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EFFECT OF ZINC NANOPARTICLES ON WATER POLLUTION TREATMENT

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Abstract
Due to concerns about rising demand and falling supplies, the world now faces a growing problem of enough clean water. Although there are already technologies in place to disinfect water, these technologies have drawbacks, most notably the production of disinfection byproducts, which has prompted research into alternate techniques. Zinc oxide has generated interest as an antibacterial agent since it is a crucial ingredient in the rubber and pharmaceutical sectors. Zinc oxide has demonstrated antibacterial qualities at the nanoscale, making it potentially excellent for a variety of applications. This review examines zinc oxide synthesis with a focus on the precipitation process, its antimicrobial characteristic and the variables impacting it, disinfection mechanisms, and the possible use of water disinfection.

Keywords: Zinc Oxide, zinc nanoparticles, Water Pollution, and wastewater.

1. Introduction

Water is a crucial component of life. However, issues with water quality and sufficiency have emerged due to population increase, industrialization, and the threat of climate change. Poor water quality has a wide range of negative effects on human welfare in terms of both the economy and society. Pathogens are killed by disinfecting water, which is done using a variety of traditional techniques such as ozonation, ultraviolet therapy, and chlorination. These techniques do have certain drawbacks, though. When chlorine is added to water, it tends to produce carcinogenic disinfection by-products (DBP), which renders chlorination ineffective against some extremely resilient aquatic infections. Due to some water-borne bacteria's greater resistance to existing disinfectants, more disinfectant doses are needed, which causes higher levels of DBP to develop [1]. Ozone disinfection produces fewer by-products than chemical disinfection, but it is more expensive and can produce dangerous bromate when it combines with bromide ions in water. UV treatment does not leave a residual in treated water, like ozone treatment, and as a result, does not provide any protection against reinfection in the distribution network [2]. Therefore, new strategies must be considered to increase disinfection efficacy. The creation of an antibacterial agent that can successfully combat water pathogens is a significant issue. Because current

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disinfection techniques have their limitations, nanotechnology offers fresh approaches for treating water without producing DBP. Due to the increase in surface area, nanomaterials can exhibit several improved properties from their bulk scale. Zinc oxide is one of the nanomaterials that has sparked interest in recent years as an antibacterial agent. To absorb UV light, zinc oxide is frequently added to sunscreens, varnishes, and paints. It also has a critical place in several sectors, including the rubber, pharmaceutical, and food industries. To prevent microbial development, ZnO is used as an antimicrobial in textiles [3], surface coatings [4], cosmetics [5], and cellulose fibers [6]. ZnO has improved applicability, though, at the nanoscale. ZnO, along with other inorganic oxides including titanium dioxide (TiO2) and silver nanoparticles (AgNP), has generated interest because it demonstrates robust activity even in small concentrations. ZnO is regarded as a reliable antibacterial agent due to its stability under demanding processing circumstances and reputation as a non-toxic substance for both people and animals [7,8]. Inorganic materials, like ZnO, have better heat resistance, selectivity, and durability than organic materials [9]. To learn more about their antibacterial capabilities, many strains of microorganisms have been examined.

2. Wastewater

Wastewater is a municipal waste liquid product that contains contaminants such as organic materials, microorganisms, inorganic soluble compounds, and the use of toxic heavy metals. The chemical, biological and physical characteristics of clean water are changed by these contaminants [10]. Wastewater can be separated into home components, organic and inorganic chemicals, industrial and agricultural wastewater sources, and municipal and industrial wastewater from waste sources, which usually comprise feces and urine [11]. Various wastewater sources are depicted in Fig. 1. Large microorganisms including viruses, bacteria, protozoa, and harmful materials like heavy metals, radionuclides, and trace elements can all be found in wastewater. Water-borne illnesses like cholera and typhoid, which can be fatal, are also frequently brought on by wastewater. In 2004 [12,13], more than 1.5 million children under the age of five died because of contaminated water. The many contaminants present in water are depicted in Fig. 1. The destructive effects of pathogens and the risks of wastewater pollution on people, crops, and animals make wastewater treatment necessary in modern times. To prevent pollution of the environment, wastewater treatment on a personal and governmental level must be taken into consideration. The treatment of wastewater might entail physical, chemical, and biological techniques for water purification from various contaminants [14,15]. Wastewater has a wide range of physical properties, such as total solids, dye, and others (fixed, volatile, dissolved, and suspended) [16]. Total dissolved solids, or TDS, are the dissolved matter in wastewater and may include minor amounts of organic compounds as well as inorganic salts and metals such as bicarbonates, chlorides, calcium, magnesium, potassium, and sodium. For dissolved solids, these particle sizes range from 0.01 to 1.00 μm [17,18]. Organic,

