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Purification of Wastewater by Metal Oxide Nanoparticles

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ABSTRACT

In today's world, nanotechnology is becoming increasingly popular for water treatment. In this review, we will summarize recent advances in the development of typical metal oxide materials (TiO2, Fe3O4/Fe2O3, MnO2, CeO2, MgO and Al2O3) and the related processes for the treatment of various water resources which have been contaminated by organic solutes, inorganic anions, radionuclides, bacteria and viruses.

KEYWORDS: *nanotechnology, wastewater, treatment, metal oxides, microbes, purification*

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INTRODUCTION

Wastewater treatment, also called sewage treatment, the removal of impurities from wastewater, or sewage, before it reaches aquifers or natural bodies of water such as rivers, lakes, estuaries, and oceans. Since pure water is not found in nature (i.e., outside chemical laboratories), any distinction between clean water and polluted water depends on the type and concentration of impurities found in the water as well as on its intended use. In broad terms, water is said to be polluted when it contains enough impurities to make it unfit for a particular use, such as drinking, swimming, or fishing. Although water quality is affected by natural conditions, the word *pollution* usually implies human activity as the source of contamination. Water pollution, therefore, is caused primarily by the drainage of contaminated wastewater into surface water or groundwater, and wastewater treatment is a major element of water pollution control.[1,2]

Wastewater treatment is a process used to remove contaminants from wastewater and convert it into an effluent that can be returned to the water cycle. Once returned to the water cycle, the effluent creates an acceptable impact on the environment or is reused for various purposes (called water reclamation). The treatment process takes place in a wastewater treatment plant. There are several kinds of wastewater which are treated at the appropriate type of wastewater treatment plant. For domestic wastewater (also called municipal wastewater or sewage), the treatment plant is called a sewage treatment plant. For industrial wastewater, treatment either takes place in a separate industrial wastewater treatment plant, or in a sewage treatment plant (usually after some form of pre-treatment). Further types of wastewater treatment plants include agricultural wastewater treatment plants and leachate treatment plants.

Processes commonly used in wastewater treatment include phase separation (such as sedimentation), biological and chemical processes (such as oxidation) or polishing. The main by-product from wastewater treatment plants is a type of sludge which is usually treated in the same or another wastewater treatment plant Biogas can be another by-product if anaerobic treatment processes are used. Treated wastewater can be reused as reclaimed water. The main purpose of wastewater treatment is for the treated wastewater to be able to be disposed or reused safely. However, before it is treated, the options for disposal or reuse must be considered so the correct treatment process is used on the wastewater.[3,4]

The term "wastewater treatment" is often used to mean "sewage treatment".

Pollutant removal from industrial effluents is a big challenge for industries. These pollutants pose a great risk to the environment. Nanotechnology can reduce the expenditure made by industries to mitigate these pollutants through the production of eco-friendly nanomaterials. Nanomaterials are gaining attention due to their enhanced physical, chemical, and mechanical properties. Using microorganisms in the production of nanoparticles provides an even greater boost to green biotechnology as an emerging field of nanotechnology for sustainable production and cost reduction. In this mini review, efforts are made to discuss the various aspects of industrial effluent bioremediation through microbial nanotechnology integration. The use of enzymes with nanotechnology has produced higher activity and reusability of enzymes. This review also provides an insight into the advantages of the use of nanotechnology as compared to conventional practices in these areas. Nanotechnology refers to the branch of science and engineering devoted to designing, producing, and using structures, devices, and systems by manipulating atoms and molecules at nanoscale, i.e. having one or more dimensions of the order of 100 nanometres (100 millionth of a millimetre) or less.

In the natural world, there are many examples of structures with one or more nanometre dimensions, and many technologies have incidentally involved such nanostructures for many years, but only recently has it been possible to do it intentionally. Many of the applications of nanotechnology involve new materials that have very different properties and new effects compared to the same materials made at larger sizes. This is due to the very high surface to volume ratio of nanoparticles compared to larger particles, and to effects that appear at that small scale but are not observed at larger scales. The applications of nanotechnology can be very beneficial and have the potential to make a significant impact on society. Nanotechnology has already been embraced by industrial sectors, such as the information and communications sectors, but is also used in food technology, energy technology, as well as in some medical products and medicines. Nanomaterials may also offer new opportunities for the reduction of environmental pollution.[5,6]

Discussion

A nanoparticle is a small particle that ranges between 1 to 100 nanometres in size. Undetectable by the human eye, nanoparticles can exhibit significantly different physical and chemical properties to their larger material counterparts. The definition given by the European Commission states that the particle size of at least half of the particles in the number size distribution must measure 100 nm or below. Most nanoparticles are made up of only a few hundred atoms.

Clean water is a vital element for all living organisms. The contamination of present water resources, however, has increased globally due to rapid industrialization and the massive population explosion .In agriculture, the demand for and consumption of clean water has increased on a large scale. The consumption of fresh and clean water with a high range of pollutants in industry, household sectors, and other forms of consumption is about 70%, 22%, and 8%, respectively .The main classes of pollutants are heavy metal ions and dyes. Water containing such pollutants should not be used for drinking purposes without purification. Once these heavy metal ions enter water, it is extremely difficult to completely treat it . These aquatic pollutants are hazardous for all living organisms and strongly affect ecosystems. Therefore, these pollutants need to be eliminated from contaminated water to prevent their harmful effects on humans and the environment. Currently, water supply entrances face many diverse challenges. All over the world, about 780 million people do not have access to clean drinking water .

