pb (II) and Cd (II)[59,60].

Magnesium oxide (MgO) nanoparticles.
Magnesium oxide (MgO) can be used in wastewater to eliminate various types of heavy metal. MgO microsphere is a modern structure that enhances adsorption affinity to eliminate heavy metals. The morphology of the NPs was modified to increase the adsorption potential of MgO by various forms. Nanotubes, nanobeads, nanostructures triggered by nanotubes, nanostructures, and 3D entities would be included. Fractal nanostructure of the fish bone Strong mesoporous Pb(II) and Cd floral adsorption (II)[61,62].

Electrospun nano-fiber membranes
The recent development of electrospun nanofiber membranes (ENMs) gives rise to a new approach to waste water management. The key benefits of this modern technology provide a reduced consumption of oil, lower costs and a lighter process than conventional methods. Moreover, increased porosity and volume-to-surface ratios are the key compensation of this process[63]. In order to generate fibers of less size, electrospinning is improved conventional spinning technique[64]. The fiber diameter regulates the surface area by volume and determines the porosity of the membrane. Several studies over the years have demonstrated that electrospun- nanofibers can be used. The nanofibre polymer protects the catalyst particles and helps to ensure electronic continuity in reactants, protons and fuel cells[65]. Algal membrane bioreactor (A-MBR) incorporated nanoparticles

Algae cultivation is one of the promising methods for the production and purification of energy in wastewater. A large number of algae species develop efficiently in wastes such as cyanocobalamine, thiamine and macronutrients (NO3, PO34, Ca, Na, K, NH4+) required to grow the species. Solutions are produced by the combining the materials needed for algal growth. The result is the elimination from waste water of nutrients and algal biomass for energy production[66,67]. Different techniques, such as sedimentation, flotation, and centrifugation, support the processing of algal biomass but these techniques cannot be offered to a broad range because of the high cost. The most sophisticated approach to development techniques is achieved by means of the simple membrane bioreactor[68]. The benefits of membrane technology include the lack of more chemicals, such as membrane filtering coagulants, which helps to promote water reuse and simplifies the separation of algal biomass after filtration[69].

Many techniques are available for increasing hydrophilicity and reducing membrane fouling, such as plasma processing, surface coverage and nano-installation. Studies have shown that nanoparticles improve hydrophilicity and reduce isolating membranes. For example, mixing carbon nano tubes with TiO_2 nanoparticles with hollow fibre (H
investigated in order to monitor emissions. The hydrophobicity and fouling of these nano-particles can be reduced by the membranes due to these properties[71-73].

Nano-adsorbents
Nanofilters are used to remove heavy metals from variety of polluted water. Numerous metal oxides are most often employed nanoparticles for removing heavy metals from aqueous solutions. It has qualities including high BET surfaces, microporous structure, and excellent dispersion capabilities. However, particle matter and issues in removal are associated with secondary pollution. Heavy metals also alter the bioavailability, mobility, and environmental toxicity. Economic re-use and have also altered the project to solve these issues[74,75].

Nano-catalysts
In the wastewater treatment for catalyst waste water, including photocatalysis, electro-catalysis and Fenton catalysis, the usage of nanoparticles would be extremely significant. The ubiquitous use of ZnO and TiO_2 catalysts for photocatalysis was subject to decreased demand for ultraviolet light as a result of their broadband energy ga[78]p. UV light, which poses a major health concern for people, including skin malignancies and DNA alteration, is exposed in industrial applications to these materials. TiO_2 is also a possible cancer agent that might cause human pneumoconiosis and pulmonary adenocarcinoma. Since high quality water must be

generated by the drinking or safe disposal business, it is necessary to build dependable materials and procedures for these needs[79,80].

Another drawback that hampers photocatalytic activity is that of different types of Nano-catalysts, such as AgBr, that cannot be recycled for reuse when disseminated into this solution. At present, the focus is on the synthesis with metal oxide and semiconductor oxides composite materials for new photocatalysts for the treatment of conventional catalyst issues. The major disadvantages in the Fenton catalytic fundamental reaction are recurring catalyst loss and acidic environments. The usage of the nano-based reagent of Fenton has been used as indicated in several investigations[81-85].

Nano-membranes

The most significant advantages of membrane filtering technologies are high-quality water treatment, effective disinfection, and reduced plant space requirements. The other sorts of care tend to be exceedingly expensive and difficult to create. Using a nano-membrane separator for dyes and heavy metals is a beneficial application of this technology[86]. When it comes to environmental considerations, the production phase of nano-membranes has a huge ecological footprint. Carbon nanofibers have 100 times the lifespan of normal materials, leading to more harmful chemicals in the environment, global warming, and ozone depletion. An additional problem is that the membrane can become fouled by an accumulation of organic compounds in the water coming into contact with the hydrophobic membrane[87,88]. The risk of membrane fouling increases if the particles are disposed on the membrane surface or inside the membrane pores. Fouling the membrane reduces water flow and thus requires a chemical or mechanical purification procedure, or even a complete membrane replacement for a certain time. To alleviate these issues, the researchers focus on membrane phase with a hydrophilic polymer layer, such as polyvinyl alcohol and chitosan. Nanoparticles such as TiO_2 may also be applied to eliminate fouling and increase membranes permeate flow[89-91].