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inorganic, and gaseous substances can all be found in wastewater as contaminants. Fats and oils, carbohydrates, and proteins make up most of the organic pollutants in wastewater, accounting for 50 percent, 40 percent, and 10 percent, respectively [19]. The organic contaminants found in wastewater are primary impurities, surfactants, and impurities [14]. The most useful markers of the quality of organic contaminants in water are chemical oxygen demand and biological oxygen demand. Numerous inorganic contaminants, including heavy metals, phosphorus trace elements, nitrogen compounds, and other harmful inorganic components, are found in wastewater.

Fig. 1. Different sources of wastewater.

Wastewater has biological features in addition to chemical and physical qualities. Living pathogenic microorganisms are the biological contaminants found in wastewater. The primary microorganisms in wastewater include bacteria, viruses, and protozoa, which can have both short-term and long-term negative effects on health. The many bacteria found in wastewater can lead to cholera, typhoid, and Shigella, among other waterborne illnesses. However, a variety of bacteria, including *Escherichia coli, Enterobacter, Klebsiella pneumonia, Streptococcus faecalis,* and others, can be found in wastewater and cause less severe problems. For catalysis, adsorption, electrostatic, reactivity, and adjustable pore volume, sensors, and optical electronics with high aspect ratio, as well as hydrophilic and hydrophobic interactions, nanotechnology offer creative water treatment options [18]. Processes based on nanotechnology are efficient, flexible, and adaptable, providing high-performance, inexpensive water, and wastewater solutions. Nanotechnology can also be used to rehabilitate and clean up odd water sources inexpensively. Table 1 provides an overview of the methods employed for eliminating pollutants from wastewater. Table 2 lists the main drawbacks of traditional water purification techniques.

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Table 1: Conventional techniques used for the wastewater treatment

Method	Main characteristic(s)
Chemical precipitation	separating the products produced and absorbing the contaminants.
Flocculation/ Coagulation	separating the products produced and absorbing the contaminants
Flotation	Separation process
Chemical oxidation	Use of an oxidant (e.g., Cl2, O3, KMnO4, ClO2, H2O2)
Biological treatment	Use of biological (mixed or pure) cultures
Filtration (Nano, Ultra, Micro, and Carbon fitler)	Use of solid material and nondestructive process
Ion exchange	Nondestructive process
Incineration / Thermal oxidation	Destruction by combustion
Electrochemistry	Electrolysis (E)
Membrane filtration	Nondestructive separation
Evaporation	The separation process, Thermal process, and Concentration technique,
Liquid-liquid (solvent) extraction	Separation technology
Advanced oxidation processes (AOP) Photolysis	Emerging processes, Destructive techniques

Table 2: Limitations of conventional methods of water purification

Method	Limitations
Flotation	pH-dependent selectivity, a high initial capital cost, and a high operating and maintenance expense.
Chemical precipitation	The reagent must be used in excess. The blend in its product can be of inferior quality, which might restrict consumption. It's not a very discerning technique.
Flocculation and coagulation	This procedure is difficult and ineffective since it requires adding alkaline chemicals to get the ideal ph.
Biological treatment	Microbes are sensitive to the environment. Microbial cells can be eliminated by intermediates. This process is time- and money-consuming.
Ion exchange	High initial capital expenditure, as well as high operating and maintenance costs.
Incineration / Thermal oxidation	costly initial startup and ongoing costs.
Electrochemistry	the equipment's high initial purchase price and significant maintenance costs.
Membrane filtration	High expenses of investment for small and medium-sized businesses. high demand for energy Systems for membrane filtration can have a wide range of designs
Evaporation	expensive for large wastewater volumes. High expenses of investment for small and medium-sized businesses.
Liquid-liquid (solvent) extraction	High investment (equipment).
Advanced oxidation processes (AOP) Photolysis	Pre-treatment and powerful high-water cleaning are necessary for this procedure Retention of salt and univalent ions were minimal
Nanofiltration	This technique uses a lot of energy and cannot get rid of dissolved inorganics.
Microfiltration	Metals, fluoride, sodium nitrates, volatile organics, pigments, and other contaminants cannot be removed with this procedure. Regular cleaning is necessary for this technique, and membrane fouling can also happen
Carbon filter	This process is unable to get rid of fluoride, nitrates, salt, metals, etc. This can become clogged with undissolved particles and is mold-prone.