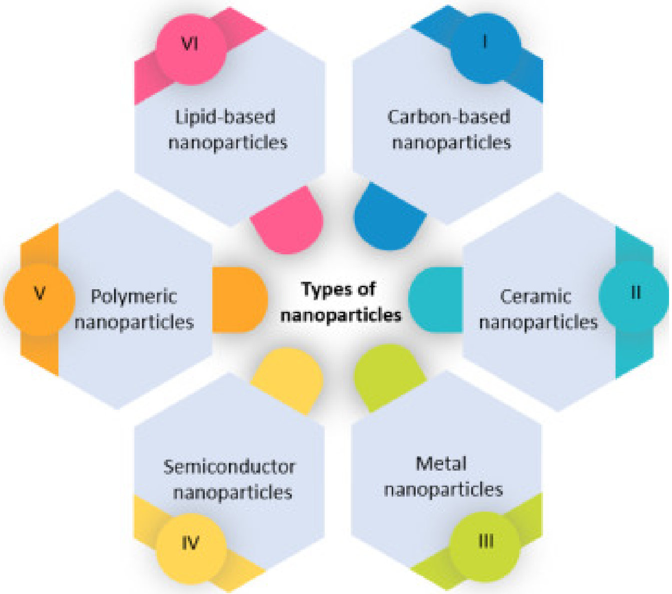
In the affected areas, which are mostly developing countries where wastewater management is usually non-existent, urgent action is required. However, existing wastewater management and technologies are improving their ability to provide satisfactory clean water to meet human needs and other environmental needs. [7,8]

Current improvements and advances in nanoscience and nanotechnology suggest opportunities for the development of improved water resources and arrangements .The extremely effective, integrated, and multifunctional progress facilitated by nanoscience and nanotechnology are predicted to offer high rates of performance and reasonable and affordable wastewater treatment solutions compared to large infrastructure .

The removal of these pollutants through environmentally friendly and efficient methods is crucial .In the literature, numerous strategies have been used for wastewater treatment, such as solvent extraction, ultrafiltration, evaporation, and reverse osmosis. These techniques, however, remove impurities from water without making them harmless end products . Full decomposition, either chemically or photochemically, can easily be achieved by oxidation . The purpose of each oxidative process is to generate and use a hydroxyl free radical as a powerful oxidant to reduce the effects of pollutants. After activation, hydrogen peroxide may be used as an oxidant, such as UV radiation , as a metal ion, or as a Fenton reagent.[9,10]

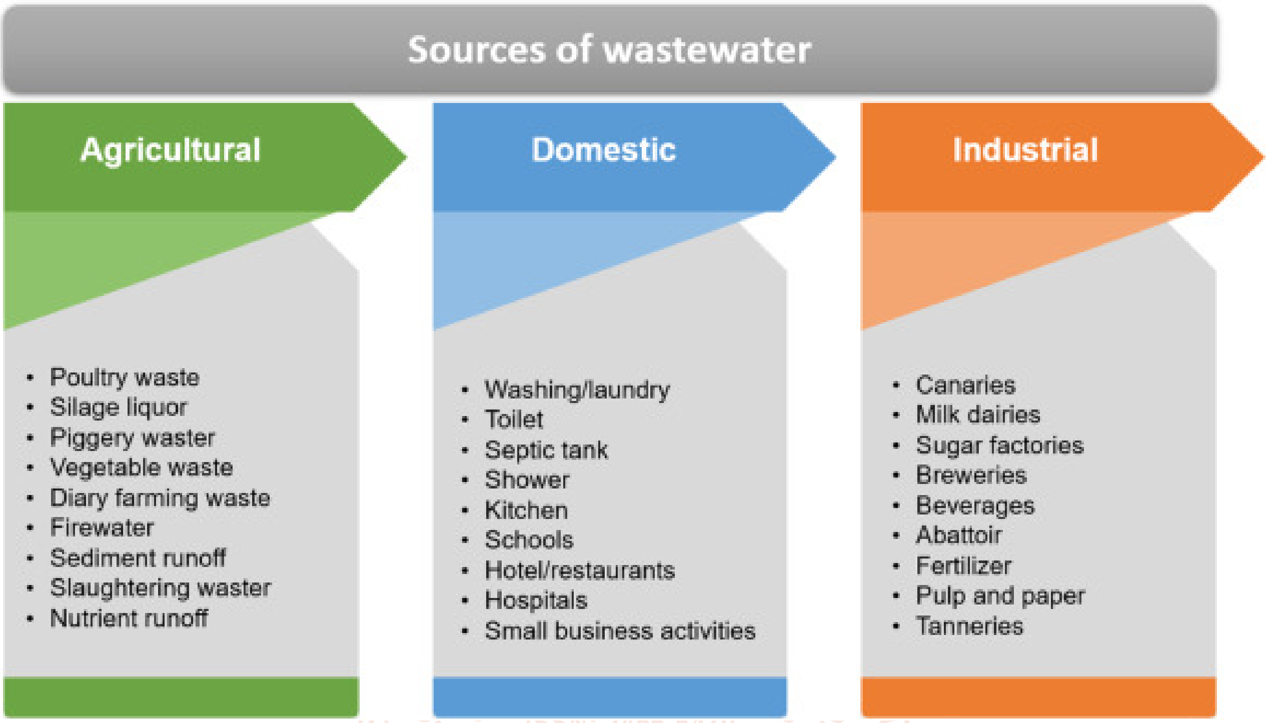
Nanomaterials are mainly used to overcome major water and wastewater problems. The term “nanomaterial” refers to a nanometer that is a trillionth of a meter in size . Nanomaterials are widely used in the fields of environmental detection, biomedicine and pharmaceuticals, electronics and optoelectronics, the clothing industry, and cosmetics. These tiny nanomaterials lead to several changes in its physical properties such as the enhancement of the volume to surface-area ratio and the effect of quantum properties on the particle size. In contrast with conventional materials, the properties of nanoparticles, such as their magnetic, visual, and electrical properties, are significantly different compared to conventional materials. Characteristics such as high adsorption, catalytical activity, and reactivity are associated with nanomaterials . Over the past few decades, nanoparticles have attracted widespread attention and have been applied effectively in different fields, including biology, sensing, medicine, catalytic chemistry, and active research and development . Nanoparticles are commonly used in the treatment of wastewater . Since nanoparticles having a large area and small sizes, they possess a strong adsorption reactivity and capacity . Several pollution sources have been reported worldwide to have disintegrated into various kinds of nanomaterials, including bacteria, emerging pollutants, organic pollutants, and inorganic anions . Nanoparticles are promising tools for application in different wastewater ecosystems, including carbon nanotubes, zerovalent nanoparticles, metal oxide nanoparticles, and nanocomposites.