Integrated nano-particles and biological process

The need for a high degree of technological action, specialized biological agents to handle each pollutant (nutrients, dyes, organic compounds)[92] and the balance of each microbial and nano-particle, assembled in each technology, on a large scale constitute significant constraints. Likewise, these processes take time, such as pre-treatment, with biological-processed nano-particle, wastewater algae cultivation and nanofibre matting microbial immobilization[93,94].

Nano- and Micromotors

In recent years, nano/micro-motor-driven devices have been employed to deal with environmental challenges, such as wastewater treatment and environmental monitoring. Reactive nano-based material has the potential to help change hazardous contaminants into nontoxicity. In contrast to typical cleanup agents, nanomachines have different advantages. The establishment of smaller machines increases the prospect of in situ and ex situ nano-remediation rules that seek to help the environment while also reducing expenses. Nanoscale continuous movement is particularly advantageous in transporting and discharging reactive nanomaterials from polluted samples, and in supplying essential mixing processes with reactants[95,96].

Existing technologies, as defined in polluted water treatment, are inadequate to meet the demand for scaling, so further effort is needed. Before moving into commercial implementations, such issues must be clarified[97]. For example, the multifunctional nano/micromotor life cycle is restricted to residual physical materials used in locomotive reactions or oxidation responses. Pt layer poisoning is another downside, as waste water compounds can chemically bind to other surface-active areas of the catalyst or large waste water based on viscosity, which prevents micro-engine movement. A host of environmental therapies will be used to introduce the latest nano/micro engine development to achieve versatile and challenging operations[98].

Nanosorbents

Nanosorbents have broad characteristics, such as high sorption, which make nanosorbents better suited and more effective for water treatment. These nanosorbents are very rare in the form of consumer products, but researchers and experts are working hard to produce nanosorbents at a higher quantity/commercial level. Carbon-based nanosorbents are the most known (e.g., carbon black, graphite, graphene oxide)[99]. There were also metal/metal oxides and polymer nanosorbents. The composition of various materials such as ag/polyaniline, ag/carbon, C/TiO2, etc. is essential in order to reduce the toxicity effect in wastewater treatment. For example, dendrimer-ultrafiltration reduced copper ions. They are regenerated simply by altering the pH, showing bio consistency, biodegradability and toxic environment.

In addition, color removal or other chemical contaminants is almost 99%. Another effective nanosorbent are zeolites with an absorbent structure that can be implanted in numerous nanoparticles such as copper[100]. Zeolites have the advantage of regulating and acting as an anti-microbial agent the volume of metals. In addition, magnetic nanosorbents play an important role in water treatment and are a novel method of extraction from water of different organic pollutants. Filtration by magnet also eliminates some organic containments. Magnetic separation nanosorbents are synthesized with magnetic nanoparticles at a certain affinity[101-103].

Nanoadsorbents for water and wastewater remediation

Traditional sorbents like activated carbons, clay minerals, chelates, and natural zeolites can, however, remove water or wastewater cations from heavy metal, but their efficiency can be reduced by certain characteristics, such as low-sorption ability[104].

Synthesis of nanosorbent materials

The manufacture of nanosorbent materials is two fundamental approaches: the downgrading process and the downgrading process. A standard approach is used to synthesize non-absorbent materials during the top-down process. Corrosion and other techniques such as mechanical alloys, reactive friction and high energy ball friction reduce particle size. The downstream process is the newest. It depends on the building of the substance behind this process: atom by atom or molecular assembly, sol-gel and chemical/physical vapor[105].

Table 3: Comparative investigation of wide range of nanoparticles used for elimination of dye

S.No	Dye	Adsorbents Name	Elimination Efficiency (mg/g)
1.	DB, RB19	Chitosan/SiO_2/carbon nanotubes nano-composite	61.35, 97.08
2.	MO	Ag-NP-AC	98.75%
3.	MB	CuO NPs	88.93%
4.	MB	Magnetic nanoparticles (MNPs)	14.00
5.	RB	Surface modified silica aerogels MSA	34.25
6.	RhB	Hydrogen titanate nanosheets	52.9
7.	MG	Alkaline treated timber sawdust	694.44
8.	BG	ZnO nanorods loaded activated carbon	61.73
9.	MB, RhB	Tungstate oxide nano urchins	150.3
	DR 80	Cellulose nanocrystal-reinforced keratin	1070
11.	DB, RB,AO7	Mixed silica-alumina oxide	45.25
12.	Reactive Black	Chitosan/polyamide nanofibers	487.5
13.	Malachite Green	Iron oxide NPS	333
14.	Anionic dye	Bare ZnO nanoparticles	42.5
15.	Malachite	TiO_2 Nanoparticles	6.7

16	CR	Cu-NPs	37.5
17	RR195, OG	Magnesium oxide nanostructures	207
18	Reactive Black	Zerovalent iron nanoparticles (nZVI)	39.9
19	EBT	Magnetic bioadsorbents	280, 235 and 199
20	MB	Graphene oxide (GO)-based materials	275.5
21	MB	Silica NPs	935
22	BV 3	Mn_2O_3/MgO microsphere	398.41
23	MB	Fe_3O_4-wheat straw	1374.60
24	MB	Activated carbon/Mn0.6Zn0.4Fe_2O_4 composites	274.0
25		$NiFe_2O_4$@Ca-alginate	1243 and 845
26	Mono and di-azo dyes	Aluminum carboxylate-based metal organic frameworks	559.28 and 332.48
27	CR	Amino-coated Fe_3O_4 nanoparticles	97.3