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3. Synthesis of ZnO

White to yellowish-white crystalline powder, zinc oxide (ZnO) is almost water soluble. Its two most frequent crystal forms are zinc blende and hexagonal wurtzite [20]. ZnO has physicochemical characteristics that support its antibacterial action. Materials on a nanoscale can display several better features compared to what they display on a microscale, primarily because of the increase in surface area, which leads to an increase in the rate of a chemical reaction. Nanoparticles can penetrate bacterial cell walls due to their smaller size relative to the bulk scale, which ultimately results in cell death. Additionally, the surface of nanomaterials can produce reactive oxygen species (ROS) that can destroy bacterial cell walls, increasing antibacterial action. Another characteristic is the existence of surface flaws like corners and edges, which cause ZnO to have an abrasive effect and break down bacterial cell walls [21]. Different readily available zinc-containing minerals are used as feedstock in several potential processing processes. The bulk industrial processes (pyrometallurgical and hydrometallurgical synthesis) or laboratory/pilot plant scale processes may be used to synthesize ZnO. The use of unit operations, process conditions, size of production, and zinc precursors are the key technological distinctions across the various processing processes [22]. Precipitation, hydrothermal, solvothermal, and sol-gel procedures are a few of the lab-based methods for synthesizing ZnO that have been documented [23]. The process control of parameters including particle size, size distribution, shape, surface area, and dispersity is necessary for the application of ZnO nanoparticles as an antibacterial agent [24]. The control of all variables during the synthesis of ZnO may be challenging, and different processes and process variables will lead to diverse nanoparticle shapes and sizes [25]. This section of the review on the precipitation method, which is the most often used approach because of its simplicity, is examined in this portion of the review. A zinc supply and a precipitating agent are needed for this procedure. Different precursors, reaction temperatures, and calcination temperatures were used by various researchers to generate ZnO nanoparticles of various sizes and shapes. The study on precipitation-based ZnO synthesis is compiled in Table 1. Zn $(NO_3)_2 \rightarrow 6H_2O$ and $(NH_4)_2CO_3$ were used in the direct precipitation method by El Saeed et al. [26] to create ZnO at a temperature of 40 °C. The precipitate was calcined for two hours at 550 °C. The ZnO nanoparticles were non-agglomerated and had an average particle size of 20 nm, according to the study of the transmission electron microscope (TEM), which provides information on nanoparticle morphology. Using Zn $(NO_3)_2$ and NaOH as the zinc source and precipitating agent, respectively, Menaka and Subiya [27] produced ZnO nanoparticles at 75 °C for two hours before calcining the precipitate at 100 °C for several hours. The generated ZnO nanoparticles were typically 42 nm in size. ZnO was created by Padmavathy and Vijayaraghavan [28] by precipitating Zn $(NO_3)_2$ and NaOH while operating at

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room temperature with vigorous stirring for two hours. The precipitate was then treated with 1 mol H2O2 at 75 °C. After that, the precipitate was dried in the oven and calcined for three hours at 350 C to create ZnO nanoparticles with diameters between 20 and 40 nm. The identical precursors were also used by Premanathan et al. [29] to create ZnO, which resulted in particles with an average size of 25 nm. The following are the reactions that occur during precipitation and calcination:

Zn (NO3)2 ➡ 6H2O + 2NaOH ➡ Zn (OH)2 + 2NaNO3

Zn (OH)2 ZnO + H2O.