Nanomaterials provide new strategies that expand on existing water supply and unconventional water sources. Over the past few years, several techniques for treating wastewater have been developed .Some of the most important methods are reverse osmosis, solvent extraction, sedimentation, gravity separation, microfiltration, ultrafiltration, precipitation, coagulation, distillation, oxidation, adsorption, electrodialysis, electrolysis, flotation, and ion exchange .[11,12]



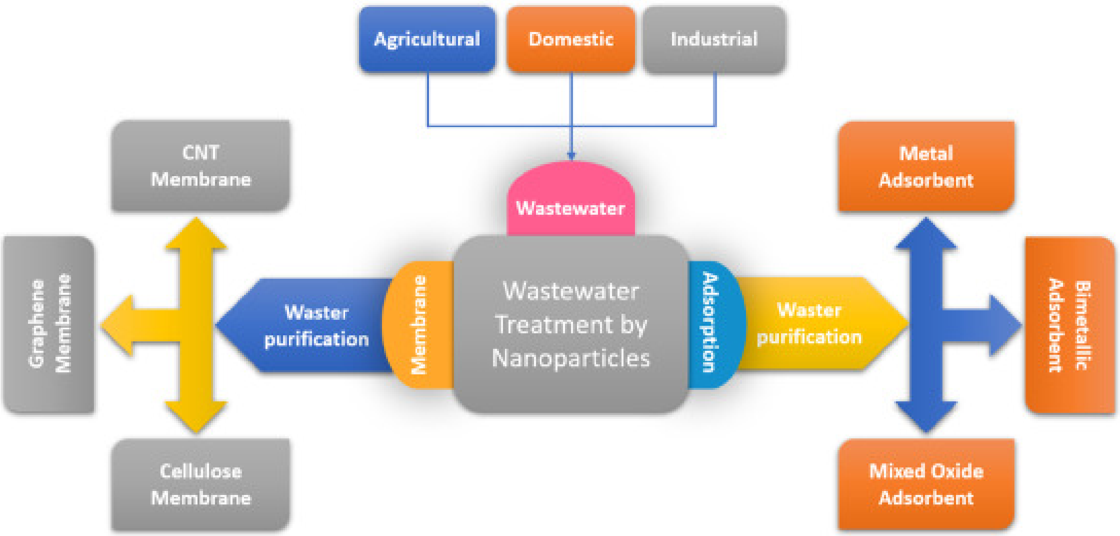
Review work on metal oxide nanoparticles for wastewater applications is limited in the literature. Scientists discussed the current use of metal oxide nanoparticles and their impact on biological wastewater treatment processes in their review. They also summarised the different methods used to measure the inhibition of nitrification by metal oxide nanoparticles and highlight the corresponding results obtained using these methods. Researchers in their review discussed the fate and potential effects of four types of nanoparticles: nano Zinc oxide (ZnO), silver nanoparticles (AgNPs), nano zero valent iron, and nano TiO_2 on wastewater treatment and anaerobic digestion. They discussed the impact of metal and non-metallic oxide nanoparticle on both wastewater and anaerobic sludge digestion. Investigators focused on the application of nanoparticles in wastewater treatment. In this review, the authors discussed in detail three metal oxide nanoparticles: TiO_2, ZnO, and iron oxide. Junbai et al. focused on several types of metal oxide nanoparticles including MgO, TiO_2, MnO_2, Fe_3O_4/Fe_2O_3, MnO_2, Al_2O_3, and CeO_2 and their applications in water treatment. In addition, in some reviews (on nanoparticles) some metal oxides have been outlined, but they lack a detailed review on metal oxides for wastewater treatment . Scientists discussed in detail nanomaterials for industrial wastewater treatment . In their work, the industrial applications of three metal oxides (TiO_2, Fe_3O_4/Fe_2O_3, and ZnO) are presented. To fill this gap and give a detailed review, this paper focuses on some recent advances and applications in wastewater treatment for metal oxide nanoparticles and highlights the potential uses of such techniques to tackle various challenges confronting existing wastewater treatment technologies. Several types of metal oxide nanoparticles i.e. iron oxide nanoparticles, ZnO nanoparticles, copper oxide nanoparticles, silver oxide nanoparticles, and titanium oxide nanoparticles are discussed in detail. The reason why these nanoparticles are chosen for wastewater treatment is because of their capability to be oxidized or dissolved in water and release metal ions, leading to metal toxicity. These metal oxide nanoparticles are chemically stable (have no adverse effects) and are used in a variety of different applications such as adsorption, photocatalytic activities, antibacterial and antifungal activities.[12]