Advantages of Nano-Engineered Adsorbent

Activated carbon, clay minerals, garbage, and biomass are commonly utilized in the decoloring of colored water. However, isolating them from the water after equilibrium is a complex, expensive, and time-consuming procedure. Exhausted materials are normally filtered and centrifuged. Filtration is both affordable and quick, whereas centrifugation is both quick and expensive[106]. The low cost, fast separation, and convenience of handling afforded by NPs benefit the manufacture of magnetic NPs. By following a cycle of adsorption and desorption, this separation process improves the adsorption capability of a given magnetic adsorbent. Recently, adsorption-capable magnetic NPs have been made utilizing abundant materials such as active carbon, biomass, farm waste, and clay minerals[107]. Addition of NPs to the aforesaid materials modifies their porosity, while also enhancing the superficial field. Magnetic NPs are used to give these materials magnetic properties so that they can be distinguished from water, which exhibits higher adsorption capabilities after several adsorption-desorption cycles[108]. Functional nano adsorbents, which have several functional groups on their surfaces, have overtaken all other types of water purification methods as the most attractive and intelligent methods. At changing pH, the color components are held firmly within functionalized NPs. For waste water cleanup, a significant number of useful nano-sized adsorbents are used[109-112].

2. Conclusion

Several techniques exist for remediating water and wastewater, but suitable for extracting contaminants from a supply of water. Nano adsorbent materials have recently been used because of their unusual adsorption properties. Where the properties of the nano adsorbent increase its use and become more advantageous in many fields than older adsorbents. Nano adsorbent materials are also considered to be an adsorbent of the next decade, and have many practices and are very effective in the purification of water and wastewater contaminants. These technologies are quick, efficient and solid wastewater treatments by eliminating specific types of water poisons. This paper focuses on the possible impact of nanotechnology on wastewater treatment. However, nanoparticles have another fundamental aspect to make them an acceptable all-round technique: their ability to recognize and to abstain from spoiling.

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3. References

L. Mohammed, H. Gomma, D. Ragab, and J. Zhu. Magnetic nanoparticles for environmental and biomedical applications: Review. Particuology. 2016. 30: 1.

M. Barathi, A. S. K. Kumar, and N. Rajesh. Impact of fluoride in potable water - an outlook on the existing defluoridation strategies and the road ahead. Coordination Chemistry Reviews. 2019. 387: 121-128.

Koteswar Rao M, Metre M. Effective low-cost adsorbents for removal of fluoride from water. International Journal of Science and Research. 2014. 3(6):120-124.

Yadav RK, Sharma S, Bansal M, Singh A, Pandey V, Maheshwari R.

Effects of fluoride accumulation on growth of vegetable and crops in Dausa District Rajasthan. India. Adv Biores. 2016. 3 (4):14-16.

R. Nagarajah, K. T. Wong, G. Lee. Synthesis of a unique nanostructured

magnesium oxide coated magnetite cluster composite and its application for the removal of selected heavy metals. Separation and Purification Technology, 2017. 174: 290-300.

Zare, E.N., Motahari, A., Sillanpaa, M. Nanoadsorbents based on

conducting polymer nanocomposites with main focus on polyaniline and its derivatives for removal of heavy metal ions/dyes: a review. Environmental Research. 2018. 162: 173-195.

E. Bazrafshan, D. Balarak, A. Panahi, H. Kamani, and A. Mahvi. Fluoride

removal from aqueous solutions by cupricoxide nanoparticle. Fluoride. 2016. 49: 233-244.

M. Zazouli, A. Mahvi, Y. Mahdavi, and D. Balarak,. Isothermic and kinetic

modeling of fluoride removal from water by means of the natural biosorbents sorghum and canola. Fluoride. 2015. 48: 1: 37-44.

M. I. NiyasAhamed, S. Sathya, Ragul. V. An in vitro study on Hexavalent Chromium [Cr(VI)] Remediation using Iron Oxide Nanoparticles Based, V. Ragul, S. Anand, K. Kaviyarasu, V. Chandru and B. Prabhavathi. Green synthesis and toxicity assessment of nanozerovalent iron against chromium Beads. Environmental Nanotechnology, Monitoring & Management. 2020. 14, 1-5.

M.I. NiyasAhamed contaminated surface water. International Journal of Nanoparticles. 2018. 10: 4: 312-325

H. Akbari, F. Jorfi, A. Mahvi, M. Yousefi, and D. Balarak. Adsorption of fluoride on chitosan in aqueous solutions: determination of adsorption kinetics. Fluoride. 2018. 51: 4: 319-327.

Abdelhafez, A.A., Li, J. Removal of Pb (II) from aqueous solution by using biochars derived from sugar cane bagasse and orange peel. J. Taiwan. Inst. Chem. Eng. 2016. 61: 367-375.