Zn(C2H3O2)2+2H2O and xylene were used to create ZnO nanoparticles by Navale et al. [30] in methanol at a pH of 6.7e6.8. A white precipitate was produced after 6 hours of refluxing the solution at 65 °C. The precipitate was further crushed with a mortar and pestle to obtain nanosized ZnO nanoparticles after being dried for 24 hours at 100 °C in a hot air oven. The size of the resultant ZnO particles, according to TEM pictures, was in the region of 20e25 nm. Zn (NO3)2+6H2O and KOH were used to create ZnO nanoparticles by Ghorbani et al. [31] in an aqueous solution. TEM and Dynamic Light Scattering, a method for measuring particle size in colloidal solution, were employed to determine the size of the particles. The particles ranged in size from 20 to 40 nm.

4. Mechanisms for Disinfection

4.1. The literature has identified several mechanisms for the antibacterial activity of ZnO nanoparticles (Fig. 2). These are listed below:

4.1.1. *Release of ROS*

The ZnO nanoparticles' antibacterial activity includes the release of oxygen species from their surface, which kill microbes. ROS are well known for causing oxidative stress by harming cellular proteins, cell membranes, and DNA. The dissolution of the cell wall and subsequent breakdown of the cell membrane, leakage of the contents of the cell, and ultimately cell death are the results of ZnO's surface activity, which also results in the rupture of the cell wall [32,33]. Padmavathy and Vijayaraghavan [34] described the mechanism as follows: UV and visible light activate ZnO to create electron-hole pairs:

ZnO þ *HV* ⟶ e^- þ $h^þ$

The electron-hole couples divide the OH and Hþ water molecules from the ZnO suspension:

$h^þ$ þ H_2O ⟶ •OH þ $H^þ$

O_2 molecules yield superoxide anion: e^- þ O_2 ⟶ •O_2^-

Superoxide anion reacts with $H^þ$ to generate HO_2• radicals:

•$O_{\bar{2}}$ þ H^{þ} ⟶ HO_2•
When HO2 interacts with electrons, hydrogen peroxide anions are produced, which combine with Hþ to form hydrogen peroxide molecules:

HO_2• þ H^{þ} þ e^{-} ⟶ H_2O_2
The bacteria can be killed by the hydrogen peroxide by penetrating the cell membrane:

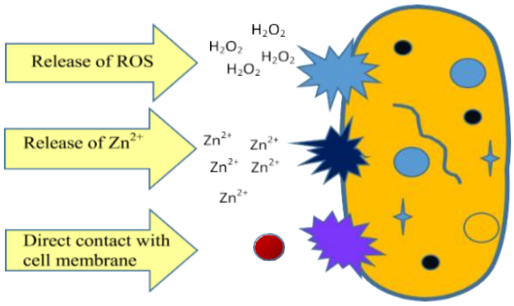

Fig. 2. ZnO disinfection mechanisms.

4.1.2 *Release of Zn^{2}þ*

The release of Zn^{2}þ ions, which can rupture cell membranes and enter intracellular contents, is another potential explanation for ZnO's antibacterial effect. According to Li et al. [35] experiments on the physicochemical characterization and antibacterial testing of ZnO nanoparticles in five media, nano-harmful ZnO's effects on *Escherichia coli* were primarily related to the released Zn^{2}þ ions, according to Kasemets et al. [36], the solubility of the Zn^{2}þ ions in the media containing microorganisms may be the cause of the toxicity of ZnO nanoparticles against *Saccharomyces cerevisiae*.

4.1.3 *Direct contact of nanoparticles with cell membrane*

Heinlaan et al. [37] assert that the presence of metal oxide particles inside the cell does not always lead to cell damage. More significant is the interaction between the bacterial cell and the particle, which alters the microenvironment in the region where the two objects come into touch. Additionally, Brayner et al. [38] demonstrated that bacterial cell walls were harmed and disordered after coming into touch with ZnO nanoparticles. Increased membrane permeability brought on by the abrasive ZnO led to the internalization of the nanoparticles by the cells.