Results

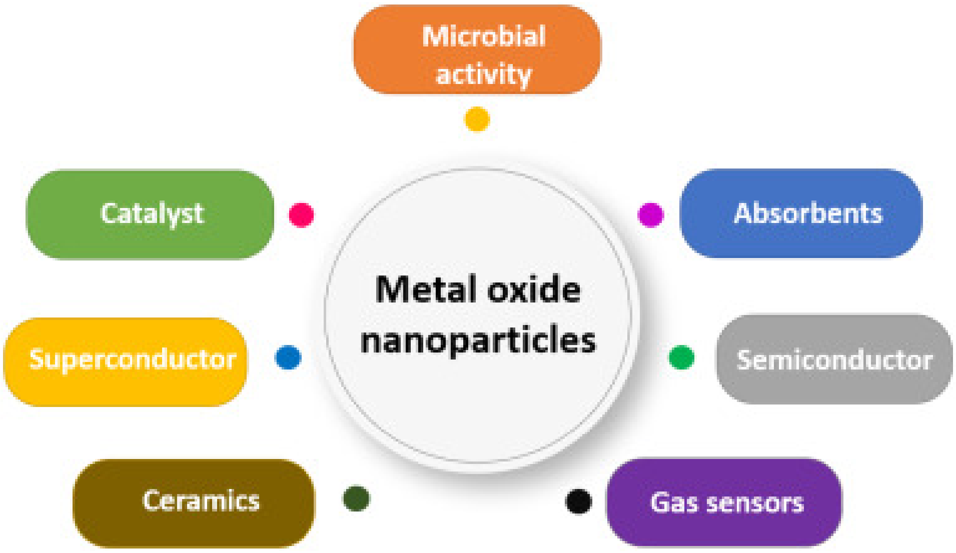


The biological pollutants are living pathogenic microorganisms that exist in wastewater. The main wastewater microorganisms are bacteria, viruses, and protozoa, which can cause acute and chronic health effects. The different kinds of bacteria in wastewater can cause different waterborne diseases such as cholera, typhoid, and shigella. However, many types of bacteria can exist in wastewater that have less serious impacts such as *Escherichia coli*, *Enterobacter*, *Klebsiella pneumonia*, *Streptococcus faecalis* and others.

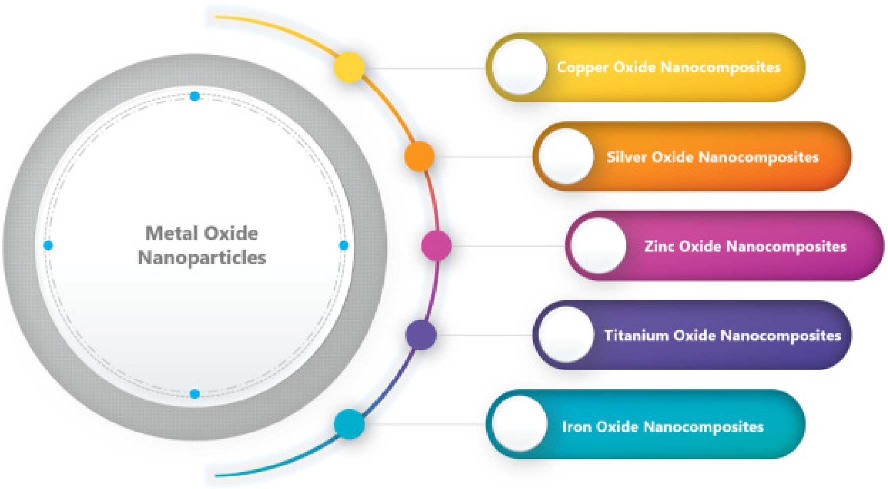
The nanoparticles are designed for water attraction and are highly porous and absorb water, like a sponge, repelling dissolved salts and other impurities. Hydrophilic nanoparticles embedded in the membrane repel organic compounds and bacteria that are more likely to obstruct conventional membranes over time. Metal oxide nanoparticles (MONPs) are made of purely metal precursors. These nanoparticles play a significant role in many areas of physics, chemistry, and material sciences. Thermal elements are capable of forming a wide range of oxide compounds. These can adopt a vast number of structural geometries with an electronic structure that can exhibit insulator, semiconductor, or metallic characteristics. These nanoparticles have unique opto-electrical features because of their well-known localized surface plasmon resonance characteristics. Alkali nanoparticles and noble metals such as Ag, Au, and Cu have a wide absorption band in the visible electromagnetic spectrum zone. In today's state-of-the-art materials, the facet, size, and shape of the synthesis of metal nanoparticles have significant importance[13]