Abdolali, A., Ngo, H.H., Guo, W., Lu, S., Chen, S.S., Nguyen, N.C., Zhang, X., Wang, J., Wu, Y. A breakthrough biosorbent in removing heavy metals: equilibrium, kinetic, thermodynamic and mechanism analyses in a lab-scale study. Sci. Total Environ. 2016. 542: 603-611.

Ahmad, A., Ghazi, Z.A., Saeed, M., Ilyas, M., Ahmad, R., Khattaka, A.M., Iqbal, A. A comparative study of the removal of Cr (VI) from synthetic solution using natural biosorbents. New Journal of Chemistry. 2017. 41: 10799-10807.

Arora G, Bhateja S. Estimating the fluoride concentration in soil and crops grown over it in and around Mathura, Uttar Pradesh, India. Am J Ethno Med. 2014. 1(1):36-41

.J. He, Y. An, and F. Zhang. Geochemical characteristics and fluoride distribution in the groundwater of the Zhangye Basin in Northwestern China. Journal of Geochemical Exploration. 2017.135, 22-30.

L. Bo, Q. Li, Y. Wang, L. Gao, X. Hu, and J. Yang. Adsorptive removal of fluoride using hierarchical flower-like calcined Mg-Al layered double hydroxides. Environmental Progress and Sustainable Energy. 2019. 35(5): 1420- 1429.

Bai, C. Hu, H. Liu, and J. Qu. Selective adsorption of fluoride from drinking water using NiAl-layered metal oxide film electrode. Journal of Colloid and Interface Science. 2016. 539: 146-151.

Kim, S., Chu, K., Al-Hamadani, Y., Park, C., Jang, M., Kim, D., Yu, M., Heo, J., Yoon, Y., Removal of contaminants of emerging concern by membranes in water and wastewater: a review. Chem. Eng. J. 2018. 335: 896-914.

Krauklis, A., Ozola, R., Burlakovs, J., Rugele, K., Kirillov, K., Trubaca-Boginska, A., Rubenis, K., Stepanova, V., Klavinsa, M. FeOOH and Mn_8O10Cl_3 modified zeolites for As(V) removal in

aqueous medium. J. Chem. Technol. Biotechnol. 2017. 92,: 1948-1960.
Kumarasinghe, U., Inoue, Y., Saito, T., Nagamori, M., Sakamoto, Y., Mowjood, M., Kawamoto, K. Temporal variations in perched water and groundwater qualities at an open solid waste dumpsite in Sri Lanka. Int. J. of. Geomate. 2017. 13(38): 01-08.
Nawab, J., Khan, S., Ali, S., Sher, H., Rahman, Z., Khan, K., Tang, J., Ahmad, A. Health risk assessment of heavy metals and bacterial contamination in drinking water sources: a case study of Malakand Agency. Pakistan. Environ. Monit. Assess. 2016. 188 (5): 286-297.
Nawab, J., Khan, S., Khan, M., Sher, H., Rehamn, U., Ali, S., Shah, S. Potentially toxic metals and biological contamination in drinking water sources in chro- mite mining-impacted areas of Pakistan: a comparative study. Expo. Health. 2017. 9, 275-287.
H. A. Dharmagunawardhane, S. P. K. Malaviarachchi, and W. Burgess. Fluoride content of minerals in gneissic rocks at an area of endemic dental fluorosis in Sri Lanka: estimates from combined petrographic and electron microprobe analysis. Ceylon Journal of Science. 2016. 45(1): 57-66.
Neris, J., Luzardo, F., Silva, E., Velasco, F. Evaluation of adsorption processes of metal ions in multi-element aqueous systems by lignocellulosic adsorbents applying different isotherms: a critical review. Chem. Eng. J. 2019. 357: 404-420.
Sulyman, M., Namiesnik, J., Gierak, A. Low-cost adsorbents derived from agricultural by-products/wastes for enhancing contaminant uptakes from wastewater: a review. Pol. J. Environ. Stud. 2017. 26 (2): 479-510.
G. Mishra, B. Dash, and S. Pandey. Layered double hydroxides: a brief review from fundamentals to application as evolving biomaterials. Applied Clay Science. 2018. 153: 172-186.
U. Maheshwari, Removal of metal ions from wastewater using adsorption: experimental and theoretical studies, Ph.D. thesis, Birla Institute of Technology and Science, Pilani, Rajasthan, India, 2015.
Abdolali, A., Ngo, H.H., Guo, W., Lu, S., Chen, S.S., Nguyen, N.C., Zhang, X., Wang, J., Wu, Y. A breakthrough biosorbent in removing heavy metals: equilibrium, kinetic, thermodynamic and mechanism analyses in a lab-scale study. Sci. Total Environ. 2016. 542: 603-611.
Ahmad, A., Ghazi, Z.A., Saeed, M., Ilyas, M., Ahmad, R., Khattaka, A.M., Iqbal, A. A comparative study of the removal of Cr (VI) from synthetic solution using natural biosorbents. New J. Chem. 2017. 41: 10799-10807.
Arora G, Bhateja S. Estimating the fluoride concentration in soil and crops grown over it in and around Mathura, Uttar Pradesh. India. Am J Ethno Med. 2014. 1(1):36-41.
J. He, Y. An, and F. Zhang. Geochemical characteristics and fluoride distribution in the groundwater of the Zhangye Basin in Northwestern China. Journal of Geochemical Exploration. 2013. 135: 22-30.
L. Mohammed, H. Gomma, D. Ragab, and J. Zhu. Magnetic nanoparticles for environmental and biomedical applications: Review. Particuology. 2016. 30: 1-8.
M. Barathi, A. S. K. Kumar, and N. Rajesh. Impact of fluoride in potable water - an outlook on the existing defluoridation strategies and the road ahead. Coordination Chemistry Reviews. 2019. 387: 121-128.
Chen, M, Zhu, L.; Dong, Y.; Li, L.; Liu, J. Waste-to-Resource Strategy to Fabricate Highly Porous Whisker-Structured Mullite Ceramic Membrane for Simulated Oil-in-Water Emulsion Wastewater Treatment. ACS Sustainable Chemistry & Engineering. 2016. 4: 2098-2106.
Gitis, V.; Hankins, N.Water treatment chemicals: Trends and challenges. J. Water Process Eng. 2018, 25, 34-38.
Hodges, B.C.; Cates, E.L.; Kim, J. Challenges and prospects of advanced oxidation water treatment processes using catalytic nanomaterial. Nat. Nanotechnol. 2018, 13, 642-650.
Umar, K.; Haque, M.M.; Mir, N.A.; Muneer, M. Titanium Dioxide- Mediated photocatalyzed mineralization of Two Selected organic pollutants in aqueous suspensions. J. Adv. Oxid. Technol. 2013, 16, 252-260.
Umar, K.; Ibrahim, M.N.M.; Ahmad, A.; Rafatullah, M. Synthesis of Mn- Doped TiO_2 by novel route and photocatalytic mineralization/intermediate studies of organic pollutants. Res. Chem. Intermediat. 2019, 45, 2927-2945.
Wu, Y.; Pang, H.; Liu, Y.; Wang, X.; Yu, S.; Fu, D.; Chen, J.; Wang, X. Environmental remediation of heavy metal ions by novel-Nanomaterials: A review. Environ. Pollut. 2019, 246, 608-620.
Yaqoob, A.A.; Ibrahim, M.N.M. A Review Article of Nanoparticles; Synthetic Approaches and Wastewater Treatment