5. Methods and Materials

Activated sludge effluent is sampled and modified mixed liquor (MML)media are made to support the expansion of the activated sludge bacterial community in

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laboratory batch reactors. A sterile 20 L container was used to collect raw wastewater from the Salah al-Din Governorate's Tikrit wastewater treatment facility at the primary zone output. After allowing the effluent to settle for two hours, biomass and other suspended particles were removed using Whatman No. 1 filter sheets. utilized the filtrate to make the modified mixed liquor (MML) culture media by including the following carbon sources and nutritional supplements: 5 g/L sodium acetate; 2.5 g/L d-glucose anhydrous; 0.5 g/L $MgSO4•7H2O$ and 0.18 g/L $KNO3$. The pH was adjusted at 7.2 ± 0.3 using 1.0 M HCl and 1.0 M NaOH, and finally, the modified mixed liquors were sterilized at 121 °C and a pressure of 200 kPa for 15 min in an autoclave before use in any of the experiments conducted.


Figure 3. A sampling of Activated sludge effluent
Figure 4. water after using filter paper.

Before usage, a suspension of the test nanoparticles (ZnO) was made with sterile Milli-Q water at a concentration of 1000 mg/L, which was obtained from The Scientific Office for Chemical Trade in Baghdad, specifically (Bab Al-Moazzam). Each sterile 250 mL flask holding the culture medium received aliquots of this solution to be added to reach the final volume of 100 ML at the following concentrations: 0 mg/L, 5 mg/L, 10 mg/L, and 100 mg/L. The identical wastewater treatment facility's return-activated sludge samples were taken in the winter of 2021/11/10 and served as the source of the microbial community (inoculum). Samples of activated sludge were collected in sterile plastic containers (1 L), which were kept in the refrigerator at a temperature of ±2 oC until usage. For every batch reactor in the lab, the study was carried out twice.


Figure 5. for the test with Sterile Milli-Q water
Figure 6. Test nanoparticles (ZnO)

6. Results and Discussion

Nanomaterial characterization. Using a transmission electron microscope, the effects of ZnO on microbial populations, and activated cells that hadn't been treated, as well as treated cells, were examined under a microscope (TEM). It has been claimed that TEM pictures can reveal the precise size and form of particles [39]. (Fig. 7) demonstrates that the particles were 100 nm in size and had irregular shapes (circular, oval, stretched, or even irregular shapes).

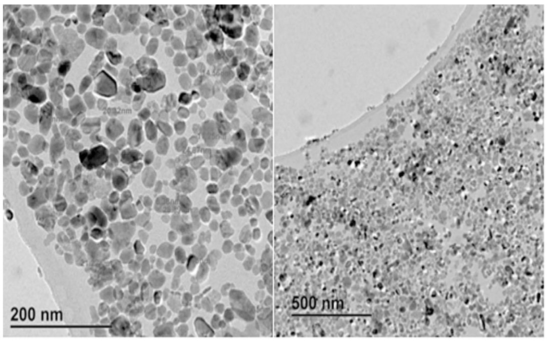

Figure 7. TEM images of ZnO.

This may be the result of the synthesis protocol used to create these nanoparticles, as morphological uniformity of ZnO can be achieved by adjusting the concentration of the ionic template such as potassium nitrate, potassium sulfate, or lithium nitrate at different molar ratios [41] or by optimizing the calcination temperature [40]. The diameter of the particles was discovered to range from 6 nm to 60 nm. The manufacturer's instructions, which state that particles should be <100 nm, are consistent with this observation. However, neither the dominating size nor the size distribution information was given. The high concentration of nanoparticles in the TEM images shown in (Fig. 7) correlates to the high concentration of scattered ZnO in water (1.7 × 106 mg/L). Because of this, it would be challenging to determine if the ZnO disseminated in the water was composed of singlets, aggregates, or agglomerates based on the descriptions provided by earlier researchers [53,54]. Further analysis performed from selected areas showed the presence of zinc up to 50 ± 0.35% and oxygen at 17 ± 0.28% by weight of the dried sample on the copper grid, as determined by further analysis from chosen regions, confirming the nature of these nanoparticles as Zn.

Table 3. Diversity indices of activated sludge metagenome influenced by ZnO.