As promising adsorbents to heavy metals, they have great potential. Metal oxide-based nanomaterials include manganese oxides, nanosized iron oxides, titanium oxides, cerium oxides, ZnOs, magnesium oxides, aluminum oxides, and zirconium oxides.



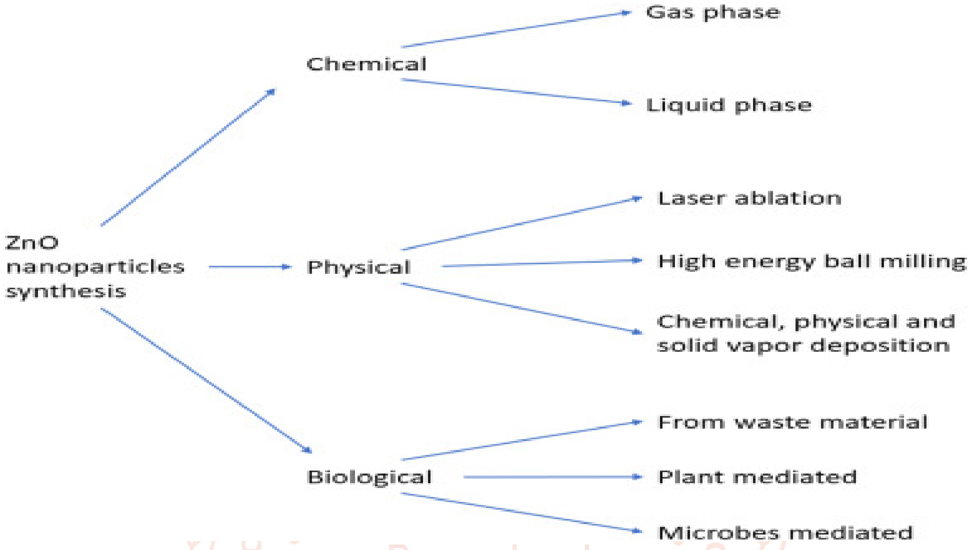
Several studies have shown that nanoparticles are more active against gram-positive bacteria than gram-negative bacteria as lipopolyzaccharides, lipoproteins and phospha-lipids are part of the gram-negative cell wall, which create a binding obstacle that allows only macromolecules to enter. In comparison, the cell wall of the gram-positive bacteria contains a slim, peptidoglycan, teichoic acid and abundant pores, which allow foreign molecules to enter, which result in damage to the cell membrane and death of cells. Indeed, unlike bacteria which are gram-negative, gram-positive fungi have increased adverse stress on the cell wall surface, which can hold the nanoparticles. The process of causing bacterial mortality for nanoparticles depends on the bacterial cell's parts and components.[14]



Plants interact continuously with soil, air, and water, all of which may contain engineered nanoparticles. Since plants are also consumed by animals, nanoparticles may be transferred to them. There is a also risk that nanoparticles could invade the food chain and become hazardous to humans.

ZnO has a particle size of 20–40 nm and has been synthesized from $Zn(NO_3)_2$ and $(NH_4)_2CO_3$. Increased photocatalytic efficiency leading to an increase in the constant decay of bacteria has been reported as a result of the reduced particle size and the effect of quantum containment activating ZnO to produce reactive oxygen species (ROS).

Nanoparticles quickly aggregate and precipitate into pure water on the stability of three metal oxide nanoparticles: SiO_2, ZnO, and TiO_2, in an aqueous solution. The most efficient method for partitioning nanoparticles in water is using ultrasound effects. The results show that nanoparticles changed their stability under various water conditions. The presence of organic colloids (surfactants and humic compounds) means that samples of water and wastewater aggregate faster than pure water.[12,13]



Implications

Table 1. Existing methods of ZnO nanoparticles and their application for wastewater treatment.

S. No.	Year	Application	Characteristics
1	2012	Antimicrobial Activity: *Staphylococcus aureus* and *Escherichia coli*	Surface area: Sample1 = 34.27 cm^2, Sample2 = 47.54 cm^2 and Sample3 = 39.12 cm^2. Particle type: nanorods. Average patcile size 5–7 nm. Under sunlight, 99% *Staphylococcus aureus* and *Escherichia coli* could be immobilized. 80% of *Escherichia coli* and 59% of *Staphylococcus aureus* cells could be inactivated under room lighting conditions.
2	2010	Antimicrobial Activity: *Escherichia coli* Photocatalytic degradation: methylene blue	Particle sizes 80 and 260 nm. Particle type: nanorods. For *Escherichia coli*, maximum inhibition zone was 4.4 cm^2. Under white-light irradiation at 963 Wm^{-2}, Methylene blue photodegradation was 93%, methyl orange photodegradation was 35%.
3	2010	Photocatalytic degradation: methylene blue	Average patcile size 5–7 nm. Particle type: nanorods. Surface area: Sample1 = 34.27 cm^2, Sample2 = 47.54 cm^2 and Sample3 = 39.12 cm^2. The photocatalytic activity of methylene blue was observed to improve by ≈8%.