Methods. Int. Res. J. Eng. Technol. 2019, 6, 1-7.

Sekoai, P.T.; Ouma, C.N.M.; Du Preez, S.P.; Modisha, P.; Engelbrecht, N.; Bessarabov, D.G.; Ghimire, A. Application of nanoparticles in biofuels: An overview. Fuel 2019, 237, 380-397.

Wang, J.;Wang, Z.; Carolina, L.Z.V.;Wolfson, J.M.; Pingtian, G. Review on the treatment of organic pollutants in water by ultrasonic technology. Ultrasonics Sonochem. 2019, 55, 273-278.

Liu, C.; Hong, T.; Li, H.; Wang, L. From club convergence of per capita industrial pollutant emissions to industrial transfer effects: An empirical study across 285 cities in China. Energy Policy 2018, 121, 300-313.

Bayoumi, T.A.; Saleh, H.M. Characterization of biological waste stabilized by cement during immersion in aqueous media to develop disposal strategies for phytomediated radioactive waste. Prog. Nucl. Energy 2018, 107, 83-89.

Umachandran K., Sawicka B., Mohammed A., Nasir N.N-B., Pasqualone A. Relevance of nanotechnology in food processing industries. International Journal of Agriculture Sciences 10(7) 2018: 5730-5733.

Marchiol L. Nanotechnology in Agriculture: New Opportunities and Perspectives. Publisher: InTechOpen 2018.

Sawicka B., Pszczółkowski P., Noaema A.H. Nanotechnologia w rolnictwie i przetwórstwie spożywczym. Red. D. Łuczycka, Wydawca: Idea Knowledge Future, Wrocław, 2018 582-599,

Lukashev, A. N.; Zamyatnin, A. A. Viral Vectors for Gene Therapy: Current State and Clinical Perspectives. Biochemistry (Moscow) 2016, 81, 700−708.

Kostarelos, K. Nanoscale Nights of COVID-19. Nat. Nanotechnol. 2020, 15, 343.

Vincent, M.; de Lazaro, I.; Kostarelos, K. Graphene Materials as 2D Non-Viral Gene Transfer Vector Platforms. Gene Ther. 2017, 24, 123−132.

Watkins, K. Emerging Infectious Diseases: A Review. Curr. Emerg. Hosp. Med.Rep. 2018, 6, 86−93.

Gorbalenya, A. E.; Baker, S. C.; Baric, R. S.; de Groot, R. J.; Drosten, C.; Gulyaeva, A. A.; Haagmans, B. L.; Lauber, C.; Leontovich, A. M.; Neuman, B. W.; Penzar, D.; Perlman, S.; Poon, L. L. M.; Samborskiy, D. V.; Sidorov, I. A.; Sola, I.; Ziebuhr, J. Coronaviridae Study Group of the International Committee on Taxonomy of Viruses. The Species Severe Acute Respiratory Syndrome-Related Coronavirus: Classifying 2019-nCoV and naming it SARS-CoV-2. Nat. Microbiol. 2020, 5, 536−544.