Sample ID	No. of sequences	OTU	Chao 1	Shannon	Evenness index (E)
Positive control	29 103	27 737	554 104.06442	10.20133	0.99715
S_5 mg/L nZnO	25 139	23 743	356 974.84407	10.04318	0.99684
S_10 mg/L nZnO	18 504	17 733	344 286.66519	9.76002	0.99763
S_100 mg/L nZnO	13 963	13 324	236 445.14865	9.47239	0.99738

Diversity indices and community species richness. The results of this investigation demonstrated that when ZnO concentration rose, there was a net loss of metagenomic sequences across all domains (Table 3). When activated sludge was exposed to the presence of 5 mg/L, 10 mg/L, and 100 mg/L ZnO, respectively, it was discovered that the number of sequences was decreased by 13.6%, 36.4%, and 52.0%. However, the read tags were allocated to various OTUs using the RDP pipeline at a 5 percent nucleotide cut-off to determine how the bacterial populations were impacted. Based on the results of Dalevi et al. [42], the 5% nucleotide cut-off was chosen for this study. In general, a progressive decline in OTUs was seen as the sample's ZnO content rose. The nZnO-free sample (control) yielded a total of 27 737 OTUs with a nucleotide cutoff of 5%, whereas the treated samples yielded 23 743 OTUs (5 mg/L ZnO), 17733 OTUs (10 mg/L ZnO), and 13 324 OTUs (100 mg/L ZnO). This showed that higher ZnO concentrations had a substantial impact on the number of OTUs in the activated sludge cultured in samples treated with ZnO because $p = 0.000650767$ ($p < 0.05$) [43]. The diversity was estimated using the Shannon index (H) and richness estimator Chao1. Like OTUs, the Shannon index (H) revealed the impact of ZnO on microbial diversity with the nZnO-free sample (control) having a Shannon index of 10.20133, and the nZnO-treated samples subjected to 5 g/L, 10 g/L, and 100 g/L ZnO having a diversity index of 10.04318, 9.76002, and 9.47239, respectively. It is possible that bacterium diversity was higher and more uniformly distributed in the control sample (nZnO-free sample) than in samples containing ZnO based on the steady decline in the Shannon index as the ZnO concentration increased. Additionally, the species richness of nZnO-free and nZnO-treated samples was estimated using the Chao 1 richness estimator. The analysis showed that the species richness of the samples decreased as the ZnO concentration rose (Table 3). The community species richness of the control and samples with different concentrations of ZnO differed significantly from each other, according to a statistical analysis using ANOVA ($p = 0.001335214$). To evaluate the complexity of various microbial communities within samples, the evenness index (E) was also calculated. In contrast to the Shannon index, the data revealed little to no variation in the evenness of all samples, ranging from 0.99763 to 0.99684. The relative abundance percentage of each taxon was determined by comparing the various sequences belonging to the same taxon with the total number of sequences acquired for each sample. But when severely dissimilar or underestimated samples were taken into account, the evaluation's flaws were clear, leading to incoherent values that were also previously noted by other researchers [44]. The species richness of each sample was also determined using the rarefaction curve, which graphs the OTU number versus the sequence number. This method also revealed whether or not the bacterial diversity and community of the samples were comparable or distinct. Simberloff [45] states that an individual base rarefaction curve, which depicts the relationship between the numbers of species and OTUs at various levels, can be used to estimate the species richness of a given sample. A standard comparison of the species richness for four individual-based rarefaction curves is shown in (Fig. 8). Results in the same picture

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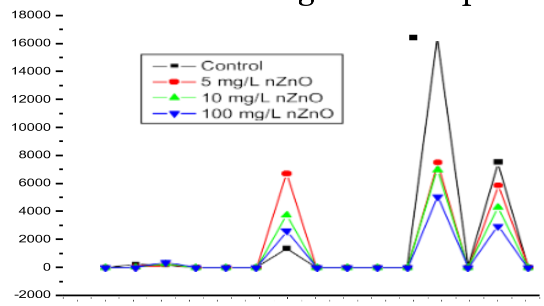
also demonstrated a relationship between the species richness found in laboratory batch reactor samples and the cumulative amount of total sequences at any given phylogenetic level (on the x-axis) (on the y-axis). The rarefaction curve, like the Chao 1 richness estimator, showed a decline in bacterial diversity with rising ZnO concentrations in the samples. In addition to having a low species richness, samples treated with ZnO showed a significant difference (p 0.05) from controls. Additionally, a tiny plateau on each sample's rarefaction curve (Fig. 8) showed that a sufficient number of species had been recovered and taken into account. Only a small portion of the many species have yet to be identified. Schloss et al. [46] took note of this observation as well. In addition, a little plateau on the rarefaction curves for each sample (Fig. 8) showed that a sufficient number of species were recovered and taken into account. Nevertheless, only a small portion of the many species have been identified. Schloss et al. [46] made a similar observation. The dissimilarity between samples was evaluated using additional statistical analysis using the Bray-Curtis dissimilarity metric, and it was shown using a heat map. It should be mentioned that