S. No.	Year	Application	Characteristics
4	2011	Antimicrobial Activity: *Escherichia coli*	Average particle size 20–40 nm. A quite high (0.24 min^{-1}) bacterial decay constatnt was observed for antibacterial activity.
5	2006	Antimicrobial Activity: *Escherichia coli* and *Bacillus subtilis*	Particle sizes 67 and 820 nm. 90% growth reduction of *Bacillus subtilis* was observed at 10 ppm. For *Escherichia coli*, only 48% growth reduction was observed at 1000 ppm.
6	2008	Antimicrobial Activity: *Staphylococcus aureus*	Average particle size 84 nm. Nanoparticles with smaller particle sizes had 95% growth inhibition at 1 mM concentration (0.008%), with relatively larger particle sizes, with 5 mM of ZnO showed only 40–50% growth inhibition.
7	2011	Antimicrobial Activity: *Escherichia coli*	Average patcile size 19 ± 7 nm. The toxicity to *Escherichia coli* of nano-ZnO in the 5 media deceased as follows: ultrapure water > NaCl > minimal Davis > Luria-Bertani > phosphate-buffered saline.
8	2015	Antimicrobial Activity: *Enterobacter aerogenes* and *Bacillus subtilis*	Length and diameter of particle 400 and 50 nm. Nanocomposites containing 2 and 4 wt% ZnO can reduce the growth of both *Bacillus subtilis* and *Enterobacter aerogenes.* Stronger inhibility effect was found for 4 wt% ZnO containing nanocomposite.
9	2015	Antimicrobial Activity: *Escherichia coli* and *Bacillus subtilis*	Average patcile size 20 nm. aT 2.0 wt% loading level, the ZnO nanoparticles showed the obvious inhibitory effect on the growth of both *Bacillus subtilis* and *Escherichia coli*
10	2015	Antimicrobial Activity: *Escherichia coli* and *Enterococcus faecalis*	Average patcile size 86 nm. Maximum removal efficiency was found to be 78%.
11	2013	Antimicrobial Activity: *Escherichia Coli*	The pH ranging from 5.7 to 8.7 showed no viable effet. Sharp decrease of bacterial mortality was observed from 80 to 90% at pH 8.3 to about 10–20% at pH 8.7.
12	2011	Antimicrobial Activity: *Pseudomonas aeruginosa, Staphylococcus aureus* and *Escherichia coli*	Average patcile size 25 nm. The effect on the Gram-positive bacterium *Staphylococcus aureus* were more than Gram-negative bacteria *Pseudomonas aeruginosa* and *Escherichia coli.*
13	2018	Antimicrobial Activity: *Escherichia coli* and *Salmonella typhimurium* Photocatalytic degradation: methylene blue	Particle size between 2 and 50 nm. MB equilibrium data was best fitted to the Dubinin-Radushkevich model. The adsorption energy (E) was between 1.76 and 2.00 kJ/mol.

S. No.	Year	Application	Characteristics
14	2019	Adsorption: Cr(VI)	Average patcile size 31 nm. The maximum adsorption capacity for Cr(VI) was at pH of 2. Increasing the pH value results in decreaing adsorption capacity. The maximum monolayer adsorption capacity was 139.47 mg/g at 50°.
15	2018	Adsorption: Reactive Blue 19 (RB19) and Acid Black 210 (AB210) dyes	Average patcile size 12 nm. Fast Adsorption rate with an equilibrium adsorption established after 15 min of shaking times. RB19 removal efficiency was highest at pH ~3. Both dyes followed the pseudo-second-order model. The isothermal model Langmuir was best suited to the experimental data. The maximum of adsorption capacities for RB19 and AB210 were 38.02 and 34.13 mg/g.
16	2017	Adsorption: Pb(II)	Particle sizes 10.01 ± 2.6 nm The pseudo-second-order model was followed by the adsorption process. The maximum removal was observed to be 93% at pH 5. The adsorption process was endothermic and spontaneous.
17	2018	Adsorption: As(III)	The pseudo-second-order model was followed by the adsorption process. The maximum removal was observed to be 52.63 mg/g at pH 7. The adsorption process was endothermic and spontaneous. The isothermal model Langmuir was best suited to the experimental data.
18	2019	Adsorption: Azo dyes	Particle sizes 75–150 nm. ZnO-NPs of amount 0.3 g showed maximum removal efficiency of each dye (40 ppm) at pH 6. The isothermal model Langmuir was best suited to the experimental data. The adsorption process followed the pseudo-second-order model.
19	2019	Adsorption: Arsenic (As(V))	Average width of particle around 7 nm and average length about 80 nm. The maximum capacity of 4421 mg/g at neutral pH (7). The isothermal model Langmuir was best suited to the experimental data.
20	2008	Antimicrobial Activity: *Crustaceans Daphnia magna*, *Vibrio fischeri*, and *Thamnocephalus platyurus*	Particle sizes 25–70 nm. All Zn formulations were very toxic: L(*E*)C$_{50}$ (mg l^{-1}) for nanoZnO, bulk ZnO and ZnSO$_4$ 7H$_2$O: 8.8, 3.2, 6.1 (*Daphnia magna*); 1.8, 1.9, 1.1 (*Vibrio fischeri*) and 0.24, 0.18, 0.98 (*Thamnocephalus platyurus*), respectively.
21	2010	Antimicrobial Activity: *Escherichia coli*	Average particle size 30 nm. Surface area (m2g-1) 12.9 Toxicity (30-min and 2-h EC$_{50}$, mg compound l^{-1}) of bZnO for *E. coli* AB1157 = 849 ± 180, E. coli JI130 = 932 ± 143, E. coli JI131 = 624 ± 81, E. coli AS393 = 612 ± 107, E. coli JI132 = 43 ± 6.9, E. coli AS391 = 16 ± 6.1.