Lovato, A.; de Filippis, C. Clinical Presentation of COVID-19: A Systematic Review Focusing on Upper Airway Symptoms. Ear Nose Throat J. 2020, No. 014556132092076

Huang, C.; Wang, Y.; Li, X.; Ren, L.; Zhao, J.; Hu, Y.; Zhang, L.; Fan, G.; Xu, J.; Gu, X.; Cheng, Z.; Yu, T.; Xia, J.; Wei, Y.; Wu, W.; Xie, X.; Yin, W.; Li, H.; Liu, M.; Xiao, Y.; et al. Clinical Features of Patients Infected with 2019 Novel Coronavirus in Wuhan, China. Lancet 2020, 395, 497−506.

Lauer, S. A.; Grantz, K. H.; Bi, Q.; Jones, F. K.; Zheng, Q.; Meredith, H. R.; Azman, A. S.; Reich, N. G.; Lessler, J. The Incubation Period of Coronavirus Disease 2019 (COVID-19) from Publicly Reported Confirmed Cases: Estimation and Application. Ann. Intern. Med. 2020, 172, 577.

Dai, C.; Lin, H.; Xu, G.; Liu, Z.; Wu, R.; Chen, Y. Biocompatible 2D Titanium Carbide (MXenes) Composite Nanosheets for pHResponsive MRI- Guided Tumor Hyperthermia. Chem. Mater. 2017, 29, 8637−8652.

Mahler, B.; Hoepfner, V.; Liao, K.; Ozin, G. A. Colloidal Synthesis of 1T-WS2 and 2H-WS2 Nanosheets: Applications for Photocatalytic Hydrogen Evolution. J. Am. Chem. Soc. 2014, 136, 14121−14127

Mayra Abril, Hugo Ruiz, Luis H. Cumbal. Biosynthesis of Multicomponent Nanoparticles with Extract of Mortiño (Vaccinium floribundum Kunth) Berry: Application on Heavy Metals Removal from Water and Immobilization in Soils. Journal of Nanotechnology 2018, 2018, 1-10

Mahmoud Nasrollahzadeh, Mohaddeseh Sajjadi, S. Mohammad Sajadi. Biosynthesis of copper nanoparticles supported on manganese dioxide nanoparticles using Centella asiatica L. leaf extract for the efficient catalytic reduction of organic dyes and nitroarenes. Chinese Journal of Catalysis 2018, 39 (1), 109-117.

Stanford, M. G.; Li, J. T.; Chen, Y.; McHugh, E. A.; Liopo, A.; Xiao, H.; Tour, J. M. Self-Sterilizing Laser-Induced Graphene Bacterial Air Filter. ACS Nano 2019, 13, 11912−11920

Siddharth V. Patwardhan, Joseph R.H. Manning, Mauro Chiacchia. Bioinspired synthesis as a potential green method for the preparation of nanomaterials: Opportunities and challenges. Current Opinion in Green and Sustainable Chemistry 2018, 12 , 110-116.

Aradhana Sukhwal, Devendra Jain, Arunabh Joshi, Pokhar Rawal, Himmat S. Kushwaha. Biosynthesised silver nanoparticles using aqueous leaf extract of Tagetes patula L. and evaluation of their antifungal activity against phytopathogenic fungi. IET Nanobiotechnology 2017, 11 (5) , 531-537.

64.Kavitha Pathakoti, Manjunath Manubolu, Huey-Min Hwang.

Nanotechnology Applications for Environmental Industry. 2018, 894-907. 65.Brad A. Krajina, Amy C. Proctor, Alia P. Schoen, Andrew J. Spakowitz, Sarah C. Heilshorn. Biotemplated synthesis of inorganic materials: An emerging paradigm for nanomaterial synthesis inspired by nature. Progress in Materials Science 2018, 91, 1-23.oxide decorated with Ag nanoparticles (rGO/Ag NPs) nanocomposite: A reusabl e catalyst for the degradation of environmental pollutants in aqueous mediu m. Journal of Molecular Liquids

Krishnanand Shivanand Iliger, Tariq Ahmad Sofi, Nazir Ahmad Bhat, Farooq Ahmad Ahanger, Jagan Chandra Sekhar, Ahmed Zohier Elhendi, Asma A. Al-Huqail, Faheema Khan. Copper nanoparticles: Green synthesis and managing fruit rot disease of chilli caused by Colletotrichum capsici. Saudi Journal of Biological Sciences 2020,

Ghazaleh Jamalipour Soufi, Siavash Iravani. Nanomaterials against pathogenic viruses: greener and sustainable approaches. Inorganic and Nano-Metal Chemistry 2020, 7 , 1-17.

Ahmad Almatroudi. Silver nanoparticles: synthesis, characterisation and biomedical applications. Open Life Sciences 2020, 15 (1) , 819-839.

M.B. Lava, Uday M. Muddapur, Nagaraj Basavegowda, Sunil.S. More, Veena S. More. Characterization, anticancer, antibacterial, anti-diabetic and anti-inflammatory activities of green synthesized silver nanoparticles using Justica wynaadensis leaves extract. Materials Today: Proceedings 2020,

Haleema Saleem, Syed Zaidi. Sustainable Use of Nanomaterials in Textiles and Their Environmental Impact. Materials 2020, 13 (22) , 5134.