the software utilized did not offer a feature to choose a specific domain, such as bacteria in our investigation, from the list of available domains. As a result, all sequences, including unclassified groups and non-bacterial sequences, will be displayed in the heat map's results (i.e.: Ixodes). Results showed the influence of ZnO on the metagenomic profile by demonstrating the relative abundance at the genus level in several laboratory batch reactors (Fig. 8). Depending on the kind of species, the effect of zinc oxide nanoparticles on bacterial abundance varied; some could not survive in even low quantities, while others could only survive in the presence of ZnO. Similar findings revealed a significant alteration in other genera when cultivated with ZnO.

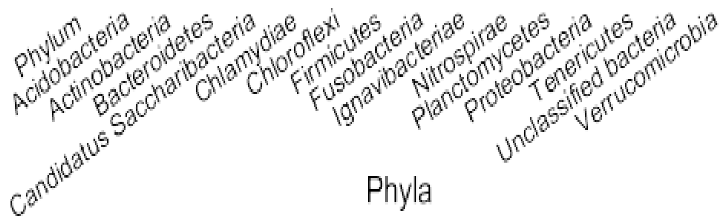


Figure 8. Influence of ZnO concentrations on phylum abundance in wastewater community data obtained at a 95% confidence level.

Fluctuation of bacterial communities in the presence of ZnO. According to the technique outlined by earlier authors [47,48] and recommended in the current investigation, the modified mixed liquor (MML) appeared to support the expansion of the bacterial community of the activated sludge in laboratory batch reactors. Variations in the development of microorganisms were observed after 5 days of exposure to different ZnO concentrations in MML as well as in the nZnO-free MML (controls). Raw sequences were filtered to remove artifacts to compare the bacterial communities in the nZnO-free samples and nZnO-treated samples [49,50]. Chimeric sequences were detected and deleted using UCHIME. According to earlier descriptions [51,52], each non-chimeric sequence was allocated to a different bacterial taxon. It was also observed that as readings were categorized into lower taxonomic categories, the bacterial community become more diverse. As seen in Fig. 4a, the diversity of the detected bacterial community often reduced over time as the samples' ZnO concentrations rose.

Conclusion

Zinc oxide is a crucial component for many industrial applications. Numerous studies in this field have shown that ZnO is efficient against a variety of microbe strains, demonstrating its promise as an antibacterial agent. According to the review, various precursors and experimental setups have been examined for the lab synthesis of ZnO. However, because these published studies produced inconsistent findings regarding the effects of particle size, the type of microorganisms, and the optimum concentration on ZnO toxicity, it may be challenging to conclude which could produce the best results in terms of antimicrobial activity. This reflects, among other things, differences in bacterial species and concentration between laboratories as well as differences in techniques. The use of ZnO for sewage and water treatment shows potential. It has the advantage of resolving the drawbacks of traditional water treatment techniques, chief among them DBP production. To improve ZnO's effectiveness as an antibacterial agent, however, there are still a lot of areas that need to be investigated. For instance, there are few publications on the treatment of actual wastewater to evaluate the efficacy of ZnO or the durability of these nanotechnologies. Additionally, research is required, notably on methods to preserve nanomaterials. Future development must overcome several obstacles, including social, economic, and technical. Making ZnO use cost-competitive or integrating it with traditional water treatment is difficult. Despite the numerous areas still needing to be investigated, the prospect of intensifying and diversifying research on ZnO is proof of its promise as an industrial water disinfectant.

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