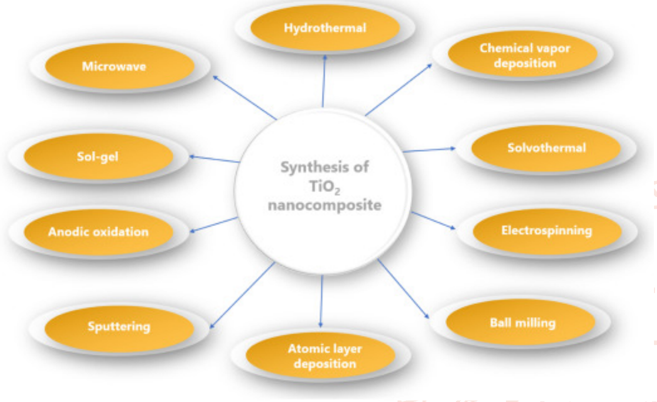
Bacterial disinfectants are one of the major applications of copper and copper compounds, which are critical to low levels of human and biological activity due to their versatility and low cost. Synthesized CuO nanoparticles have good antibacterial activity against meticillin resistant Staphylococcus aureus and Escherichia coli, with minimum bactericidal concentrations [13]

Table 2. Existing methods for working with CuO nanoparticles and their application for wastewater treatment

S. No.	Year	Application	Characteristics
1	2009	Antimicrobial Activity: *Escherichia coli* and *Staphylococcus aureus*	Particle sizes in the range 20–95 nm. Mean surface area 15.69 m^2/g. In the presence of 1000 g/ml of CuO, populations of Gram-negative (×3 strains) and Gram-positive (×4 strains) organisms tested were reduced by 65% and 68%, respectively,
2	2008	Antimicrobial Activity: *Bacillus subtilis*, *Staphylococcus aureus,* and *Escherichia coli*	Average particle size 9 nm. Disk diffusion studies with *Staphylococcus aureus,* and *Escherichia coli* revealed effectiveness with CuO. The highest sensitivity to CuO nanoparticle was depicted by *Bacillus subtili.*
3	2010	Antimicrobial Activity: *Escherichia coli*	Average particle size 30 nm. Surface area ($m^2 g^{-1}$) 12.9 Toxicity (30-min and 2-h EC_{50}, mg compound l^{-1}) of cCuO for E. coli AB1157 = 50.5 ± 15, E. coli JI130 = 39.7 ± 16, E. coli JI131 33.0 ± 1.9, E. coli AS393 = 47.6 ± 5.5, E. coli JI132 = 14.8 ± 0.1, E. coli AS391 = 11.4 ± 5.4.
4	2019	Photocatalytic degradation: methylene blue (MB) and textile effluent (TE) Antimicrobial Activity: *Staphylococcus aureus*, *Escherichia coli*, *Bacillus licheniformis* and *Pseudomonas aeruginosa*	The nanoparticle sizes range from 10 to 26 nm, 36–73 nm and 30–90 nm for the unannealed Cu2O, 300 °C and 600 °C annealed CuO respectively. The best degradation ability was shown by 600 °C annealed CuO, methylene blue (MB) = 91%, textile effluent (TE) =90%. 300 °C annealed CuO showed best antimicrobial activities on *Staphylococcus aureus*, *Escherichia coli*, *Bacillus licheniformis* and *Pseudomonas aeruginosa.*
5	2015	Antimicrobial Activity: *Enterococcus faecalis*, *Fecal coliform* and *Total coliform*	Particle sizes in the range 7–12 nm. The best activity on *Enterococcus faecalis = 92%*, *Fecal coliform = 89%* and *Total coliform = 88% was at pH = 6.* The bactraial inhibition growth rate was decreased when pH is increased after 6.
6	2018	Antimicrobial Activity: *Vibrio anguillarum, Proteus mirabilis, Bacillus cereus, Edwardsiella tarda, Staphylococcus aureus, Aeromonas hydrophila,* and *Aeromonas caviae*	Average particle size 61.7 nm. *Bacillus cereus* was more susceptible to biosynthesized CuO NPs than all other pathogens tested. Best inhibition zone was found to be 25.3 ± 1.80 for *Bacillus cereus* using 100 (µg/ml) of CuO nanoparticle.
7	2019	Antimicrobial Activity: *Staphylococcus aureus and Escherichia coli*	Particle sizes in the range 7–14 nm. The CuO nanprticle's minimum inhibitory concentration (MIC) against *Escherichia coli* and *Staphylococcus aureus* were 3.75 and 2.50 mg/ml, respectively.
8	2014	Antimicrobial	Particle sizes in the range 5–8 nm.