Suman Kumari, Nimisha Tehri, Anjum Gahlaut, Vikas Hooda. Actinomycetes mediated synthesis, characterization, and applications of metallic nanoparticles. Inorganic and Nano-Metal Chemistry 2020, 3, 1-10. https://doi.org/10.1080/24701556.2020.1835978

M. K. Shreya, C. Indhumathi, G. R. Rajarajeswari, Veeramuthu Ashokkumar, T. Preethi. Facile green route sol-gel synthesis of nano-titania using bio-waste materials as templates. Clean Technologies and Environmental Policy 2020, 49

Shafqat Rasool, Muhammad Akram Raza, Farkhanda Manzoor, Zakia Kanwal, Saira Riaz, Muhammad Javaid Iqbal, Shahzad Naseem. Biosynthesis, characterization and anti-dengue vector activity of silver nanoparticles prepared from Azadirachta indica and Citrullus colocynthis. Royal Society Open Science 2020, 7 (9) , 200540.

Bamidele M. Amos-Tautua, Olayemi J. Fakayode, Sandile P. Songca, Oluwatobi S. Oluwafemi. Effect of synthetic conditions on the crystallinity, porosity and magnetic properties of gluconic acid capped iron oxide nanoparticles. Nano-Structures & Nano-Objects 2020, 23 , 100480.

Vennila raj, P. Kamaraj, M. Sridharan, J. Arockiaselvi. Green synthesis, characterization of yttrium oxide, stannous oxide, yttrium doped tin oxide and tin doped yttrium oxide nanoparticles and their biological activities. Materials Today: Proceedings 2020,

Asmaa Mohamed El Shafey. Green synthesis of metal and metal oxide nanoparticles from plant leaf extracts and their applications: A review. Green Processing and Synthesis 2020, 9 (1) , 304-339.

Vineeta Kumari, A. K. Tripathi. Remediation of heavy metals in pharmaceutical effluent with the help of Bacillus cereus-based green- synthesized silver nanoparticles supported on alumina. Applied Nanoscience 2020, 10 (6), 1709-1719.

Jagdeep Singh, A. S. Dhaliwal. Plasmon-induced photocatalytic degradation of methylene blue dye using biosynthesized silver nanoparticles as photocatalyst. Environmental Technology 2020, 41 (12) , 1520-1534.

Dipyaman Mohanta, Md. Ahmaruzzaman. Addressing Nanotoxicity. 2020, 103-112.

Seraj Mohaghegh, Karim Osouli-Bostanabad, Hossein Nazemiyeh, Yousef Javadzadeh, Alireza Parvizpur, Mohammad Barzegar-Jalali, Khosro Adibkia. A comparative study of eco-friendly silver nanoparticles synthesis using Prunus domestica plum extract and sodium citrate as reducing agents. Advanced Powder Technology 2020, 31 (3), 1169-1180.

Gajanan Ghodake, Min Kim, Jung-Suk Sung, Surendra Shinde, Jiwook Yang, Kyojung Hwang, Dae-Young Kim. Extracellular Synthesis and Characterization of Silver Nanoparticles—Antibacterial Activity against Multidrug-Resistant Bacterial Strains. Nanomaterials 2020, 10 (2), 360.

Samreen Heena Khan. Green Nanotechnology for the Environment and Sustainable Development. 2020, 13-46.

Oluranti Agboola, Patricia Popoola, Rotimi Sadiku, Samuel Eshorame Sanni, Sunday Ojo Fayomi, Olawale Samuel Fatoba. Nanotechnology in Wastewater and the Capacity of Nanotechnology for Sustainability. 2020, 1-45.

Sourav Das, Ananyo Jyoti Misra, A. P. Habeeb Rahman, Aradhana Basu, Amrita Mishra, Ashok J. Tamhankar, Cecilia Stålsby Lundborg, Suraj K. Tripathy. Designing Novel Photocatalysts for Disinfection of Multidrug-Resistant Waterborne Bacteria. 2020, 441-476.

Shakeel Ahmad Khan, Chun-Sing Lee. Green Biological Synthesis of Nanoparticles and Their Biomedical Applications. 2020, 247-280.

Vandana Singh, Tulika Malviya, Shehala, Surabhi Gupta, Lalit Mohan Dwivedi, Kirti Baranwal, Mani Prabha, Aayushee. Polysaccharide-Based Nanoparticles: Nanocarriers for Sustained Delivery of Drugs. 2020, 151- 181.

Atrab A. Abd El-Aziz, Heba Al Shater, A. Dakhlaoui, Aboul Ella Hassanien, Deepak Gupta. Optimized Twin Support Vector Clustering in Transmission Electron Microscope of Cobalt Nanoparticles. 2020, 829-842.

V. T. Anju, Busi Siddhardha, Madhu Dyavaiah. Saccharomyces cerevisiae: Model Organism to Evaluate Nanoparticle Toxicity. 2020, 317-332.

Fatemeh Soroodi, Parveen Jamal, Ibrahim Ali Noorbatcha. Experimental Methods for the Phytochemical Production of Nanoparticles. 2020, 83-95.

Hafezeh Nabipour, Yuan Hu. Sustainable drug delivery systems through green nanotechnology. 2020, 61-89.

Sahana Sadhasivam, Vimalraj Vinayagam, Malathi Balasubramaniyan. . Journal of Molecular Structure 2020, 128372.

Runjhun Tandon, Khushboo Sharma, Nitin Tandon. Synthesis and Characterization of Nanoparticles of Iron(II) Gluconate Complex. Asian Journal of Chemistry 2020, 32 (12), 3043-3046.

Akos Kokai, Alastair Iles, Materials sovereignty: Pathways for shaping nanotechnology design. Elementa: Science of the Anthropocene 2020, 8

Fatemeh Elahian, Razieh Heidari, Vahid Reza Charghan, Elham Asadbeik, Seyed Abbas Mirzaei. Genetically modified Pichia pastoris, a powerful resistant factory for gold and palladium bioleaching and nanostructure heavy metal biosynthesis. Artificial Cells, Nanomedicine, and Biotechnology 2020, 48 (1), 259-265.

Y. Valentina, Mohd Yousuf Rather, A. Yogamoorthi. Biosynthesis of Gold Nanoparticle using Cell-free Extract of Clinical Isolates Staphylococcus Aureus and Escherichia Coli. Malaysian Journal of Medical and Biological Research 2019, 6 (2), 107-116.

Yan Wang, Nathalia Aquino de Carvalho, Susheng Tan, Leanne M. Gilbertson. Leveraging electrochemistry to uncover the role of nitrogen in the biological reactivity of nitrogen-doped graphene. Environmental Science: Nano 2019, 6 (12), 3525-3538.

Oscar A. Douglas-Gallardo, Carlos A. Christensen, Miriam C. Strumia, Manuel A. Pérez, Cesar G. Gomez. Physico-chemistry of a successful micro-reactor: Random coils of chitosan backbones used to synthesize size-controlled silver nanoparticles. Carbohydrate Polymers 2019, 225, 115241.

Katayoon Karimzadeh, Elham sharifi, Nahid Bakhshi, Mahdieyeh Ramzanpoor. Biogenic silver nanoparticles using Oxalis corniculata characterization and their clinical implications. Journal of Drug Delivery Science and Technology 2019, 54 , 101263.

Eslam Ibrahim El-Aswar, Moustafa Moawad Zahran, Maged El-Kemary. Optical and electrochemical studies of silver nanoparticles biosynthesized by Haplophyllum tuberculatum extract and their antibacterial activity in wastewater treatment. Materials Research Express 2019, 6 (10) , 105016.

Sheik Haseena, Ravva Mahesh Kumar, Varatharaj Rajapandian, Venkatesan Subramanian. Interactions of thiol and alkoxy radical with coinage metal nanoclusters. Applied Surface Science 2019, 487 , 1409-1419.

Aditi Dey, Subhankar Manna, Jaydeep Adhikary, Sourav Chattopadhyay, Sriparna De, Dipankar Chattopadhyay, Somenath Roy. Biodistribution and toxickinetic variances of chemical and green Copper oxide nanoparticles in vitro and in vivo. Journal of

Trace Elements in Medicine and Biology 2019, 55, 154-169.

Umachandran K., Sawicka B., Mohammed A., Nasir N.N-B., Pasqualone A. Relevance of nanotechnology in food processing industries. International Journal of Agriculture Sciences 10(7) 2018: 5730-5733.

Marchiol L. Nanotechnology in Agriculture: New Opportunities and Perspectives. Publisher: InTechOpen 2018.

Sawicka B., Pszczółkowski P., Noaema A.H. Nanotechnologia w rolnictwie i przetwórstwie spożywczym. Red. D. Łuczycka, Wydawca: Idea Knowledge Future, Wrocław, 2018 582-599,

21st Century Nanotechnology Research and Development Act. Public Law 108- 153, 2003; 15 USC 7501 (available from http://thomas.loc.gov/cgi- bin/bdquery/ z?d108: s.00189: accessed February 2008).

Nanotechnology Environmental and Health Implications Working Group. Strategy for Nanotechnology-Related Environmental, Health, and Safety Research, February 2008. National Nanotechnology Initiative Web site.http://www.nano.gov/ NNI_EHS_Research_Strategy.pdf (accessed February 2008)

EPA Office of Research and Development. Draft Nanomaterial Research Strategy (NRS), January 24, 2008. U.S. Environmental Protection Agency Web site. http://es.epa.gov/ncer/nano/publications/nano_strategy_012408.pdf (accessed February 2008).

Lubick, N. Risks of Nanotechnology Remain Uncertain. Environ. Sci. Technol.Online News, February 20, 2008 (http://pubs.acs.org/subscribe/journals/ esthag-w/2008/feb/science/nl_nanorisks.html).

Maynard, A. D. Nanotechnology: A Research Strategy for Addressing Risk [Online]; Project on Emerging Nanotechnologies PEN 3; Woodrow Wilson International Center for Scholars: Washington, DC, July 2006. http://www.nanotechproject.org/process/files/2707/77_pen3_risk.pdf (Accessed February 2008).

Project on Emerging Nanotechnologies. Consumer Product Inventory. http://www.nanotechproject.org/ inventories/consumer/ (accessed February 2008).

Environmental DefenseDuPont Nano Partnership. Nano Risk Framework, June 21, 2007. Environmental Defense Fund Web site. http://www.environmentaldefense.org/documents/ 6496_Nano%20Risk%20Framework.pdf (accessed