S. No.	**Year**	**Application**	**Characteristics**
		Activity: *Salmonella typhimurium, Klebsiella pneumoniae* and *Enterobacter aerogenes*	The CuO nanprticle's minimum inhibitory concentration (MIC) against *Salmonella typhimurium, Klebsiella pneumoniae* and *Enterobacter aerogenes* were 0.15, 0.55,and 0.30 µmg/ml, respectively.
9	2014	Antimicrobial Activity*: Pseudomonas aeruginosa, Escherichia coli, Enterococcus faecalis, Klebsiella pneumonia, Proteus vulgaris, Shigella flexneri, Salmonella typhimurium, and Staphylococcus aureus*	Average particle size 23 nm. *Escherichia coli,* and *Enterococcus faecalis* exhibited the highest sensitivity to CuO nanoparticles *Klebsiella pneumonia* was the least sensitive.
10	2019	Antimicrobial Activity: *Escherichia coli* and *Salmonella typhimurium*	Particle size 190.93 ± 2.84 nm. CuO nanoparticle showed effective antibacterial nanomaterial, significantly inhibiting the growth of both *Escherichia coli* and *Salmonella typhimurium* bacteria.
11	2014	Antimicrobial Activity: *Bacillus anthracis*	Average particle size 60 nm. Best efficacy was 99.92% of 7 × 105 CFU/ml *Bacillus anthracis* cells within 30 min for CuO of 0.5 mg/ml.
12	2016	Adsorption: basic red 14 (BR 14) and basic violet 16 (BV 16)	Average particle size 9 nm. The optimum conditions were selected as adsorbent dosage of 0.5 g/l, pH 7 and contact time of 30 min. The isothermal model Langmuir was best suited to the experimental data. Maximum adsorption capacity for BR 14 = 27.4(mg/g) and BV 16 = 16.8 (mg/g). The pseudo-second-order model was followed by the adsorption process.
13	2017	Adsorption: malachite green oxalate (MGO) and methyl orange (MO)	The pseudo-second-order model was followed by the adsorption process. The adsorption process was endothermic and spontaneous. The isothermal model Freundlich was best suited to the experimental data. For CuO nanoparticle, the maximum dye removal was observed at pH 8 for MGO (83.4%) and at pH 2 for MO (93.2%).
14	2012	Adsorption: Arsenic (As(V))	Average particle size 40 nm. The isothermal model Langmuir was best suited to the experimental data. The adsorption process was endothermic and spontaneous. 100% arsenic was removed from water at pH more than 8.
15	2014	Adsorption: Pb (II)	Average width of particle around 5 nm and average length about 50 nm. The adsorption process was endothermic and spontaneous. 90% removal efficiency was found at basic pH (9.0).
16	2019	Adsorption: Lead (Ii)	Average particle size 20 nm. 95% removal efficiency was found at basic pH (6).

Nanofluids are generally defined using surfactants or surface charge technology in the solution as suspended nanoparticles. Other nanostructures include nanohorns, nanocomposites, nanorods, nanopyramids, and nanowhiskers. Silver oxide nanoparticles, which have excellent antibacterial activity, are being studied and are currently being used for many commercial products and are among many of the nanomaterials reported as antibacterial agents. The antibacterial activity of the Ag_2O nanoparticle was tested against two gram-positive and two gram-negative bacteria. The synthesized Ag_2O nanoparticles have strong growth inhibitors of gram-negative bacteria.[14]



Conclusions & Future Scope

The need to expand the use of nanoparticles in therapeutic applications and reduce toxicity is also an important challenge. New strategies are being developed to overcome such challenges through the use of noble metal nanoparticles through developments in nanoscience; however, their impacts on anthropological health factors must be taken into account before their extensive use. Given that most nano-materials so far have been inexpensive compared to traditional materials such as activated carbon, future applications will focus on efficient processes, where only small quantities of nanomaterials of metal oxide will be needed. In addition, more work is necessary to develop cost-effective methods of synthesis, and large-scale testing is required for the successful field application of metal oxide nanomaterials.

Metal oxide nanomaterials are preferred for the absorption of heavy metals and organic pollutants, as they have shown promising results when they are used in various applications. These types of nanoparticles are called immobilization carriers and can also be used as support carriers for biosensors and bio sorbents, though they are rarely discussed. Their success has been attributed to their physical and chemical properties, but their application to wastewater treatment is still limited.

In the literature, ZnO, CuO, and TiO_2 are used in a variety of different applications such as adsorption, photocatalytic activities, antibacterial and antifungal activities. Silver oxide is mostly used in antimicrobial and photocatalytic activities. Iron oxide is mostly used in adsorption.

Although metal oxide nanoparticles, like other nanoparticles, are useful for many applications, there are still some health hazard concerns due to their uncontrollable usage and release to the natural environment. These concerns should be addressed to make the use of nanoparticles more effective and environmentally friendly.[14]

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